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Volume IV, Water Resources

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Mr. A. E. GOLDSCHMIDT

[1]Concluded on Monday 22nd August.

The Economic Aspects of Experimental Meteorology

VINCENT J. SCHAEFER

As basic research along the frontiers of science advances, there are few of the natural sciences which do not receive careful scrutiny. As each study expands, it encounters the borderlines of related phenomena which often become so completely interrelated that it is difficult to determine where one ends and the other begins.

This is particularly true when the study involves a subject such as the earth's atmosphere and the physical processes which occur within a few hundred miles of its surface.

The general subject I should like to discuss at this time involves an area of even shallower depth with few, if any, of the problems to be considered involving a region exceeding ten miles above the earth. Despite this relatively narrow zone in the physical dimensions of the earth, the problems encountered are of considerable magnitude and of a nature which, if we are to approach their solution with any hope of success, must employ as many scientific techniques as possible.

As in any pioneering venture, success is much more likely if the investigations are carried out with enthusiasm, imagination, and an active curiosity and without too much regard for older theories or prejudices.

THE ROLE OF CLOUDS IN THE HYDROLOGIC CYCLE

In considering clouds and their formation owing to the interactions between air, water, and sunlight, we have the essential constituents of an important mechanism for the release of energy on the earth. The water molecule is the basic unit in this energy transfer system, since the water involved is continually passing through the closed cycle of evaporation, condensation, and precipitation—the sequence starting again by evaporation.

Because of its physical nature, the lower atmosphere serves as a vast reservoir for water. A relatively high concentration of water vapour may be stored in the form of gaseous molecules before condensation forms. In fact, even when this occurs, the small size of the condensed droplets often permits the atmosphere to support this additional moisture for a considerable time—often long enough, in fact, for the cloud thus formed to evaporate into warmer or drier air. It is in this manner that large air masses become modified. Warm and moist maritime air encountering colder, drier continental air mixes with it at the contact interface and thus changes the nature of both air masses.

In addition to forming clouds, water molecules in the very low levels of the atmosphere often condense as frost or dew. This is really a precipitate but, except in regions where it is common, is not of great economic importance since much of it soon evaporates again. Where cloudless skies occur and dew deposits are common, they may constitute an important source of moisture on the earth. Improved methods for enhancing this precipitation by artificial means is an important problem that should receive more attention.

The presence of clouds in the atmosphere tends to decrease the flow of energy from the sun to the earth, since most clouds absorb much of the visible and near infra-red radiation of the sun. Even a thin layer of clouds reduces insolation (incoming solar radiation). At night, however, the presence of clouds provides an insulation blanket and slows down the loss of heat from the earth to outer space.

When a cloud forms in the atmosphere, the amount of heat released to the air amounts to about 580 calories per gramme of condensed water. This energy may be considered lost insofar as the water resources of the earth are concerned if the cloud evaporates before it is precipitated. Not until precipitation develops in the clouds as snow or rain and then falls to the earth may we consider the hydrologic cycle completed and the maximum energy recovered. Extremely complex relationships in this respect result from the interaction between the seasonal changes of temperature and humidity, variations in the wind, the effect of topography, land use, and similar factors, all of which exert an influence on the delicate balance existing between the sun, the atmosphere, water, and man's welfare.

In discussing experimental meteorology, I would like to limit my consideration to experimental studies in the lower ten miles of the atmosphere and with air samples ranging in volume from a few cubic millimetres to several hundred cubic miles.

Among the interesting problems related to the atmosphere which require a solution is a logical and comprehensive understanding of precipitation processes. That there is more than a single mechanism involved in the formation of snow and rain as precipitation is now becoming well recognized. It was only a few years ago, however, when heavy rain was only thought of (1)[1] as necessarily preceded by the initial formation of snow.

It seems to me that when we consider the economic aspects of precipitation processes, it is important to evaluate not only the quantity of moisture that reaches the earth but also the related effects, such as winds, lightning, hail, intensity of the precipitation, and the related amounts of sunshine.

If any of these factors can be modified artificially, even to a limited degree, it is of great importance that every feature of the modification should bear careful scientific scrutiny.

While it is true that it is relatively easy to assign a definite value to an inch of rain on a square mile of newly planted seed corn; 10,000 acre feet of water added to an irrigation reservoir; two feet of snow on the upper drainage basin of a stream used for power purposes; or to supply a large metropolitan district with adequate drinking water, it is nevertheless of great economic importance to evaluate other weather phenomena. The loss in timber resources and recreational areas occasioned by fires started

[1]Numbers within parentheses refer to items in the bibliography.

by lightning storms; the devastation resulting when high local winds flatten banana plantations; the bruised fruit or smashed vegetables following an intense hailstorm, and the muddied streams and eroded farm lands left in the wake of a torrential rain all serve as examples of the by-products of unstable cloud systems which occur in the atmosphere.

Most cloud systems are examples of colloidal instability. Many of them rigorously follow the reactions which have well known counterparts in colloid chemistry. In most instances, where colloidal instability occurs, it is possible to shift the system to a more stable form by the proper and judicious use of chemical or physical reagents or reactions.

Even though glycerine and boric acid, for example, can exist as supercooled liquids in a relatively stable condition, methods are known whereby they can be changed to their less common, though more stable, crystalline form. The water in cloud systems also has a tendency to develop supercooling as a common characteristic.

CLOUD TYPES TO BE CONSIDERED

Before going into a detailed description of this interesting phenomenon, it will simplify the discussion to establish a certain terminology at this time. The clouds which we shall refer to consist of the three common forms—cirrus, cumulus, and stratus. The many variations in which each of these may be classified will, in general, be neglected, for, although they are very important from the standpoint of the genetic development of a weather pattern, these variations are not of prime concern in relation to the subject under consideration. A physical feature of great importance, however, is the freezing level in the atmosphere and its relationship to the clouds under discussion. In general, the temperature in clouds follows the wet adiabatic lapse rate with the temperature lowering with increase of altitude at the rate of about 2.1 degrees C (3.8 degrees F) per 1,000 feet at 0 degrees C (32 degrees F). With relation to the freezing level, we shall be dealing with clouds existing under one of three temperature conditions. The term "warm cloud" shall be used to designate a cloud of liquid water droplets warmer than 0 degrees C (32 degrees F). A "cold cloud" shall then designate a cloud of liquid water droplets colder than 0 degrees C, while a "cool cloud" will be a cloud extending above and below the freezing isotherm, thus combining the features of "warm" and "cold" clouds. The term "cool cloud" may thus designate a cumulus cloud, cooling according to the wet adiabatic lapse rate and thus becoming colder with increase of altitude, or it may be used to describe a more stable stratus cloud extending through an inversion and thus inverting the normal temperature sequence. These various cloud conditions are illustrated in Figure 1.

THE AMOUNT OF CONDENSED WATER IN CLOUDS

The variation in the amount of condensed water vapour in natural clouds covers a considerable range. In general, it is lowest in cirrus and highest in cumulus, with stratiform types intermediate. The temperature of the source air is the major factor governing the limit to the amount of moisture which may appear in clouds from condensation. Table 1 shows the amount of gaseous water vapour which may be contained in saturated air of different temperatures.

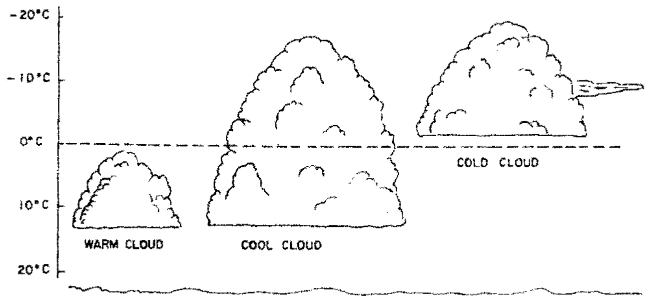
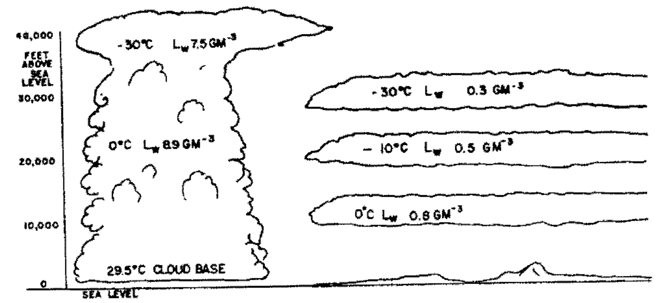


FIG. 1
TEMPERATURE RELATIONSHIPS IN WARM, COOL, AND COLD CLOUDS



APPROXIMATE MAXIMUM VALUES OF THE LIQUID WATER CONTENT OF SUPERCOOLED CUMULUS AND STRATUS CLOUDS AT SEVERAL TEMPERATURES
FIG. 2

This difference in the amount of water which may be held as a gaseous vapour at different temperatures is the direct cause of cloud formation in air cooled by radiation, convection, or advection.

The size and size distribution of the cloud droplets contained within such clouds are also variables involving many complex relationships. Cloud studies have now progressed to the point (2) where limiting values may be given in sufficient detail to be quite satisfactory. These are assembled graphically in Figure 2.

As might be expected, the lowest values in condensed water occur in cirrus clouds as ice crystals, the intermediate values in stratiform clouds, while the highest liquid water contents and particle sizes are found in towering cumulus type clouds.

THE DEGREE OF TURBULENCE IN CLOUDS

Studies of turbulence and convection in clouds show that of the three general types under discussion in this paper, only the cumulus type exhibit turbulence and convection of high order. While it is true that vertical velocities of a considerable degree may sometimes occur in stratus clouds subjected to orographic or frontal lifting, i.e., displacement due to the encounter of the cloud with a land barrier or an air mass having a different density, such effects are of a temporary nature and generally fail to produce marked changes in the nature of the cloud. It is likely that vertical velocities in stratus clouds rarely exceed 2 metres per second. The vertical velocities in cirrus clouds are even lower, since they generally form at very high altitudes and in relatively stable air. Cumulus clouds, on the other hand, contain high velocities which may exceed 20 metres per second in towering cumulus. Even in relatively small cumulus, 1 km. in thickness, vertical velocities of more than 3 metres per second often occur.

Liquid water content and particle size are physical features of clouds which are not affected by the location of the freezing level, except as they may be a function of the absolute humidity. High values of particle size and liquid water content may occur at temperatures far below the freezing temperature. The factor which affects the liquid water content of a particular parcel of air is the initial saturation temperature and its final temperature. If, however, in reaching this final temperature, the cloud particles have grown so large that the effect of gravity on them is great enough to overcome the vertical air velocity of their surroundings, the liquid water content may become lower. By a somewhat similar process, the liquid water content of a given air sample may be temporarily enriched by an invasion of falling precipitation from depleted clouds above. These are features of old clouds and are of much importance in reaching a proper understanding of precipitation processes.

TYPES OF NUCLEI IN THE ATMOSPHERE

In understanding the structure of natural clouds, it is of much importance to consider the initial formation of the cloud particles. All of the features of this phase of cloud physics are not understood, although rapid advances are under way. Three types of nuclei are of importance—condensation, sublimation, and freezing.

Condensation Nuclei

If ordinary atmospheric air is saturated with water vapour and then suddenly cooled, a cloud appears consisting of small water droplets. The number of droplets which form is directly related to the effective condensation nuclei present in the air before cooling occurred. If these observations are made using an enclosed chamber, and its temperature and humidity are adjusted so that the cloud droplets reach the bottom of the chamber before they evaporate, it is an observable fact that successive expansion cycles fail to produce a new cloud unless a higher expansion ratio is used at which time effective nuclei serve as centres of condensation.

It is a well known fact (3) that condensation nuclei are formed in great quantities by many processes. Fine, hygroscopic salt particles, which become air-borne as waves and bubbles break at sea, seem to be an important source of very active condensation nuclei. The smoke from forest fires, like most other burning processes, produces vast quantities of condensation nuclei which permeate the atmosphere to a thickness in excess of a mile. In some industrial regions, these particles become so numerous that they form a dense pall of smoke and fog which restricts visibility to a fraction of a mile.

If air samples are used from industrial regions or other places where the foreign particle concentration in the air is high, a dense cloud is observed in the cloud chamber containing from 10^4 to 10^5 particles per cub. cm. On mountain tops, at sea, or at higher levels of the atmosphere, the number of effective nuclei may drop to values of only a few hundred per cub. cm. It can easily be shown that the preponderance of such particles continue to serve as water drop nuclei to a temperature of —38.5 degrees C. Supercooled clouds of this temperature can easily be formed, even when the concentration is as high as 10^5/cub. cm.

Sublimation Nuclei

Among the foreign particles carried in the dust of the air are certain special forms which in a proper environment serve as sublimation nuclei. These become active in the formation of ice crystals at specific temperatures below 0 degrees C and in air supersaturated with respect to ice but not necessarily saturated with respect to water. Figure 3 shows typical results observable with samples of natural soils and similar materials. Many of these were gathered in regions where extensive dust-storms are common occurrences.

It is perhaps of considerable significance that very few particles have been found which serve as effective sublimation nuclei at temperatures warmer than about minus 12 degrees C. No observational evidence is known of snow-storms starting in clouds warmer than this temperature.

A study of considerable significance in relation to the occurrence of sublimation nuclei in the natural atmosphere has been made on Mt. Washington during the past eighteen months. Every three hours, day and night, in conjunction with the regular weather observations, the number of sublimation nuclei in a typical air sample are determined as part of our Project Cirrus weather research studies. The cold chamber method (4) is used in making these observations. The results are summarized in Table 1. This indicates that the level of sublimation nuclei in the atmosphere is generally very low throughout the year. The highest level observed during approximately 4,300 observations is 10 per cub. cm. In contrast, the level of condensation nuclei at the same time would show values ranging from 10 to 10,000 times greater.

While sublimation nuclei in the natural atmosphere may apparently have a number of different molecular properties, there is one pure chemical compound which to date has not been equalled in its effectiveness as a foreign particle ice nucleus. This is silver iodide, a hexagonal crystal which is almost identical in its crystalline structure to that of ice.

Work in our laboratory (5) and in the field is actively under way evaluating the effectiveness of silver iodide as a sublimation nucleus under various atmospheric conditions. To date, it appears to have exceptional value for cloud modification where dry ice cannot be used. One of its most important applications may be to inoculate clouds from ground generators placed in such a manner that the submicroscopic particles are carried up into the clouds where they will become active at temperatures colder than —5 degrees C, the threshold of activity of silver iodide smokes. Further details in relation to silver iodide will be given in a subsequent section of this paper.

Freezing Nuclei

Only brief mention will be made of freezing nuclei at this time, since not much is known about them. It is apparent, however, that they seem to possess different properties from those of sublimation nuclei. Where the latter permit the formation of ice crystals by the direct deposition of water molecules from the vapour to the solid phase, freezing nuclei appear to initiate the freezing of supercooled water droplets (6). It is apparently the presence of freezing nuclei in bulk water that leads to the crystallization of water in the temperature range of —6 degrees C to —20 degrees C, under conditions where care is exercised to prevent the seeding of the water by frost crystals deposited just above the water meniscus on the container. It might be that the presence of certain water insoluble sublimation nuclei is partially responsible for the development of snow in cold and cool clouds at temperatures below —12 degrees C when they come in contact with supercooled cloud droplets and cause them to freeze. It is a matter of observation that a considerable number of snow crystals have as a nucleus what appears to be a cloud droplet such as that shown in Figure 4.

CAUSES OF NATURAL PRECIPITATION

THE ICE CRYSTAL PROCESS

Since 1933 when Bergeron proposed (1) a mechanism for the formation of rain by the initial development of snow in the upper parts of cool clouds, it has been generally accepted that heavy rains could only be accounted for in this manner. Experiences during the past war, especially in tropical regions, convinced fliers and some meteorologists that another mechanism could also lead to the formation of heavy rain. Such precipitation was often observed to fall from warm clouds.

Bergeron's theory proposed that the difference in the saturation vapour pressure with respect to ice and water would lead to the preferential growth of an ice crystal at the expense of the cloud droplets in its vicinity. Without doubt, this process is of major importance in the middle latitudes.

THE VAPOUR PRESSURE DIFFERENTIAL PROCESS

Another precipitation mechanism parallel in some respects to that of Bergeron has been proposed by Petterssen (7). This would account for the development of raindrops in clouds due to the difference in temperature of small raindrops falling into a warmer environment, the difference in saturation vapour pressure of water at two temperatures producing a differential growth in a manner akin to that of the ice crystal effect. A variation in temperature of 0.01 degrees C at 25 degrees C would lead to the same differential as that which produces the optimum condition for the growth of snow crystals.

While this mechanism would lead to a logical development of raindrops, it is not easy to explain the method which starts the process. From a theoretical consideration, it is difficult to account for the early increase in size of the cloud particles from their relatively stable dimensions. Langmuir's (8) calculations suggest that it is impossible to maintain the necessary temperature difference between small particles long enough for some of them to grow large enough to start falling away from the others. From the experimental studies in our laboratory, high velocities and large temperature differentials fail to demonstrate this growth mechanism, although it is extremely easy to illustrate the ice crystal effect.

THE SALT NUCLEI PROCESS

It is quite possible that the mechanism of natural rain formation in warm clouds is intimately related to the presence of certain hygroscopic nuclei in the air.

Woodcock has obtained experimental evidence recently (3) that there are considerable numbers of large salt particles present in air over the sea in the trade-wind area. Salt particles as large as 2×10^{-11} grammes were collected by him at altitudes ranging from a few metres to a kilometre above the sea surface.

A recent series of observations (9) by our Project Cirrus group in the vicinity of Puerto Rico showed that rain developed in extremely thin clouds below the trade-wind inversion at temperatures of 8 degrees C. Light rains were measured coming from clouds whose measured thickness was less than 300 ft. Figure 5 shows a photograph of one of these. An estimate of the rainfall rate calculated from the observed rate of collection in flight showed that it would be approximately 0.05 inch per hour. A similar measurement of a thicker cloud 2,000 metres (6,500 ft.) in vertical thickness showed a rain-water content falling from the cloud into the sea at the rate of approximately 25 mm./h. (1 in./h.). The coldest part of this warm cloud had a temperature of +8 degrees C.

Such amounts of rain from relatively thin clouds are

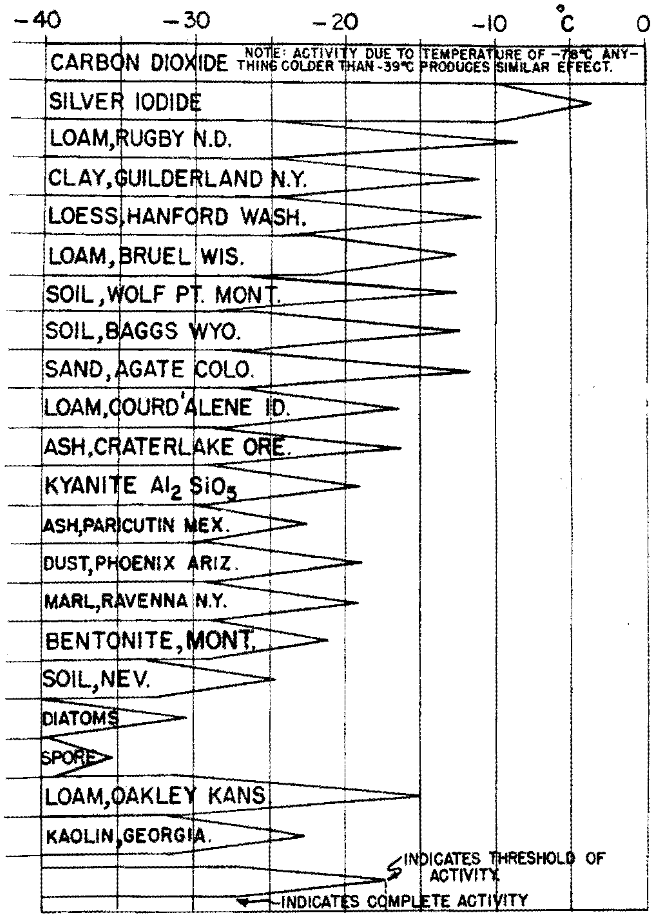


Figure 3. The temperature dependency for activity as ice nuclei of certain natural substances which may occur as aerosols in the atmosphere. Such particles may be responsible for the start of snow storms.

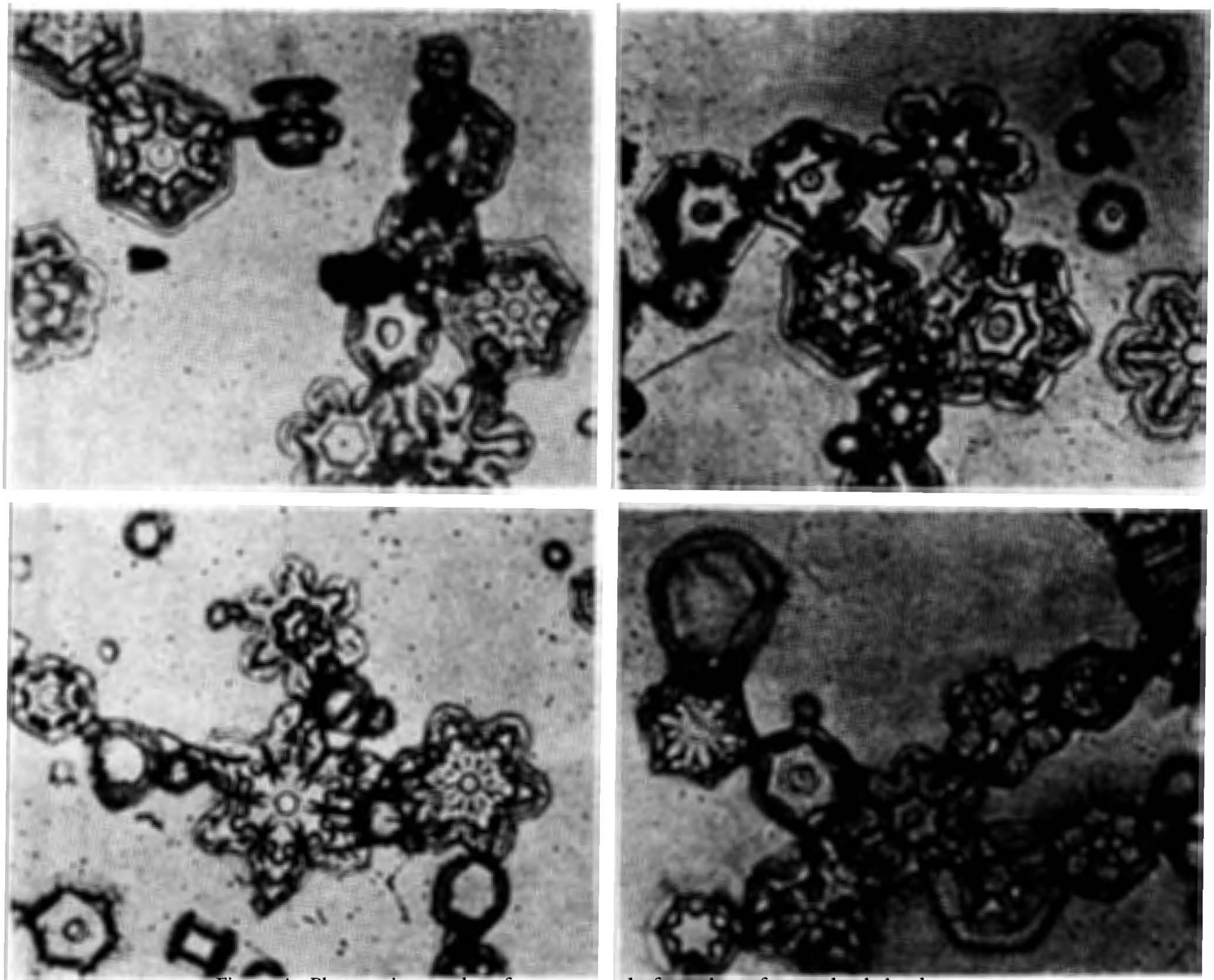


Figure 4. Photo micrographs of snow crystals formed on frozen cloud droplets.

rarely observed over continental America and obviously require a mechanism for rain formation different from the ice crystal effect.

While studying clouds in Puerto Rico, we also made some rough observations on the concentration of condensation nuclei in the air. Invariably, with air coming in from the sea, the levels were extremely low, the number rarely exceeding 200 per cub. cm. Similar observations have since been made along the New England Coast. In this latter case, however, the concentration jumps to high levels within a few miles inland as the high levels inherent to continental air raise the concentration from 10^3 to 10^5/cub. cm.

The experimental evidence thus far known seems to be compatible with the view that the salt crystal nuclei are extremely effective centres for rain formation. Due to their hygroscopic nature, they have considerable mass even before a normal cloud forms. Due to the larger size of these particles, there will be a tendency for them to start falling within the cloud at a different rate to that of the small droplets in their vicinity, thus gathering in by collision more and more of them. In this way, rain would form quite readily, and if the cloud had a vertical thickness of 1 km. or so, the particles could easily reach the maximum size that may fall without break-up. In addition to the growth by collision as the drop became larger, it might also add to its growth by the vapour pressure differential which, in the early stage, would be somewhat enhanced because of its salt content and in the later stages by the difference in temperature as the colder drop fell into warmer rising air.

MAN'S EFFORTS TO PRODUCE RAIN

Down through the ages, man in various ways has tried to get rain, prevent hail, and eliminate lightning. These efforts have ranged in method from ceremonial sacrifices to rain gods to spraying electrified sand and dumping such things as liquid air and dry ice to "cool the air". Since 1875, the literature is replete with pamphlets, books, patents, and popular stories giving reasons why such methods should be successful or detailed arguments to show that they could not possibly be effective.

During the past thirty years, several methods have been tried to modify atmospheric conditions which have claimed to make use of scientific principles. Most prominent of these have been the activities of Bancroft and Warren using electrified sand and Veraart using dry ice.

The electrified sand was used with the hope that the charged particles would attract oppositely charged cloud droplets and thus form raindrops. While considerable interest was displayed in these activities, the plan was doomed to failure because of the tremendous quantities of materials required, and the relative unimportance of the results obtained.

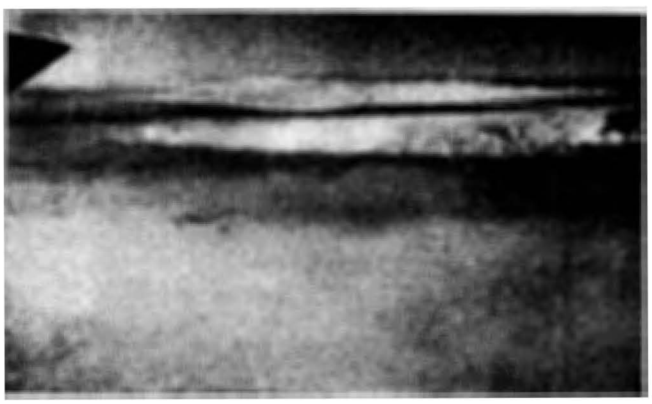
The next experiments which attracted considerable attention were centred on the claims of Veraart (10) of Holland who dropped dry ice from an airplane to affect clouds. A study of his theories and practices suggests that he was merely putting into practice methods proposed by Gathmann of Chicago (11) in 1891.

The effects expected from the introduction of dry ice into the atmosphere was to reduce the temperature of the air to either form clouds where no clouds previously existed or to augment the amount of condensed water already existing as a cloud with the expectation that it would produce precipitation of the cloud.

In his use of dry ice, Veraart proposed using very large quantities of this material. He apparently failed to recognize the importance of the effect of dry ice in supercooled clouds and, consequently, missed the chance to use this material in an effective way.

In 1938 Findeisen (12) in concluding an important paper entitled, "Colloidal Meteorological Processes in the Formation of Atmospheric Precipitation", made the following prophetic statement:

"The recognition of the fact that quite minute, quantitatively inappreciable elements, are the actual cause setting into operation weather phenomena of the highest magnitude, gives the certainty that, in time, human science will be enabled to effect an artificial control on the course of meteorological phenomena. It would be going beyond the limits of the present work to discuss in detail the possibility of exercising a kind of technical control over the course of weather conditions. From the considerations under survey here, we have now come to quite new points of view on this. It can be boldly stated that, at comparatively moderate expense, it will, in time, be possible to bring about rain by



(Official photo, U.S. Signal Corps Eng Lab.)

Figure 5. Thin stratus clouds of maritime origin which produced light drizzle rain. Temperature about 10°C and thickness about 100 metres. Flight 64, Project Cirrus, Puerto Rico.

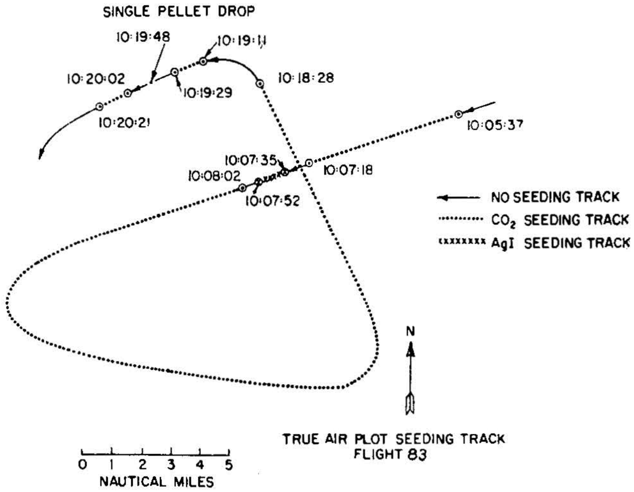


Figure 6. Seeding pattern used in Flight 83, Project Cirrus.

scientific means, to obviate the danger of icing, and to prevent the formation of hailstorms. Through the energy transformations thus secured, various other weather phenomena (e.g. temperature, wind) will be brought under a certain kind of control, which perhaps never, in a direct manner, could, to an appreciable extent, be acted upon in the atmosphere. The colloido-meteorological investigations, by themselves with the assistance of only research work on the means to get some control over the weather factors, have opened up a new field for their efforts. They obviously only can solve those various problems with the close assistance of aerology."

In recognizing the possibility of modifying unstable cloud systems, Findeisen pointed out the tremendous energies that might be released when the proper type of "seeding agent" was discovered and properly used.

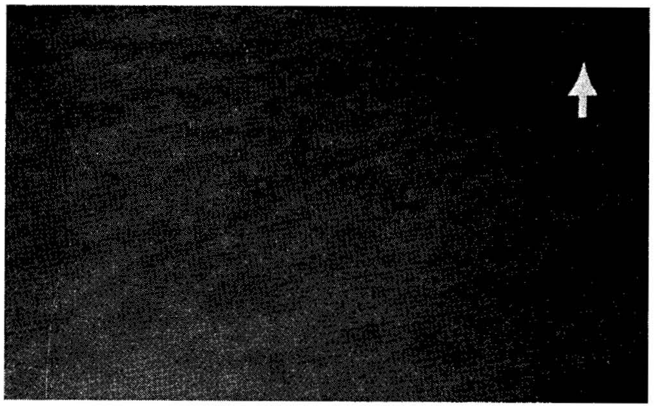
It is now believed that methods are now available to profoundly modify cloud systems and thus realize some of the effects predicted by Findeisen.

A study of the literature shows that at least one person observed that ice crystals could be produced in air supersaturated with respect to ice if the air was locally cooled to a very low temperature (13). The significance of this observation as it might be related to meteorology was apparently not considered by Adams.

METEOROLOGICAL STUDIES AT THE G.E. RESEARCH LABORATORY

In 1946, after spending the previous three years studying the nature of snow-storms and aircraft icing, the writer (14) described some laboratory experiments concerning the seeding of supercooled clouds with dry ice. He pointed out the important relationship between this effect, and the modification of supercooled clouds in the natural atmosphere.

On 13 November 1946, the first experiment with seeding supercooled clouds in the atmosphere was accomplished, producing results which had been anticipated on the basis of the laboratory results. A four-mile cold cloud was profoundly modified within a few minutes by dispensing 6 lb. of crushed dry ice into it. The cloud, which was supercooled to a temperature of approximately —17.5 degrees C and which before seeding showed no sign of



(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 7. View of rapidly spreading seeding.
Track behind plane dispensing dry ice. The plane is the dark spot just right of centre and is flying several hundred feet above the cloud deck being seeded. Flight 83, Project Cirrus.

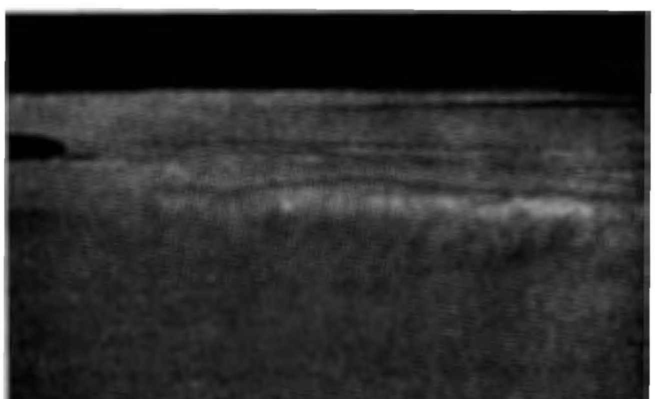
ice crystals, was completely changed to snow within five minutes after seeding.

Subsequent experiments in the fall and winter (15) of 1946 included the initiation of an extensive snow area in the Hudson and Champlain valleys of New York, the modification of a supercooled valley fog which initially reduced the visibility to a remarkable degree, the production of snow showers from cold stratocumulus clouds, and the production of extensive grooves and holes in a solid deck of stratus clouds.

In addition to these flight experiments in the natural atmosphere, the laboratory studies which had started in 1943 in the G. E. Research Laboratory were carried out on an increased scale in the fall of 1946 and winter of 1947.

These experiments pointed the way for further scientific work which would require extensive facilities. The General Electric Company is not in a position to supply such facilities and, consequently, a joint Army, Navy, and Air Force instrument wherein the General Electric Company provides scientific and technical guidance as consultants and the Government carries out all experiments other than those done within the General Electric Research Laboratory. This activity is identified as "Project Cirrus" and is administered by a Technical Steering Committee consisting of representatives of the Army, Navy, and Ari Force. Dr. Irving Langmuir and myself act as scientific consultants to this committee.

At the present time, the Operations Group of Project Cirrus uses a flight facility at the G. E. Flight Test Hangar at the Schenectady County Airport which includes two B-17s, one PB4Y-1, one JRB, and one L-5, and the necessary pilots, mechanics, cameramen, aerologists, and technicians to carry out flight operations for studying the various phases of the precipitation process.



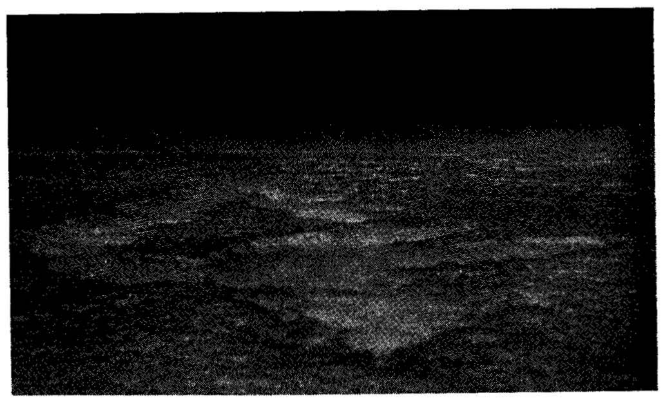
(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 8. Large subsiding area of snow crystals produced by the dry ice seeding of stratus clouds. Flight 73, Project Cirrus.

FUNDAMENTAL EXPERIMENTS IN CLOUD PHYSICS

THE FORMATION OF A SUPERCOOLED CLOUD

It is a simple matter to form a supercooled cloud (16). A chamber having dimensions of approximately 30 cm. wide, 50 cm. long, and 40 cm. deep is quite suitable for cloud experiments. Means should be provided to cool the air in the chamber down to a temperature of at least —25 degrees C, if possible. The walls of the chamber should be painted black or lined on sides and bottom with black cloth, such as velvet. Illumination may consist of a flashlight or similar type of focused light beam. With the chamber[2] cooled below ambient room temperature, a cloud may be formed within it by the introduction of moist air. Within a few seconds after condensation occurs, the droplets reach the temperature of the chamber. Under ordinary laboratory conditions, the cloud droplets reach a diameter in the range of 10 to 25 microns and a concentration of 200 to 1,000 per cub. cm. Occasionally, a few ice crystals appear in the chamber if the temperature is colder than —10 degrees C. Generally, however, this is a transient effect with rarely more than 1 crystal/cub. cm. forming. The supercooled cloud droplets persist until the air is no longer supersaturated with respect to water. During this period, a wire or miniature propeller will be coated with ice if rotated within the cloud. Eventually, the cloud disappears, the droplets slowly settling to the



(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 9. View of "Figure 4" seeding. One portion of pattern (the diagonal strip in the right foreground) was seeded with 25 grams of silver iodide. The rest of the seeding was with dry ice using less than 1 pound per mile. Flight 83, Project Cirrus.

[2]A very convenient type of chamber is a 4 cub. ft. home freezer, although it is possible to conduct effective experiments with much cruder apparatus if necessary. Two galvanized tubs separated by a water-ice-salt solution may be quite adequate for short experiments.

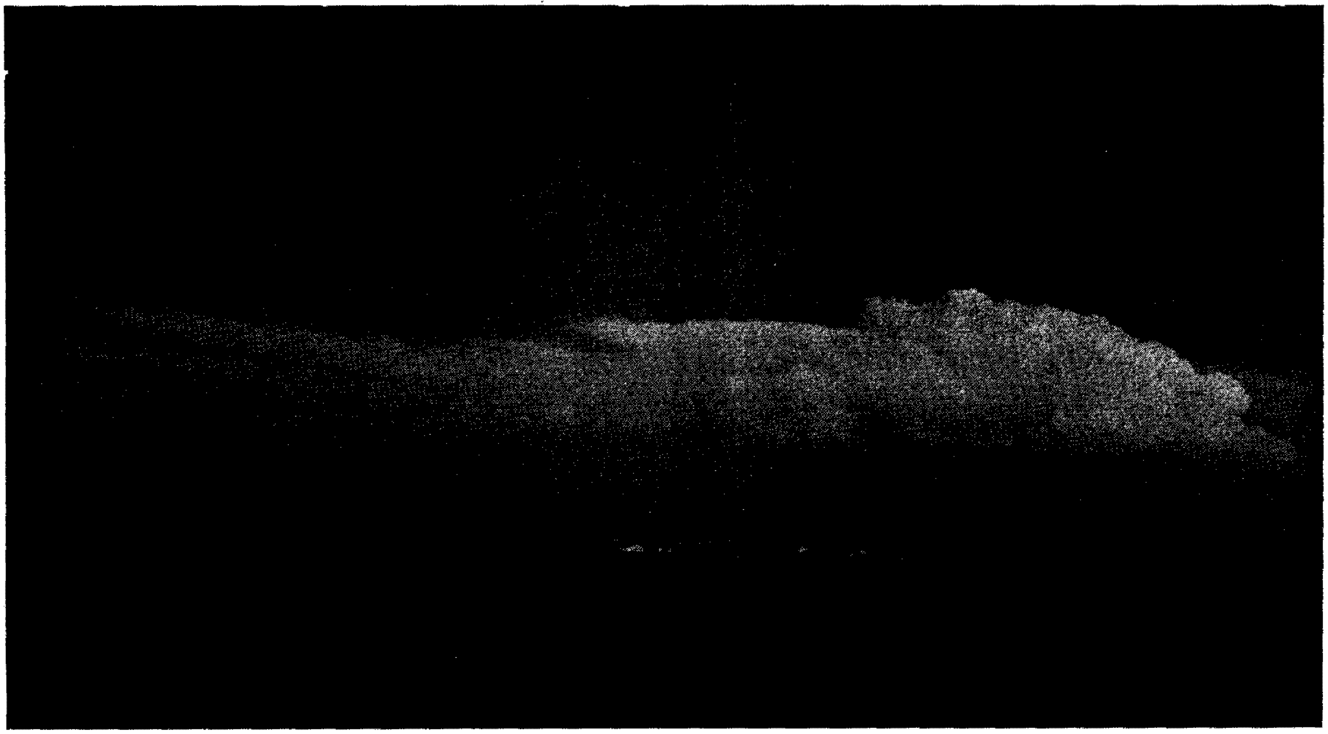


Figure 10. Cumulus cloud generating large quantities of ice crystals at high altitude. Streamers of "false cirrus" were produced by successive cumulus build-ups.

bottom of the chamber or evaporating onto the frosty walls.

Such relatively stable supercooled clouds may be formed to a temperature of nearly —39 degrees C. If, however, the temperature is reduced below this value, it is impossible to form a supercooled cloud.

THE FORMATION OF CONDENSATION NUCLEI

In most air samples likely to be used in laboratory experiments, there is no lack of condensation nuclei. Concentrations ranging between a thousand and a million per cub. cm. are normally observed. If the level is low, it may be increased by burning a bit of charcoal, striking a match, heating a nichrome filament, sparking a Tesla coil, or atomizing a salt solution. In fact, some very striking experiments may be carried out to demonstrate the optical effects possible with variations of type and concentration of condensation nuclei.

THE FORMATION OF SUBLIMATION NUCLEI

To demonstrate the presence of natural sublimation nuclei in the air under laboratory conditions is not easy. Sometimes the free air contains relatively high concentrations with the number occasionally reaching 10 particles per cub. cm. However, under ordinary conditions, the concentration seems to range between 50 and 500 per cub. metre. Under such conditions, a few particles will be seen in the beam of a light directed into the cold chamber containing a supercooled cloud.

As indicated in an earlier chapter, certain clays and other mineral dusts serve as effective sublimation nuclei at definite temperature ranges below 0 degrees C. A given sample may be evaluated by using particles of such a size that they readily form an aerosol. Shaking a box containing the sample while held in the chamber will produce a cloud, since the finer particles will float out of the container. The particles, if effective as ice nuclei, will become coated with a frost layer if the air is supersaturated with respect to ice. This normally occurs within 30 seconds. They become visible as twinkling crystals if allowed to grow and generally form asymmetrical crystals unless the initial particles are smaller than 1 micron in diameter. Methods already described in detail (16) may be used to study such particles.

The role played by silver iodide serving as a sublimation nucleus is outstanding. It may be introduced into the air some distance away from the laboratory and still have an appreciable effect in the laboratory if the air trajectory is favourable. A few simple laboratory experiments will be mentioned. A wire filament dusted with a few minute particles of silver iodide will, if heated in air supersaturated with respect to ice, produce many millions of ice crystals. The particles formed in this way are submicroscopic with many less than 100 Å in diameter. By drawing an arc with a pure silver wire using either a Tesla coil or by momentarily shorting the leads of a dry battery with a silver wire, a smoke of silver particles may be introduced into the cold chamber. In a supercooled cloud formed subsequently, no ice crystals will be observed if iodine vapour is absent. If, however, a small iodine crystal is then passed briefly through the chamber, large numbers of ice crystals will be seen to form in the wake of the crystal within the supercooled cloud. A still simpler means of demonstrating the silver iodide effect is to place a few particles on the end of a match which will be volatilized as the match is ignited, thus producing many nuclei.

As shown (5) by Vonnegut, the nature of silver iodide smokes in forming sublimation nuclei seems to be related to a probability function which has a fairly high temperature coefficient. Thus, at a temperature of —6 degrees C some sublimation nuclei will appear. At —10 degrees C with all other factors the same, many more particles will be observed in the same unit time. Space does not permit a detailed discussion of the interesting relationships which have been found. The original reports and papers of Vonnegut should be studied carefully if plans are contemplated to use this material for laboratory or field experiments.

PROJECT CIRRUS AND EXPERIMENTAL METEOROLOGY

Project Cirrus is a fundamental research study of the physical and chemical processes which occur in the lower atmosphere and produce clouds, snow, rain, atmospheric electricity, and associated phenomena.

One of the major activities of Project Cirrus is in the field of experimental meteorology. In this respect, observations and experimental studies are made with cloud systems having volumes ranging from less than one to more than several hundred cubic miles. The limitations in size are related primarily to available cloud systems and the physical conditions required for each particular experiment.

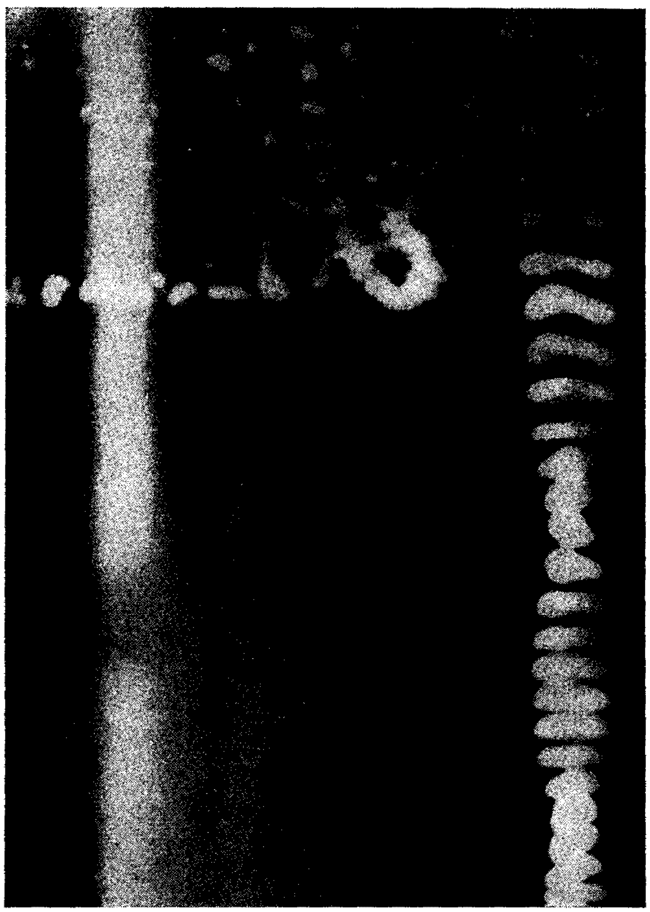


Figure 11. The oscillations and breakup of a single large drop of water floating in air having an upward velocity equivalent to the terminal velocity of the drop. Illumination with stroboscopic lamp flashing 90 per second. Drop dia. 8.1 mm.

These studies are planned and carried out insofar as possible as laboratory type experiments. Each operation is planned to supplement others previously accomplished so that some features are checked as new aspects are under exploration. In so far as possible, controls are maintained so that comparative evaluations may be achieved.

The major objective in this particular phase of our study has been directed toward the detection of unstable atmospheric conditions which develop in the atmosphere and often persist for some time. When such conditions are discovered various "triggering" actions are then applied in an attempt to shift the system to its more stable form. Such modifications of clouds often involve the release of tremendous quantities of energy. As pointed out recently by Longley (17), the energy release following the condensation and subsequent fall of one inch of rain on one square mile of the earth is equivalent to 1.7×10^{21} ergs. For comparison purposes, this is about twice that of the energy said to be released by an atom bomb of the type dropped on Hiroshima. Although much of this energy is released as the cloud forms, unless it is precipitated on the earth in an effective and useful way, it may be regarded as lost energy in so far as the earth and its water resources are concerned.

Evidence is now accumulating which shows that under certain conditions it is feasible to initiate the precipitation cycle artificially in some types of cloud systems so that their increased output forms a valuable addition to the natural resources of the earth.

Before going into a discussion of this fascinating subject, it may be in order to review briefly the operational facilities and procedures which we are now using in our basic research and studies of clouds and the atmosphere.

These activities may be divided into three major parts: (1) laboratory research; (2) field studies; (3) flight operations.

LABORATORY RESEARCH UNDER PROJECT CIRRUS

The main laboratory studies are conducted at the new General Electric Research Laboratory building at the Knolls in the lower Mohawk Valley in eastern New York. Complete facilities for physical and chemical studies with many unique features are available in this laboratory. Part of the laboratory in use includes a weather observatory equipped with standard, as well as special, meteorological instruments, radio communications, a small wind-tunnel, and a complete photographic dark room. In addition to the laboratory areas, excellent shop facilities are available including the services of skilled technicians for special developments in mechanical and electronic instrumentation.

In addition to these facilities, meteorological observations of a specific nature are carried on by special observers at the Mt. Washington Observatory on the summit of Mt. Washington in the state of New Hampshire. This mountain observatory, at an elevation of 6,288 feet above sea level, is world famous for its exceptionally severe weather, especially high winds and extended rime storms produced by supercooled clouds sweeping over the mountain. Besides having projects carried out by Observatory personnel for Project Cirrus, the research facilities on the mountain are always available to members of

Project Cirrus for testing instruments and studying various types of natural orographic clouds.

In addition to the experimental research activities at the Research Laboratory, an important phase of the laboratory programme is the analysis of flight data by photogrammetric methods and detailed studies of meteorological conditions present during the experiment. Considerable space in the laboratory is used for these purposes, and at least one person spends full time on this activity.

FIELD STUDIES UNDER PROJECT CIRRUS

Supplementing experimental research in the laboratory, the Research Group is involved in a considerable variety of field studies ranging from a study of the effect produced in the atmosphere by ground generators dispensing silver iodide smokes, detailed observations of various types of natural rain and snow-storms, studies of the development of all types of clouds using lapse time motion pictures, determination of the concentration of condensation and sublimation nuclei which occurs in the atmosphere, and activities of a similar nature dealing with weather phenomena associated with the formation of clouds and the subsequent development of precipitation. Many observations are made in regions other than eastern New York. For example, cloud studies have been conducted by one or more members of the Research Group in northern Idaho, Wyoming, and other parts of the North-west, Florida, Puerto Rico, various parts of New England, and Central America, particularly in Honduras. It is of great importance that cloud systems in various parts of the world be studied and their local peculiarities understood, since it is quite obvious that large differences exist in clouds, not only in their general development and life cycles, but even in their microstructure. Until these variations are better understood, it will be impossible to draw general conclusions about them.

FLIGHT OPERATIONS BY PROJECT CIRRUS

At the present state of our knowledge of clouds, it is of great importance that the general structure, as well as the microstructure, of clouds be explored by going into them. This may be accomplished to a limited degree by observing them at a mountain observatory using the summit as a stationary probe to study their structure as they pass by the station. The information gained in this manner is of great value but does not provide much data on convection, turbulence, and three dimensional structure which is of basic importance in studies of clouds in the free atmosphere.

The only method now reasonably satisfactory involves the use of one or more aircraft which can probe clouds at various levels and in doing so, register on automatic instruments some of the properties characteristic of the clouds explored. Good photographic techniques are of extreme value in this respect because of the complexity of clouds and the rapidity with which they change some of their features. It is impossible to obtain a satisfactory record by visual observation alone.

In this respect, some of our seeding techniques are of unique value since, for the first time, they provide a method of marking a cloud that will persist for a long time and may be seen for large distances. By taking consecutive pictures of a cloud area marked in this way, much information may be obtained during periods of an hour or more which shows the various mechanisms that are of importance in the formation and dissipation of clouds.

To carry out such a flight programme effectively requires much organization and specialized training of the personnel engaged in the work. The planes involved must have a considerable amount of workable scientific equipment especially suited for meteorological studies. In addition, it is of great importance that a special schedule is followed in reporting the results of each experimental flight study.

A TYPICAL FLIGHT OPERATION OF PROJECT CIRRUS

It may be of interest to describe a typical experimental flight study conducted by the Project Cirrus Flight Operations Group. For this example, Flight 83 will be described since it was a two plane operation employing both dry ice and silver iodide in the seeding operation.

At 1500 on the previous day, the weather group assigned to Project Cirrus, comprised of Navy personnel, notified the Chairman of the Operations Group that the synoptic situation suggested the strong possibility that a suitable supercooled deck of stratus clouds might be expected the next morning. An alert was sounded, crews were assigned duties, and tentative plans set for 0900 take-off in the morning using two B-17 planes.

Early the next morning, a check on the weather developments showed that the forecast was good, and each member of the flight groups carried through his assigned duties prior to take-off. These duties included, besides normal preflight preparations, such extra things as cleaning the windows used by the photographers, crushing and packing the dry ice in canvas bags, loading the silver iodide dispenser with fragments of impregnated charcoal, loading and checking the photopanel camera for operation, checking the operation of the automatic recording instruments, and making sure that the inking pens and charts were ready for operation.

Except for the preparation of the silver iodide and dry ice and their dispensing mechanisms, the above special activities were required for both planes.

On B-17 No. 5667 used as the seeding and probing plane, a crew of ten men were assigned for the operation including: 1 pilot, 1 co-pilot, 1 navigator, 1 flight controller (alternate), 1 photographer, 1 technical observer, 1 aerologist, 1 radio operator and 2 flight mechanics.

On B-17 No. 7746, the photographic and observation plane, a crew of seven men included the following: 1 pilot, 1 co-pilot, 1 flight controller, 1 photographer, 1 aerologist, 1 radio operator and 1 flight mechanic.

Just before take-off, both flight crews assembled for a briefing at which time a brief description of the proposed flight was given by the flight controller, including the general objectives of the operation. After take off, the planes were to rendezvous over the Albany Radio Range at approximately 20,000 ft. When the rendezvous was accomplished, the planes would again check radio contacts and proceed together to a position about 30 miles northwest of the range with the seeding plane holding a position on top of the stratus deck, the photo plane climbing but maintaining visual contact with the lower plane.

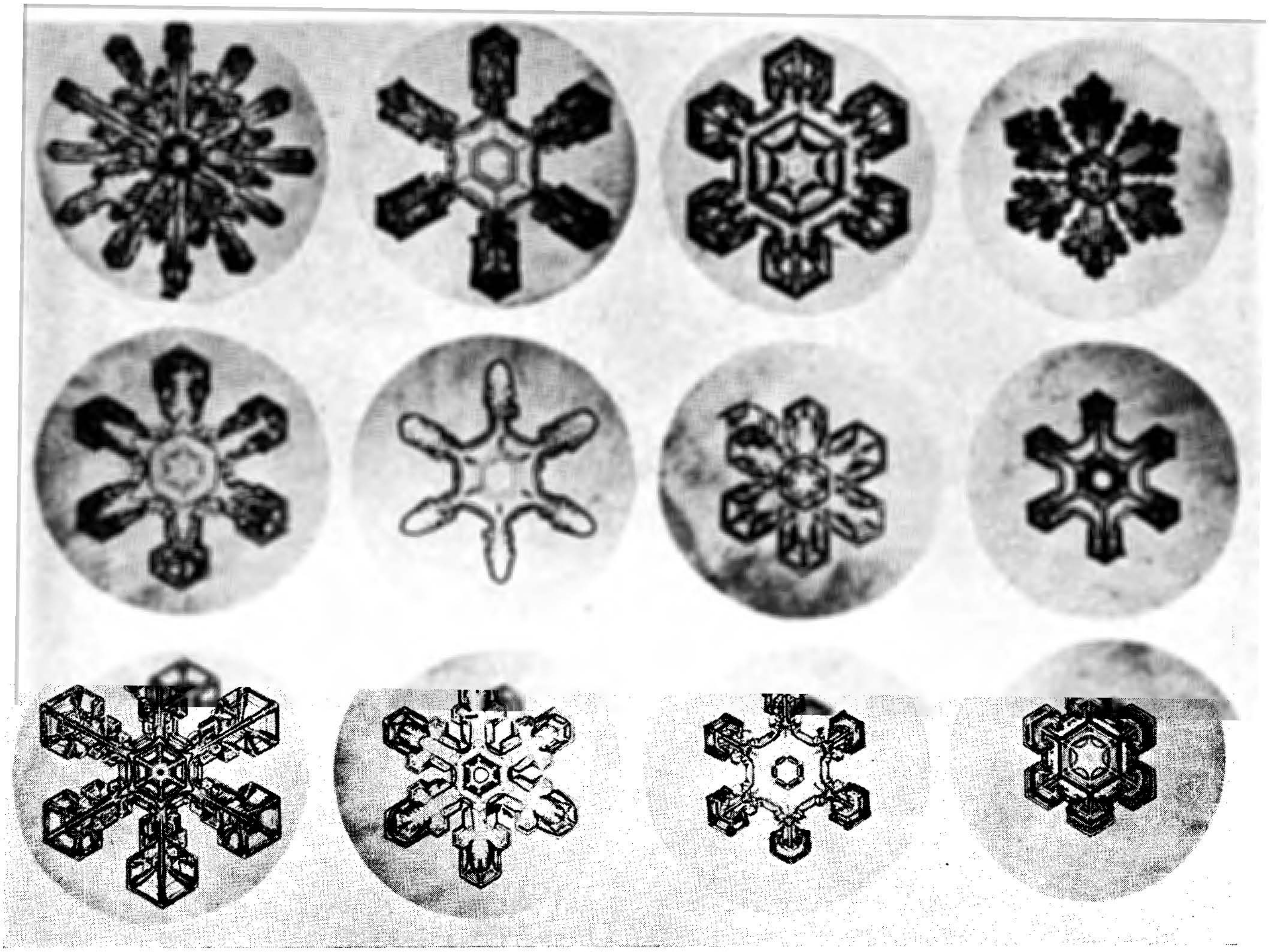


Figure 12. Photomicrographs of stellar crystals formed on cirrus type hexagonal plates.

From his vantage point in the photo plane, the flight controller sized up the situation as favourable for a "Figure Four" seeding pattern using $^1/_2$ lb. of dry ice pellets per mile of flight with a short seeding with silver iodide. He then ordered the preparations to start for dispensing the silver iodide charcoal since the seeding flight would start within a few minutes. The proposed "Figure Four" flight plan as suggested by the Research Group and adopted by the Operations Group is shown in figure 6.

As soon as the order to seed was given, the seeding plane went into its pattern, flying several hundred feet above the top of the slightly ragged top of the stratus deck putting out dry ice pellets for five miles, after which for one mile no seeding agent was used. The order to dispense the small burning charcoal fragments producing silver iodide was then given. About 20 seconds was required to dispense the silver iodide particles. Another one mile gap without seeding was next ordered, after which time dry ice seeding was again started and continued at the rate of $^1/_2$ lb. per mile until the "Figure Four" was outlined. Following this, a single dry ice pellet drop was made bracketed by a line of continuous seeding parallel to the first leg of the four pattern.

Throughout all of the seeding operation, the photo plane was cruising at 21,300 ft. For the first time, the seeded track immediately behind the seeding plane was photographed. Figure 7 illustrates one of several remarkable photographs obtained at this time showing the speed with which the dry ice effect spreads in the wake of the seeding plane.

Shortly after take-off the photopanels in both planes were started. Each panel holds the following instruments: rate of climb, air speed, altimeter, bank and turn, compass, clock, counter, free air temperature and battery of station indicator lights.

Automatic photographs are obtained of this instrument panel every 55 seconds while, in addition, whenever any one of four other switches at various positions are tripped an additional picture is taken. This permits the photographers, the aerologists, the flight controller, special observers or those with special assignments, such as dispensing the seeding agent, to produce a special record of any operation he might make individually as part of the flight operation.

After the seeding flight was completed, plane No. 5667 was directed by the flight controller to obtain low level photographs of the developing seeded pattern and, in addition, to probe the infected area to observe optical phenomena and other features that might be of interest. Figure 8 illustrates typical photographs obtained from this plane. Since the flight was made over mountainous terrain, it was decided to forego a descent through the deep trough cut by the ice crystals. After 30 minutes of probing studies and low level photographic coverage, it was released from further co-operative observations by the flight controller. A total of 24 photographs were taken at various altitudes up to 3,000 ft. above the cloud deck.

Meanwhile, plane No. 7746 was cruising above the seeded track taking still photographs and a few moving pictures. This continued for a period of 40 minutes during which time a total of 48 photographs were obtained. Figure 9 is a typical photograph taken during this period. By this time, the flight controller decided that an adequate set of photographs had been obtained since the pattern was beginning to deteriorate and no new phenomena were in evidence. It should be mentioned at this point that throughout the observation flight, the entire crew in plane No. 7746 were on oxygen since the flight occurred at an altitude of 21,300 feet. The flight was then terminated with both planes heading for the base where they landed at about 1130. Thus the operation required a total flight time of approximately 150 minutes, about 40 per cent of this time being employed in the experimental studies.

PROCEDURE FOR REPORTING ON AN EXPERIMENTAL FLIGHT STUDY

At the completion of a flight, the procedure now in use by the Flight Operations Group to effect a close relationship with the Research Group may bed ivided into four stages.

The pre-flight briefing. This involves the development by the Research Group of a series of experiments required to provide specific data on certain types of clouds. These requirements are studied by the Operations Group and adapted to flight procedures. A flight controller is designated who is directly responsible for the carrying out of the complete experimental flight. Personnel are kept on the alert for suitable cloud systems whenever the aerologists report suitable conditions within 200 miles. As soon as reasonable assurance is at hand that the type of clouds needed may be found, the planes take off, approach the system, and then follow through according to the briefing plan.

It is of great importance that the flight controller has several alternate plans for immediate substitution in the event that the cloud system is somewhat different from that expected from the reported synoptic situation. He must have the ability to size up the situation while approaching the experimental area and thus take advantage of whatever cloud system is found.

The preliminary report. Within an hour after the flight is completed, a brief report is transmitted to the Research Group by the flight controller which summarizes the results as observed and the general data obtained. This includes enough detail so that it is possible for the Research Group to determine immediately whether there is need for another flight to supplement the data obtained.

Detailed flight report. A more detailed report including copies of all the raw data, all logs and notes of observers, and contact prints of still photographs obtained are supplied to the Research Group within two days. Following a review of the contact prints, the Research Group orders enlargements of all photographs which appear suitable for analysis.

Final report. Within a week or two, all supplemental data not available at the time of the second report, reduced data from the photopanel, enlargements of selected prints, moving picture film and a meteorological analysis of the weather preceding, during, and subsequent to the flight study are supplied to the Research Group to aid in the analysis. The detailed analysis of the flight is then scheduled with relation to other flight operations under study. The summary of this work is subsequently published in an Occasional Report of Project Cirrus.

It should be pointed out at this time that the above procedure is carried out beyond the third and fourth stages on only those operations where the accumulated data is reliable and has sufficient detail to warrant spending the time involved in carrying through a complete analytical study.

TYPES OF CLOUD SEEDINGS USED IN PROJECT CIRRUS OPERATIONS

Two types of cloud seeding as related to flight studies shall be discussed at this time—the formation of ice crystals in supercooled clouds and the development of a chain reaction in cumulus clouds using large water drops.

The Dry Ice Effect

When solid carbon dioxide is introduced into a supercooled cloud in the atmosphere, enormous quantities of ice crystals form and produce profound changes in the cloud by the mechanism explained by the Bergeron-Findeisen theory. Crystals may be produced in such large quantities that it is sometimes possible to create conditions unlike those which occur naturally in the free atmosphere.

As mentioned earlier, it is extremely uncommon to find any ice crystals forming in natural clouds until some region has a temperature of —12 degrees C. Since the introduction of carbon dioxide ice (henceforth called dry ice) will produce ice crystals at any temperature below 0 degrees C, many cloud systems that would not shift to snow naturally may be affected by this type of artificial inoculation.

The enormous numbers of snow crystals produced in this manner also allow us to modify unstable supercooled clouds in several ways which rarely, if ever, happen in Nature. For example, it is possible by artificial means to shift all of the condensed water in a massive supercooled towering cumulus cloud to snow crystals in considerably less than five minutes. A similar cloud by natural processes normally requires an hour or more to reach the same condition and even after that time, might not be completely modified. The quantity of dry ice required to accomplish artificial modification is insignificant, since, as pointed out earlier, one gramme of dry ice is capable of producing at least 10^{16} ice crystals. Laboratory experiments show that tremendous members of ice crystals stream from a small pellet as it falls through the air. In order that these crystals


(Official photo, U.S. Army Signal Corps Eng. Lab.)

Figure 13. Portion of "Letter L" Pattern produced with about 1½ pounds of dry ice fragments per mile of flight. This "over-seeded" the cloud. Note the reflection of sun in the ice crystal region. Flight 3. Project Cirrus.

become effective, they must form in air colder than 0 degrees C which is supersaturated with respect to ice. By flying above or through the cloud, dry ice particles having sizes ranging from 1 to 20 mm. in diameter fall down or are carried aloft, depending on their size and the turbulence in the clouds. Natural convection and turbulence of cumulus clouds, augmented by the heat released by the change in phase from water to ice, assist in causing the rapid infection of a large region of the cloud system. Experiments show that if a concentration of crystals exceeding about 50 per cubic centimetre is present, the supercooled cloud thus infected is completely evaporated in less than ten seconds. With a concentration ten to twenty times more than this, the competition between particles for the available cloud water is so great that none of the particles grow as large as the original supercooled cloud droplets. As a result, the cloud is "overseeded" and becomes extremely stable. Such overseeded clouds rapidly lose their convective activity and become very stable and persistent. Examples of overseeded clouds may often be seen to form naturally when cumulus clouds pass through the transition temperature of —39 degrees C. Figure 10 illustrates a typical cloud of this sort. This generally occurs at altitudes of 28,000 ft. to 32,000 ft., the results appearing as anvil tops or as long streamers of cirrus clouds drifting across the sky in the tropopause region of the atmosphere. These overseeded effects, however, are rarely, if ever, observed in the natural atmosphere at warmer temperatures unless the clouds are seeded artificially or at times when natural seeding takes place due to the entrainment of snow crystals carried down from higher altitudes through stable air.

Since it is demonstrable that cold clouds may be overseeded, it follows that lesser amounts may be introduced as desired. This makes it possible to produce many interesting effects in cold and cool clouds. For example, it is feasible to seed and dissipate clouds at specific altitudes above the freezing level in the atmosphere and thus permit the development of large vertical thicknesses of supercooling. In this way, high supercooled clouds cannot form. Consequently, the sudden release of a large amount of energy necessary to produce thunderstorms and similar disturbances may be checked or at least reduced in intensity.

On the other hand, if it is desirable under certain conditions to go to the other extreme and attempt the release of the maximum amount of energy possible from a particular cloud system, this may be accomplished also. For this to be successful, it is necessary to wait until the maximum vertical development occurs at which time the cloud is seeded in such a manner that the optimum number of crystals are introduced to cause a rapid shift from the water to the ice phase and, at the same time, obtain the most effective particle size to initiate rapid precipitation. By properly carrying out such operations, it might at times be possible to release enough energy to break through inversions limiting the vertical development of the clouds.

The Development of Precipitation by Water Seeding

Langmuir has proposed (8) a mechanism for initiating precipitation in cumulus clouds. The method involves the introduction of relatively large water drops into clouds having the following properties:

(1) They must be actively growing cumulus clouds having vertical thicknesses greater than 1-1/2 km.

(2) The upward vertical convection in some region of the clouds must exceed 2-1/2 metres/sec.

(3) The droplets in the cloud must have a diameter of 15 microns or more.

(4) The average liquid water content of the clouds should exceed 2.7 grammes per cub. metre.

Field studies show that most actively growing cumulus clouds having a vertical thickness of 1-1/2 km. possess the other characteristics mentioned above.

When water drops larger than 0.01 cm. diameter are introduced into a region of the cloud having strong upward convection, they sweep up the smaller droplets in their path as they are carried aloft. Most of this coalescence occurs on the under-surface of the drop since the cloud droplets move faster than the larger droplets and are thus intercepted and collected. When the growing drops become so large that the pull of gravity exceeds the vertical lift of the air current, the drops begin to fall and sweep up even more cloud particles in their path. In addition, the falling drops by virtue of their lower vapour pressure grow by diffusion since they are continually invading air that is warmer than the residual temperature of the falling drops. When the drops reach a weight of about 0.5 grammes, they are no longer spherical but are flattened out in the peculiar manner shown in Figure 11. Such drops are potentially unstable and become susceptible to break-up. A small shearing force of the kind common to turbulent air is all that is required to shatter the drops into two or more smaller drops. Blanchard's experimental studies (18) in our laboratory show in a very elegant manner the limiting conditions of stability which restrict the size of falling rain drops.

If a growing raindrop in a cumulus cloud breaks apart before reaching the level from which it started growing, the mechanism constitutes a chain reaction. Thus one drop produces two or more; these droplets passing through the same cycle produce two or more, and within a very short time, many millions of particles have developed from the initial drop. If, for example, such an unstable drop breaks into five droplets (a common occurrence as seen in Blanchard's experiments), it requires only ten cycles for more than two million new drops to form.

The Effects Which May Develop from Water Seeding of Cumulus Clouds

Under most conditions, the introduction of large water drops into a convective cloud exceeding these critical dimensions might be expected to do no more than initiate a chain reaction within the cloud which would lead to its dissipation.

Since this mechanism is a mechanical one and is not related to a change in phase, no energy release is effected and, consequently, one would not normally expect anything to happen, save the disappearance of the cloud.

If, however, the precipitation develops as a chain reaction so that heavy rain forms on one side of a large convective cell, the down drafts might be so strong that an upward counter current is produced. If the air is unstable, this upsurge of air may lead to a local convergence which would certainly produce more precipitation than would normally result by the mere dissipation of the treated cloud.

The normal effect, however, which seems to be most commonly experienced when clouds are seeded by water is dissipation. This is an important feature, however, since even supercooled clouds may be affected in this manner. In respect to the dissipation of clouds, it should be emphasized at this point that many large clouds dissipate naturally, especially when the air aloft is dry. The best way to evaluate such results is to become familiar with the growth and disappearance of clouds by the use of lapse time moving pictures. Successive pictures of clouds taken by a movie camera at 2-1/2 second intervals and then viewed at the normal rate of 16 per second, speed the apparent development of clouds by a factor of fortyfold. A familiarity of cloud development gained in this manner permits the observer to make a critical evaluation of results which follow seeding operations.

THE APPLICATION OF SEEDING METHODS TO CLOUDS OF VARIOUS TYPES

THE MODIFICATION OF OROGRAPHIC CLOUDS

The modification of orographic clouds by seeding methods presents a particularly intriguing possibility. These are clouds which form as moist air is forced to rise as it encounters a barrier such as a mountain range. In rising, the air expands and cools as its pressure decreases. If the amount of cooling drops the air below the dew point temperature, a cloud forms.

Under many conditions, the clouds formed by orographic processes are cool or cold clouds, especially in the wintertime or when towering cumulus develop over certain mountain peaks or ridges.

The condensed water in orographic clouds in the wintertime is not very high, since it rarely exceeds 1 gramme per cub. metre. Such clouds, however, are very common in mountainous regions and often form continuously for many days. Even a cursory study of them reveals that relatively little precipitation reaches the earth from them except as rime deposits on trees and rocks or in the form of scattered snow crystals. Under most conditions observed on mountains in the north-eastern United States, snow crystals do not form in sufficient numbers to use up the available supercooled cloud droplets. Consequently, only a small fraction of the clouds which form in this manner are precipitated. If techniques can be devised to cause a widespread and effective precipitation of such clouds, the depth of the snow pack in the vicinity of mountains might be markedly increased. Such a result would be of much importance since the snow pack on mountain slopes is of great importance in stabilizing the streams which flow from such regions.

The use of ground generators using silver iodide smokes is one way in which orographic clouds might be seeded. Unless such clouds form at relatively low temperatures, however, this seeding material will not be of much importance since temperatures below —10 degrees C are necessary if an efficient production of nuclei is to occur. The concentration of nuclei must be of the order of 50 to 100 per cub. cm. where the vertical rise of the cloud is rapid if the available cloud droplets are to be converted to snow. Whether particles of this concentration will subsequently grow large enough to form precipitation is a question which is answered best by experimentation with varying types of clouds, temperatures, wind velocities, and vertical accelerations in mountainous regions. Such particles will probably grow large enough to fall to the earth's surface if the cloud beyond the mountain summit is of sufficient thickness to sustain the growth of the particles until they become large enough to precipitate. In many instances when orographic clouds have temperatures of —10 degrees C or colder, the liquid water content of the clouds is so low that it is questionable whether the precipitation initiated with silver iodide would be economically feasible.

The production of ice crystals in orographic clouds by the use of dry ice, liquid carbon dioxide, or similar methods requires that the crystals be introduced into air supersaturated with respect to ice. In addition to this requirement, it is also necessary that the seeding be a continuous operation. This imposes rather severe limitations on the region where such operations may be carried out effectively. For this reason, it is at present questionable whether a feasible method is known for carrying out the seeding of relatively thin and cold orographic clouds on a scale that would have economic importance.

A method might possibly be developed, however, making use of the riming nature of cold clouds so that very weak rime feathers are formed which continually shed tiny ice fragments into the wind. That this might be feasible is suggested by the fact that small rime fragments form a considerable percentage of the ice particles observed in the air during an icing storm. If the source of these particles was better understood, a more effective way of forming them in larger quantities could probably be developed which might not require more than the planting of certain types of sub-alpine trees or the construction of man-made structures in certain regions on the upwind side of the mountains.

THE PRODUCTION OF REGIONS OF ICE NUCLEI IN THE SKY

It sometimes happens that large snow storms from low, cold clouds are started and kept going by their contact with a thin layer of middle or upper clouds, such as altostratus or cirrus. Conover has described (19) an interesting case of this kind.

It is a fairly common experience to note examples of the seeding of lower clouds by cirrus crystals. This latter type of observation may be deduced by a study of the snow crystals reaching the ground during a snow storm. This condition generally produces stellar snow crystals with cirrus type hexagons in the centre. This is illustrated by figure 12 which shows a few samples of crystals which grew in this manner.

The production of specific regions in the free atmosphere containing high concentrations of ice nuclei or potential ice nuclei is now an interesting possibility. Cold middle clouds, even though having no appreciable moisture, may be used as "holding reservoirs" to store ice crystals until they come into contact with lower clouds of greater thickness or are entrained into cool or cold cumulus. An example of this type of seeding is contained in the seeding operation during our high level study (20) of Hurricane King on 13 October 1947. A relatively thin layer of stratus clouds covering an area of nearly 300 square miles was transformed to snow crystals. The subsequent fate of these ice crystals is still a moot question, but if a considerable region of them was entrained into the lower levels of a line of towering cumuli observed during the flight and located in the southeast quadrant of the storm, the entrainment of these snow crystals might have exercised a profound effect on the subsequent development of these cumuli.

Similarly, the ice crystal residue from seeded, but small, cumulus clouds may be entrained at a low level into much larger cumuli forming in their vicinity. In this way, an effect of considerable magnitude is produced as the supercooled regions are infected at a lower level than would otherwise be possible.

It will take much careful study to establish methods for utilizing this type of seeding. Eventually, it may become one of the most important of all.

A discovery that would have great importance in this respect would be a stable sublimation or freezing nucleus which would be effective at a temperature within 1 or 2 degrees below 0 degrees C. It is obvious from the observations made thus far that natural nuclei of this kind are rarely, if ever, formed. It thus remains for us to find or develop a substance in the laboratory which will fit the requirements.

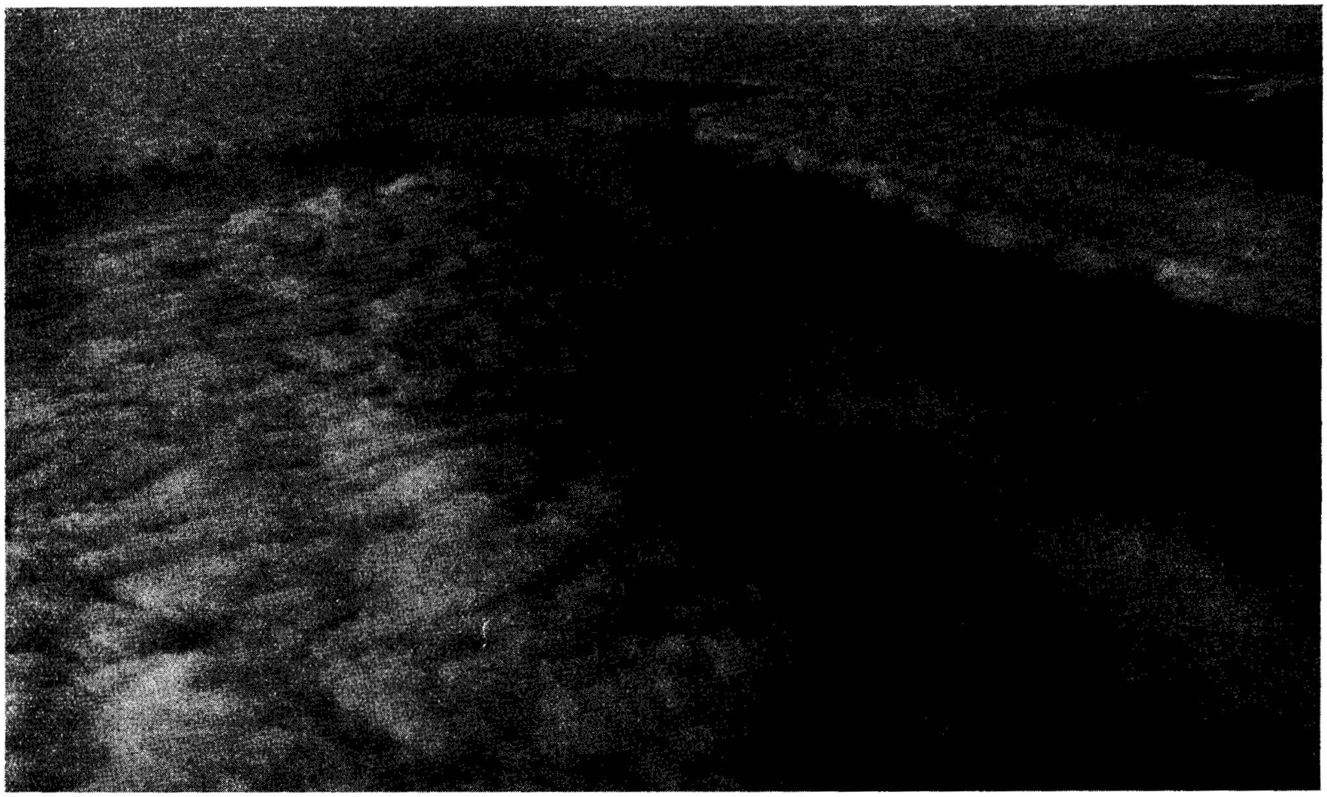
THE MODIFICATION OF STRATIFORM CLOUDS

The widespread modification of stratus clouds by artificial means is possible at the present time whenever such clouds are supercooled. Under such conditions, the clouds may be further stabilized by over-seeding them or their precipitation may be accomplished by using an optimum number of ice nuclei. This latter result is achieved by using only enough ice nuclei to cause the cloud particles to evaporate completely as they condense onto the crystals thus formed which then grow large enough to fall as snow.

Typical results obtained in seeding cold stratus clouds are shown in figures 13, 14, 15 and 16.

Stratus clouds may be seeded by flying 30 to 100 metres above them and dropping dry ice fragments ranging in size from 0.1 to 1 cm. diameter at the rate of approximately 250 grammes (1/2 lb.) per mile. Except with clouds thicker than 2 km. (6,500 feet), the use of more than one pound of dry ice per mile will tend to produce overseeding.

Besides seeding stratus clouds from on top, it is also possible to seed them effectively by flying through them as well as by flying at the cloud base. At this lower position, however, there is no need of using large fragments since the dry ice is only effective in air supersaturated with

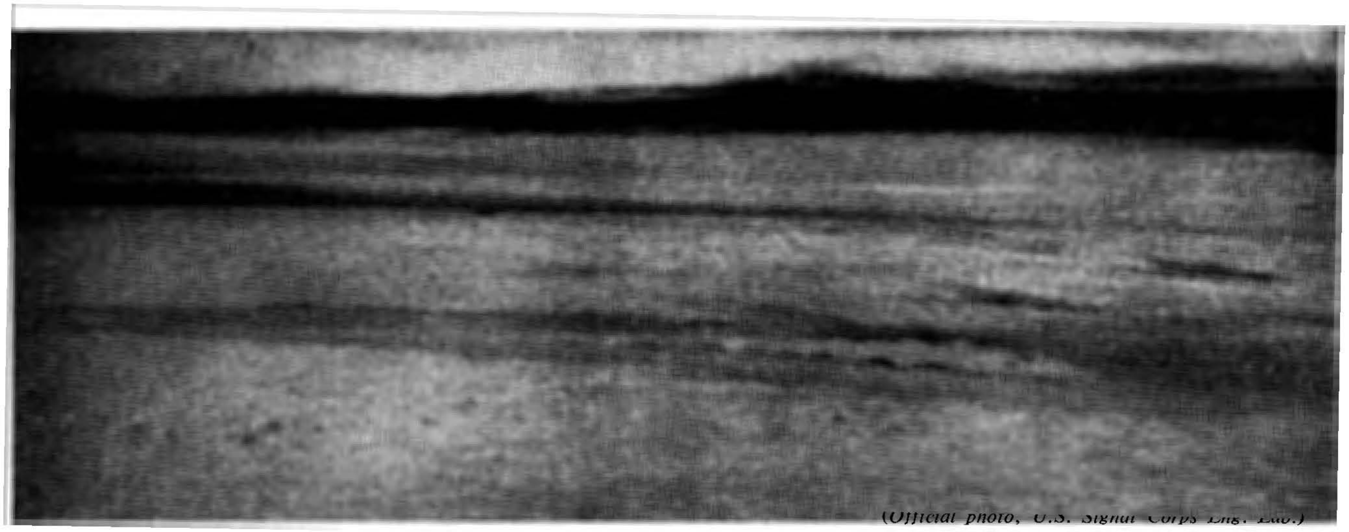


(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 14. A view of a "Gamma" pattern 21 minutes after seeding a solid deck of stratus clouds using dry ice fragments at the rate of 1.3 pounds per mile. Each leg (not all shown) about 30 miles long. Flight 52, Project Cirrus.

(*Official photo, U.S. Signal Corps Eng. Lab*).

Figure 15. View of "Racetrack" pattern produced with dry ice seeding using less than 1 pound of dry ice per mile of flight. Straight legs are 18 miles long. Flight 53, Project Cirrus.



(Official photo, U.S. Signal Corps Eng. Lab.)

Figure 16. View of "Figure Four" pattern produced by dry ice seeding with legs 10 miles long. Flight 73, Project Cirrus.

respect to ice. A zone below the cloud base equivalent in depth to approximately 10 metres per degree C below freezing will support the formation of ice crystals formed with dry ice. Thus, if the temperature at the cloud base is —10 degrees C, a distance of 100 metres below the cloud will become filled with ice crystals if dry ice fragments are sprinkled or liquid CO_2 is sprayed into that region.

THE MODIFICATION OF SUPERCOOLED GROUND FOGS

While warm ground fogs formed by advection or radiation may only be modified at present by heating the air to cause its evaporation, supercooled ground fog formed in a similar manner may be modified and even dispersed if care is exercised to prevent overseeding.

In order to disperse a cold fog of this sort, it is necessary to use up the available condensed water by seeding with only enough ice nuclei so that the crystals grow large enough to precipitate. An average concentration of about 20 ice nuclei per cub. cm. is about the number required to produce this effect.

If higher concentrations are used, there is a real danger that the density of the fog will actually increase, thus reducing the visibility to a remarkable degree. Since most ground fogs rarely contain more than 200 particles per cub. cm., it is a simple matter to produce 10,000 per cub. cm. of ice crystals in the same volume of air. This not only reduces the visibility but also makes the fog considerably more stable due to the very small particle size and the further removal of moisture from the air.

Very peculiar optical effects occur in an overseeded cold fog. The outlines of objects near the limit of visibility become extremely fuzzy and of an unreal appearance. In addition, the light scattered in the fog has a peculiar bluish cast due to the Rayleigh scattering from particles small with respect to the wavelength.

The prevention of the formation of ice fog is another possibility that may be attained by the proper manipulation of seeding techniques. By introducing an optimum number of sublimation nuclei into the air in regions where such fogs are troublesome, it may be possible to continuously remove the moisture from the air which is responsible for the formation of this interesting but often troublesome type of ground fog.

The ice crystals generated in the vortices of airplane propellers plus the moisture added to the air by the combustion engine of the plane are the effects which generally lead to the formation of ice fogs at airports.

Whether the removal of supersaturation with respect to ice by seeding methods will be of sufficient magnitude to prevent ice fogging effects produced by plane operations can be determined most conclusively by actual experimentation.

THE MODIFICATION OF ICING CLOUDS FOR THE PROTECTION OF AIRCRAFT

This effect suggests an interesting possibility—the elimination of icing clouds in the vicinities of airports and along heavily traveled air lanes. There is no question about being able to accomplish the modification. The problem which exists at present is whether or not it may have a practical application.

Low clouds which restrict the visibility for landing approaches around airports, thick clouds in which planes must cruise as they wait for permission to land, and thick clouds which might deposit a serious icing load on a plane as it tries to climb up through them—these comprise hazards to safe plane operations. Whenever such clouds are supercooled, they may be profoundly modified as shown in figures 17, 18 and 19. The practical and economic importance of such operations can only be determined after detailed studies are made in regions where such problems are thought to exist.

The simplest means for carrying out such cloud modification operations is to employ a plane well equipped for flying under serious icing conditions. Such a plane would be assigned the job of patrolling the air lanes, reporting weather and cloud conditions and whenever serious supercooled clouds occurred, would carry out seeding operations. A more direct means for protecting individual planes may be the use of projectiles for modifying the cloud directly

(Official photo, U.S. Army Signal Corps Eng. Lab.)

Figure 17. View of the gap produced by dry ice seeding of a deck of stratus clouds. Flight 52, Project Cirrus.

ahead of a plane. This hardly seems practical for peace time operations, however, since a considerable hazard is involved in shooting anything into clouds.

Perhaps the most serious limitation to this use of cloud modification is the fact that, at the present extent of our knowledge, icing clouds are nearly unpredictable. The indefinite persistence of such clouds because of their unstable nature is the feature that will probably prevent any effective use of this application of cloud seeding within the near future.

In flying through a supercooled cloud, the airplane itself may produce a fairly effective modification since the vortices which form at the trailing edge of the wings and particularly from the propeller tips form large numbers of ice crystals as the expanding air in the vortex cools below —39 degrees C. Laboratory studies of this effect indicate that as many as 10^{12} nuclei per cub. cm. may be formed in this manner. It is significant that when aircraft icing studies are carried out in supercooled clouds, it is difficult to obtain an accumulation of ice on the plane by making successive passes through a particular cloud. After the first traverse, the icing property of the cloud is radically changed, and it is often impossible to find any supercooled cloud in a region where heavy icing was present a few minutes earlier.

THE MODIFICATION OF OROGRAPHIC THUNDERSTORMS

An extremely important type of orographic cloud is the towering cumulus. In most mountainous regions, certain peculiar topographic features combine to favor the local formation of clouds. At certain seasons of the year, the clouds generated by these "cloud breeding" regions develop into such large cumuli that they become thunderstorms. Such storms once formed often become detached from their site of development and produce violent disturbances. This aspect of these clouds will be discussed in a later section.

Since orographic cumulus formations are common in specific regions (21), they provide nearly ideal conditions for research studies and the evaluation of various techniques in experimental meteorology.

It may be possible that silver iodide seeding from ground generators would be particularly useful in modifying orographic cumuli to prevent their growth into thunderstorms. By determining the air trajectory from the ground into the cold part of the cloud, potential ice nuclei may be sent aloft by a very simple procedure. Since silver iodide particles become quite effective in the region between —12 degrees C and —16 degrees C at which temperature the largest differential exists between the partial vapour pressures of water and ice, it is quite possible that such clouds could be profoundly modified by permeating their general area with effective ice nuclei. If subsequent experiments indicate that it is important to seed such clouds at a temperature only a few degrees colder than the freezing point (0 degrees C), it may become necessary to use dry ice dispensed from planes or carried into the clouds by free balloons or projectiles.

The pioneer work, however, must be accomplished using, if possible, both ground observation stations and aircraft. Aircraft alone must be used if the nature of the region precludes the use of ground stations.

THE POTENTIAL PRECIPITATION CONTAINED IN CLOUDS

From quantitative considerations, it is obvious that unless convergence of moist air occurs during the development of clouds and precipitation, the amount of rain or snow that may reach the ground is at best of minor importance in relation to the water resources of the earth. For example, a cloud having a vertical thickness of 2 km. and an average liquid water content of 1 gramme per cub. metre would produce only about 2 mm. of rain if completely precipitated.

With a towering cumulus, however, having a vertical thickness of 5 km. and an average liquid water content of 3 grammes per cub. metre, the precipitable water is more than 1/2 inch. Since such clouds are potentially unstable, the sudden conversion to rain might also lead to a local lifting of moist air which could produce even more precipitable water. Such clouds may often be seen to form and dissipate without producing any precipitation. It is for this reason that careful studies should be conducted to learn everything possible about the physical and colloidal properties of towering cumulus.

THE MODIFICATION OF TOWERING CUMULUS

As indicated in the last paragraph, the cloud structure of great economic importance is the towering cumulus. While such clouds often are produced by orographic lifting, they also form over flat country at times when the atmosphere is conditionally unstable. Differences in ground heating and contact effects between warm and cold air along frontal systems often lead to the formation of large regions of such cloud structures. If local conditions permit the continued development of such storms within two to five hours, they may develop into thunderstorms. Dangerous and often deadly lightning strokes, torrential rains, destructive winds, and sometimes hail and tornadoes are the end products of such developments.

Invariably such storms in their formative stages are characterized by a high liquid water content, strong vertical velocities, and supercooled clouds whose vertical thickness may exceed 5 km. before any ice crystals form.

This large volume of supercooled cloud is invariably observed during the initial stages of a thunderstorm and must, to a large extent, be responsible for the sudden outbreak of such storms once their growth exceeds a critical stage. The large degree of instability due to supercooling may be altered within a few minutes as ice crystals invade the cloud. The large amount of energy released in this process provides additional impetus to the vertical development of the storm. The rate at which this shift in phase takes place is one of the important variables determining the subsequent progress and development of the storm. Since under some conditions, the increase in temperature alone may exceed 3 degrees C, the total amount of energy released in this manner is of tremendous magnitude. In a relatively small storm, it may be equivalent to that released by several atomic bombs.

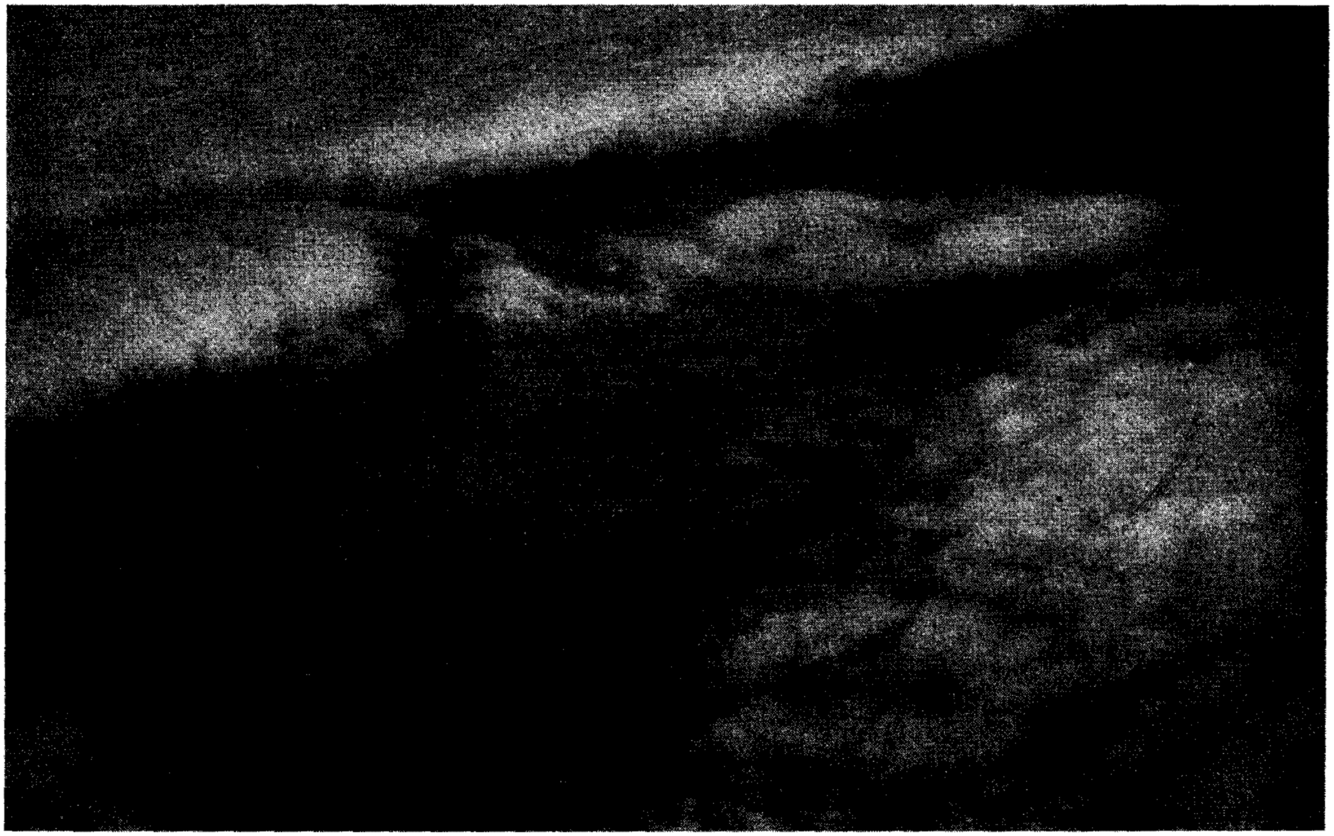
It is the presence of thick supercooled clouds which raises the distinct possibility that profound changes may be induced in cloud systems which are growing into thunderstorms.

Since the high, vertical thickness of a supercooled cloud seems to be a basic requisite in the formation of a thunderstorm, it may be quite feasible by proper seeding methods to prevent this phase from developing.

The manner in which this seeding is done may produce a wide variation in the end results obtained. By seeding each cumulus tower with large numbers of crystals shortly after it rises above the freezing level, the cloud would be continuously dissipated and no extensive regions of supercooled cloud could develop.

On the other hand, it might be desirable to seed such clouds to realize the maximum possible energy release. This presumably would involve seeding each cumulus tower just previous to the point of its maximum development. If this could be done effectively, it might be possible to build the storm into a much larger one than would develop under natural conditions. There is some evidence to believe that such a result was realized by Flight 45, a Project Cirrus experiment conducted 14 October 1948 at Albuquerque, New Mexico. The preliminary analysis (22) of this operation prepared by Langmuir suggests that the seeding of some large supercooled towering cumulus may have initiated a convergence over a considerable area. A total amount of 50 lb. of dry ice particles were dropped into three regions of a cloud system forming over the Manzano Mountains southeast of Albuquerque in New Mexico on 14 October 1948. These seedings apparently released enough energy to break through a layer of stable air existing at 23,000 ft. which had been limiting the formation of large cumulus clouds in that region. This "break through" apparently started a convergence of air into the region and led to the development of an extensive thunderstorm which traveled to the north and northeast.

In his preliminary analysis of the operation, Langmuir concludes that this storm which seems to have been started



(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 18. Portion of nearly 250 square miles of stratus clouds removed by dry ice seeding at rate of 1.3 pounds per mile. Flight 52, Project Cirrus.

by the seeding operation produced an average rainfall of 0.37 in. over an area of more than 12,000 square miles. There is some evidence, he believes, that another nearby area of precipitation may also have been an off-shoot of this storm. If this area is included, the total rainfall would be nearly doubled amounting to about 500 million tons of water.

If this interpretation of the results of Flight 45 is substantiated by further studies and, particularly, if the observed phenomenon is repeated under similar meteorological conditions, it will be quite obvious that this phase of experimental meteorology will become of major importance in its relationship to the development of more adequate water resources.

THE PREVENTION OF HAIL BY SEEDING METHODS

Of considerable economic importance is the possibility that hail storms might be prevented by seeding techniques. Hail is believed to form under conditions of strong vertical convection in cumulus clouds having a high liquid water content but low concentrations of ice nuclei. With relatively few active nuclei within supercooled clouds at temperatures between —5 degrees C and —20 degrees C, hail particles may grow very rapidly by the difference in the partial vapour pressures of water and ice aided by the agglomeration of relatively large supercooled water droplets.

If large numbers of ice nuclei were present, the competition for available water would be so keen that no particles could grow very large. The importance of silver iodide for this type of modification is obvious since it might be practical to use ground generators positioned in such a way that these sublimation nuclei would be carried into the clouds by entrainment. Since silver iodide particles become quite active at temperatures colder than —10 degrees C, this substance should be quite valuable for this application if a reliable technique can be developed to get the nuclei into the critical regions where it could be effective.

A considerable amount of basic information is needed on the various properties of storms that produce hail. In some parts of the country where severe hail damage is frequent, storms are formed over certain mountain ridges and peaks that serve as cloud breeders. Such clouds should be particularly suited for modification by ground generators since the air trajectory is definitely related to the flow of air up the mountain and into the clouds.

To accomplish the desired results, it may be necessary to build up a concentration of nuclei of the order of not less than 100 per cub. cm. in all the air likely to be involved in forming the cloud. With efficient generators, this should be possible using approximately 100 mg. of silver iodide for 1 cub. km. of air.

THE APPARENT LIMITATIONS TO THE MODIFICATION OF CLOUD SYSTEMS

As in any of the physical phenomena, there are definite limitations to the degree in which experimental meteorology may be employed in modifying clouds in the free

(Official photo, U.S. Signal Corps Eng. Lab.)

Figure 19. Large area of supercooled stratus cloud modified by dry ice seeding. Flight 83, Project Cirrus.

atmosphere. Some of these apparent limitations may disappear as our knowledge increases although most of the restrictions now recognized are imposed by known physical laws.

Foremost of these is the factor of cloud size and type. Certain clouds, such as the fair weather cumulus (*cumulus humilus*), have such a small volume and restricted area that, even though they are easily modified when supercooled, their total liquid water content is inconsequential. As pointed out in a previous section, even clouds of considerable vertical thickness contain but relatively small amounts of condensed water. Another complicating factor is that the air below larger clouds is sometimes so dry that a considerable amount of precipitation evaporates before it reaches the ground.

Another type of cloud which is difficult to modify is the warm ground fog formed by radiation or advection. Such fogs are often extensive and of considerable economic importance, especially from the standpoint of airplane traffic control. The natural structure of a fog precludes any simple method of modifying it. Generally, the vertical thickness is not more than 100 metres or so with a cloudless sky above. This rules out the modification from above by forming precipitation in higher clouds to "rain out" the fog. On the other hand, supercooled ground fog may be modified and, in some cases, dispersed by the intelligent application of presently known methods of infecting the atmosphere with seeding agents.

Another weather situation where no method of relief is now apparent is in the case of drought. This condition generally results from the stability of a complex weather pattern in a manner which, at present, is not very well understood. Drought is generally accompanied with either cloudless skies or by clouds of small vertical and horizontal development due to strong inversions or thick layers of dry air.

A typical drought condition of this type occurred in New York state between 1 June and 25 June 1949. A dome of high pressure of great stability developed over the north-eastern part of the United States and resisted the encroaching movement of a cold front to the westward. This high became stagnant for nearly a week and then slowly moved eastward causing the persistent movement of fairly moist and very warm air from the south. Cumulus clouds occurred with increasing frequency after a week of nearly cloudless skies but were restricted in their vertical development by a layer of dry air existing between 8,000 ft. to 16,000 ft. where the temperature ranged from +8 degrees C to —6 degrees C and the mixing ratio fell from 6 grammes per kg. to less than 1 grammes per kg. of air. The cloud structure was mostly of a diurnal nature with the nights being cloudless, while the greatest development occurred toward evening due to the convection produced by the sun.

On the evening of the fourteenth day, a few widely scattered and very local showers occurred coming from single cloud systems. Figure 20 illustrates a cloud which produced a brief shower as it passed across a strip about

Figure 20. Appearance of large cumulus clouds which produced the first local showers on the fourteenth day of a drought in Eastern New York.

two miles wide by ten miles long. The cloud dissipated in about an hour, the average amount of rainfall within this area being considerably less than 0.05 in. — scarcely enough to lay the dust. If a number of clouds of this kind formed rain in succession, the accumulated moisture might be of importance. Unfortunately, the development and dissipation of this cloud required nearly two hours and eventually reduced the cloud cover to zero since the heating effect of the sun needed for this type of cloud formation was no longer present due to the late hour of the day.

The development of convergence is an important feature in the formation of appreciable amounts of rainfall in many parts of the world. As a rule, such developments are generally accompanied by the occurrence of natural precipitation which continues so long as the convergent movement is present. About the only thing that artificial modification of clouds might do under such atmospheric conditions is the initiation of the precipitation cycle a few hours before it would start naturally or, under some conditions, to delay the onset of precipitation by overseeding.

An interesting and valuable analysis of the relationship of cloud types and systems and the possible effect which might be produced in them by artificial seeding operations has been presented recently by Bergeron (23). Papers of this kind are of the utmost value, especially when they consider and evaluate the results of laboratory and field operations. It is the feeling of the writer, however, that such evaluations must be limited at the present time to a consideration of the cloud systems in regions of the world familiar to the observer. Generalization without observational data may raise obstacles which are not truly valid.

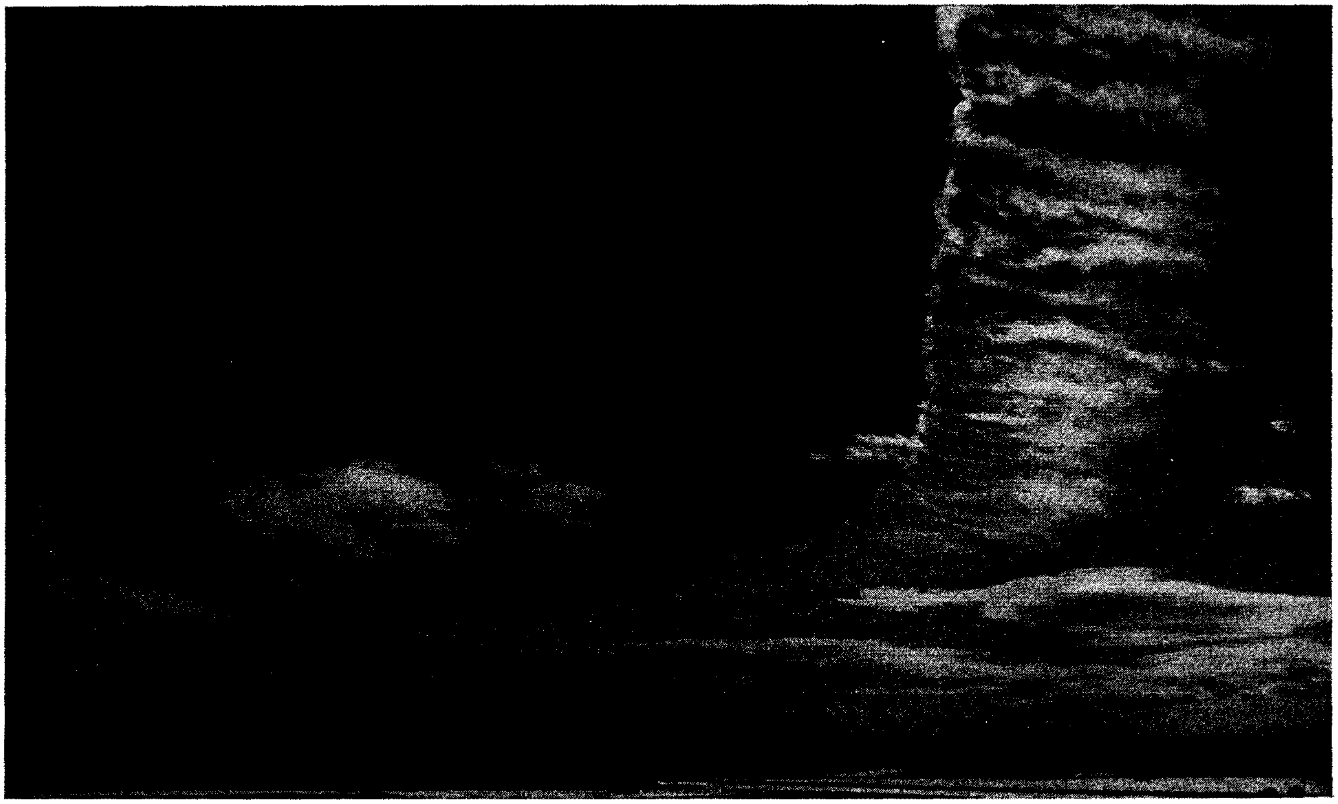
A series of experiments (24) carried out in Ohio by a group associated with the United States Weather Bureau have reported results which they have interpreted as of doubtful economic importance. A study of the results which they describe could be interpreted with a more optimistic viewpoint as confirming many of the claims made thus far by other workers in the field.

In view of the present relatively crude techniques and rapid advances now being made in the field of experimental meteorology, it may be wisdom to refrain from making world-wide generalizations until more experimental and observational data become available.

THE WORLD-WIDE INTEREST IN EXPERIMENTAL METEOROLOGY

The world-wide interest in cloud seeding techniques and the considerable success which has resulted in their proper application is an example of applied research that is quite typical of the application of fundamental scientific knowledge.

The successful results obtained by some groups and the negative results experienced by others seem, in general, to be directly related to the scientific attitude of those carrying out the experiments and their understanding of the basic processes involved.



(*Official photo, U.S. Signal Corps Eng. Lab.*)

Figure 21. The formation by dry ice seeding of a snow crystal area in a region previously free of clouds. This occurred because the air was super-saturated with respect to ice due to the absence of ice crystal nuclei.

It is naive, to say the least, to expect that promiscuous and random seeding of clouds will relieve droughts and in other ways lead to profound changes in the weather cycle. That is not the way progress is achieved with a new science.

It is first necessary to have a thorough knowledge of the basic principles involved and a concept of the conditions which seem favourable to their successful application. It is then necessary to devise experiments which will supplement the obvious relationships with new approaches to the problem in such a manner that the possibilities and limitations of each technique may be properly delineated and evaluated.

The research related to experimental meteorology which is underway in such places as Australia (25), South Africa (26), Hawaii (27), Canada (28), and Honduras (29) are typical examples of the attitude which is necessary to gain a proper perspective of the possibilities and limitations of cloud modification in various parts of the world.

Insofar as practicable, it is of great importance that the results of such research become available to everyone interested as soon as possible.

Since the beginning of our weather research activities and continuing with Project Cirrus, all of our basic research studies have been of an unclassified nature. The flight operations under Project Cirrus, though classified, are generally declassified within a short period. This far-sighted and laudable attitude on the part of our sponsoring agencies has engendered a co-operative attitude among most of those engaged in cloud physics studies throughout the world. Such international scientific co-operation is of paramount importance at the present time.

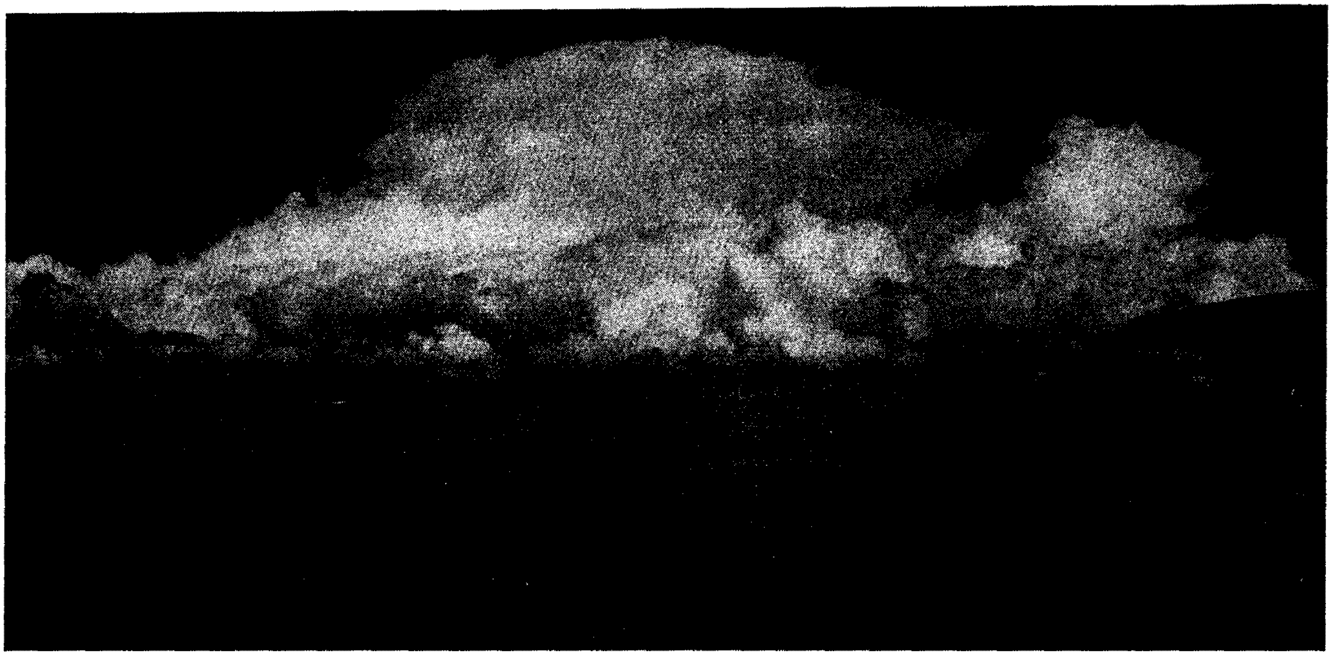
The basic information concerned with the various phases of our laboratory, field, and flight studies has been issued as reports and, in some instances, published in scientific periodicals. These have been sent to interested representatives of 22 countries. In addition numerous letters containing specific questions have been answered during the past several years. In all such communications, great emphasis has been placed on the need for carrying out experiments and observations in as objective and scientific a manner as is possible with the facilities available.

Perhaps the most effective means for passing on scientific information, as well as gaining it, is in the personal visits to our laboratory which we have enjoyed from scientists in our own country, as well as other parts of the world.

In addition, members of the Research Group have presented more than 20 papers before annual meetings of scientific societies. Many more talks have been given before Sigma Xi Clubs and Chapters, local sections of the American Meteorological Society, American Geophysical Union, American Chemical Society, and other scientific assemblies.

Probably as a result of this attitude toward the interchange of ideas, we enjoy an unusually fine co-operative interchange of ideas, reports, and discussions with most of the active groups in this field throughout the world.

If our world is to progress and become a better place to



(Official photo, U.S. Signal Corps Eng. Lab.)

Figure 22.[f] Heavy rain showers falling from a cumulus cloud which had been seeded 90 minutes previously with less than 5 pounds of dry ice. The initial radar return due to precipitation occurred 15 minutes after seeding. The rain continued for at least 2 hours and affected an area of more than 200 square miles. At the time this rain occurred the nearest precipitation area was at a distance of 113 miles.

live in, this co-operative attitude in science and all other intellectual pursuits is of prime importance.

Insofar as experimental meteorology is concerned, there is no question whatsoever that some phases of its development will be of great importance to the science of meteorology and the conservation of our natural resources. The economic aspects of this science must eventually be weighed, the important phases recognized, and the others put aside for later reference or eventual discard.

As in any science, however, as the basic studies advance and new knowledge throws light on hitherto obscure facets of the general problem, advances in wholly unexpected directions will be made.

It is for this reason that we should plan our studies in such a manner that the prime objective is the increase of scientific knowledge. If we adopt this philosophy, we shall find that not only experimental meteorology and our knowledge of the atmosphere and its relationship to our natural resources shall benefit, but advances will also be made in the fields of nucleation, supercooling, crystallography, diffusion, and small particle studies, to mention a few.

The degree of success which may be anticipated in the near future shall be in direct ratio to the enthusiasm, initiative, curiosity, imagination, and perseverence of those concerned with the general field of experimental meteorology. As long as unsolved problems exist, progress will be made if man is permitted to use his inherent capabilities.

It is my sincere hope that this initial phase of the United Nations discussion of the resources of the world will lead to the proper realization of the interdependency which exists, not only among all the sciences, but also among all men. I trust that those of us interested in experimental meteorology may do our part to advance the welfare and happiness of the human race, as well as the proper conservation of our natural resources.

ACKNOWLEDGMENTS

The size and scope of many research projects at the present time make it difficult, if not impossible, to adequately define and give credit to those responsible for the success of a project. A well co-ordinated team of enthusiastic workers becomes more and more a necessity. Because of their inter-related responsibilities, it is nearly impossible to place credit where it is due.

This is particularly true with respect to Project Cirrus which enjoys the co-operative effort of members of the Army, Navy, and Air Force, as well as the General Electric Research Laboratory.

With a realization of this fact, I should like to mention particularly the excellent co-operation extended to the general project by the members of the Technical Steering Committee, Dr. Michael Ference of the Army Signal Corps, Mr. Earl Droessler of the Office of Naval Research, and Col. Herbert M. Spencer of the Air Force. In addition, the excellent co-operation among the Operations Committee at Schenectady is due at the present time to the Chairman, Major Rudolph C. Koerner, Jr., of the Army Signal Corps, Lt. Commander Paul J. Siegel of the Navy, Capt. Carl F. Wood of the Air Force, and Mr. Kiah Maynard of General Electric.

Since teamwork is the basis of our present activities, I shall list those members of the Project who have been associated with it for six months or more. Any success achieved in the advances of the general aims of Project Cirrus must be attributed to their co-operative efforts.

(Official photo, U.S. Signal Corps Eng. Lab.)

Figure 23. The early stage of an extensive all day rain-storm which it is believed was initiated and sustained by seeding the area with silver iodide. This was produced by a small ground generator and carried into the clouds by convection.

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[2] Personnel no longer with the project.

[3] Personnel on part time basis with project.

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Canadian Experiments on Induced Precipitation

JOHN L. ORR, assisted by K. G. PETTIT and D. FRASER

ABSTRACT

A co-operative investigation into induced precipitation has been undertaken in Canada and a total of fifty-nine trials have been made using dry ice as an inoculant. In addition, the results of twenty similar trials performed in Australia are compared.

The analyses of these experiments show that precipitation reached the ground on 24 per cent of all Canadian trials whereas in selective tests with only supercooled cumulus clouds precipitation reached the ground on 43 per cent of the trials.

The meteorological conditions favourable to inducing precipitation and for ensuring that such precipitation reaches the ground are stated.

Reference is made to the generation of clouds of ice crystals in clear air by inoculation.

It is concluded that precipitation can be artificially induced under the appropriate meteorological conditions. The limitations of the method are discussed and it is emphasized that induced precipitation can only supplement natural rainfall. Comments are made on the application of the method to agriculture, forestry and waterpower.

The economic significance of induced precipitation is considered to be specific to a given application and to a particular region and therefore its usefulness can only be assessed on the basis of individual requirements.

From the scientific standpoint the results that can be obtained are noteworthy and it is considered that the subject merits further study.

INTRODUCTION

A co-operative programme of investigations into induced precipitation was established in Canada in June 1948 under the aegis of the Co-ordinating Committee on Induced Precipitation. The participants were the Canadian National Research Council, Meteorological Service, Defence Research Board and the Royal Canadian Air Force.

Altogether a total of fifty-nine trials have been made, under both summer and winter conditions, and over diverse geographic areas. Twenty-seven of these trials were of a selective nature, being specifically intended to produce rain, so that only promising clouds were seeded (Figure 1). Twelve of these were carried out in the Mississagi district (near Lake Superior) in an attempt to quench forest fires (1)[1]; twelve in the Kapuskasing region in connexion with the shortage of water for hydro-electric power (2); and three at Suffield, Alberta. The remaining thirty-two trials which were made at Arnprior, Ontario, were of a random nature; all types of clouds not suspected of containing ice crystals (Figure 2) being inoculated, regardless of their potentialities (3, 4).

Experiments of a similar nature have been performed in Australia (5, 6) and acknowledgement is made to the Council for Scientific and Industrial Research for granting permission to include some of their results in this paper.

EXPERIMENTAL TECHNIQUE

Seeding procedure. The dry-ice seeding method as proposed by Schaefer (7) was employed exclusively throughout these tests.

The procedure and equipment used followed that outlined in a Laboratory Note of the National Research Council (8). In all cases an aircraft was employed for seeding and wherever possible the inoculant was discharged at the top of the cloud at altitudes up to 21,000 ft. When it was not possible to climb to the top of the cloud, seeding was done as high as possible, and at least above the freezing level, in the case of supercooled cloud.

Dry ice which had been crushed to pellets approximately 3/8 in. mesh was discharged at rates varying from 2 lb. to 10 lb. per mile. The experimental results did not give any evidence of the existence of a critical rate of seeding beyond which precipitation could not be induced.

Observational Technique. With few exceptions, the observations of precipitation were purely visual and qualitative, as there was a lack of ground observers and of radar facilities in the regions of the tests.

All of the recorded precipitations occurred within 20 minutes of seeding and the majority occurred within 10 minutes. This time of reaction is considered sufficiently short so that the effects could be attributed to inoculation.

PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

Over-all results. A general analysis of the over-all results is presented in tables 1, 2 and 3, which are largely self-explanatory. However some definition of the terms used is necessary.

[1]Numbers within parentheses refer to items in the bibliography.

"*Supercooled*". A cloud is supercooled when all or a portion of it consists of liquid water droplets at a temperature below 0 degrees C.

"*Precipitation*" is defined in this paper as rain or snow leaving a cloud. Whenever precipitation reached the ground without total loss by evaporation, it is so stated.

"*Virga*" are precipitations which do not reach the ground.

"*Unique*" implies that precipitation was not occurring naturally within a 25-mile radius.

Perhaps the most remarkable thing about these results is that, although over half of the fifty-nine tests were non-selective, yet precipitation or modification occurred in 76 per cent and precipitation reached the ground in 24 per cent of the total number.

Twelve cases of unique precipitation leaving cloud give so high an incidence as to preclude coincidence or faulty observation.

Non-supercooled clouds: The only results obtained from non-supercooled clouds were subsidences, and there is a reasonable doubt as to whether these were actually caused by seeding, and not by aerodynamic disturbances or natural causes. It may be of interest to note that the maximum depth of non-supercooled cloud which was seeded was 7,000 ft.

Supercooled clouds: Supercooled clouds, on the other hand, gave some most definite results, which are shown in table 4 for cumulus clouds and in table 5 for stratus type clouds.

Supercooled cumulus: From table 4 it will be seen that the percentage results from supercooled cumulus clouds are notable, precipitation or modification occurring in 83 per cent of the total thirty-five trials. If the criterion of success is precipitation reaching the ground, the percentage is 34 per cent and if it is unique precipitation reaching the ground, then the percentage is 11 per cent.

Supercooled stratus. A comparison of the tests on supercooled cumulus (table 4) and supercooled stratus type clouds (table 5) shows that with the latter there was a lower percentage of results and precipitations, with precipitation reaching the ground in only 12 per cent of the trials compared with 34 per cent. On the other hand, there was a higher proportion (57 against 35 per cent) of unique precipitation leaving the cloud. This is readily understood since stratus type clouds have less tendency than cumulus to precipitate naturally.

FACTORS AFFECTING PRECIPITATION LEAVING SUPERCOOLED CLOUD

The variation of precipitation successes with cloud-top temperature (where success is defined as precipitation leaving cloud), is shown in table 6 for cumulus clouds. For comparison this table also contains the results of experiments made by the Australian Council for Scientific and Industrial Research. The agreement between the completely independent Australian and Canadian tests is very interesting. The single Australian failure which occurred at —22 degrees C. has not been explained and it is unfortunate that there was no comparative Canadian test. The combined results in Figure 3 show a smooth

<table>
<tr><td rowspan="11">CUMULUS CLOUDS
A - 19
M - 11
K - 8
S - 3
(41)

A -Arnprior
M -Mississagi
K -Kapuskasing
S -Suffield</td>
<td rowspan="7">SUPERCOOLED (Below 0°C.)
A - 14
M - 11
K - 8
S - 2
(35)</td>
<td rowspan="6">RESULTS (Precipitation or Modification)
A - 12
M - 9
K - 6
S - 2
(29)</td>
<td rowspan="4">PRECIPITATION (Leaving Cloud)
A - 9
M - 6
K - 6
S - 2
(23)</td>
<td rowspan="2">PRECIPITATION (To Ground)
A - 3 K - 1
M - 6 S - 2
(12)</td>
<td>UNIQUE
A-0 K-1
M-3 S-0 (4)</td></tr>
<tr><td>NON-UNIQUE
A-3 K-0
M-3 S-2 (8)</td></tr>
<tr><td rowspan="2">VIRGA (Not to Ground)
A - 6 K - 5
M - 0 S - 0
(11)</td>
<td>UNIQUE
A-4 K-0
M-0 S-0 (4)</td></tr>
<tr><td>NON-UNIQUE
A-2 K-5
M-0 S-0 (7)</td></tr>
<tr><td rowspan="2">MODIFICATION (Only)
A - 3
M - 3
(6)</td>
<td>DEVELOPMENT</td><td>A-0 K-0
M-2 S-0 (2)</td></tr>
<tr><td>SUBSIDENCE</td><td>A-3 K-0
M-1 S-0 (4)</td></tr>
<tr><td colspan="4">NO RESULTS A - 2, M - 2, K - 2, S - 0 Total - (6)</td></tr>
<tr><td rowspan="4">NON-SUPERCOOLED (Above 0°C.)
A - 5
M - 0
K - 0
S - 1
(6)</td>
<td rowspan="3">RESULTS
A - 4
M - 0
K - 0
S - 0
(4)</td>
<td colspan="3">PRECIPITATION (0)</td></tr>
<tr><td rowspan="2">MODIFICATION
A - 4
(4)</td><td colspan="2">DEVELOPMENT (0)</td></tr>
<tr><td>SUBSIDENCE</td><td>A-4 K-0
M-0 S-0 (4)</td></tr>
<tr><td colspan="4">NO RESULTS A - 1, M - 0, K - 0, S - 1 Total - (2)</td></tr>
</table>

Table 1

<table>
<tr><td rowspan="11">STRATUS CLOUDS
A - 13
M - 1
K - 4
S - 0
(18)</td>
<td rowspan="7">SUPERCOOLED
A - 11
M - 1
K - 4
S - 0
(16)</td>
<td rowspan="6">RESULTS
A - 8
M - 1
K - 2
S - 0
(11)</td>
<td rowspan="4">PRECIPITATION (Leaving Cloud)
A - 4
M - 1
K - 2
S - 0
(7)</td>
<td rowspan="2">PRECIPITATION (To Ground)
A - 0 K - 1
M - 1 S - 0
(2)</td>
<td>UNIQUE
A - 0 K - 1
M - 0 S - 0 (1)</td></tr>
<tr><td>NON-UNIQUE
A - 0 K - 0
M - 1 S - 0 (1)</td></tr>
<tr><td rowspan="2">VIRGA
A - 4 K - 1
M - 0 S - 0
(5)</td>
<td>UNIQUE
A - 2 K - 1
M - 0 S - 0 (3)</td></tr>
<tr><td>NON-UNIQUE
A - 2 K - 0
M - 0 S - 0 (2)</td></tr>
<tr><td rowspan="2">MODIFICATION
A - 4
(4)</td>
<td colspan="2">DEVELOPMENT (0)</td></tr>
<tr><td>SUBSIDENCE</td><td>A - 4 K - 0
M - 0 S - 0 (4)</td></tr>
<tr><td colspan="4">NO RESULTS A - 3, M - 0, K - 2, S - 0 Total - (5)</td></tr>
<tr><td rowspan="4">NON-SUPERCOOLED
A - 2
M - 0
K - 0
S - 0
(2)</td>
<td rowspan="3">RESULTS
A - 1
M - 0
K - 0
S - 0
(1)</td>
<td colspan="3">PRECIPITATION (0)</td></tr>
<tr><td rowspan="2">MODIFICATION
A - 1
(1)</td><td colspan="2">DEVELOPMENT (0)</td></tr>
<tr><td>SUBSIDENCE</td><td>A - 1 K - 0
M - 0 S - 0 (1)</td></tr>
<tr><td colspan="4">NO RESULTS A - 1, M - 0, K - 0, S - 0 Total - (1)</td></tr>
</table>

Table 2

Figure 1. Typical cumulus cloud formations: A. Composed of water droplets (note "hard" outline)—suitable for seeding. B. Composed of ice crystals (note diffuse outline)—not suitable for seeding.

Figure 2. cumulus cloud with natural ice veil (20,000 ft. —12° C)

trend toward increasing success with decrease in cloud-top temperature. The histogram shape is similar to that of the curve of the difference between vapour pressure over water and over ice, as a function of temperature.

Nevertheless, it is not suggested that temperature is the sole controlling factor as it is obvious that the effect of inoculation must also depend on other factors such as total water content, depth of supercooling and mixing activity.

Another histogram, figure 4, of percentage successes against depth of supercooling, for the Canadian and combined results, also shows a definite trend toward 100 per cent success at a depth of 4,000 ft. or more, regardless of the degree of supercooling. Unfortunately, from the analytical aspect, cloud-top temperature and supercooled depth can be treated neither as independent variables nor as direct functions of each other. Accordingly tables 7 and 8 show success ratios in terms of both temperature and supercooled depth for the Canadian and combined results respectively. From these tables it would appear that there are limiting lines at both 4,000 ft. depth of supercooling and —12 degrees C. cloud-top temperature beyond either of which 100 per cent success can be achieved.

PRECIPITATION REACHING THE GROUND

From the purely practical aspect, the only interest is in precipitation which reaches the ground. A considerable number of Canadian experiments were directed toward

Table 3. Overall Tests

(Total: 59 trials)

		Per cent
Results (precipitation or modification)	45/59	76
Precipitation leaving cloud	30/59	51
Precipitation reaching ground	14/59	24
Unique precipitation to ground	5/59	9
Unique precipitation leaving cloud.................	12/30	40

this practical application and the results of these selective tests are shown in table 9.

The only significant differences between the results for all supercooled cumulus and selected supercooled cumulus are, first, that a higher percentage (43 per cent as against 34 per cent) of precipitation reached the ground from the selected clouds, and second, that curiously enough, unique precipitation to the ground was also higher (19 per cent compared with 11 per cent) in the case of the selected clouds.

The first difference is to be expected, as the selected clouds were chosen for depth and density, but the second difference presents an anomaly since the selected clouds were of a type which occur in conditions conducive to natural precipitation. However, in comparison with the over-all tests (table 3) the precipitation to the ground from the selected clouds was 43 per cent as against 24 per cent.

Actually, the most noteworthy feature of the selective tests was the occurrence of three unique cases of heavy

CUMULUS CLOUDS VARIATION OF PRECIPITATION SUCCESSES

FIG. 3

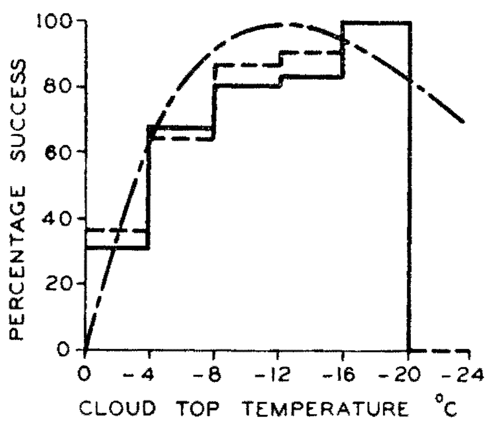
WITH CLOUD TOP TEMPERATURES & COMPARISON WITH Δe

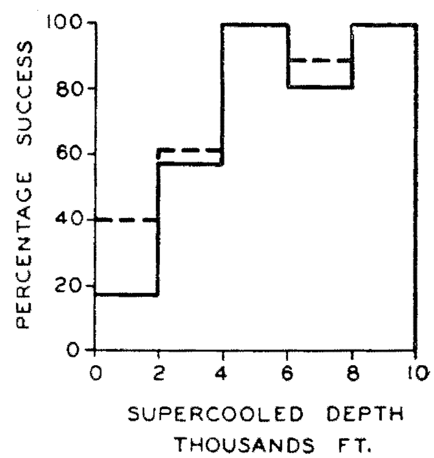
FIG. 4

WITH SUPERCOOLED DEPTH

——— CANADIAN EXPERIMENTS

– – – – CANADIAN & AUSTRALIAN EXPERIMENTS





—·—·— CURVE OF $\frac{100\,\Delta e}{\Delta e\ \text{MAX.}}$ WHERE

Δe = DIFFERENCE IN VAPOUR PRESSURES OVER ICE AND OVER WATER.

Table 4. All Super-cooled Cumulus-Type Clouds

(Total: 35 trials)

		Per cent
Results (precipitation or modification)	29/35	83
Precipitation leaving cloud	23/35	66
Precipitation reaching ground	12/35	34
Unique precipitation to ground	4/35	11
Unique precipitation leaving cloud	8/23	35

rates of rainfall, two of which were measured to be of the order of 0.2 inches in 20 minutes.

As two of the obvious criteria used in selecting a cloud for practical results were considerable depth of cloud and a reasonably low base, it is interesting to examine these criteria in the light of the subsequent results. Probably the main factors determining whether precipitation leaving the cloud will reach the ground without total loss by evaporation are, the amount of precipitation, the raindrop or snow-flake size, the height of the cloud base above the ground and the humidity existing between the cloud base and the ground. For a given cloud density, the amount and drop size must largely be functions of cloud depth. An increase in amount of precipitation or drop size or a decrease in cloud base height will reduce the effect of humidity. It would seem therefore, that the possibility of precipitation reaching the ground could be reduced to some function of cloud depth and cloud-base height.

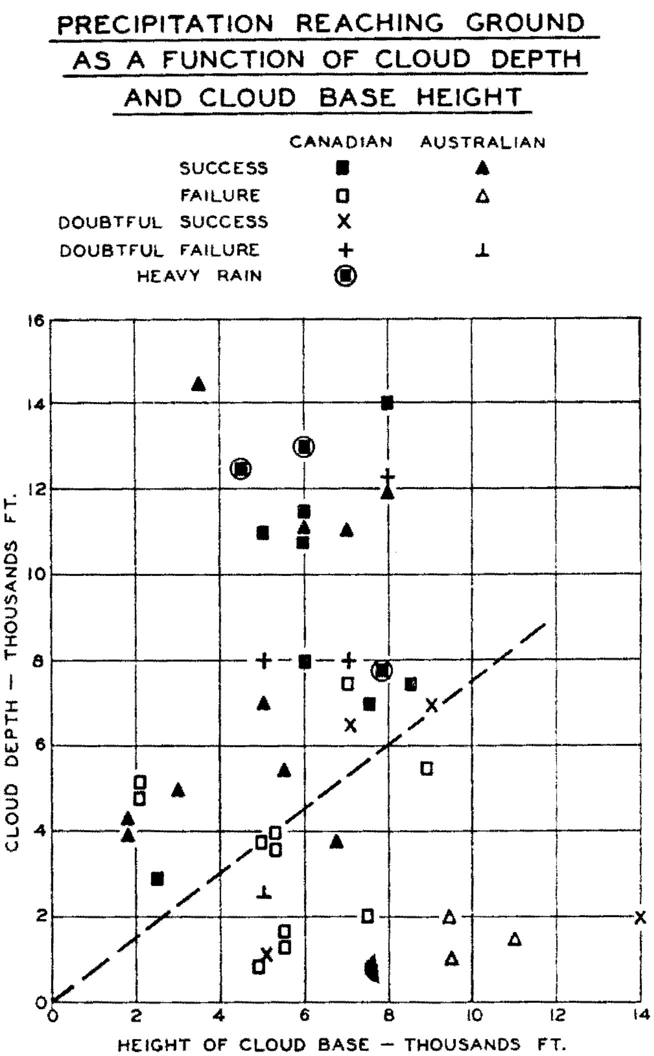


Figure 5

This supposition is supported to some degree by figure 5, showing for both Canadian and Australian experiments a fairly clear dividing line between success and failure in inducing precipitation to reach the ground as a function of cloud depth and height of cloud base. The dividing line appears to be in the region given by the ratio of cloud depth to height of cloud base of 0.75. This is a somewhat more conservative figure than that of 0.5 proposed by the Australian experimenters on the basis of their own tests alone.

CLOUD MODIFICATION

In the majority of cases when precipitation occurred from cumulus type cloud, it was accompanied by dissipation. This is illustrated by figures 6a and 6b. However, in one Canadian experiment when heavy rainfall occurred, the associated cloud development was very spectacular. A heavy cumulus formation, based at 7,000 ft., with top at 19,000 ft. and —10 degrees C., was seeded and within 20 minutes the cloud had billowed up to 30,000 ft. and assumed a cumulo-nimbus aspect. A similar spectacular development is reported by the Australians on one occasion (9).

In the case of supercooled stratus clouds, there was no observation of large-scale dissipation, nor of extensive lateral growth of precipitation activity.

GENERATION OF CLOUD FROM CLEAR AIR

It is well known to meteorologists that portions of the atmosphere are sometimes supersaturated with water-vapour, which does not resolve into clouds because of the lack of suitable nuclei. This condition normally seems to occur at low temperatures and also, in many instances, at high altitudes, as is demonstrated by the occurrence of aircraft vapour trails. The amount of water-vapour existing under these conditions is not likely to be significant from the precipitation aspect, but the ability to release the supersaturation in the form of clouds is nevertheless of considerable scientific interest, and might eventually have some practical application.

On a number of flights from Arnprior it was found that clear air was supersaturated with respect to ice. On eighteen occasions when dry ice was dropped into such air, clouds were generated and on thirteen of these tests, the clouds persisted or even appeared to grow until out of sight (4). Figure 7 shows the initial and final stages of one of these generated clouds.

These clouds were all formed at temperatures lower

Table 5. All Supercooled Stratus-Type Clouds

(Total: 16 canadian trials)

		Per cent
Results (precipitation or modification)	11/16	69
Precipitation leaving cloud	7/16	44
Precipitation reaching ground	2/16	12
Unique precipitation to ground	1/16	6
Unique precipitation leaving cloud	4/7	57

Figure 6. Dissipation of cloud by seeding (a) Bank of cumulus cloud before seeding.

Figure 6. Dissipation of cloud by seeding (b) Remains of same cumulus cloud one ahour fter seeding.

than —10 degrees C., and micro-photographs showed them to be composed of ice-crystals. Measurements and theoretical considerations indicated that their specific free water-content was very small, being about 1 to 2 per cent of that of a normal cumulus cloud.

From the scientific point of view, the main interest in these clouds at present is that they are formed in a manner analogous to the formation of ice-crystals in a super-cooled cloud, and so offer a technique for the better study of the effect of various inoculants.

APPRAISAL

A total of fifty-nine Canadian and twenty Australian tests have been compiled which allows a general appraisal to be made, as follows:

1. It has been shown that precipitation can be artificially induced under the appropriate meteorological conditions.

2. On the basis of the foregoing results the following conclusions have been drawn with respect to the meteorological conditions appropriate for this technique:

(i) Supercooled cloud is essential for the artificial induction of precipitation when employing dry ice as an inoculant.

(ii) Cumulus cloud gives a much higher percentage of successes as regards precipitation reaching the ground than does stratus cloud (in the ratio of 3: 1).

(iii) The percentage chance of success in inducing precipitation increases with increasing depth of supercooling and reaches 100 per cent in the vicinity of 4,000 ft. depth.

(iv) The percentage chance of success in inducing precipitation from supercooled cloud increases with decreasing cloud-top temperature and reaches 100 per cent in the vicinity of —12 degrees C.

(v) To ensure that precipitation will reach the ground without total loss by evaporation, a ratio of cloud depth to the height of cloud base above ground greater than 0.75 is necessary.

It should be noted that these conditions are also conducive to natural precipitation.

The feasibility of inducing precipitation depends upon the supply of suitable clouds and this can be determined from a study of meteorological records for any particular region.

3. There are not yet sufficient quantitative measurements to permit an estimation of the amounts of rainfall which may be induced under any given conditions.

It is of interest that for the three cases of heavy rates of rainfall (0.2 inch in 20 minutes) the ratio of cloud depth to height of base above ground was greater than 1. In each case the total cloud depth exceeded 8,000 ft. while the supercooled depth exceeded 5,000 ft.

4. The usefulness of the technique is dependent upon the requirements of the application and is subject to the following limitations:

(i) Induced precipitation can only supplement natural rainfall in any particular locality.

(ii) It is extremely difficult to direct induced rainfall to any particular small area because of the random nature of clouds.

(iii) The duration of any induced precipitation is relatively short since, in general, rainfall occurs only at the expense of dissipation of the cloud.

(iv) There is no control over the rate of release of precipitation with the method of inoculation employed here.

(v) Since induced precipitation is strictly local it cannot be expected to affect the general character of any air mass and therefore its effectiveness may be offset by subsequent evaporation. For certain applications precipitation in the form of snow may be more efficient because of reduced evaporation loss.

(vi) The available water content of winter cloud is appreciably less than summer cloud and therefore the amount of precipitation that can be obtained is less.

(vii) There has been no evidence of extensive lateral growth of the effects of seeding, nor has there been any indication that self-sustaining storms could occur.

5. The relative importance of the above limitations is indicated for the three major applications with which these tests have been concerned.

(i) *Agriculture*. The usefulness of any supplementary induced moisture is critically dependent upon timing with respect to the growth cycle of any particular crop. It is also necessary to direct the rainfall, to supply the minimum useful amount, to minimize evaporation losses and to avoid excessive rates of rainfall.

(ii) *Forestry*. The main usefulness here lies in the prevention rather than the extinction of fire, owing to the difficulty of directing the rainfall. For this purpose even an increase in forest humidity can be of benefit.

(iii) *Water-power*. Because of the large areas used as catchment basins, directing of the precipitation is relatively unimportant. It may be more advantageous in this case to precipitate snow by reason of reduced evaporation losses.

Table 6. Cumulus Clouds : Variation of Precipitation Success with Cloud Top Temperature

(Total: 35 Canadian trials + 20 Australian)

Temperature Interval	*Canadian*			*Australian*			*Combined success (Per cent)*
	Success	*Failure*	*Success (Per cent)*	*Success*	*Failure*	*Success (Per cent)*	
0°C. to -3°C.	3	7	30	2	2	50	36
-4°C. to -7°C.	4	2	67	3	2	60	64
-8°C. to -11°C.	8	2	80	5	0	100	87
-12°C. to -15°C.	5	1	83	5	0	100	91
-16°C. to -19°C.	3	0	100	0	0	—	100
-20°C. to -23°C.	—	—	—	0	1	0	0

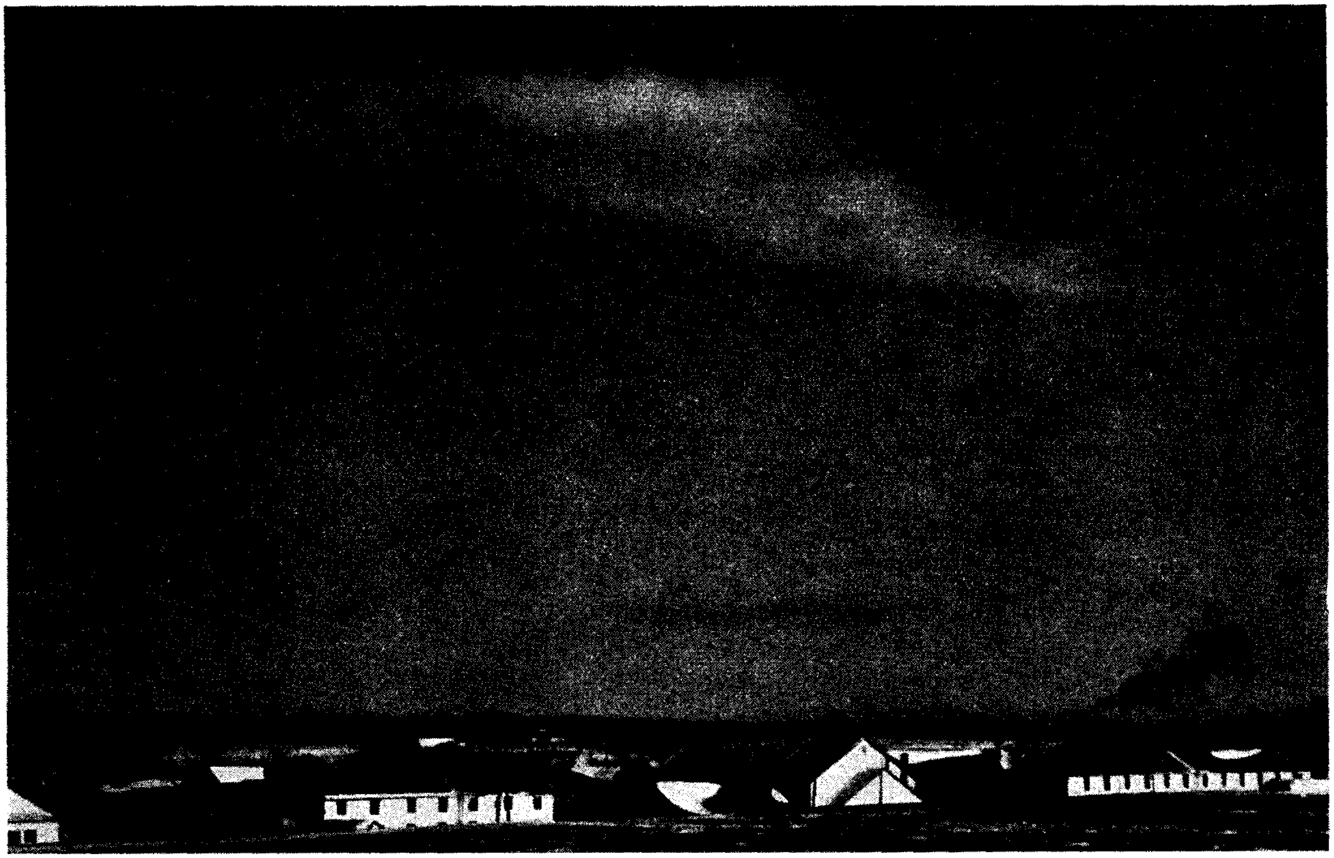


Figure 7. Cloud generation from clear air. Resulting horizontal cloud ten minutes after seeding.

Table 7. Cumulus Clouds : Distribution of Precipitation Success With Cloud Top Temperature and Depth of Supercooling

(Total: 35 Canadian trials)

		Cloud Top Temperature				
		0 to −3°C.	−4° to −7°C.	−8° to −11°C.	−12° to −15°C.	−16° to −19°C.
Depth of Supercooling	0 to 1,500 ft.	1/6				
	2,000 to 3,500 ft.	2/4	0/2	3/5	3/3	
	4,000 to 3,500 ft.		3/3	4/4	2/2	
	6,000 to 7,500 ft.		1/1	1/1	*0/1	2/2
	8,000 to 9,500 ft.					1/1

*Doubtful observation.

Table 8. Cumulus Clouds : Distribution of Precipitation Success With Cloud-Top Temperature and Depth of Supercooling (Combined Canadian and Australian Results)

(Total: 35 Canadian + 20 Australian trials)

		Cloud Top Temperature					
		0 to −3°C.	−4° to −7°C.	−8° to −11°C.	−12° to −15°C.	−16° to −19°C.	−20° to −23°C.
Depth of Supercooling	0 to 1,500 ft.	2/8	1/1	1/1			
	2,000 to 3,500 ft.	3/3	2/6	5/7	4/4		0/1
	4,000 to 5,500 ft.		3/6	4/4	4/4		
	6,000 to 7,500 ft.		1/1	3/3	1/2	2/2	
	8,000 to 9,500 ft.				1/1	1/1	

Table 9. Selective Tests

(Super-Cooled Cumulus Likely to Produce Precipitation)

(Total: 21 Canadian trials)

		Per cent
Results (precipitation or modification)	17/21	81
Precipitation leaving cloud	14/21	67
Precipitation reaching grounds[a]	9/21	43
Unique precipitation reaching grounds[a]	4/21	19
Unique precipitation leaving cloud	4/14	29

[a]Includes three heavy rates of rainfall greater than 0.6 inch per hour.

CONCLUSIONS

1. The ability to induce precipitation under certain conditions has been demonstrated. The economic significance of induced precipitation is specific to a given application and to a particular region. Its usefulness can therefore only be assessed on the basis of individual requirements.

2. This subject appears to have particular importance for the field of meteorology and further study is required in order to obtain a clear understanding of the processes involved and to evaluate the usefulness of the technique.

3. From the scientific standpoint, the results achieved are noteworthy, and the ability to alter the structure of the great majority of clouds, to produce precipitation from many clouds, and even under certain conditions to generate clouds, with so slight an agent, is remarkable.

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Current Concepts in Apprasial of Water Resources

C. G. PAULSEN

ABSTRACT

As an approach to the consideration of the appraisal of the water resources, current concepts that are fundamental to such appraisal are discussed. The significance of water as a basic necessity of life and as a limiting factor in the progress of modern civilization is noted. In many places the development of our industrial and social economy has created water demands of a magnitude and variety that exceed all previous expectations. Adequate knowledge of the available water resources of a region is a prerequisite to wise planning and successful operations of the resources no less than is the adequate coverage of the area by suitable topographic and geologic maps.

It is increasingly recognized in water investigations that the various phases of the hydrologic cycle in a region must be studied and understood. The elements which are particularly essential to a study of water as it moves through this cycle are precipitation, stream flow, ground water flow, evaporation and transpiration. An appraisal of the water resources will logically include a balanced system for the continuing observation, accounting and interpretation of these factors.

The advances that are being made in methods and equipment are generally the result of gradual evolutionary improvements. However the field seems to be ripe for the application in these methods of recent developments in the physical and chemical sciences.

The attached bibliography gives reference to publications which afford an introduction to the principles, methods, and equipment at present used in the appraisal of the water resources in the United States.

The phenomenal increase in the use of water in the city, on the farm, and by industry has been an impelling force in accelerating the inventory and appraisal of water resources in the United States. Despite expanded programmes it is debatable whether facts and concepts have kept pace with the development and utilization of water resources.

The basic need for water may be compared with that for air and food. Water has also great potentialities for control and utilization for the benefit of man in ways indicated by the subjects of succeeding papers of this programme. Wherever the supply of fresh water has been scarce or lacking, as in the arid and semi-arid regions of the earth, the significance of water as a fundamental necessity of life and as a limiting factor in the utilization of other resources and in the progress of modern civilization has been keenly appreciated. Fortunately, in large parts of the earth the supplies of fresh water are comparatively plentiful. However, in many places the development of our industrial and social economy has created water demands of a magnitude and variety that have exceeded all previous ideas or expectations. Consequently, supplies which until recently have been considered as essentially inexhaustible are now recognized to have limits, which, either immediately or prospectively, fix the extent of development.

The recent general acceptance in this country of the river basin as the logical unit for regional planning and development, as exemplified by the programmes of the Tennessee Valley Authority and in the Missouri River Basin, emphasizes further the manner in which the water resources of a region constitute a focus on which the integrated development and utilization of other resources of the region tend to converge. Such development involves not only the obtaining of potential benefits from the water resources but the reduction of losses by floods and droughts and the effectual control of critical conditions involving such other resources as soil, range lands, and forests. Adequate knowledge of the occurrence and characteristics of the available water resources is a prerequisite to wise planning and successful operations pertinent to the development of the resources of a region no less than is the adequate coverage of the area by suitable maps and by knowledge of the geologic formations and conditions which affect both surface water runoff and ground water movement and storage. It is evident that the key position of water in regional economy requires that current activities and planning for the future along many or all lines be conducted in the light of a well-considered appraisal of the water resources.

In water investigations there is a need to recognize the importance of each phase of the hydrologic cycle—the system of never-ending circulation of water by movement through streams and underground formations, by evaporation and transpiration from the surface of the earth to and through the atmosphere, and by its return to the surface of the earth as precipitation. While current progress in the realization of this concept is especially noteworthy, it must be emphasized that more research is needed to place the appraisal of the water resources on a sounder and more rational basis.

Water for man's needs is obtained chiefly from surface water and ground water sources—streams, springs, and wells. The supply fluctuates in availability as a result of variations in the natural processes of the hydrologic cycle and although storage may in some instances be effective in producing a degree of uniformity, the uses made of water must still, in a large measure, be adapted to those natural fluctuations. Moreover, the fluctuation of water in various parts of the hydrologic cycle may be significantly affected not only by topographic and geologic features but also by the functioning of soils and vegetation. An analysis of the cycle thus becomes a possible source of information on the effects of works of man on the fluctuations in the water available for use in a basin. For this approach, a working knowledge of the functioning of the factors that are involved in the hydrologic cycle is necessary. An accounting or inventory of water as it moves through the hydrologic cycle may be called quantitative hydrology. The quantitative elements of the cycle—precipitation, stream flow, ground-water flow, evaporation and transpiration—are particularly essential to the application of accounting procedures to the fluctuating supplies of fresh water. An appraisal of the water resources will logically include a balanced system for the continuing observation, accounting and interpretation of these factors. The quantity of detail needed will depend upon the uses to be made of the information and may be much more general for preliminary planning than for the operation of reservoirs and water-power and industrial plants under conditions of fairly complete development.

Knowledge of the chemical and physical qualities of surface and ground waters must be utilized in order to evaluate their fitness for a wide variety of purposes. Increasingly exacting requirements by many types of industries for water having specific characteristics make it essential to investigate systematically the variations in chemical and physical quality of the available water supplies and the changes in quality that result from use. The chemical quality of water is also becoming widely recognized as an important factor in the use for irrigation. Detailed studies of the amount of sediment transported by streams are likewise necessary in order to provide essential information affecting the design of dams and the operation of reservoirs.

The appraisal of water resources may be logically conducted along three lines: surface water, ground-water, and quality of water, the distinction between the lines relating primarily to the skills and techniques that are required in the investigations. Surface-water investigations dominantly require civil and hydraulic engineers; ground-water investigations require engineers and geologists experienced in ground-water hydraulics; and quality of water investigations require chemists and engineers experienced in techniques of sampling and analysing water. The methods used by the United States Geological Survey, whose water-resources investigations have been conducted along these lines, are described in some of the reports listed in the attached bibliography. The continual advances that are being made in methods and equipment have generally not been revolutionary but are in the nature of gradual evolutionary improvements. However, it is believed that there are also opportunities for the application of recent developments in the physical and chemical sciences and in mechanical and electronic devices for performing mathematical and statistical operations that may materially increase the efficiency and economy of the investigations. The time seems ripe for active and expanded research to take full advantage of these opportunities.

In the appraisal of surface water it is important to recognize that as the observational record gains in length, significant deductions are possible, such as flood frequencies, intensities of flow, dependability of sustained flow and peculiarities of minimum or drought flows. These characteristics may be deduced from statistical analyses of flow duration curves, and, with a study of the geology and soil characteristics of the basin, many anomalies can be explained, thereby making the records more valuable for wise planning and development of the surface-water resources.

The techniques of sediment sampling and associated analyses for relating sediment data to erosional processes and the means of checking them are probably more in a stage of pioneer development than others in the field of water investigation. Notable development, principally in equipment for collecting samples of sediment and in technical procedures, has been and currently is in progress through a collaborative arrangement with several interested Federal Agencies and the Universities of Iowa and Minnesota.

Because of the emphasis that has been placed in recent years on ground-water utilization, the United States Geological Survey has been called on increasingly for investigations leading to the definition of the various factors that determine the dependable yield of aquifers. Accordingly, new methods and techniques have been devised so that many ground-water investigations now have a quantitative as well as a descriptive aspect. Moreover, as groundwater utilization has approached the safe yield of the aquifers, it has been necessary to devise techniques for maintaining a continuous inventory of the available water supplies and to devise methods of augmenting those supplies by such means as induced river infiltration, relocation of wells to obtain the most efficient spacing, and artificial recharge of the underground reservoirs. The United States Geological Survey has in large part succeeded in keeping pace with the needs by expanding its geologic and reconnaissance-type investigations to include geophysical and pumping test studies and periodic measurements of water-levels in a broad network of observation wells. In addition, detailed studies of the discharge and recharge of aquifers, and the quality of water in them, have been made and correlated with the other data to form for the areas under consideration a complete record of the ground-water phase of the hydrologic cycle.

In nearly all problems involving a broad consideration of the water resources of a region, it is desirable to know at least the areal distribution of precipitation and run-off and also, by analysis of the difference between them, the general magnitude of the quantity of water that passes into the air by the processes of evaporation and transpiration. These data are as elemental as the contours of a topographic map, and knowledge of them is quite as essential to assure a sound approach to effective utilization of the water resources of a region. Precipitation represents the extreme limit of the water supply. Except as to possible very minor artificial influence, precipitation is beyond the control of man. Moreover, it is the accepted view that within the range of normal fluctuations the long-time average precipitation has not changed significantly for many hundreds of years. The run-off, representing the outflow from surface-water and ground-water sources, is an over-all measure of the water resources which may be utilized without materially changing conditions within the region. The major part of evaporation and transpiration is in the main beyond the influence of man to increase or decrease. However, in some situations these factors may be decreased by lowering the water table or by destroying useless vegetation, with the result that additional ground-water supplies may be made available for beneficial use. For example, in the arid and semi-arid regions of the western United States, the portion of the precipitation that makes up the usable water supply is small and the incentives for conservation and avoidance of waste are especially urgent. Among the means of conservation which is receiving increasing attention is that of the control of consumption of water by phreatophytes—plants that habitually grow where they can send their roots down to the water table and that through the processes of transpiration, discharge relatively large quantities of water into the air. In general, the large amount of ground-water so discharged has little or no beneficial use. In fact, of the common phreatophytes, only one—alfalfa—has a highly beneficial use.

It is estimated that many millions of acres of land in western United States produce relatively worthless vegetation at a cost of many more millions of acre-feet of water that might conceivably be put to more beneficial use. It is inevitable that the scarcity of water for further development and the increasing costs of reclamation by irrigation will transform a wasteful to a beneficial consumptive use.

Because of the inequalities of rainfall, large quantities of flood-water escape from the land without being used beneficially. Extensive developments have been made for storing as much flood-water as possible in surface reservoirs; but because of natural conditions surface storage is inadequate in amount and is wasteful in causing evaporation and increasing attention is being given to storage in natural underground water reservoirs. Such storage requires careful study of the geology to delineate the areas of outcrop of subterranean reservoirs where flood-waters may be spread and more intensive studies of infiltration and other factors affecting artificial recharge. In some areas that are especially favourable, a large percentage of the flood-water may be salvaged in this manner. In some areas artificial recharge of the ground-water reservoirs is being accomplished successfully.

The term "diminishing water supply" is sometimes used in relation to our water resources in a way that seems to signify that the sources of supply may be diminishing and that if the trend were continued, a comparatively humid region would become a desert. It is apparent from the preceding discussion that such a view is misleading and not supported by the facts. Rather the picture should be that water utilization must be adjusted to the hydrologic cycle with the extent of utilization dependent upon the variations in the occurrence of water in the cycle.

Adjustment of water utilization to the hydrologic cycle implies that all the factors of the cycle are known. Such knowledge can be obtained only by research and by a widespread intensive and continuous system of measuring, recording and interpreting all elements of the cycle.

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The following bibliography furnishes references to publications which afford an introduction to the principles, methods and equipment currently used in the appraisal of the water resources in the United States. Many of these publications give further references to publications and thereby open a reading list which the student may follow according to his interest.

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Conservation of Ground-Water in Britain

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ABSTRACT

In order to implement the national water policy set out in the Water Act of 1945 and to make the best use of the water resources of Britain, powers were given by Parliament to the Minister of Health to promote their conservation and most advantageous employment.

To ensure the success of this policy of planned economical development of resources, the Minister was also given powers to inaugurate such surveys and systematic collection of data as were deemed necessary. The task of ground-water study, including the assembly of data has been assigned to the Geological Survey, which has been collecting records of wells and investigating ground-water supplies for many years. Surveys of both existing abstractions and future requirements are being made by the Ministry of Health, and have been completed for much of the country.

Where protection of ground-water resources for public or industrial use are necessary in the public interest, the Minister is empowered to define areas within which licences are required to construct wells and to abstract water. He has issued Orders under such powers to cover most of the important aquifers.

A century of progress in Britain, since the first general legislation dealing solely with public water supplies became law in 1847, has brought a piped supply of pure water to the homes and workplaces of over 95 per cent of its people. All the towns have been supplied and over 70 per cent of the rural population. The remainder, with no piped supply, are scattered over a wide area.

The latter part of this century of progress, in particular, has seen a steady improvement in the quality of the water supplied and an almost complete elimination of water-borne diseases. The consumption of water per head has progressively increased with improved housing conditions, higher standards of living and growth of the needs of industry. But, not content with this achievement, the British Government by its recent legislation aims at providing a piped water supply to every community that can be supplied at a reasonable cost. The over-all resources of the country are ample enough both to extend the piped systems and to satisfy expansion of the domestic, agricultural and industrial requirements of the area at present supplied, but some difficult problems arise in making sure that all available resources are used to the best advantage. In the Water Act, 1945, the Minister of Health was charged with the duty of promoting the conservation and proper use of water resources and the provision of water supplies in England and Wales and of ensuring the effective execution of a national water policy. Similar duties were given to the Secretary of State for Scotland in the Water (Scotland) Act, 1946.

The first essential for a planned development of water resources is an assembly and assessment of all the relevant basic data. Facts about the existing sources of supply quality and distribution of water, information about the extent and availability of natural resources not yet tapped, and details about the present and potential domestic, agricultural and industrial requirements, must be collected and studied. Much is known about these matters, but more information is required, and the Minister of Health has inaugurated the necessary surveys to collect the data for the whole country; indeed a large area has already been covered.

The main sources of ground-water and their position, extent and nature are known from geological maps and reports that cover the whole country and a considerable amount is known about the availability, behaviour, replenishment and quality of these ground-waters through the work of the Geological Survey. Where information is inadequate, it is being augmented by current surveys and by returns called for under Regulations. Both public and industrial users of large quantities of water now measure their total abstraction throughout the year and keep records of water-levels, to facilitate an assessment of consumption and replenishment in each of the ground-water regions. The Geological Survey is notified of the intention to sink new wells, to give them an opportunity of studying the strata and of collecting ground-water data. Analyses of raw waters from various positions in the geological formations are being made from time to time and the results are being examined to note any alteration in the quality.

This collection of basic ground-water data is no new undertaking arising from the necessities of the Water Act, for the Geological Survey's contribution to the assemblage of information required for planning the development of ground-water resources dates back to 1835 when a systematic geological survey of the country on the scale of 1 : 63,360 was initiated. Since then the primary geological survey of the whole country has been followed by a detailed resurvey on the scale of 1: 10,560 that has covered more than half of the country and is still in progress. In the course of these geological surveys the surface distribution of the main aquifers has been defined, their underground extensions determined, and, during the last fifty years, a wealth of information collected about more than a hundred-thousand bores. This basic survey, the scientific results of which have very wide application, has cost 2½ million pounds in the last fifty years—equivalent to about one farthing per head of population per year.

Quantitative ground-water surveys which follow the assemblage of basic facts are also being undertaken by the Geological Survey. It is only when these surveys have been completed that full development of ground-water resources can safely proceed. As an example of the potential benefit of these studies, it has been shown that in one coastal region the quantity of water lost underground to the sea is more than double the present abstraction from wells and springs within that area. To harness this surplus, without adversely affecting present users and without drawing salt water into the water-bearing strata may prove difficult and costly, but not impossible unless embarrassed by unrestricted development.

Some parts in the west of Britain have an average yearly rainfall exceeding 200 in. and it is particularly fortunate that this is combined with topographical and geological conditions favourable for impounding. In the east of the country, the average rainfall is lower and in some districts it is less than 20 in. Conditions here are generally unsuitable for major surface impoundings, but the rocks and structures are suitable for natural underground storage. Nevertheless, although the rainfall is high enough and dependable enough to provide ample water for all our needs, the existing or potential surface and underground storage is by no means everywhere adequate or conveniently situated for economical development.

Many of the large towns have outgrown their local source of supply and others have allowed it to become polluted by industrial waste, but have been wealthy enough to go farther afield in order to maintain the life and industry of the town. Elsewhere, unfavourable conditions for impounding, an inadequate flow or the impure nature of the streams or the absence of ground-water in the vicinity, have restricted industrial or agricultural expansion and lack of finance in such regions has in turn prevented supplies from outside sources being brought in for the development of the community. In some instances an impoverished area lies near the administrative boundary of a neighbouring community where the water resources are only partially developed and where there is wastage of water through carelessness or lack of understanding, or where surplus resources flow to waste through some natural outlet. Until recently these administrative boundaries have been formidable barriers to development, but for the future, after an assessment of the resources and requirements of the region has been made, reallocation of resources or redistribution of supplies will be encouraged where desirable and it may be possible, without in any way reducing the supply of the community with plenty, to provide an adequate supply to its neighbour. The Water Act envisages the possibility of amalgamations of water undertakers, if such grouping would provide skilled supervision, reduce costs and waste of resources or would provide adequate finance to carry into effect the national water policy. Pooling of supplies would allow flexibility in their use, as for example, in switching between overground and underground sources to avoid the use of the former in summer droughts and to rest the latter in winter.

Although extension of supplies is thus contemplated and provision is made for transference of bulk supplies, many rural communities can only be supplied economically by the development of local resources, which will not be neglected. Full development of local resources will usually precede the augmenting of supplies from outside sources.

Aiming as it does to provide for both the extra needs of the urban communities and the increasing needs of the rural areas, Britain's water policy can only succeed if waste is eliminated. The escape of potable ground-water to the sea or into any aquifer containing polluted water, and access of all polluted water to potable ground-water resources must of necessity be prevented.

One of the methods by which waste and pollution are being obviated today is by the application of Regulations which allow the Minister of Health to control the areas where important resources are threatened by over-development or by pollution and which it is in the public interest to protect for the benefit of established or potential public or industrial users. During the past three years most of the important aquifers have been controlled. Within these controlled areas, which are defined by Order in Parliament boring for water is licensed only when it has been proved that new large-scale abstraction is essential and will not endanger the public and industrial supplies already being obtained. Abstraction by an individual, solely and to the extent necessary for the domestic purposes of his household, is exempt from licence. In the areas where full development has not yet been achieved, boring is not prohibited, but control is being exercised to ensure that the utmost use is made of the aquifer, with the minimum of waste. Boring for minerals within the scheduled areas is only permitted after approval of the precautions to be taken to avoid any loss of potable water or any entry of polluted water from the strata penetrated.

It is today an offence to cause pollution of ground-water used for human consumption; to abstract water within the controlled areas in excess of reasonable requirements; or to allow ground-water to flow to waste; although steps have not yet been taken to control completely the natural flow from all existing artesian bores.

Until powers were given to the Minister of Health, little was done in Britain to conserve ground-water supplies beyond the limitation on abstraction imposed when water undertakers were given authority by Parliament to abstract for public supply—private and industrial users were in general subject to no such limitation. Competitive boring and wasteful use of water resulted in harmful over-development in a number of areas, the best known of these being in London where the multiplicity of wells, sunk since the beginning of the 19th century, firstly resulted in a cessation of artesian flow and, by 1938, a lowering of water-levels to as much as 300 ft. below sea-level in some places. Such depletion of resources not only restricted the amount of water available to wells in the central area, but also induced a flow of brackish water from the River Thames into the aquifer so that wells in a 25-mile long belt have had to be abandoned and industrial requirements met by supplies piped from outside the area. The measures applied to an area for the conservation of resources or to prevent pollution do not affect established users. In the London area, however, the number of wells in use was reduced by enemy action, and subsequent control has arrested the spread of pollution. Other measures will be necessary to restore the use of the area for potable supplies.

Although the new water policy has emphasized the necessity for conservation of resources in Britain and brought an awareness that ground-water is by no means inexhaustible, some measure of conservation is being achieved by other means than direct control. In the last few years substantial economies have been effected in the controlled areas by industries that have expanded their output by cooling and re-circulation of water.

For a number of purposes such as cooling, operation of hydraulic lifts and presses, supplying fire hydrants and washing vehicles, more use is being made of water from gravel deposits, which may have been condemned for drinking or food processing. Much of this water is returned to the soil.

Abandonment of wells through the entry of brackish water following competitive boring causes a loss to industrial concerns, in the pollution belt of the London area referred to above, of many thousands of pounds per annum.

To estimate the total waste in money and in human effort resulting from the delay in conserving the water resources of other areas, and conversely to estimate the benefit that would accrue from the conservation measures now proposed are well-nigh impossible tasks and little would be gained by attempting them.

Methodology of the Austrian Waterpower Register[1]

ALFRED LERNHARDT

ABSTRACT

The work of the old Austrian water-power register which was begun about forty years ago was not brought to a conclusion in any of the successor States of the Austro-Hungarian Empire. The new edition of the Austrian water-power register—in preparation since 1946—far exceeds the original scope and is truly to be regarded as a water-power register in the widest sense.

Hydraulic structure and water management, which together form a unit, are of vital importance to Austria: the most hopeful efforts of Austrian reconstruction are concentrated on them. The new water-power register is to be the foundation of water management, of the framework planning and of general as well as sectional planning.

Of the many sectors of hydraulics thoroughly dealt with in this new work only two are apparently lagging: the improvement register, since this is being prepared as an independent publication, and the register of subsoil water for which, apart from a few distinct subsoil areas, the data are lacking and which may ultimately be added on to the larger publication (water resources register).

The present dissertation attempts to prove, by demonstrating the methodology employed in the volumes now already published as part of a wider programme, that there is full justification for universal technical interest in this novel creation. This paper explains the guiding lines individually and gives reasons for the selection of the methods.

HISTORY OF THE MODERN DEVELOPMENT OF WATER-POWER IN AUSTRIA

The modern development of water-power in Austria began about fifty years ago. Towards the end of the nineteenth century a few isolated hydro-electric plants were built which, from the point of view of construction and engineering, were then up to date but which, from the point of view of water management, did not yet take into account the future systematic development of the entire river valley concerned as a unit. In individual cases and as a result of the quest for maximum return, which was then the prevalent idea, there was ruthless neglect of sections involving a minimum distance of diversion under conditions of maximum fall of river—in other words, the consequence was ruthless exploitation comparable to the working of the most accessible seams in coal-mines, a process in which the deposits that could only be worked with difficulty were disregarded.

1893—THE YEAR IN WHICH THE MODERN ELECTRICITY SYSTEM WAS BORN IN EUROPE

The origin of the modern system of electricity in Europe may be traced back to 1893 when, on the occasion of the World Exhibition at Frankfort-on-Main, electric power was transmitted over the distance of 183 km. between Lauffen-on-the-Neckar and Frankfort-on-Main. Up to that time our federal territories entirely lacked general hydro-technical foundations. Every individual water-power project required its own research; in particular, much time had to be wasted in solving problems on which the views of the various planners widely diverged.

In order to remove these difficulties there was created in Austria in the same year, 1893, the Hydrographic Service, with a network of stations for observing precipitation and the water-level of watercourses. The observations were published annually in the hydrographic yearbooks. The year 1895 saw the publication of the rules governing the Hydrographic Service and the regulations relating to the rainfall-measuring stations, water observations, the volumetric measurement of water, data concerning the snow-cover and so forth; the valuable contributions to the hydrographic knowledge of Austria began to appear in 1896. Actually, the water discharge had begun to be measured in Austria before 1881, though only sporadically and often only in the form of estimates.

Most of the volumetric measurements of water were published in the hydrographic yearbooks until 1920. After that, these measurements were published only in part and it was not until 1948 that all the water mensurations made up to 1945 were published.

The annual growth in water-power was much greater between 1896 and 1906 than before.

In spite of the warnings by the advocates of hydro-electric power the share of water-power in the production of electric-power remained very low in the twenty-five years up to 1918, in relation to the coal resources of the Empire as it then was.

BEFORE THE FIRST WORLD WAR

Before the 1914–1918 war it began to be realized that the Alpine water resources were natural potential auxiliary sources of power. The war halted the realization of plans to utilize these auxiliary sources. Evidence of the desire and willingness to utilize these sources before the First World War, particularly in the regions deficient in coal, is furnished by the fact that the old Austrian water-power register was established about forty years ago. Since then

[1]Original Text: German.

the hydrographic survey for each river system has been the rule. The first publications of the register aroused well-justified interest. They showed for each watercourse, on a double-octavo sheet 35 × 52 cm., a survey of the whole theoretical natural supply of power (on the assumption of a 100 per cent utilization of the resources discovered) and gave a representation of the water-power already utilized; they consisted of text, tables of figures and diagrams and showed water conditions per 10, 8 and 6 months. The unit selected was the theoretical gross horsepower at low water. As a rule only a few years' observations could be used as bases. The number of publications was relatively small.

The first era of development of Austrian water resources, which roughly coincides with the period of the old water-power register, entered a decline owing to economic difficulties. A second era in the development of Austrian water resources began in the second World War, with a view to the maximum export of power, and since 1945 development has been designed, firstly, to meet the rapidly growing domestic demand and, secondly, by means of export installations, to promote the export of power.

THE PRESENT SITUATION

The demands on the water resources must now take into account all the interests of water management. Hence, the new edition of the Austrian water-power register, which has been in preparation since 1946, had to go far beyond the original scope and give a general survey of water-power and to serve as far as possible all the purposes of water management.

The difficulties to be overcome have thereby been greatly increased. At the same time, the greatly expanded publication is to be brought out with the minimum delay.

The only way to cope with the activities which, as a result, are expanding greatly, both financially and technically, is the co-ordination of a widely spread network of technical collaborators drawn from the central offices, the provincial authorities, the autonomous electricity companies and the Austrian Society for Water Management. In this way alone was it possible to create a maximum of highly valuable publications of lasting use with a minimum of financial means. Some volumes have already been prepared; the remaining volumes are to be completed in a few years. These volumes will create the best and the safest foundation not only for current needs, but also, beyond the immediate future, for the plans of all sectors of water management, ranging from general planning down to the individual project.

Nowadays the mere statement of the available supply of power and existing installations is no longer sufficient for the purposes of water management. Even though the predominant consideration is the desire for the most suitable, most economic and fullest development of water-power in the Austrian Alpine valleys, every water-power installation affects the entire river regime and all other water management interests.

Hence the new water-power register is so designed that beyond water utilization it offers a general plan, not only for the present but also for the future, and a basis for official control and licensing in all matters pertaining to water resources.

TECHNICAL DIFFICULTIES IN AUSTRIA

Technical difficulties in Austria were due to the peculiar hydrographic conditions: the greatest possible variations in the type of watercourses, ranging from the mountain torrents with their extreme fall, their catchment areas of perennial snow and ice, their extremely turbulent water flow and highly variable load of mud and other matter, including very large blocks of rock—cases where the normal methods of measuring the water fail—to the navigable Danube, which carries a large volume of water and has a very slight fall.

The peculiarities of some of these watercourses are so marked that they require individual treatment in the methods of observation and mensuration.

In regard to these river basins, which are so different in their climatic, meteorological, geographical and geological nature and the discharge of surface and subsoil water, there are the additional general difficulties of the decentralization, incompleteness, defects in or absence of observation material, for this material should, if possible, go back for decades.

Many old hydrographic data, for example, are private property owned by undertakings which, at the time, annually spent large sums of money over many years. in connexion with the preparatory works for large projects Only by consultation and appraisal of all sources can insight be gained into the matter such as has never yet been possible in any one place.

METHODS FOR BRIDGING REMAINING GAPS

In earlier periods, when the methods were concerned largely with parallel flow and built up almost exclusively on Woltmann's measurements with vanes, there was in addition a failure to appreciate the need for a larger number of volumetric measurements of water in the most diverse conditions of water-flow and, in particular, in changed conditions of profile, notably in connexion with a marked movement of detritus and the after-effects of structures for regulating the rivers and of bridges and gravel extraction.

In the case of mountain torrents the volume discharged over a measured profile at a given level, even if the elevation of the bed remains equal, differs considerably with the variations in fall, in the nature and size of the movement of detritus and mud (clear water, turbid water, mud detritus, rocks) and the degree of turbulence. One chief problem is to find the best gauge-keys for consulting the old observation material dealing with water-levels, particularly in the case of a steady or sudden change of the discharge capacity at a given flood-measuring point. Each gauge-key, strictly speaking, is valid only for one more or less short period of observation in the course of which relatively insignificant changes took place in the bed and profile. These limits are not yet known, however, and must first be ascertained by general examinations of stability or water balances for the river valley or by comparative hydrographic methods. Theoretical methods, including the processes of mathematical statistics and calculations of probability, are to be used and the unreliable material weeded out so as to separate the most valuable data from the less useful in the hydrographic data; the remaining gaps are to be bridged by theoretical and comparative methods.

These difficulties become even more numerous and diversified by the modern demand for mean values going back over as long a period as possible. We now consider it entirely mistaken to accept the average of any one decade or of any two five-year periods as a kind of normal year.

The ideal is an observation covering several decades and at least an approximation to values covering a century. This can be done by means of meteorological stations (measuring of precipitation) since precipitation began to be measured long before water. Thus, for example, we have stations with precipitation records dating back more than one hundred years: Wien-Hohe Warte, Kremsmünster, Innsbruck.

DESCRIPTION OF THE AUSTRIAN WATER-POWER REGISTER

The Austrian water-power register was divided into a generally descriptive part, a tabular survey containing the results of measurements and surveys calculated for the specific requirements of water management with maps as appendices, and had the following aims: firstly, by means of statistical data to furnish existing water-power plants of the most varying stages of development with the foundations for a planned power economy; and, secondly, to supply the necessary hydrographic calculations for the future development of such plants, as well as to make it possible to form a judgment of the fall of the watercourses.

Apart from the representation of the river regime in the form of contour lines in various profiles of flow, the Austrian water-power register uses the tables of the characteristic water levels or characteristic water-flow. In this way it is possible in many cases important for practical application, to characterize the river regime satisfactorily by means of a few magnitudes.

The characteristic volumes of flow are distinguished by the same processes as are used for water-levels.

In addition, the water-power register indicates the annual level and annual supply of water in terms of an average evaluated over a long period. As of particular importance we would mention the evaluation of the mean water supply (1/s square km.). All these data very clearly identify the individual river basins and sections thereof from the hydrographic point of view and according to precipitation and discharge.

There is a longitudinal survey of the profile which, by means of various scales, clearly represents the general longitudinal section, the line of the catchment area in square kilometres, the mean flow of water, all bridges, power plants and other plants utilizing water, the points of confluence of tributaries, all flood-measuring stations with special mention of the levels at those points, the boundaries of the riparian communes or provinces, the division of the river into kilometres and, lastly, a diagrammatic map of the river system. All the water-power plants lying along the river or planned are shown under numbers on a river chart (scale 1: 50,000). These numbers reappear later in a further appendix to the tables—the longitudinal profile in writing.

It is also desirable to give exact indications of elevations, particularly along watercourses, where the river fall is entirely divided up by an uninterrupted series of existing installations; an exact demarcation of the areas permitted for utilization is indispensable if disputes are to be avoided. Hence, generally speaking, special mensuration (length and elevation) is unavoidable. For the purpose of measuring length, zero level is taken to be at the mouth of the river and the measurement in kilometres is taken upstream to the furthest point at which the utilization of water-power is at all conceivable. On many watercourses this upper limit is marked by the highest installation upstream unless it is necessary, for the purpose of planning large water-power installations, to take measurements right up to the source area.

Apart from the figures necessary for representing a continuous fall of the water-level, the bed of the river, of one or both river banks and the flood dykes, the following are noted:

(1) The points of confluence of tributaries, the branching off and junction of diversion channels;

(2) Structural works (weirs, sills, bridges, footbridges, flood gauges, pipeline crossings);

(3) The boundaries of communes for the purposes of the register.

Elevations are measured from th ereference points of the ordnance survey. Apart from the points marking beginning and end of sections, the levels of the following are given:

(1) The crests of weirs, the upper edges of sills;

(2) Zero levels at flood-measuring posts;

(3) High-water and low-water marks;

(4) All points at which a change in water-power is to be expected, i.e. all points of confluence and breaks of the fall.

Simultaneously with the measurement of the river, the map marks the dimensions of the individual water-power installations which, on the middle and lower course of rivers, are usually situated on working channels, a series of installations often using a common weir successively. In the profile so plotted, the watercourse appears divided into numerous utilized reaches which alternate with unencumbered stretches. The length of the utilized reach is the distance measured along the watercourse between the point at which the utilized water rejoins the natural watercourse and the end of the power basin. The difference in mean level at both points is the total head used. The longitudinal sections have been drawn to various scales. As a rule scales of 1: 25,000 and 1: 50,000 were used for lengths, and scales 1: 100 to 1: 1,000 were used for elevations; if smaller scales were used the small changes in fall which are used by the plants could not be represented. Owing to the great differences in level the co-ordinates are at an angle to the margin, in order to avoid separating the lengthwise profile.

There is a further appendix to the technical part of the publication in the form of appendices to the profile and river chart. They contain the post number which also appears in the sectional lengthwise profile and in the river chart, and also give position, configuration of the river banks, all further particulars concerning structures, extent and nature of water utilization, volume of water for development, head of water utilizable, annual potential performance and entries from the water records. In most cases separate appendices with sketch maps are added for major installations utilizing water.

BIBLIOGRAPHY AND COSTS

The publication is rounded off by a bibliographical part in a folder which contains a compilation of all publications relating to the river which have appeared since 1900. The technical execution is by means of the photographic process of reproduction, which is particularly suitable for writing and drawings. Printing costs by this process are much lower for the small number of editions involved than if the normal printing processes were used.

The total costs for the completion of a river-basin survey, including new measurements, vary from 20,000 to 50,000 schillings, according to the size of the catchment area or length of the river to be measured. These estimates are extremely low compared with the expenditure made at the time of the work of the old Austrian water-power register; indeed, they are infinitesimal if the greatly expanded scope of the total work is borne in mind. Each individual volume is so designed that each single appendix and each individual sheet may be exchanged at any time; in other words the publication may be added to and chapters needing revision may be interpolated.

The volumes, each of which normally comprises one river basin, are not bound but are folders which, for further protection, are inserted in a dust cover and thus may be placed on any library shelf.

With the help of this proposed plan Austria will, in a few years, possess a complete water-power register, comprising all important river basins and probably answering in every respect any requirements in regard to water management.

Dew Observations and Their Significance[1]—New Methods in Dew Estimation

S. DUVDEVANI

ABSTRACT

A new method for dew measurements was devised and country-wide regular dew observations at a number of standard levels have been introduced since 1943 by the Meteorological Service in Israel.[2] At the Dew Research Station special *inter alia* problems of vertical dew distribution, mainly from the ground up to 100 centimetres were studied.

Dew studies are made on the surface of differently treated soils: bare and covered by grass, dry and irrigated, ploughed and compact. It was found that:

1. Dew gradient curves and their "distortions and recoveries"[3] for a rain or irrigation period can be elaborated to serve as an indication in irrigation practice and for soil moisture studies in general.

2. Vapour transfer from the atmosphere into the surface layer of soils was found to result in appreciable surface moisture condensation.

3. Tillage promoted such condensation.

With respect to plant physiology it was found that:

1. Dew and dewy environment is favourable for plant growth.

2. Many destructive fungi also depend on dew moisture.

The significance of dew and its measurements is therefore manifold especially in arid and semi-arid countries.

"I will be as the dew unto Israel: he shall grow as the lily...."
(Hosea 14,5)

The "Dew of Heaven" is a real blessing for Israel which is otherwise not yet very prolific in natural resources. This country brought forth the first known experiments in dew (miracle-experiment of Gideon)[4]. Judge Gideon's method, followed up by modern scientists, is based on exposing hygroscopic material (fleece and, in modern times, other materials as well) throughout the night and recording the gain, in weight.

Methods based on this principle were used first by the author, but were found inadequate and very frequently unreliable and misleading.

The dry summer season of Israel is a very suitable time for dew research. Parts of the country are rich in dew; others, especially in summer, very poor. The farmers believe that dew is useful to plants. Ancient writings (such as the Bible and the Talmud) praise the dew. There are Hebrew prayers for dew in summer, as for rain in winter.

OPTICAL METHOD OF DEW OBSERVATION

Inspired by all this the author embarked on his dew research. A number of points concerning the subject were dealt with for the past thirteen years.

The author's optical method of dew observation has been used for systematic night-by-night observations since 1938 at the Dew Research Station, Israel, situated in the coastal plain. Since 1943 it has been adopted as a standard method for dew observations throughout the country by the Meteorological Service of Palestine, now Israel.

[1]Certain tables and diagrams were to have been brought to the Conference by the author, but as he was unable to attend these were not submitted.
[2]Then Palestine.
[3]Deviations and returns to normal.
[4]Judges 7, 38.

Before the Arab-Israeli war, more than 80 stations for dew observation had been established. Dew records are taken at a level of 100 cm. above ground, this level being accepted as standard level for the whole of Israel. At some stations additional observations are also taken at a level of 30 cm.

The essential feature of the method is the exposure of a standard material called " dew gauge" (made of specially selected wood and specially treated and stained) from sunset to sunrise and identifying the optical appearance of the dew deposits with a series of standard dew photographs. These dew photographs define a certain number of an established "dew scale", evaluated[5] in millimetres, and are therefore named "dew-scale numbers".

A "dew night" is defined as one on which there was no rain and at the end of which (at sunrise or close to it) dew is visible with the naked eye on one of the standard surfaces of the dew gauge, or part of it.

Among the advantages of the routine of optical estimation the following should be noted:

1. Evaporation does not appreciably affect the estimates, even if allowed to proceed for some hours during the night. Only dew at the lowest scale numbers is sometimes an exception to this.

2. Any possibility of confusion between dew and even light rain is eliminated.

3. If necessary the dew deposit left on the gauge can easily be checked by weighing.

4. It lends itself to direct optical comparison with natural dew deposits on various plants.

5. It is inexpensive and simple for large-scale use even with unskilled observers, once the correct and typifying exposure has been fixed.

The network of dew stations may help to solve important problems for the agriculturist, the plant physiologist and, of course, the meteorologist. Systematic records promise to demonstrate how important dew may be, as a factor and indicator as well, in the study of micro-climate and macro-climate for plant growth and agricultural techniques. It is hoped that dew records will be used as an indicator of synoptic conditions.

Our late Government Meteorologist, R. Feige, addressing the Toronto I.M.O. Conference, 1947, said *inter alia*: " . . . Although our network of dew stations is still rather young, valuable results have already been obtained as to the distribution of dew in Palestine . . .

" . . . We know something about our dew regime in Palestine. There is e.g., a predominate summer regime in the coastal plain and a springtime regime in the Jordan Valley, whilst the hill region shows beyond doubt a double regime . . .

" . . . The new optical method developed by a biologist seems to be a useful and elegant way of approach to the hitherto neglected problem of dew and is important to pure as well as to applied meteorology and climatology . . ."

The dew-gauge observations are meant to indicate the dew potential, that is, the capacity for dew formation of a given place, level and period. The dew potential is determined by the interaction of moisture, temperature and air turbulence. It expresses itself through various amounts of vapour condensation on a given depositor under given conditions of exposure. Under the same conditions the actual amount will vary from depositor to depositor depending on their specific thermal and surface properties.

The relative distribution of dew deposits expressed in curves (monthly curves) and quotients gives us an insight into the problem of dew-potential distribution to the horizontal and vertical, at chosen periods.

EFFECT OF DEWY NIGHTS AND DEWY MORNINGS ON VEGETABLES AND OTHER CROPS

Field experiments conducted on various vegetable crops for a number of summer seasons established the positive effect of dew on the growth of the plants tested.

The number and length of branches, the quantity and the total area of leaves were significantly smaller in those plots which were deprived of possibility of collection of dew and of the micro-climatological favourable effects therefrom, as compared with the control plots which were freely exposed to the night dew. It is our assumption (to be published elsewhere), that dew water has also a direct, promoting effect on tissue growth.

Corn is grown in many parts of Israel as a non-irrigated crop during the season from May to August. The success of this crop is also linked in some way or other to the amount and frequency of dew available during its growing period. The yield was found to vary in different parts of the country, and it seems that the lighter the dew, the poorer is the corn growth.

The curling of corn leaves—clear evidence of their partial wilting—was observed only about three to four hours after a sunrise following a normal dewy night. It started much earlier after dewless nights.

EFFECT OF DEW ON FUNGI

Some fungi, such as downy mildews, some moulds, rusts etc., depend on dew for their spreading and development under the dry summer conditions. Observations on mildew of vine and of cucumbers, made by our phytopathologists, indicated that the distribution throughout the country of such mildews might be related to the distribution of dew. This question was studied by us recently in open air experiments with cucumber downy mildew and conclusively established. Other similar studies are planned.

Since vegetable growers in Israel suffer heavy losses because of these plant-diseases favoured by dew, the studies have considerable economic importance.

DEW CURVES AND QUOTIENTS

An interesting problem, and one that has for a long time captured the attention of meteorologists, is whether dew comes down, as it were, "from Heaven", or "rises" from below. In other words, is the dew gradient at its minimum at the soil surface or vice versa? Unrelated and fragmentary observations, recorded by different observers at different seasons and in localities with different climates, near or on soil or grass, have led to inconclusive results.

When considering the systematic observations at various two-level stations in Israel, one can find no simple inter-

[5] Mean values, each for a certain range of individual dew deposits.

pretation at first glance. Actually, three types of dew-level relationships with respect to the two selected levels (at 100 cm. and 30 cm.) have been found.

1. At some stations dew deposit at the 100-cm. level is higher than dew deposit at 30 cm. nearly throughout the whole year. This relationship may be expressed by the formula: $\text{Dew}_{100} > \text{Dew}_{30}$.

2. At other stations, dew at the 100-cm. level is always lower than dew at 30 cm., i.e., $\text{Dew}_{100} < \text{Dew}_{30}$.

3. At still other stations, there is an uncertain relation, according to season; the dew deposit at 100 cm. is sometimes greater and sometimes less than at 30 cm.

Systematic level-observations[6] over a period of years at the Dew Research Station represented in correlated curves show that during the main season (summer) for dew in the coastal plain the typical distribution is as follows:

0–1 cm.—no dew

$\text{Dew}_{2\frac{1}{2}} < \text{Dew}_{5} < \text{Dew}_{30} < \text{Dew}_{100} > \text{Dew}_{150}$.

The bare, compact soil in Israel in summer is very dry down to a depth of 25 to 30 cm. After the first proper rain or rains, opening the rainy season (winter), the ratio of dew at soil surface to dew at the 100-cm. level is suddenly changed and increases, reaching unity or even greater during the months of heaviest rain.

From various studies made by us we have concluded that under conditions of high soil moisture and reduced desiccation, the vertical dew gradient is the reverse of that for the arid summer at close to ground levels.

Moreover, watering the dry sun-baked soil only slightly in the summer results in a suddenly changed dew gradient up to a certain level above ground. The greater the amount of watering, the greater will be the distortion of this equilibrium, and the higher will be the level affected. The gradient curve will, however, recover and return to the normal with the drying up of the watered soil.

This will happen at the beginning of Israel's rainy season if, after the first proper rain, or rains, a long spell of dry weather occurs.

Another useful and anticipated conclusion is the fact that, with other conditioning factors being equal, higher humidities are found at a station where the measured dew amounts are higher.

We are now engaged in a number of experiments aiming to establish:

1. The use of dew measurements to determine the extent of inequality of moisture distribution resulting from different irrigation practices, such as various overhead irrigation devices, irrigation in rows, flooding etc.

2. The use of dew observations at appropriate levels to determine comparative humidities of ground surfaces and top layers in general, including low-lying land, sloping ground, mulch covered soil etc.

3. The use of dew measurements obtained from day-to-day records progressively following the irrigation date, to determine an index or range of indexes for specific conditions of soils and seasons. These indexes would enable the agriculturist to see how dry the irrigated ground has again become and whether it requires irrigation anew.

[6]Consisting of five levels and more, including the ground surface.

DEW AND MOISTURE BALANCE OF DIFFERENT SOILS, WITH DIFFERENT SOIL TREATMENTS

The soils in the Negeb, which we in Israel intend to exploit to best advantage, pose special questions for our Department of Agriculture:

1. Why is there in one area a fairer water balance than in another, although the rainfall is considered in both of them to be below the minimum range for vegetation?

2. Accepting these differences in water balance and after a study of their causes, the next question will be: what are the agro-technical possibilities under dry cultivation for improving the moisture balance of soils in the Negeb?

At the Dew Research Station, we have made quite extensive preliminary tests. We can state, for instance, that tillage improves the dew deposit on soils. Its main advantage in this respect is that the loosening and ridging of the soils tested involved much better cooling off than with compact soil. Regular moisture checkings in the dewy mornings showed considerable raised surface-moisture (by an additional 0.5 to 3 per cent) due to vapour condensation and absorption from the atmosphere above ground.

What fraction of this added surface moisture is ultimately transferred below surface, thus enriching the soil-water reserves, has to be studied.

This phenomenon can be noticed with the naked eye on sandy soils, because the tops of their ridges turn wet.

In connexion with the comments above, we can say already that were it not for the many dewy and otherwise wet nights (dew nights only = approximately 200 per year), the Negeb land would have been reduced to almost hopeless desert.

It is therefore of great significance to continue the study of dew relationships and the applications of such a study with the view to understanding, and if possible, improving the moisture balance in arid and semi-arid regions.

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Estimation of Flood Run-Off

B. D. RICHARDS

ABSTRACT

The approach to the problem of estimating the flood run-off of a catchment tends to be governed to some extent by the amount of data available. Where extensive records of floods exist for a river, one would naturally endeavour to make use of these as far as possible to predict future flood conditions. In America considerable records of stream flow have been built up for a large number of rivers and methods of flood analysis appear to have developed mainly along two lines—the flood frequency and the unit hydrograph methods.

The other line of approach is by flood formulas. A suitable formula requires less data for its application than the above methods but the accuracy of the results obtained will increase with the amount of supporting data available.

Many earlier formulas treated flood intensity as a function of the catchment area only and were consequently of limited application. Later investigators realized that many factors came into account and that there was a relation between the intensity and the period of concentration of a flood.

The present paper reviews in outline the author's methods of flood estimation based on the determination of the period of concentration and the development of the theory to determine the flood hydrograph.

In problems of flood regulation, the hydrograph is of far greater significance than peak intensity, which of itself provides inadequate data on which to base any scheme of regulation.

The theory and methods here briefly described are set out in detail in the author's book "Flood Estimation and Control" referred to in the bibliography.

The paper is accompanied by five diagrams and for convenience in using the method with the metric system, conversion factors are given.

The estimation of flood run-off is a problem which arises in many fields of engineering. The provision of adequate waterway for bridges and culverts calls for an estimate of the maximum intensity of the flood discharge of the river at a given point, while in problems of flood regulation the necessity arises for a complete hydrograph of the rise and fall of the flood.

The approach to the problem tends to be governed to some extent by the amount of hydrological data available. Where there are fairly long records of stream flow, the natural tendency would be to predict potential floods by a study and analysis of these. In America considerable records have been built up for a large number of rivers and methods of flood estimation have developed on these lines and the two systems of analysis, the flood frequency method and the unit hydrograph method, appear to be those most in use. (7 & 5)

The other line of approach is by the use of flood formulas. These are, in general, less dependent on stream flow records, but given a suitable formula, its results will be more accurate if there are supporting data for certain of the coefficients.

Earlier formulas, such as the Dickens formula, expressed the maximum intensity of flood as a simple function of the catchment area only, taking the form:

$$Q = C.A^n.$$

It was obvious, however, that such a formula could only be made of general application by varying the value of the coefficient C for different districts and different types of catchment. The flood intensity depends on a number of factors, among the most important of which are the intensity and duration of the rainfall, the area, shape and slope of the catchment, the herbage cover and the nature of the soil. It was later perceived that there was a connexion between the intensity of the flood and its period of concentration.

The author has used this relation as the basis of a method of estimating the maximum flood intensity and of determining the flood hydrograph. The present paper gives a brief outline of his methods and results.

Two rainfall relations are well established:

1. The average intensity of the rainfall during the period of a storm is an inverse function of the duration of the storm.

2. The average rainfall over the whole area of a storm is an inverse function of that area.

The intensity: duration function is frequently expressed in the form $I = \frac{R}{T + c}$

where I denotes the average intensity of the rainfall in inches per hour at the point of maximum rainfall and over the period of the storm,

R denotes a rainfall coefficient in inches,

T denotes duration of storm in hours,

c denotes a constant in hours.

$I = \frac{R}{T + 1}$ is found to be in fair agreement with actual records and may be adopted as a close approximation.

The intensity: area function is a more complex one. The Institution of Civil Engineers Committee on Floods(1)[1] deduced from Dr. Glasspoole's British Data(2) a curve showing the relation f(a): a, where f(a) denotes the ratio of the average rainfall over an area to the maximum spot rainfall within that area. The author adopted this curve shown in Figure 1, for the smaller areas to which it applied and from further data of Dr. Glasspoole, deduced a second curve, shown in Figure 2, and compared this with similar curves which he prepared from data from various other countries. He suggested that until further evidence is forthcoming the value of f(a) might be taken as follows:

[1]Numbers in parentheses refer to items in the bibliography.

1. For continental areas subject to widespread storms, the curve for Eastern U.S.A. as in Figure 2.

2. For islands and elsewhere where storms of area exceeding 20,000 square miles are unlikely, the British Isles curve of Figure 2.

3. For small catchments in the British Isles and elsewhere where the conditions are such as to give storms of limited extent, the British Isles curve of Figure 1.

The problem is one which requires much further research and the firm establishment of f(a): a would need a vast collection of accurate data over a period of many years and for various countries.

Combining the functions of duration and area gives

$$i = \frac{R.f(a)}{T+1}$$

where i denotes the average intensity of rainfall of a storm of area a and duration T, and R a coefficient of rainfall. If the maximum spot rainfall of a storm is F inches and the duration T hours

$$\frac{F}{T} = I = \frac{R}{T+1} \text{ hence } R = F.\frac{T+1}{T}$$

Comparisons of rainfall intensities all over the world indicate that short period high intensities occur in almost any region, even in one which is normally arid, but that prolonged high intensities are far more liable to do so in the tropics.

In the British Isles, R may be taken as 4 for normal storms and 8 for catastrophic storms, though this is occasionally exceeded. For the Highlands of Scotland the figures 6 and 12 appear appropriate. Over 20 has been found so in the U.S.A. and Australia and over 30 in India.

The average intensity of rainfall over a catchment will thus be a maximum when the storm just covers the catchment and one may conclude that the maximum intensity of flood will occur when the whole catchment is contributing and hence when the duration of the storm is equal to the period of concentration of the flood, t.

Then

$$i = \frac{R\,f(a)}{t+1} \quad \ldots\ldots\ldots \quad (1)$$

and

$$Q = K.i.a. \quad \ldots\ldots\ldots \quad (2)$$

where Q denotes the maximum intensity of flood in cubic feet per second and K denotes the coefficient of run-off.

The author has devised a method of calculating the period of concentration by visualizing the rain as running off the catchment in a thin sheet whose depth is proportional to the time. Thus the depth will vary from 0 at the head of the catchment to K.i.t. at the point of concentration. The period of concentration must therefore take into account

L = the length of the catchment which depends on its area and shape,

s = the slope of the catchment,

i = the average intensity of rainfall in inches per hour.

K = the coefficient of run-off.

and the following formula is derived

$$t^3 = \frac{C.L.^2}{K.i.s.} \quad \ldots\ldots \quad (3)$$

and since

$$i = \frac{R\,f(a)}{t+1}$$

it follows

$$\frac{t^3}{t+1} = \frac{C.L^2}{K.s.R.f(a)} \quad \ldots\ldots \quad (4)$$

From (2) Q = K.i.a. and since 1 inch of rain per hour running off 1 acre gives almost exactly 1 cusec

$$Q_m = 1000\ K.i. \quad \ldots\ldots\ldots \quad (5)$$

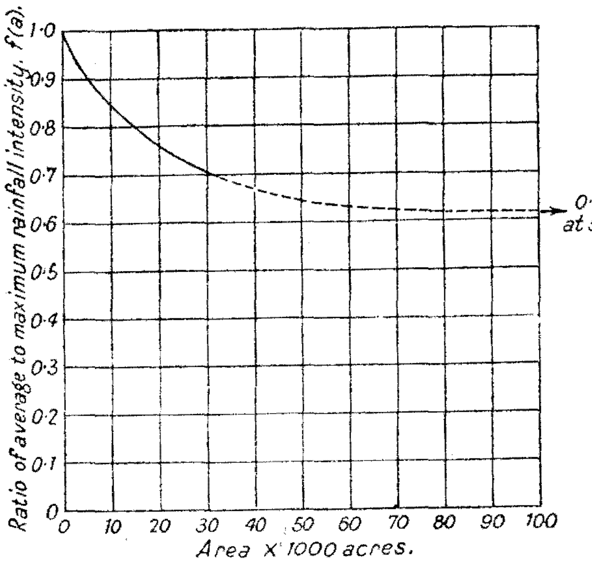


Fig. 1.

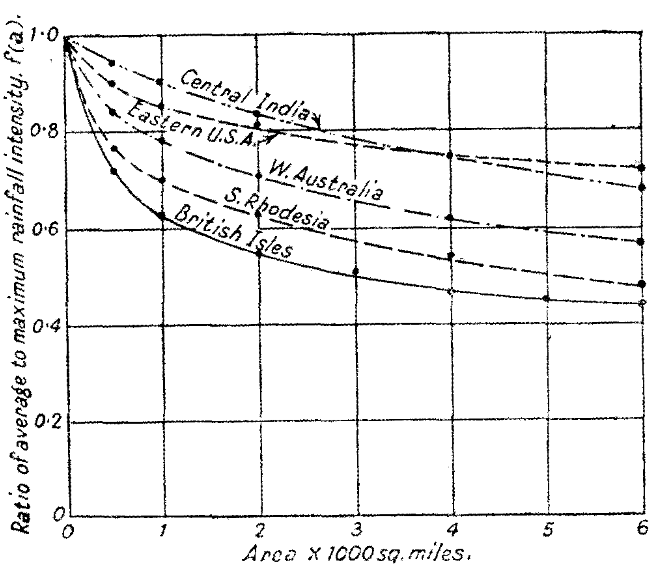


Fig. 2.

where Q_m denotes the maximum intensity of flood in cusecs per 1000 acres.

The total run-off RO = K.i.a.t.

$$= 3600\ Q_m t \text{ cu. feet per 1000 acres} \quad . \quad . \quad (6)$$

The coefficient C in formulas (3) and (4) $= \frac{9\ m}{4\ c^2}$

where m is a numerical constant and c is the coefficient of the Chezy formula $v = c\sqrt{r.s.}$

C is in itself a variable and is shown to be primarily a function of KR. Its values have been determined as follows:

KR	C	KR	C
0.6	.0365	9.6	.0071
1.2	.0216	12.0	.0065
2.4	.0137	14.4	.0060
4.8	.0096	16.8	.0056
7.2	.0079	19.2	.0054[2]

In applying the formulas, a, L and s are determined from the survey of the catchment; R is assessed from the rainfall records as the highest spot rainfall likely to occur in the catchment in any storm; K is established from actual river flow measurements or by analogy with other catchments.

The formulas give the maximum estimated flood intensity and the total run-off. If it is desired to establish the frequency of a flood of given magnitude, this can be done by finding the value of R which would produce such a flood and determining its frequency from a study of the rainfall records. The determination of t from $\frac{t^3}{t+1}$ is facilitated by a table.

The hydrograph of the flood can be drawn in the following manner: With the point of concentration as centre, a number of arcs are drawn or radii r_1, r_2 . . . . . . intercepting areas a_1, a_2 . . . . . . and the period of concentration and intensity of flood discharge for each area are successively deduced.

For the rising flood, points on the hydrograph are given by

$$t_1 = t. \sqrt[3]{\left(\frac{r_1}{L}\right)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$Q_1 = Q_m \frac{a_1}{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and for the falling flood by

$$t_1 = t. \sqrt[3]{\left(\frac{x}{L}\right)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$Q_1 = Q_m \left(1 - \frac{a_x}{a}\right) \quad . \quad . \quad . \quad . \quad (10)$$

where x denotes the distance the water has receded in time t_1 after the cessation of the storm, as shown in Figure 3.

The effect of the area of the catchment on the shape of the hydrograph is illustrated in Figure 4, where the hydographs are shown for two catchments of areas 2 and 40 square miles but with all other characteristics the same.

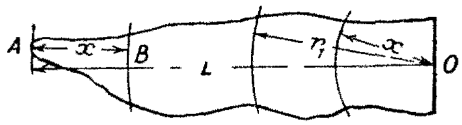


Fig. 3.

As stated, the basis of the formulas is the principle that the average intensity of rainfall is an inverse function of both the area and the duration of the storm and the assumption is made that the storm just covers the catchment and that its duration is equal to the period of concentration. This implies that the whole catchment contributes to produce the maximum intensity of flood. It is further postulated that the average intensity of rainfall and the coefficient of run-off K are uniform over the area of the catchment and within the period of the storm and that the slope is uniform. The above may be described as standard conditions and the effect of departure from any of them has been investigated and tested by the application of numerical values with the following results:

1. Duration of storm T greater than the period of concentration t.

2. Duration of storm T less than the period of concentration t.

In the first case, the flood intensity is reduced and the hydrograph assumes a flat top. The run-off is slightly increased.

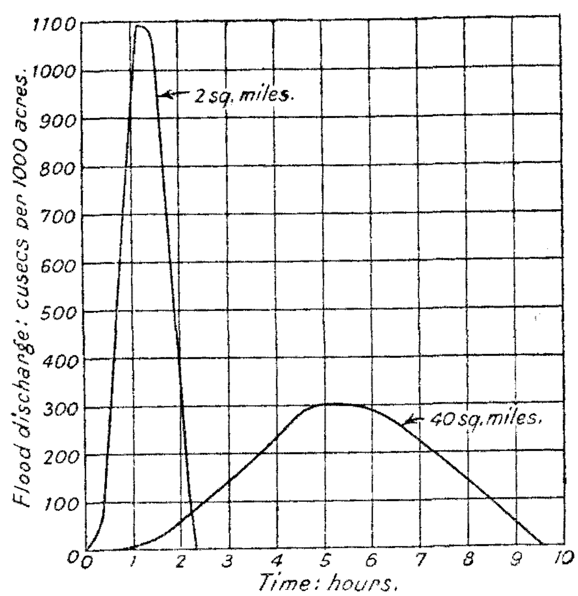


Fig. 4.

[2]If the metric system is employed, C becomes Cm = 9.80 C where L is expressed in km., R in mm. and t in hours. Again Qm = 0.279 K.i where Qm is in cub. metres per second per sq.km. and i is in mm. per hour.

In Figure 1. f(a) is given as a function of a in units of 1,000 acres. To use the curve with the metric system, the area in sq.km. must be divided by 4 to reduce it to units of 1,000 acres. In Figure 2, a is shown in square miles. To use the curve with the metric system, the area in square kilometres must be divided by 2.59 to reduce it to square miles.

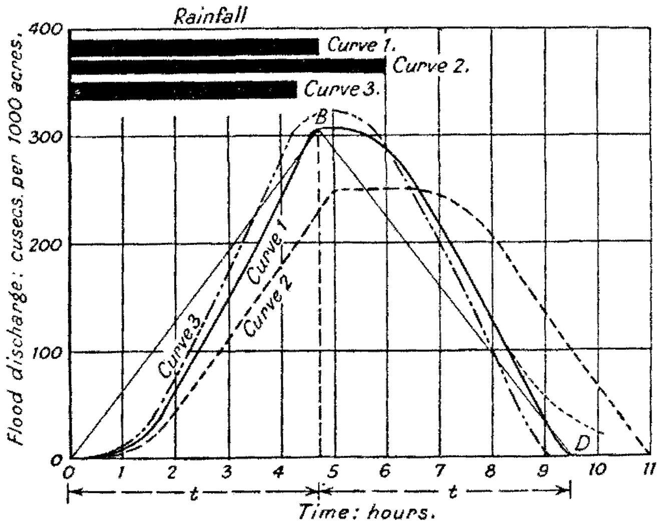


Fig. 5.

In the second case, the flood intensity is slightly increased, particularly with short but wide catchments of large size. The run-off is slightly reduced. Comparative hydrographs for T equal to, greater than and less than t are shown in Figure 5.

3. Area of the storm is less than that of the catchment.

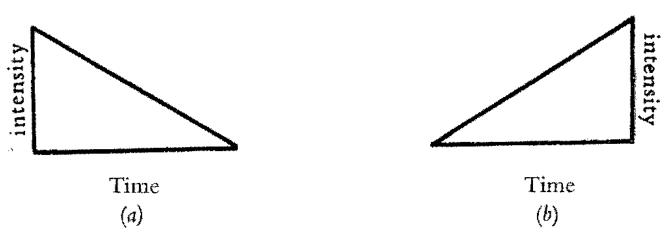
The rainfall intensity will be greater but the area contributing to the flood less. In some cases depending on the shape of the catchment, the flood intensity will be increased with a corresponding reduction of the run-off.

4. Intensity of the rainfall varying over the catchment area.

This may give rise to a slightly higher flood intensity accompanied by a reduced run-off.

5. The rainfall intensity varying during the period of the storm.

It is found that the shape of the rainfall diagram has an effect on the period of concentration and hence on the flood intensity. The flood intensity is greatest for a rainfall diagram of shape (*a*) and least for one of shape (*b*). Increase of intensity of flood is accompanied by a reduction of run-off and conversely.



6. Moving storms.

A storm moving down a rectangular catchment and having an area equal to that of the catchment, will give the same flood intensity as a stationary storm covering the catchment, but only three-quarters of the run-off. The maximum intensity is given by a moving storm of half the area of the catchment and may give an intensity of the order of 20 per cent more than that from a stationary storm covering the catchment but the run-off will be some 40 per cent less.

If the catchment is irregular in shape, then the area of the storm will be increased as its width must be equal to the greatest width of the catchment to enable it to maintain its cover of the catchment as it passes over. This tends to reduce the figures given above.

7. Variation of slope over the catchment.

It can be shown that the highest flood intensity occurs when the slope is uniform.

8. Variation of the coefficient of run-off over the catchment.

This becomes important when the catchment contains a considerable area of rocky impermeable soil, the remainder being permeable. In such a case the highest flood intensity may be given by a limited storm covering the rocky area only.

9. Variation of the coefficient of run-off during the storm.

Even if the catchment is already wet at the commencement of the storm, the coefficient of run-off will tend to increase slightly during the progress of the storm. On the other hand, if the ground is frozen, the coefficient will be initially high but will tend to decrease as the ground thaws. It is found that variation of the coefficient during the period of the storm does not have any important effect on the flood intensity. An increasing value gives a slight margin of safety and conversely.

A study of numerical results of these variations on a number of catchments indicated that nos. 2, 5, 6 and 8 have the most important effect on flood intensity and having regard to the nature and order of this, it was concluded that it would be desirable to add 25 per cent to the maximum intensity calculated for standard conditions in dealing with problems of waterway. For flood regulation, the hydrograph is more important than peak intensity and, as in every case an increase of flood intensity is accompanied by a decrease in run-off, no such addition appears necessary.

Two special points should however be considered:

1. If the catchment is very irregular in shape, the flood possibilities of a storm covering only part of the catchment should be investigated.

2. If the catchment contains a large area of rocky impermeable ground, the effect of a storm limited to this area should be studied.

It has only been possible within the limits of a short paper, to indicate in outline the nature and results of the author's investigations on flood discharge. They are set out fully in his book "Flood Estimation and Control" (3).

Given the record of a major flood, the probable maximum flood from the catchment can be estimated with the help of the formulas. Where there are sufficient rainfall records to establish a rainfall frequency relation, then the frequency of floods of any given magnitude can be determined by probability methods.

An important characteristic of the methods shown is that they enable the flood hydrograph to be drawn. In problems of flood regulation the hydrograph is of far greater significance than peak intensity which, without a knowledge of the growth, duration and decline of the flood, provides in itself inadequate data upon which to base any scheme of regulation.

This paper is accompanied by five diagrams and by a short bibliography, references to which in the text are marked by the appropriate numbers.

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Analysis of Experimental Data on River Hydrology: Classification of Hydrological Studies and of the Estimates Derived from Them[1]

AIMÉ COUTAGNE

ABSTRACT

An analysis of experimental hydrologic data leads to a number of studies, more or less specific, that are here classed in accordance with *time, meteorological* and *geographical* factors. In relation to these the yield and its variations are considered under three heads, to which three similar types of estimates correspond:

I. Study of yield in relation to the *time factor*:

(1) Time considered as a *duration factor* (*probabilities*);

(2) Time considered as a *seasonal factor* (*annual periodicity*);

(3) Time considered as a *periodic factor* (*various periodicities*).

II. Study of yield in relation to the *hydro-meteorological factors* governing it:

(4) In relation to *rain*—(*rain-river correlations*);

(5) In relation to *temperature* (*temperature-river correlations*);

(6) In relation to *snowfall* (*snow-river correlations*);

(7) In relation to *previous yields* (*internal river correlations*);

(8) In relation to *several of the above factors* (*various river correlations*);

(9) In relation to *evaporation* (*evaporative correlations*).

III. Study of yield in relation to location: *geophysical* and *geographic factors*:

(10) In relation to *geodetic co-ordinates* (*various maps*);

(11) In relation to *terrestrial and climatic conditions* (*geophysical correlations*);

(12) In relation to the *yield of another watercourse* (*inter-regional co-variations*).

The nature and possibilities of yield estimation depend upon the different kinds of study listed above, all of which permit of estimation in the broadest sense of the word: viz., the *determination of certain facts or phenomena, past, present or future, not directly observed or observable, from other facts and phenomena, permanent or variable, directly observed or observable.*

All estimates, and particularly yield estimates, are ultimately based on *probabilities* more or less *localized* in *time* and *space*, and more or less *particularized* by different *periodicities*, *correlations* and *co-variations*.

The following in particular have been distinguished:

1. Purely statistical estimates, based on *probabilities* and *periodicities*.

2. Estimates based on *hydro-meteorological correlations*.

3. Estimates based on *the consideration of location*, i.e. on *geographic correlations or co-variations*.

From the economic point of view these estimates can be used in various ways. They make it possible to extract the maximum output from water resources already being utilized, and to take stock of water resources stil unutilized and study rationally how to harness them and fit them into the existing system.

PART I. CLASSIFICATION OF HYDROLOGICAL STUDIES

An analysis of experimental data on the origin, volume and fluctuations of yield, in time and in relation to atmospheric or hydrological factors past or present, and to the terrestrial and geographical factors which determine them, leads to three types of study and consequently to three types of estimates, which can be classified as follows:

1. Purely statistical studies: variations of yield in relation to the single variable "time".

2. Hydro-meteorological studies: variations of yield at

[1]Original Text: French.

a given time or during a given period, in a particular place, and in relation to the hydro-meteorological factors which determine it.

3. Geographical studies: variations of yield in space, i.e., according to the various catchments in a region, the various regions of a country or the various countries of the world, studied either purely descriptively or in relation to the corresponding local terrestrial or climatic conditions.

A phenomenon or a fact—here the yield, Q—is observed at a certain time, instantaneous or mean (T), at a certain place on the earth (L), at the same time as a certain number of other connected or concomitant phenomena or facts (M). Synthetically it may be regarded as a function of these three variables or types of variables: $Q = \Phi (T, L, M)$. The general problem represented by this formula cannot be examined directly and so on the principle "divide et impera" it is split up into three separate problems, each of which is simpler, as it only takes into account one of the three variables T, L and M, the two others being constants in each separate problem.

Below is given a brief survey of these three types of specific studies divided into separate groups. These families and genera of studies may, moreover, give rise to a large variety of mixed studies, which may be called hybrids, as they combine several points of view.

1. STUDY OF YIELD VARIATIONS IN TIME: $Q = F_1$ (T)

The yield is studied statistically and not causally, i.e. as a function of the sole variable "time"; no account is taken of the natural factors of all kinds which govern yield, and only one place is considered.

"Time" may, however, be considered from three different points of view:

(*a*) As a duration factor. Chronological order is disregarded. This type of study relates to all problems centring in the calculation of probabilities. The yield is studied as a function of its total probability (p), giving the formula $Q = F_1$ (p).

(*b*) As an *average periodic factor*, or *seasonal factor*, in which the period is a year. Yield is studied in relation to its position in the year, i.e., as a function of the variable "month" (m); e.g., $Q = F_2$ (m).

(*c*) As a *chronological factor*, i.e., periodic where the period is any other than that of the solar cycle. All research into *periodicities* starts from this point: $Q = F_3$ (t).

To sum up, there are three types of specific study, in which yield variation is analysed in relation to its probability, or to its position in the average year, or to its position in the sequence of days, months and years.

2. STUDY OF YIELD VARIATION IN RELATION TO THE ATMOSPHERIC AND HYDROLOGICAL FACTORS WHICH CONDITION IT.

This is the starting point of all research aimed at the analysis of the approximate relationships—correlations—between the yield and the hydro-meteorological factors conditioning it causally or accompanying it chronologically.

These correlations are either simple or complex. The former express the yield as a function of a single factor which here plays a dominant part. The latter express the yield as a function of several factors all of which condition it. To make these ideas concrete, they may be classified as follows:

(*a*) *Rain-discharge* correlations: $Q = \Phi_1$ (H). The yield depends chiefly upon rain. This applies, for example, to the annual yield of catchments with average and heavy rain in temperate areas, and also to the yield of heavy flood-waters; once the soil is saturated, the yield is conditioned mainly by rain.

(*b*) *Temperature-discharge* correlations. The yield is almost entirely a function of the thermal factors or of their pilot factor temperature. This applies to ice yield: $Q = \Phi_2 (\theta)$.

(*c*) *Snow-discharge* correlations. The yield from the melting of the snows of the previous winter is governed chiefly by the quantity of snow retained: $Q = \Phi_3$ (N).

(*d*) *Base flow* correlations. This is the term here given to the correlations brought about by the internal retention of the soil, which arise when there is no rain and no melting of snow and ice; e.g., between the yield Qn of any one period and the yield Qn-1 of the preceding period: $Qn = \Phi_4$ (Qn-1).

(*e*) In addition to these four elementary types of simple correlations there are also numerous complex correlations, which involve the factors H, θ, N, Qn-1, etc., together. These need not be given in detail, but may be represented by the formula $Q - \Phi_5$ (a, b, c . . .)

(*f*) Special note is made only of studies of evaporation and run-off deficit, factors which are often regarded as auxiliary variables in the study of yield variation. These correlations may be called "evaporative" and represented by the formula D or $E = \Phi_6$ (a, b, c).

3. STUDY OF YIELD VARIATIONS IN SPACE

This "family" of studies differs from the preceding two in that the yield of any given river system is regarded from the geographical point of view and not analysed in relation to time or to factors upon which it depends.

The variable in relation to which it is studied is its geographical situation, or any resulting terrestrial or climatic factor. Comparisons are made between various watercourses and various areas, from the standpoint of their run-off and water resources. Here the general average yield is usually taken and compared with the corresponding climatic averages, or studied in relation to certain terrestrial or geographical factors such as altitude, contour, soil geology and vegetation.

These investigations may lead to formulae and correlations which are either regional or, in exceptional cases, universal. These may be divided into three main types:

(*a*) *Purely statistical studies*, arriving at general averages which make it possible to draw geographical maps of a given meteorological or hydrological factor, or a given climatic or hydro-meteorological function, by means of which a flood system, a rainfall system or a climate may be depicted by combining several simple factors. Such factors include precipitation mean temperature and run-off. Complex factors constituting climatic functions include the run-off quotient or deficit and the aridity index; the average maximum or minimum temperature and the daily or annual temperature variation.

The object of these studies is to express the climatic or hydrological factor or function under consideration as a function of the geodetic co-ordinates X and Y. They may be represented by the formula Q (or any other factor) = Ψ_1 (X, Y).

(*b*) Studies with the aim of formulating certain correlations which are valid, if not for the whole world, at least for a considerable area, between the yield (or any other given factor or function) and certain permanent factors either geophysical (e.g., altitude) or climatic (e.g., mean temperature, mean rainfall).

These studies may be classed as geographical and geophysical correlations and represented by the formula Q = Ψ_2 (a, b, c . . .).

(*c*) *Inter-regional river co-variations.* A comparative study is made, solely from the statistical standpoint and irrespective of the various conditioning factors, of the yields of two watercourses, whether adjacent or not; of the yields of the same watercourse at two different points; or of the yields themselves (annual, monthly, flood, etc.); or of various features of their water systems, e.g., their seasonal or periodic variability. These are called "inter-regional river co-variations": Q = Ψ_3 (Q^1).

The attached table summarizes the above classification which is based on the nature of the variables, the factors in relation to which yields and their characteristic features are studied. This classification may be adapted to studies of the same kind in respect of any factor or climatic function, such as temperature or precipitation.

With a different method of approach a hydrological work may be cast in a different form, that of the monograph. Instead of studying a particular water problem by analysing from a given standpoint, the greatest possible number of catchments, one particular catchment is studied from all points of view. There can be no question of standardizing "hydrological monographs" of this kind, which are bound to differ according to the personality of their authors and the branch of science to which these belong. With this reservation, however, there is no denying the advantage and value which would flow from a certain unity of view, conception and presentation, whether within any one State or on a world scale.

PART II. APPLICATION OF HYDROLOGICAL STUDIES TO YIELD ESTIMATION

The nature and possibilities of yield estimation depend upon the different kinds of study listed above, all of which permit of estimation in the broadest sense of the word: viz., the *determination of certain facts or phenomena, past, present or future, not directly observed or observable, from certain other facts or phenomena, permanent or variable, directly observed or observable.*

It has been stated that all estimates concerning a phenomenon and its manifestations in time and space result from a calculation of probabilities, a probability curve. The estimate will be the more efficient the more the probability curve is localized in time and space, and also the more closely it is related to the other permanent or variable phenomena conditioning it causally or accompanying it chronologically, i.e., the smaller will be the margin of variations bounded by that curve. This aim is achieved more or less by means of the correlations, co-variations and periodicities which may be discovered and calculated by the comparative analysis of the phenomenon with the other phenomena.

This is true also of yield estimates, which may be classified as follows:

(A) *Estimates based on probabilities and periodicities:* Q = F_1(T)

(I) The formula Q = F_1 (p) covers all purely statistical estimates of possible yields and their durations, frequencies and probabilities, irrespective of their chronological order.

The probability curves used are either experimental or interpreted by theoretical algebraic formulae. When thus extrapolated beyond the limits of observation, they permit of certain estimates, which are often illusory, e.g., estimates of the heaviest flood yields.

(II) The formula Q = F_2 (m) covers all estimates of the same kind on the seasonal plane, i.e., in which annual periodicity is taken into account.

(III) The formula Q = F_3 (t) covers all estimates, more or less long-term, that can be based on certain periodicities. Such periodicities however, have still to be found, since those that harmonic analysis reveals are not all necessarily real.

(B) *Estimates based on hydro-meteorological correlation:* Q = F_2 (M)

Estimates of this type, which are usually short-term, aim at determining in advance future yields in so far as these result from previous factors, i.e., soil retention. They are therefore very limited in scope and are rendered more or less uncertain by the impossibility of foreseeing meteorological factors.

The most efficient correlations from this point of view are Q = Φ_3 (N) and Q = Φ_4 (Q n_1), corresponding to the snow yield and the infiltration yield.

Apart from these estimates proper, such correlations allow of highly useful interpolations, such as the retrospective study of yields, over a long period, of a watercourse of which the yields have been observed over a short period only but the precipitation has been known or many years. Also, correlations of the type Q = Φ_1 (H) may be taken into account when floods are estimated in terms of rainfall.

(C) *Estimates based on geographical correlations or co-variations*

Estimates of this kind relate particularly to the estimation of yields not directly observed.

For example, rainfall maps may be used to calculate average run-off when other separate correlations, such as that between evaporation and temperature, are taken into account.

Also important from this point of view are the inter-regional river co-variations, Q = $\Psi 3$ (Q^1), whether direct or inverse.

Where the co-variation is direct and strong, it may be used to determine the average, seasonal or periodic behaviour of a watercourse whose yield has been known only for a few years, by reference to the characteristics oı another watercourse whose behaviour has been known over a long period, provided that the yields of the two

Diagrammatic Classification of Studies in Fluvial Hydrology: $Q = \Phi$ (T, L, M)

	General formula	*Specific formula*	*No.*	*Type of study*	*Applications—estimates*
Probabilities and Periodicities	$Q = F_1$ (T)	$Q = F_1$ (p)	1	Study of probabilities: Intrinsic variations	General statistical estimates
		$Q = F_2$ (m)	2	Annual periodicity: seasonal variations	Statistical estimates based on average year
		$Q = F_3$ (t)	3	Study of periodicities: periodic variations	Estimates based on periodicities
Hydro-meteorological correlations	$Q = F_2$ (M)	$Q = \Phi_1$ (H)	4	Rain-discharge correlations	Various interpolations. Study of floods in relation to rainfall
		$Q = \Phi_2$ (Θ)	5	Temperature-discharge correlations	Study of ice yield Average temperature-river year
		$Q = \Phi_3$ (N)	6	Snow-discharge correlations	Estimation of snow yield
		$Q_n = \Phi_4$ ($Q_n - 1$)	7	Base flow correlations	Estimation of infiltration yield and low water yield
		$Q = \Phi_5$ (a, b, c,)	8	Complex river correlations	Various estimates and applications
		D_{or} E $= \Phi_6$ (abc)	9	Evaporative correlations	Study of evaporation, run-off deficit—hydrological balance
Geographic Correlations and co-variations	$Q = F_3$ (L)	$Q = \Psi_1$ (XY)	10	Geographical maps and statistics	Estimation of water system of a catchment in terms of its general characteristics, in the absence of river data. Checking of river statistics—various economic applications.
		$Q = \Psi_2$ (a, b, c,)	11	Geographical and geophysical correlations	
		$Q = \Psi_3$ (Q^1)	12	Inter-regional river co-variations	

Hydrographical and hydrological monographs. Studies of a particular watercourse, region or country.

watercourses have been observed over a certain common period.

Direct and poor co-variations and, *a fortiori*, inverse co-variations provide information of a different kind. The greater the difference between the seasonal and periodic variations of two watercourses, the greater the advantage of co-ordinating their use so as to obtain a combination, e.g., of hydro-electric stations, with as constant an output as possible, either over the various months of the year or over successive years.

From the economic point of view, therefore, yield studies and estimations seem important economically for two different approaches. They permit the most rational utilization of water resources which have already been harnessed, and enable the maximum output to be obtained; and they make it possible to take stock of water resources still unutilized, to project and study their exploitation in harmony with the existing use of other resources.

Finally, correlations and co-variations can be applied generally to check river statistics one against the other and to correct and complete them. It is, however, sometimes difficult to say whether absence or paucity of correlations is due to statistical errors or to things as they are. Hence the necessity in estimation not to restrict one's self to any one formula but to use as many sources of information as possible, to base forecasts on the greatest possible number of observations and experimental facts. *Unus testis, testis nullus.*

The Appraisal of Water Resources in the United States: Analysis and Utilization of Data; Water Supply and Flood Forecasting

MERRILL BERNARD

ABSTRACT

Basic data needed to plan, design and operate the extensive control works required to make full use of the water resources of the United States are inadequate with respect to the number of observing stations, their representativeness and length of record. Steps are now being taken to extend the networks of stations at which hydrologic data are gathered. There is likewise the need for a plan to make effective use of the vast store of precipitation and related data now accumulated in the repositories of the various Federal agencies and in the National Archives. In the absence of a significantly long record of measured streamflow at all points of potential water development, the needs of the immediate future must be met by supplementing the existing streamflow records with estimates of water yield made from precipitation and related hydrometeorological data. Methods have been designed for accomplishing this.

Water supplies in the Western United States, in terms of seasonal flow volume, are forecast by two methods—one, from the water content of the snow mantle at the end of the accumulation period as obtained by snow surveying; the other, from accumulated precipitation as measured at stations maintained by the Weather Bureau. The need remains for forecasts of the rate at which water will be released from the snow pack throughout the summer and fall months.

Public interest in water in the United States varies in intensity from one part of the country to another depending upon the nature of that interest. East of the 100th meridian, which conforms approximately to the 20-in. isohyet of average annual precipitation, surface water is normally in excess of the requirements of the population, the excess reaching its extreme in the great floods which cause damage to the extent of hundreds of millions of dollars and account for an average annual loss of about 100 lives. To the west of the line dividing water abundance from water deficiency there is a progressive reduction of precipitation, and therefore of available water, tending southward to create the region of greatest deficiency which is comprised of the states of Arizona, New Mexico and parts of Texas, Colorado and California. An interior region of deficient rainfall known as the Great Basin includes the states of Utah and Nevada. Rainfall again becomes abundant along the Pacific Coast increasing northward to average annual amounts well over 100 inches in the Olympic Range of the state of Washington.

The irregular distribution of rainfall in the United States is accounted for meteorologically in the relative position of the land mass to source regions of atmospheric moisture. Moist air masses moving into the Continent from the South Atlantic and Gulf Regions are, upon reaching the land, subjected to influences that bring about precipitation at excessive rates well into the interior of the country. The great storms resulting exceed 20 in. or more at their centres, are often greater than 10,000 square miles in extent and sustain themselves for periods of from three to five days.

The lesser rainfalls of the mountainous regions of the West are deposited by storms which originate in the Gulf Region to the south-east; or approach from the south-west out of the Gulf of California; or form in the maritime regions of the Pacific to the north-west. Only those storms having sufficient intensity to surmount and survive the progressive mountain barriers guarding the interior regions bring significant amounts of precipitation to them.

WATER UTILIZATION

The pattern of water utilization in the United States is

1. Domestic use,
2. Consumptive use (agricultural crops, livestock and forests),
3. Industrial use,
4. Electrical power generation,
5. Transportation,
6. Recreation,
7. Preservation of fish and wild-life.

In attaining our present proficiency in water utilization we have unhappily acquired certain liabilities. Flood damage, soil and fertility loss through erosion, depletion of ground water through excessive pumping, and stream pollution are becoming major corollary problems. The conservation and ultimate development of our water resources, therefore, merge into programmes having the broader purpose of regional development for which the river basin appears to be the logical unit.

NATIONAL RESOURCES DEVELOPMENT AND CONSERVATION PROGRAMMES

Two approaches to basin development planning are now evolving—one, a unified control over all phases of development as is found in the Tennessee Valley; the other, the distribution of control among the Federal agencies representing the various phases of development, with unification accomplished through the co-ordinating influence of the Federal InterAgency River Basin Committee. While there is still much of the controversial in these conflicting philosophies, the decade just past has seen an end to the project devoted only to a single purpose such as flood control, irrigation, or navigation. The multiple-purpose development, with its many obvious advantages, has caught the imagination of the public, and has been accepted as a mandate by those entrusted with the planning of our national economy.

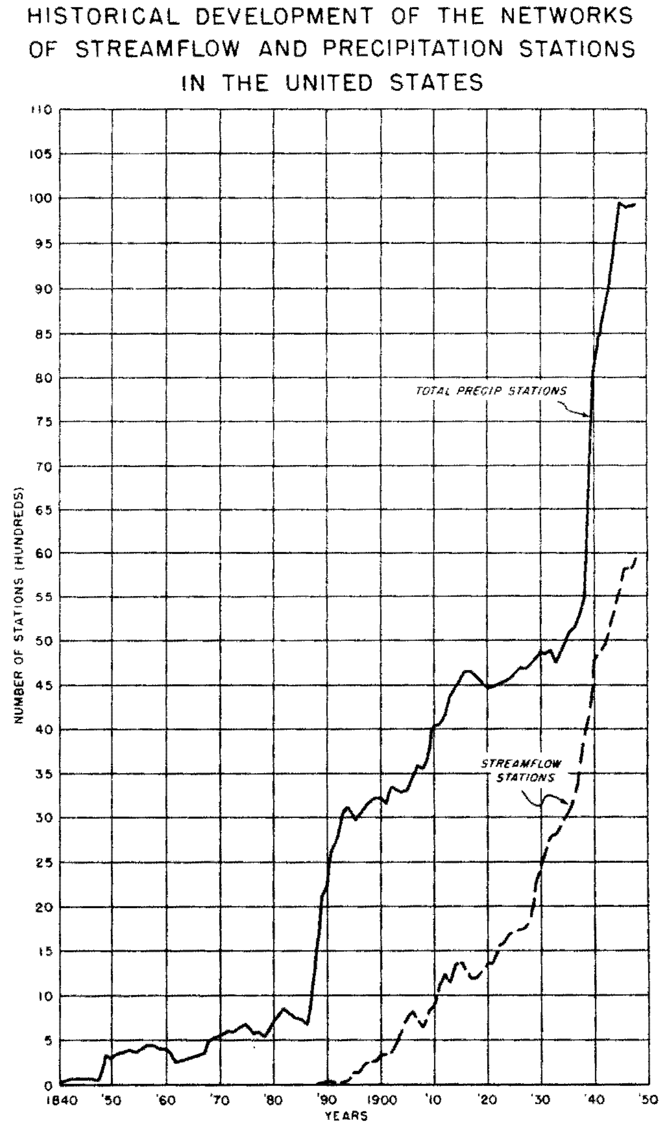

Figure 1

BASIC DATA NEEDED BY THE PLANNER

It is characteristically American to find the urge to build outstripping the urge to plan, and the urge to plan frustrated by the lack of basic data. Terrestial water is a result of complex meteorological phenomena which are operative under controls still remote to man's knowledge of the atmosphere. About all we have to go on is the knowledge that there are definite physical limits to the extremes of great storms and periods of drought and that the pattern of weather variability is represented in the records of the past with reasonable accuracy even though the average length of record is less than fifty years.

It is axiomatic in much of the United States that water must be utilized where you find it. Therefore, accurate knowledge of the geographic location of areas of water abundance and water deficiency becomes a prerequisite to planned utilization. In addition to variations in distribution over area, there are to be taken into account variations in the distribution of precipitation throughout the year, and variations in the frequency with which years of a given precipitation volume will recur. Not only is it necessary for the planner to know in detail the characteristics of the precipitation regime, but he must also have accurate knowledge of the characteristics of temperature, humidity, wind and other meteorological factors that cause snow to melt and water to evaporate from water and land surfaces—this in order that the years and months of the period of record may be classified as to their melting and evaporating potentialities. These phenomena interact in accordance with natural laws which are reasonably well understood and can be evaluated with available data and scientific knowledge. From them, it is possible to produce a dependable estimate of (*a*) the distribution of the net potential surface-water supply (precipitation volume less percolation to deep ground-water and evapo-transpiration losses), (*b*) the seasonal variation in its accumulation and release (as melting snow), and (*c*) a measure of its dependability in terms of the average recurrence interval between years of equal net volume.

The planner's Utopia would be that in which he would find a record of measured water (stream-flow) at all points of potential development covering a period sufficiently long to be representative of cycles of major periodicity and amplitude. As it is he has nothing to approach such a complete data source. His sampling points, both of stream-flow and precipitation are scanty in number and poorly distributed and the period of record in many areas so short as to be statistically unreliable. Figure 1 shows the progressive expansion of the stream-flow and precipitation networks. A base network of ground water wells is only now being developed.

It is known that many areas subject to possible water development are completely unrepresented, or at best inadequately represented, by observations of essential meteorological and hydrologic elements. Methods are available to interpolate between existing stations and to overcome in part such deficiencies. However, the interpretation of the longer records and the dependability of the conclusions reached are greatly enhanced through even a short period experience of actual observations at selected points within the areas of potential development. Such a programme would provide the opportunity to augment stream-flow, precipitation, temperature and other data and to determine the wind and humidity characteristics of valleys in which development is possible, air movement being an important factor in evaluating the rate of evaporation, both from the surface of reservoirs and from land surfaces under a variety of anticipated crops and land use practices.

Fortunately, the Sub-Committee on Hydrology of the Federal Inter-Agency River Basin Committee has recently completed a series of field conferences at which the requirements for additional stations were reviewed. The summary of these conference recommendations provides a guide to the selection of stations needed to overcome the critical weaknesses in the existing networks based on the combined judgment of all the interested Federal agencies. The totals of the recommendations for the entire country of these inter-agency conferences for hydrological and meteorological stations are as follows:

Stream-flow	3,400
Snow courses	400

Precipitation	4,456
Evaporation	242
Meteorological Stations (complete)	68

Such a programme of expansion could be implemented in from 3 to 5 years.

THE PROCESSING OF BASIC DATA

Problems of water control involve the design of structures whose dimensions and capacities must meet future experiences having the characteristics of flow magnitude, duration and frequency of occurrence. It is not likely that in any two design problems these characteristics will be found in the same combination. Particularly in multiple-purpose structures must there be maximum flexibility and the designer must identify the critical combinations and subject the structure design synthetically to them before he dare reduce the design to concrete and steel. Processing, therefore, must be so accomplished as to make it possible to express the data in summarized form, the summary to meet the precise specification of the problem in terms of (*a*) the element (or elements) involved, (*b*) range of magnitude, (*c*) duration, (*d*) frequency of occurrence. Fortunately, modern punched-card methods can accomplish this for the processing of climatological data and there is encouragement to believe that such methods can be developed for processing stream-flow and other hydrologic data as well.

The United States Geological Survey is engaged in the systematic processing and publication of stream-flow data. Continuous records of discharge are now being collected and published in the form of mean daily discharges for about 6,000 stations. Throughout the past sixty years the Geological Survey has gathered stream-flow records at about 12,000 points throughout the country. Records of major floods are published as separate reports giving instantaneous flows at hourly or less frequent intervals depending on the features of the flood. Special reports present summaries of maximum flows of record including peak-flow rates in second-feet per square mile and other pertinent data. Throughout the record continuous improvements in flow measurement techniques, stabilization of sections by artificial control, improved techniques for rating stations under conditions of backwater, and refinements in computation and processing have resulted in a steady increase in reliability of records.

The unit hydrograph continues to be an important form in which to express stream-flow. Recently the Sub-Committee on Hydrology has developed standard procedures and forms for defining the elements of the unit hydrograph from flow data, a step which will make possible the general interchange of such data between Federal agencies.

Precipitation, temperature and evaporation data have been collected by the Weather Bureau since 1891 and prior to that year by the Signal Corps, Smithsonian Institution and private observers. Many of these data have been checked by inspection and published in the monthly and annual bulletins of the Bureau. As with stream-flow there has been a steady improvement in the quality of the published data effected through improved instruments, shielding of precipitation gauges and better methods of processing. Within the past year the use of punched-card equipment has been introduced in routine data processing. Improvement in the quality of data through improved checking procedures and the advantages of ready availability for summarization are already evident. However, more than 1,000 million items of unsummarized data are to be found in the repositories of the Weather Bureau and the National Archives. The punching of cards does not constitute the whole of the data processing phase. Once the cards are available, they will be used to prepare summaries from which the analyst will work. Summaries will vary from simple listings in chronological order to complete multiple-frequency tables and even machine plotted maps. Before the summaries can be prepared in final form, all climatological station records must be checked and adjusted for changes in location, type of instruments and exposure conditions.

Much remains to be done in preparation for the mechanical processing of basic data. Many records have been interrupted for short periods; stations moved short but significant distances; changes introduced in measurement techniques, etc. Such records can be so adjusted as to form continuous long-period records by the use of double-mass curves (1)[1] (2) and similar procedures. Interpolation of missing records and extrapolation of early records is possible and necessary to the ultimate utilization of the data by the analyst.

APPRAISAL OF WATER RESOURCES

Awaiting the ultimate record of complete stream-flow data, reference to precipitation and related meteorological data can be made to supplement the records of stream-flow. If we are to utilize our water resources to the fullest an essential first step is to determine the extent and distribution of the *potential* supply which is the precipitation deposited on the land. An important part of this is the precipitation falling as snow in the high mountainous regions. From this initial supply are to be deducted the demands of Nature in the form of evaporation and transpiration. Accountability must be made for that which sinks into the ground, some moving laterally and within a short time into the stream channels—the remainder continuing downward into subterranean storage. The residual water reaching the streams, joining with that entering from ground-water sources, becomes the "net" resource of surface water.

The extent and dependability of this net resource are today matters of speculation despite the fact that works to the extent of thousands of millions of dollars are being planned in anticipation of its exploitation. Again we are fortunate in having at hand the means of overcoming, to a considerable extent, the deficiencies in the essential data. Precipitation records can be adjusted for changes in local environment throughout the period of record. Physiographical influences can be expressed in multiple correlations (3) in which elevation, slope and aspect are parameters (Figure 2). Through such relations it is possible to interpolate rainfall values between stations in mountainous terrain and to develop far more reliable maps showing

[1]The numbers within parentheses refer to items in the bibliography.

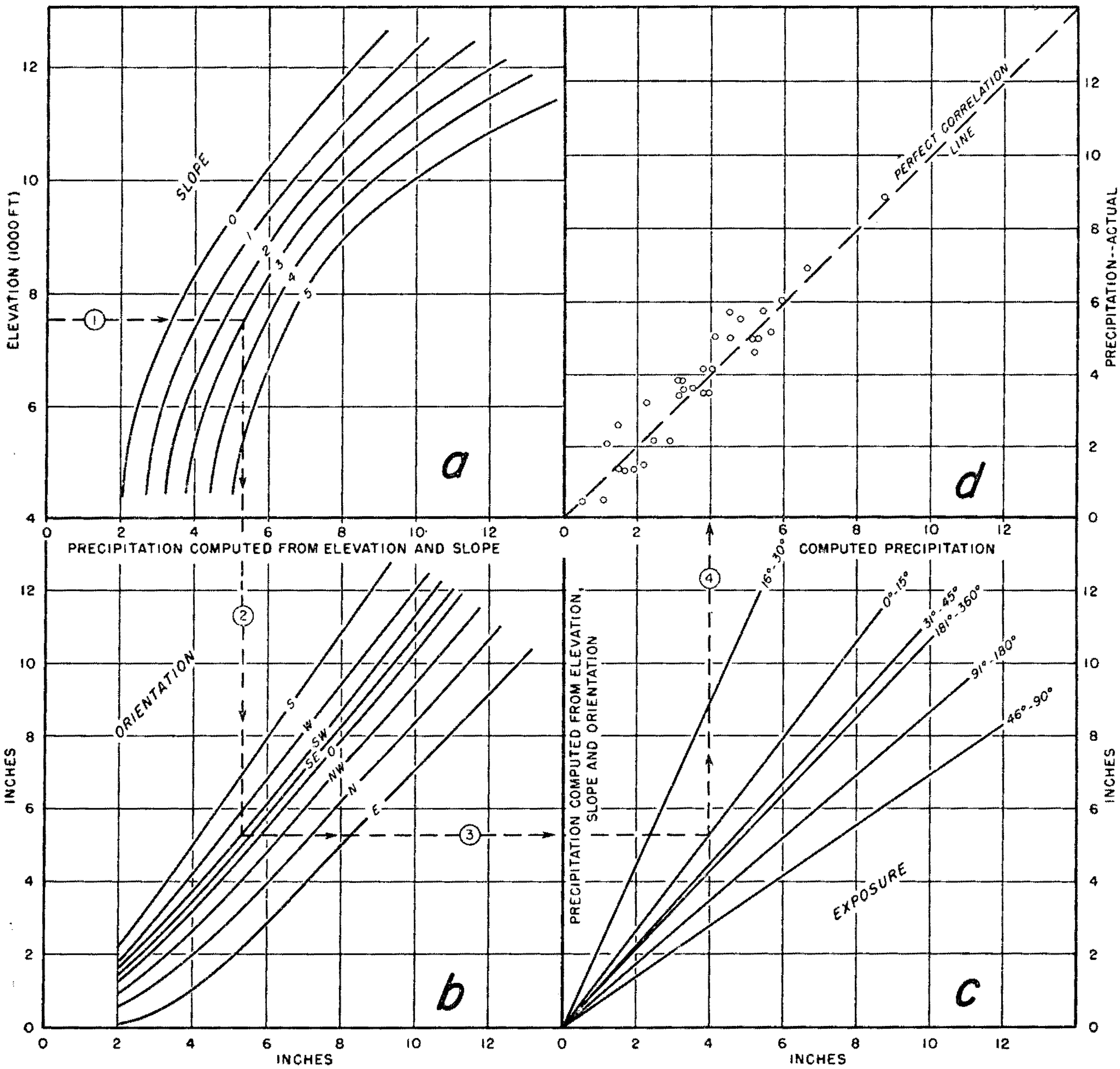

Figure 2. RELATION BETWEEN PRECIPITATION AND TOPOGRAPHIC PARAMETERS IN WESTERN COLORADO AS OBTAINED BY GRAPHIC CORRELATION FOR PERIOD 1920--1930.

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the amount and distribution of precipitation than have been used in the past (Figure 3). Finally, utilizing machine methods of processing, it is possible to express the adequacy of water supply in terms of the recurrence interval between years of equal precipitation volume, or some other statistical expression of probability, making it possible to prepare "probability" maps comparable to that in the reference figure.

Although a reasonable evaluation of precipitation volume is possible the problem of determining the extent of water "losses" is far less satisfactory. No adequate technique for the direct measurement of evaporation has yet been convincingly demonstrated and no thoroughly satisfactory correlation between evaporation from natural water surfaces and evaporimeters is available. Much remains to be done in this field.

FORECASTING WATER SUPPLY

The design of a multiple-purpose structure, such as a storage reservoir and dam is based on a "forecast" of the

NORMAL ANNUAL PRECIPITATION FOR SOUTHWESTERN COLORADO

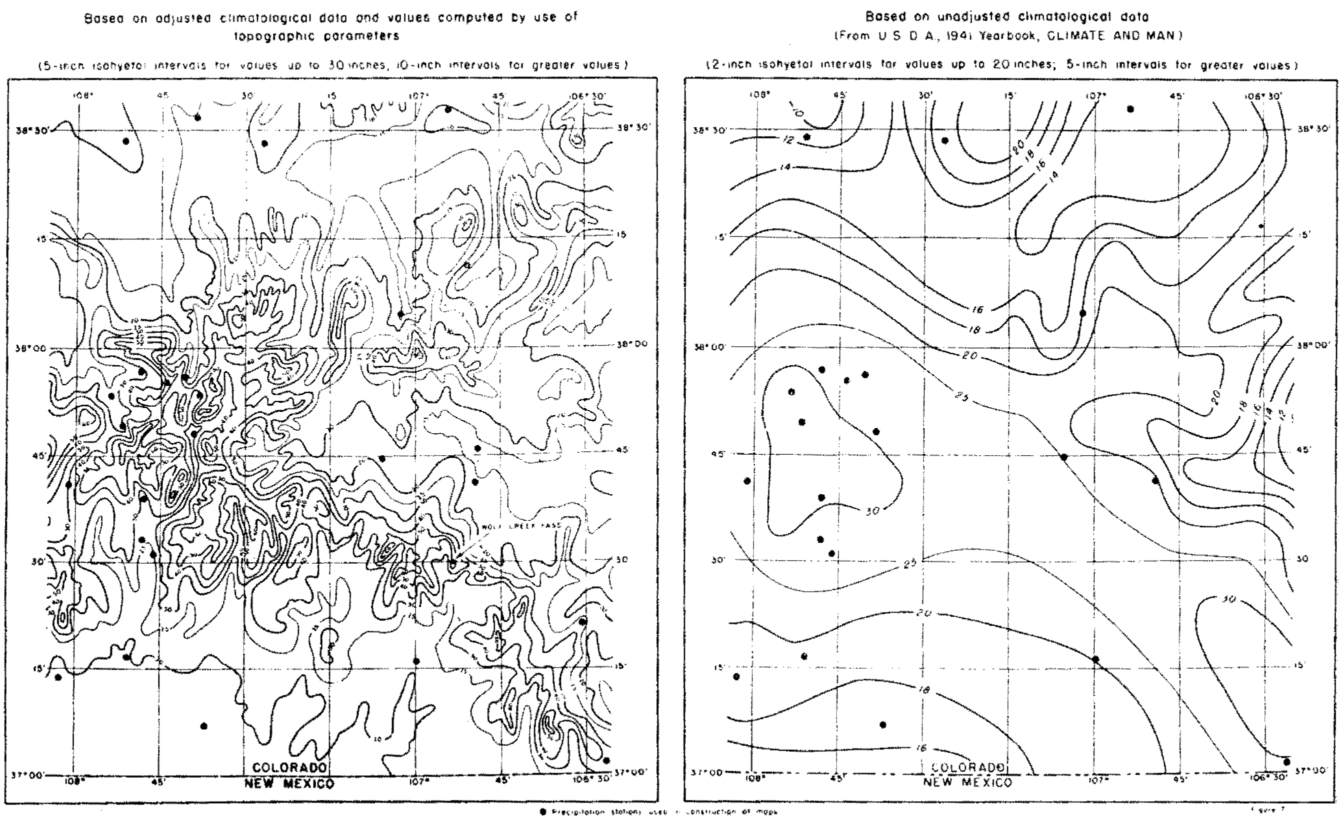
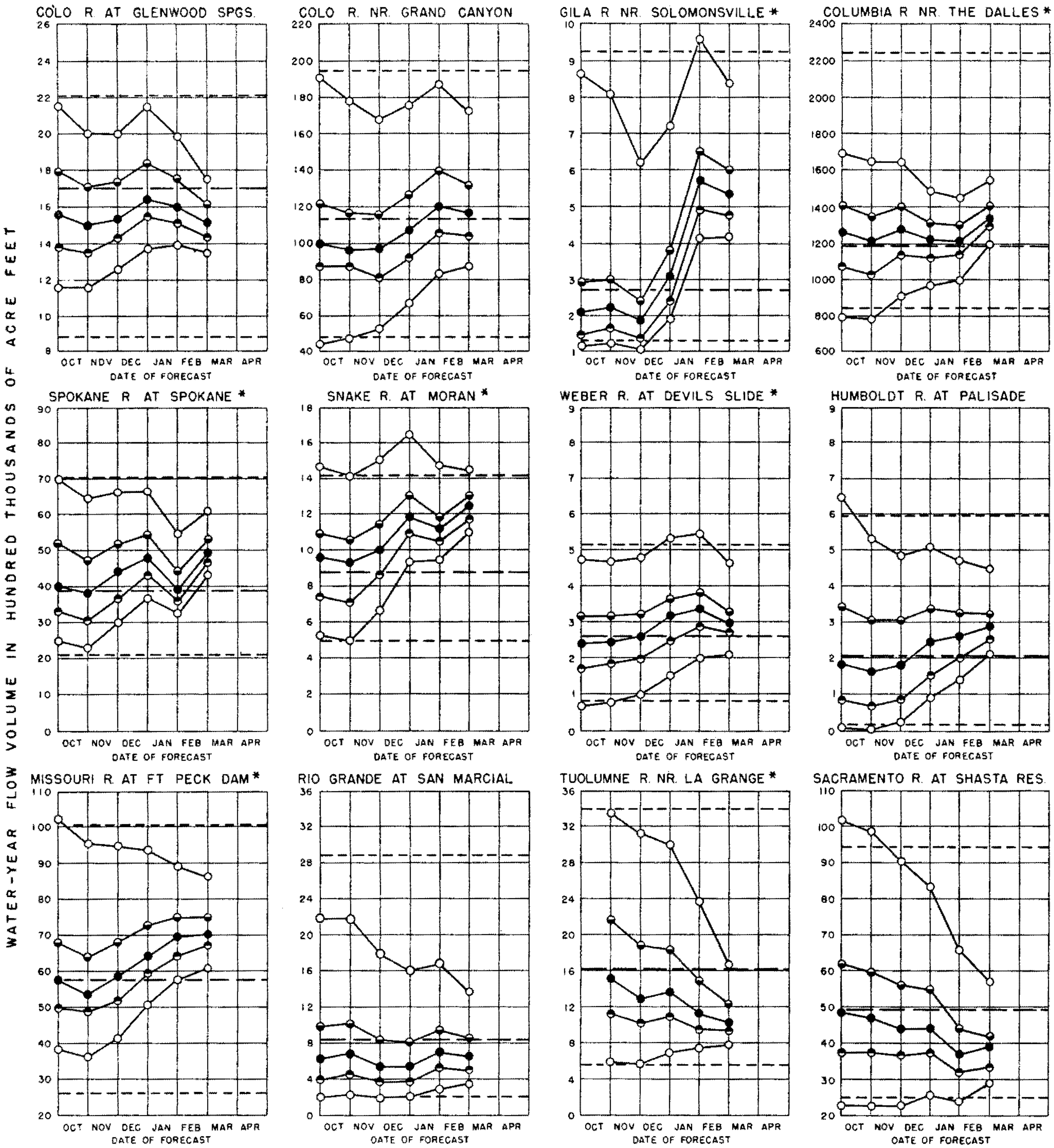


Figure 3

range of events which can be expected to occur within its physical life. Since the anticipated functioning of the structure is based on assumptions of efficient operation, another kind of forecast, that looking into the immediate future, is required. In western United States, where much of the stream-flow comes from the melting of seasonally accumulated snow at high elevations, the seasonal flow volume can be forecast with relative accuracy and well in advance. Two systems of forecasting are utilized. One utilizes measurements of density and water content of the snow mantle at the end of the accumulation season (April) which are acquired by means of snow surveying (4). Most snow surveying in the United States is under the direction of the Soil Conservation Service. The other method of forecasting is based on accumulated precipitation as measured at stations operated by the United States Weather Bureau. Because of the relatively long records of precipitation it is possible to issue the first forecast of the season as of 1 January, confirming or modifying forecasts being issued each month through May (Figure 4). The forecasting procedure, which is one of progressively substituting observed data for statistical data as the season progresses, makes it possible to keep the operator informed of changes in the current year as it will be related to the "normal" year. There yet remains to be developed a successful method for forecasting the delivery of the water-year volume through the months following the spring melting. Short range forecasts of three to fifteen days, while technically possible, must await an appreciation of their importance to multiple-purpose operations before they can be developed and made a part of the national forecasting service.

FLOOD FORECASTING

The United States is one of the relatively few countries that has assigned to its meteorological service the responsibility for forecasting floods. The desirability of this logical arrangement was early recognized. Concentrations of population along the rivers, and of industrial and agricultural wealth in the valley flood plains created the need for warnings of impending floods as early as 1890. For many years the flood forecasting service of the Weather Bureau was confined to the larger rivers and the lower reaches of the major tributaries where flat slopes and long distances made it possible to forecast from simple stage relations. Today public demand has forced this service into the very headwaters (5) (6), necessitating the development of forecasting techniques in which precipitation, both anticipated and observed, are the basic factors. Such a precipitation run-off relationship is shown in Figure 5. Flow routing procedures (Figure 6) based on the hydraulic characteristics of the river reach are replacing the empirical methods in which stage alone is the variable. These procedures make it possible to forecast the complete hydrograph and not merely the crest as was the case in the earlier years.



PROGRESSIVE FORECASTS OF RUNOFF

WATER YEAR 1948-49

These charts show graphically the forecasts and estimates of water supply for selected stations, computed as of the first of each month since October. The variations in the median forecast as the season progresses reflect the departures from normal of the observed precipitation. As each month's precipitation data are substituted for the statistical data, the estimates based on the quartiles and extremes of record converge on the median forecast.

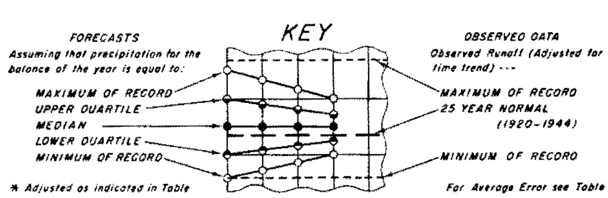


Figure 4

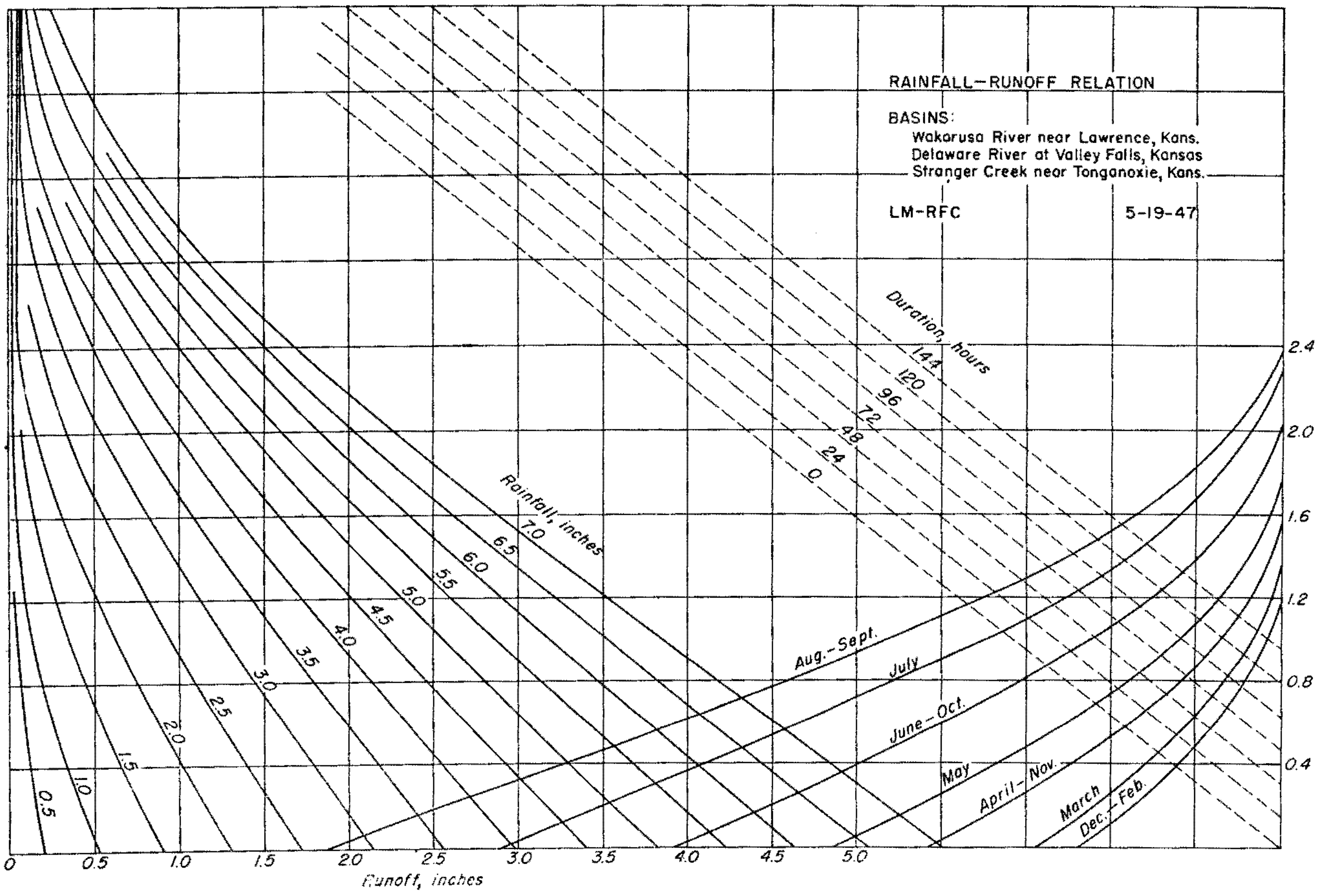


Figure 5

Recently an electronic device (7) has been developed which utilizes the analogy between the flow of electricity and the flow of water to solve problems in flow routing. This device gives promise of being as important a development as the unit hydrograph and may ultimately replace it, as well as graphical routing procedures, in forecasting operations.

Development of procedures for forecasting floods caused by melting snow have not kept pace with other phases of flood forecasting. It is believed, however, that the fundamental techniques are understood and that the necessary procedures can be developed within the framework of existing hydrologic knowledge.

In addition to the flood forecasting service rendered by the Weather Bureau, the Tennessee Valley Authority as well as certain other Federal agencies engage in flow predictions in connexion with their own operations.

HYDROMETEOROLOGICAL STUDIES

An important phase of water control and utilization design are the hydrometeorological studies (8) (9), of the Weather Bureau made in co-operation with the Corps of Engineers and the Reclamation Service. These studies are made in two parts (*a*) storm analysis and (*b*) determination of maximum possible flood producing conditions. Under a co-operative arrangement field offices of the Corps of Engineers and of the Bureau of Reclamation collect and process storm data under a carefully detailed instruction to ensure uniformity. These data, after being reviewed by meteorologists of the Weather Bureau for consistency with the weather sequences, are placed in the "master" file of processed storms and made available to all offices of the co-operating agencies.

Under the second part of the co-operative studies the Weather Bureau undertakes the meteorological analysis of storm rainfall over specific river basins in order to determine the physical maximum beyond which the precipitation-intensity-duration relationship cannot go. These estimates are considered along with other controlling factors in the design of spillways to assure the safety of important structures.

FLOOD FREQUENCY

No completely satisfactory techniques for frequency analysis have been developed, largely because statistical methods cannot be relied upon to safely extrapolate beyond the available record period. For determining recurrence intervals up to or slightly exceeding the period of record any of the recently developed techniques is acceptable. Extrapolation of recurrence intervals far beyond the period of record (thirty to fifty years in the United States) are generally admitted to be untrustworthy, there being little reality to estimated periods between flood events which must be measured in hundreds, or even thousands of years.

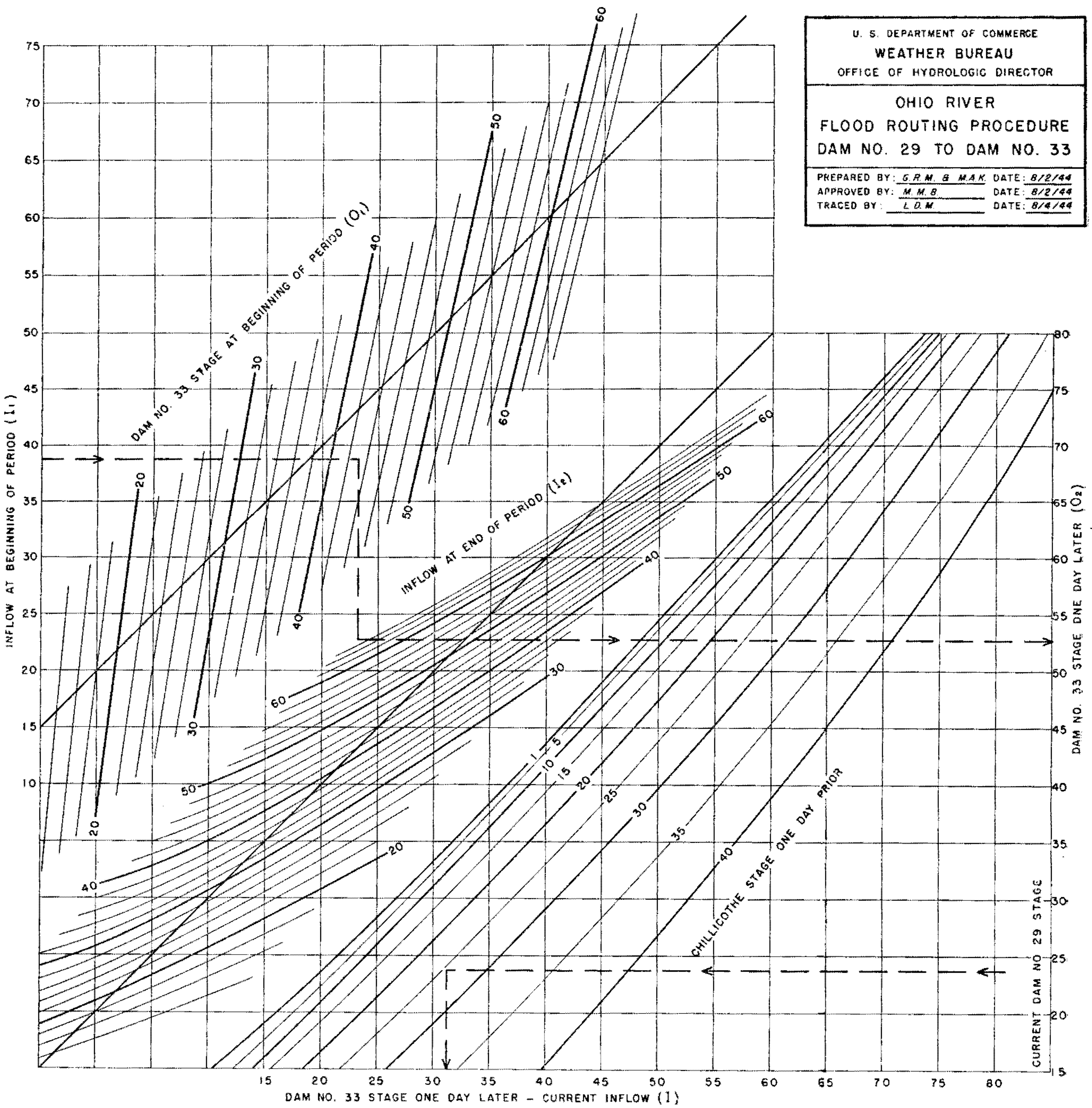


Figure 6

POWER POTENTIAL

The analysis of power potential is essentially the analysis of the flow-duration characteristics of a river reduced to terms of electrical energy on the basis of estimated developable head. In the absence of an adequate stream-flow record the basic data may be synthesized from nearby stream-flow records or from precipitation data as suggested earlier in this paper. The Federal Power Commission, Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and the leading utilities interests are far advanced in devising the means for expressing river-flow in terms of electrical energy, much of which has found its way into technical literature.

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Appraisal of Water Resources: Analysis and Utilization of Data

(Forecasting water yield, flood run-off, flood frequency, power potential)

A. N. KHOSLA

ABSTRACT

This paper deals with the determination of run-off from rainfall. The forecast of water yield is based on the rational concept that run-off is the residual of rainfall after deduction of evaporation and transpiration "loss". An analysis of data shows that this "loss" during any period is a function of the mean temperature during that period, but limited to the amount of rainfall, if the latter is less than the "loss" so calculated.

2. The author offers, what he believes to be, a universal relationship (subject to certain limitations) between mean monthly temperature (T_m) in degrees F. and monthly evaporation loss (L_m) in inches, viz.,

$$L_m = \frac{T_m - 32}{9.5} \text{ where } T_m > 40^\circ \text{ F.}$$

For $T_m < 40^\circ$ F, the loss (L_m) may provisionally be assumed as below:

T_m	40°	30°	20°	10°	0°	F.
L_m	0.84	0.70	0.60	0.50	0.40	inches.

3. The corresponding monthly rainfall (P_m)-runoff(R_m) relationship will be:

$$R_m = P_m - L_m$$

4. The formula for annual rainfall (P_A) and annual run-off(R_A) with mean annual temperature (T_A) will be:

$$R_A = P_A - XT_A$$

where X is a constant for a given catchment.

5. On the basis of the author's formula the annual water resources of India work out to nearly 1,356 million acre feet or a perennial discharge of 1.87 million cubic feet per second.

6. Only 75.65 million acre feet or 5.6 per cent of the total water resources are being utilized at present. Projects for the utilization of an additional 283 million acre feet, or 20.8 per cent, are under consideration.

RAINFALL AND RUN-OFF

For the preparation of any project for the conservation and utilization of water it is necessary to know the total yield of water from the catchment concerned and the variation of that yield from year to year and also, the peak flood discharges and the frequency with which each peak discharge occurs. Run-off is the usual term applied both to yield as well as to flood discharge. For purposes of this paper, the yield will be called "run-off volume" and the peak flood discharge as "run-off intensity". This paper will deal with "run-off volume" only. For brevity the latter will be called "run-off".

In most areas the records of rainfall extend much further back than those of run-off. In a number of cases the data on run-off are practically non-existent. It will be a great advantage if between rainfall and run-off a relationship of more or less universal application can be established. That will make it possible to make an analysis of supplies available from a particular catchment area for the full period of rainfall records and to forecast with fair approximation the probable yields and trends.

RAINFALL

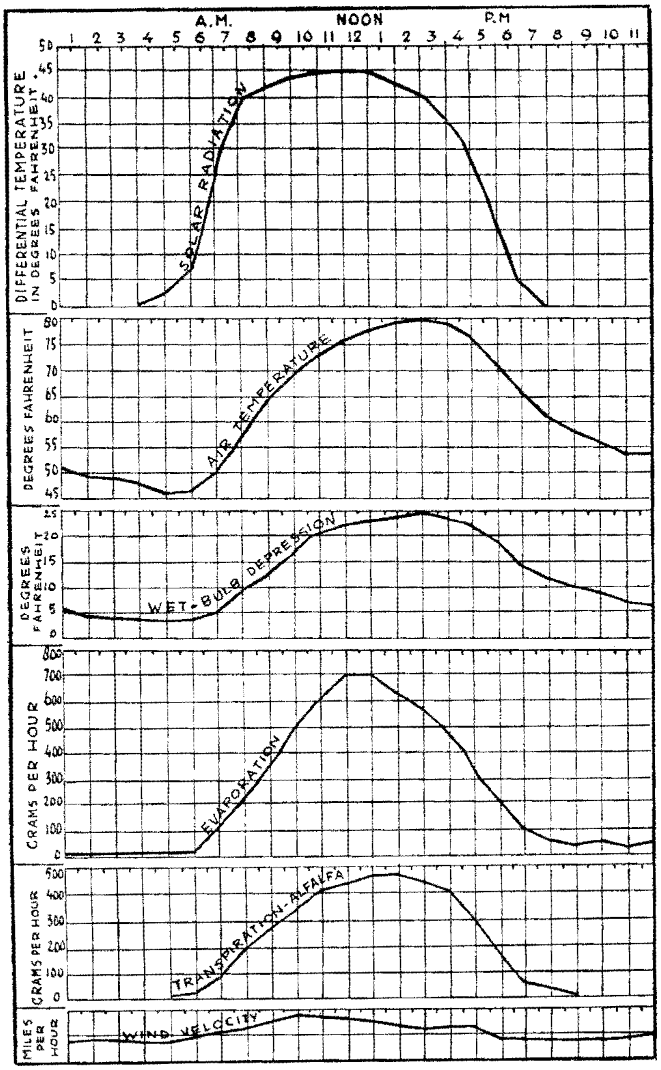
Rainfall or precipitation is the total condensation of moisture from the atmosphere that reaches the earth in the form of rain, snow or ice. The amount of rainfall is expressed in inches of water. For purposes of this paper rainfall will be denoted by P(Precipitation) and will include rainfall as well as snow. The annual, monthly and 10-daily rainfalls will be denoted by (P_A), (P_m) and (P_{10}), respectively.

MEAN ANNUAL RAINFALL

The mean annual rainfall over a catchment area will be the weighted average of the mean annual rainfall at each of the rain gauge stations in that area. This presumes that the distribution of rain gauge stations over the area will be even and representative. This, however, may not be the case in most catchments in the world.

The mean average rainfall may be determined by three methods:

(*a*) *The Isohyetal Method.* The most satisfactory method of obtaining the true mean annual or seasonal rainfall



SIMILARITY OF DAILY CYCLES OF TRANSPIRATION FROM ALFALFA, EVAPORATION AND METEOROLOGICAL PHENOMENA. (FROM BRIGGS AND SHANTZ, JOURNAL OF AGRICULTURAL RESEARCH, JANUARY 3, 1916. P 617.)

Figure 1

Table I. Losses Calculated for Various Temperatures by Khosla's Formula

$$L_m = \frac{T_m - 32}{9.5}$$

Temperature Degrees F.	*Losses in inches*	*Temperature Degrees F.*	*Losses in inches*	*Temperature Degrees F.*	*Losses in inches*
1	0.41	41	0.95	81	5.16
2	0.42	42	1.05	82	5.26
3	0.43	43	1.16	83	5.37
4	0.44	44	1.26	84	5.47
5	0.45	45	1.37	85	5.58
6	0.46	46	1.47	86	5.68
7	0.47	47	1.58	87	5.79
8	0.48	48	1.68	88	5.90
9	0.49	49	1.79	89	6.00
10	0.50	50	1.89	90	6.11
11	0.51	51	2.00	91	6.21
12	0.52	52	2.11	92	6.32
13	0.53	53	2.21	93	6.42
14	0.54	54	2.32	94	6.53
15	0.55	55	2.42	95	6.63
16	0.56	56	2.53	96	6.74
17	0.57	57	2.63	97	6.84
18	0.58	58	2.74	98	6.95
19	0.59	59	2.84	99	7.05
20	0.60	60	2.95	100	7.16
21	0.61	61	3.05		
22	0.62	62	3.16		
23	0.63	63	3.26		
24	0.64	64	3.37		
25	0.65	65	3.47		
26	0.66	66	3.58		
27	0.67	67	3.68		
28	0.68	68	3.79		
29	0.69	69	3.89		
30	0.70	70	4.00		
31	0.71	71	4.11		
32	0.73	72	4.21		
33	0.74	73	4.32		
34	0.76	74	4.42		
35	0.77	75	4.53		
36	0.78	76	4.63		
37	0.80	77	4.74		
38	0.81	78	4.84		
39	0.83	79	4.95		
40	0.84	80	5.05		

(i) For $T_m > 40°$ F

$$\text{Loss} = \frac{T - 32}{9.5}$$

(ii) Loss at 40° F = 0.84

Loss at 30° F = 0.70

Loss between 30° F and 40° F varies as a straight line.

(iii) Loss at 30° = 0.70
20° = 0.60
10° = 0.50
0° = 0.40

i.e., .01 for each Degree F.

over an area is to draw isohyetals or contours of equal rainfall for that period. An isohyetal map will indicate the variations in rainfall in much the same way as a contoured map indicates the variations in the ground levels. The mean annual (or seasonal) rainfall over the area will then be given by—

$$P = \Sigma\, pa / \Sigma\, a$$

where P = Mean annual precipitation over the catchment area in inches,

p = Mean annual precipitation between two isohyetals in inches,

a = Area between the two isohyetals in square miles,

Σ a = Total area of catchment in square miles.

In drawing the isohyetals, due consideration should be given to the topographical features, like ridges dividing the valleys, etc.

(*b*) *The Weightage Method.* A second, though less accurate, method is to assign areas to each raingauge station, and then work out the weighted mean by the formula:

$$P = \Sigma\, pa / \Sigma\, a$$

where P = Mean annual precipitation over the catchment area,

p = Mean annual precipitation at any station,

a = The area of influence assigned to that station,

Σ a = Total area of the catchment.

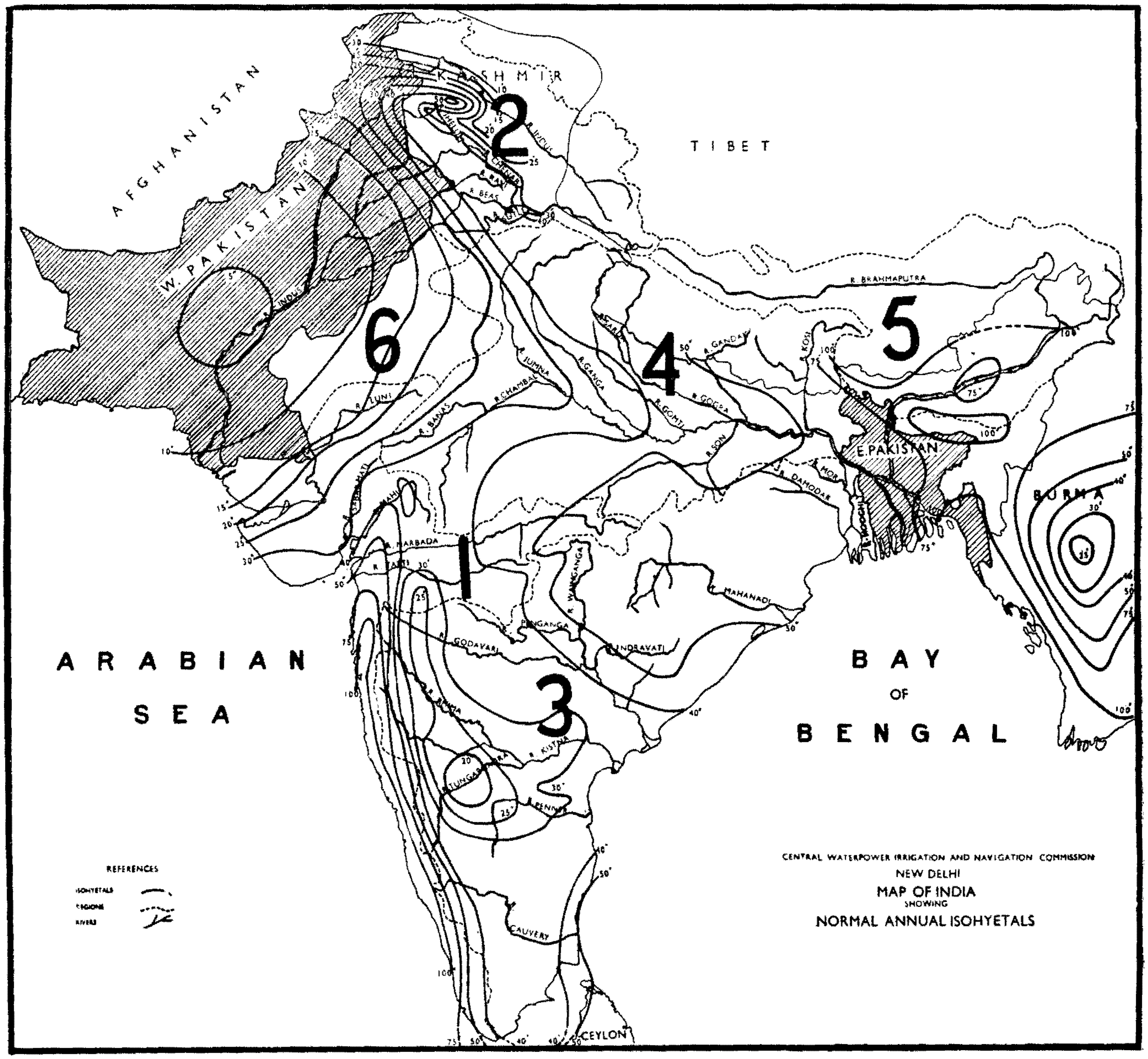


Figure 2

(*c*) The Straight Average Method.—The U.S. Geological Survey takes straight averages in general (1)[1].

Run-Off

Run-off is the residual of rainfall after the deduction of losses by evaporation and transpiration—the two losses combined being generally known as the "evaporation loss". It is expressed in inches over the catchment in the same way as rainfall. In this paper the run-off is denoted by R and the monthly, annual and 10-day run-offs, by R_M, R_A and R_{10}, respectively.

[1]Numbers within parentheses refer to items in the bibliography.

Besides losses due to evaporation and transpiration, there may be losses into the subsoil, but these latter affect the seasonal distribution rather than the annual value, as what goes in as ground water in one month of the year, reappears as regeneration water in a subsequent month. In cases where leakages occur from one catchment to another, the ground water loss will be a permanent one and should be dealt with separately, but such cases are believed to be rare.

Two methods are in vogue for computing run-off from rainfall.

(*a*) The Proportional Method,

(*b*) The Rational Method.

Table II (a). Rainfall Run-Off : Calculations of Annual Run-Off; Miami River above Dayton for year 1907 (Catchment area 2,525 sq. miles)

Month	*Precipitation inches* P_m	*Mean temperature Degrees F* T_m	*Calculated loss inches* L_m	*Calculated run-off inches* R_1	*Actual surface run-off inches* R	$R_1 - R$ *inches*
January . . .	6.88	34.7	0.77	6.11	5.21	
February . .	0.40	29.0	0.40	—	0.94	
March . . .	4.89	49.4	1.83	3.06	3.28	
April	2.39	42.8	1.14	1.25	0.76	
May	2.97	56.2	2.55	0.42	0.64	
June	5.08	67.09	3.78	1.30	1.95	
July	6.00	75.0	4.53	1.47	1.40	
August . . .	2.60	71.6	2.60	—	0.44	
September .	3.38	67.2	3.38	—	0.50	
October . .	2.06	53.8	2.06	—	0.25	
November .	3.14	41.9	1.04	2.10	0.78	
December .	3.29	33.5	0.76	2.53	0.97	
TOTAL. . .	43.08	51.9	24.84	18.24	17.12	1.12

Table II(c). Rainfall Run-Off : Calculations of Annual Run-Off ; Mahanadi River at Sambalpore for year 1932 (Catchment area 32,200 sq. miles)

Month	*Precipitation inches* P_m	*Mean temperature Degrees F.* T_m	*Calculated loss inches* L_m	*Calculated run-off inches* R_1	*Actual surface run-off inches* R	$R_1 - R$ *inches*
January . . .	—	68.5	0.00	—	0.26	
February . .	0.84	69.8	0.84	—	0.20	
March . . .	0.12	80.8	0.12	—	0.17	
April	0.30	88.0	0.30	—	0.11	
May	0.56	93.8	0.56	—	0.08	
June	4.84	92.3	4.84	—	0.06	
July	19.78	80.9	5.15	14.63	6.77	
August . . .	11.01	82.3	5.29	5.72	8.46	
September .	11.25	83.6	5.43	5.82	5.62	
October . .	2.08	81.3	2.08	—	2.02	
November .	1.24	73.5	1.24	—	1.63	
December .	—	66.7	0.00	—	0.40	
TOTAL. . .	52.02	80.1	25.85	26.17	25.78	0.39

THE PROPORTIONAL METHOD

The proportional method is the one which was adopted in the early nineties of the last century and is meant to express the run-off as a certain percentage of rainfall; the ratio depending on the magnitude of rainfall and catchment characteristics i.e., shape, slope, vegetable cover, land use, etc. This method is purely empirical and has no logic behind it. For any particular catchment area, this method may give reasonably correct values of run-off in normal years but there will be wide variations between actuals and calculated values in dry and wet years. The run-off—rainfall ratios will vary with the rainfall and from one catchment to the other with the same rainfall. The work of Sir Alexander Binnie and Messrs. Strange, Barlow, Parker and Inglis deserves mention in this connection.

THE RATIONAL METHOD

The rational method of determining the annual or seasonal run-off from the corresponding rainfall takes into account the principal factors which are responsible for a part of the rainfall being lost to run-off. These factors are evaporation and transpiration which in turn are governed mainly by the mean temperature. Sunshine, clouds, wind velocity and humidity have some effect, but these generally follow the temperature cycle and can, therefore, be represented by temperature. The shape of the catchment, the slope and vegetable cover will have an effect on the seasonal distribution of run-off but not on the aggregate run-off. The existence of glaciers may be a factor of considerable importance and will need special consideration.

Among the first to study run-off as a residual of rainfall

Table II(b). Rainfall Run-Off: Calculation of Annual Run-Off; Kosi River at Dam Site for year 1947 (Catchment area 22,988 sq. miles)

Month	*Precipitation inches* P_m	*Mean temperature Degrees F* T_m	*Calculated loss inches* L_m	*Calculated run-off inches* R_1	*Actual surface run-off inches* R	$R_1 - R$ *inches*
January . . .	0.10	33.3	0.10	—	0.79	
February . .	0.15	39.0	0.15	—	0.57	
March	1.80	44.7	1.33	0.47	0.66	
April	1.30	49.6	1.30	—	0.80	
May	2.60	50.9	1.99	0.61	1.09	
June	6.80	56.5	2.58	4.22	3.01	
July	16.60	59.0	2.84	13.76	8.29	
August . . .	12.42	59.7	2.91	9.51	9.00	
September .	8.74	52.3	2.14	6.60	6.61	
October . . .	2.09	44.5	1.31	0.78	4.23	
November .	0.10	41.6	0.10	—	1.42	
December. .	0.10	41.6	0.10	—	1.00	
TOTAL . .	52.80	47.7	16.85	35.95	37.47	—1.52

Table II(d). Rainfall Run-Off: Calculations of Annual Run-Off; Ashni River at Dochi Dam Site for year 1947 (Catchment area 65 sq. miles)

Month	*Precipitation inches* P_n	*Mean temperature Degrees F.* T_m	*Calculated loss inches* L_m	*Calculated run-off inches* R_1	*Actual surface run-off inches* R	$R_1 - R$ *inches*
January . . .	1.63	42.5	1.11	0.52	1.37	
February . .	1.65	47.6	1.64	0.01	1.22	
March . . .	3.16	54.1	2.33	0.83	1.43	
April	0.19	64.4	0.19	—	1.09	
May	1.96	70.2	1.96	—	1.02	
June	2.21	71.2	2.21	—	0.97	
July	11.46	68.9	3.99	7.47	4.43	
August . . .	10.18	66.2	3.60	6.58	5.65	
September .	22.20	63.7	3.34	18.86	13.17	
October . .	1.55	58.0	1.55	—	3.27	
November .	0.00	54.3	0.00	—	1.18	
December .	1.01	48.1	1.01	—	1.00	
TOTAL . .	57.20	58.1	22.93	34.27	35.80	-1.53

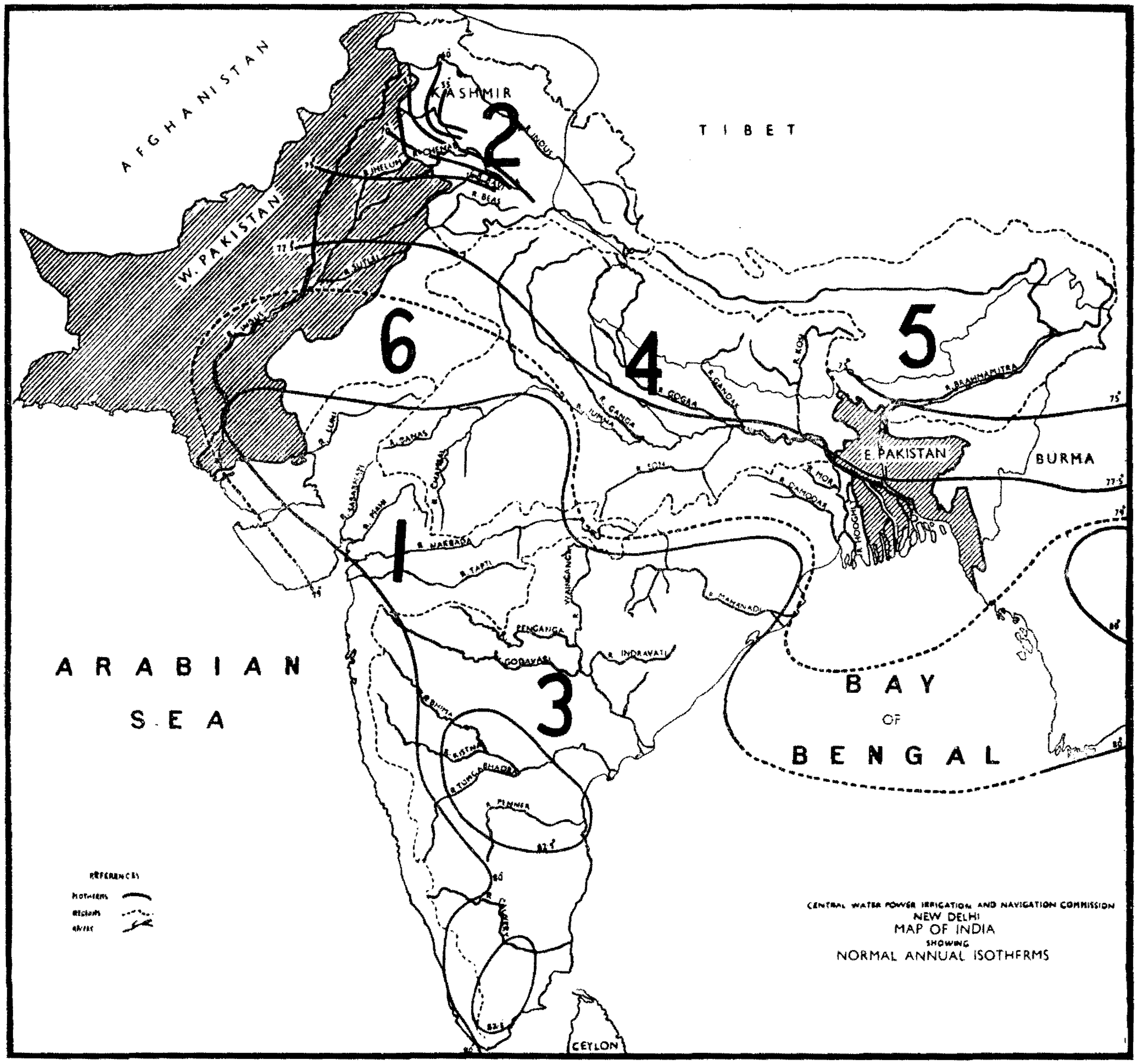


Figure 3

after deduction of losses, was Garnett in 1890 (2). C. C. Vermeule (3) advanced this study by putting forward an original formula which introduced temperature in determining relationship between rainfall and run-off. Rafter (4) studied the rainfall-run-off relationship by three periods of the year designated by him the storage period (December to May), growing period (June to August) and replenishing period (September to November). Meyer (5) investigated in great detail the effect of evaporation, transpiration, soil storage, surface and seepage flow on the rainfall loss. Houk's studies (6) on the Miami Valley were yet anothre advance in an effort to arrive at a rational relationship between rainfall and run-off.

David Lloyd, a British engineer, contributed two papers (7) and (8) in 1936 and subsequently, a formula in which, besides temperature, he introduced the total hours of sunshine and the percolation loss.

VERMEULE'S FORMULA

The Vermeule formula is as below:

$$R_A = P_A - (11 + 0.29\ P_A)\ (.035\ T_A - 0.65),$$

where R_A = Annual run-off in inches,

P_A = Annual rainfall in inches,

T_A = Mean annual temperature in degrees F.

India is a country with very great variations of temperature, but the mean temperature of the whole or any locality does not vary much from year to year, and the mean annual temperatures for almost all parts of India vary only between 75 degrees and 85 degrees F. Substituting the values of temperature as obtained in India in the Vermeule formula, the limiting values of rainfall(P_A), for which the run-off (R_A) will be nil, work out as follows:

Table III. Values of X in the Formula $R_A = P_A - X\,T_A$ Based on Mean Annual Rainall, Run-Off and Temperature Data of Some American and British Catchments

	Name of river basin	*Catchment area in square miles*	*Number of rain gauge stations*	*Period of record years*	*Precipitation inches P*	*Run-off, in inches R*	*Percentage R/P*	*Evaporation loss P — R = E*	*Temp. Fah. T*	$X = \frac{(P-R)}{T}$	*Remarks*
1	2	3	4	5	6	7	8	9	10	11	12
1.	Mississippi River above Keokuk, Iowa	119,000	227	57	29.51	6.98	23.6	22.53	45.20	.50	
2.	Red River above Grand Forks, N.D.	25,500	28	53	20.91	1.25	6.0	19.67	39.80	.49	
3.	Tennessee River Basin above Chattanooga, Tenn.	21,400	32	54	50.36	24.24	48.2	26.12	55.80	.47	
4.	James River Basin above Carter-ville	6,242	11	36	40.79	15.59	38.2	25.20	54.90	.46	
5.	Muskingum River Basin above Dresden, Ohio	5,828		8	39.70	13.02	32.9	26.68	49.5	.54	
6.	Upper Hudson River	4,500		14	44.5	23.5	32.9	21.00	42.0	.50	
7.	Merrimack River Basin above Lawrence, Massachusetts	4,461	33	55	41.63	20.13	48.4	21.50	45.6	.47	
8.	Neosho River Basin above Iola, Kansas	3,800	19	39 17	33.57 32.31	4.12	12.4	28.19	55.6 56.1	.50	
9.	Chattahoochee River Basin above West Point, Georgia	3,551	13	38	54.59	22.32	40.9	32.27	61.5	.52	
10.	Miami Valley above Dayton, Ohio	2,525		25	38.07	11.87	31.2	26.2	52.7	.50	
11.	Upper Genessee River	1,070		9	40.20	14.2	35.3	26.00	45.45	.57	
12.	Wagon Wheel Gap on the Upper Rio Grande, above San Luis Valley, Colorado	1,000		7	21.00	6.08	28.8	14.92	35.00	.43	
13.	Pomperaug Basin, Connecticut	89		4	44.48	19.53	44.0	24.95	48.8	.51	
14.	Sudbury River	77		21	45.80	23.5	51.5	22.3	47.80	.47	
15.	Lake Cochituate	18.0		33	47.5	20.50	43.2	26.6	47.50	.56	
16.	Black River Basin, Neillsville, Wisconsin			7	29.6	7.38	24.9	22.24	44.1	.50	
17.	Rock River Basin above Afton, Wisconsin			7	28.17	4.79	17.0	23.35	48.1	.49	
18.	Skunk River Basin above Augusta, Iowa			8	31.48	5.02	16.3	26.46	52.2	.51	
19.	Vyrnwy (Wales, Great Britain)	36.4		41	72.7	53.4	73.5	19.31	43.96[a]	.44	

a T° at 8 A.M. and not $\frac{\text{Max.} + \text{Min.}}{2}$ (Paper by David Lloyd, Table I, P. 226)

Temperature in degrees F.	*Limiting value of rainfall in inches*
75.0	50.7
77.5	56.3
80.0	62.6
82.5	70.3
85.0	78.1

According to this, there will be no run-off for a rainfall below 50 in. in most parts of India, which is obviously not the case. It would thus appear that the Vermeule formula does not apply to Indian conditions and, therefore, can be only of local and not of universal application.

THE AUTHOR'S FORMULA

The author has tried to evolve a formula of, more or less, general application. After a study of available data of rainfall, temperatures and run-off in the U.S.A., India and elsewhere, and with the background of the concept of run-off as a residual of rainfall after deduction of "evaporation loss", it has been possible to evolve a new formula, which (with due regard to the unit of period to be taken for calculations) appears to be of universal application. The fundamental basis of this formula is that temperature can be taken to be a complete measure of all the various factors which are responsible for the loss of rainfall to run-off. These variables are evaporation, transpiration, sunshine, clouds and wind velocity. The curves of Figure 1 indicate that the above assumption is not unreasonable.

Notations

P = Rainfall (precipitation) in inches.
P_m = Monthly rainfall in inches.
P_A = Annual rainfall in inches.
P_{10} = 10-days rainfall in inches.
R = Run-off in inches.
R_m = Monthly run-off in inches.
R_A = Annual run-off in inches.

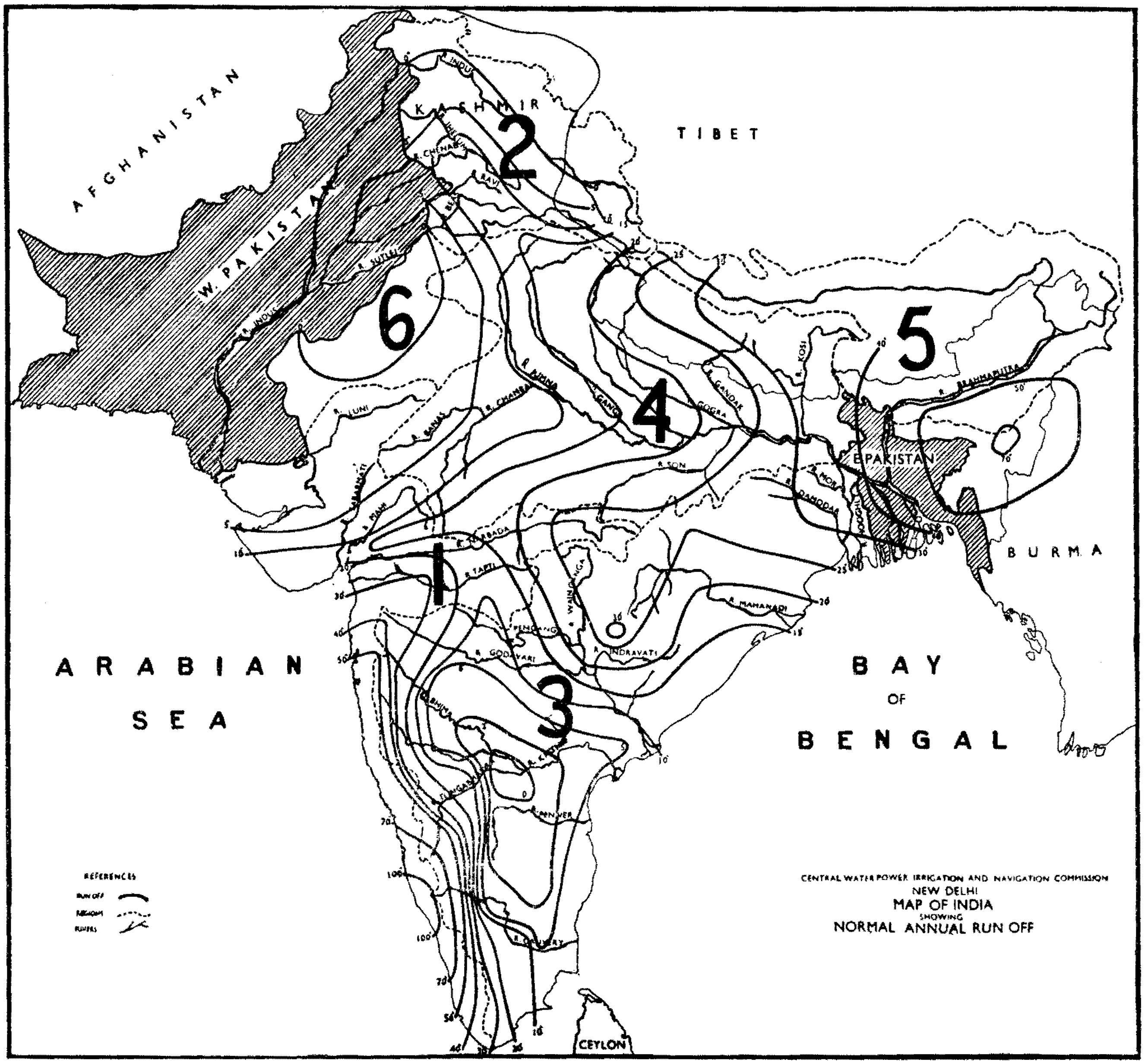


Figure 4

R_{10} = 10-day run-off in inches.
L = Loss in inches.
L_m = Monthly loss in inches.
L_A = Annual loss in inches.
L_{10} = 10-day loss in inches.
T = Mean temperature in degrees F.
T_m = Mean monthly temperature in degrees F.
T_A = Mean annual temperature in degrees F.
T_{10} = 10-day mean temperature in degrees F.

1. *Formula based on periods of one month*

$$L_m = \frac{T_m - 32}{9.5} \text{ where } T_m < 40^\circ \text{ F.}$$

for $T_m < 40^\circ$ F. the loss(L_m) may provisionally be assumed as

T_m =	40°	30°	20°	10°	0° F.
L_m =	0.84	0.70	0.60	0.50	0.40 inches.

The corresponding monthly rainfall (P_m) – run-off (R_m) relationship will be

$$R_m = P_m - L_m \text{ and } R_A = \Sigma R_m$$

The monthly Loss against Temperature is given in Table I.

2. *Formula taking the year as a unit*

$R_A = P_A - X\,T_A$ where X is a constant for a given catchment.

These formulae will apply in all cases where the rainfall is more or less well distributed over the period in question. But in areas where the rainfall is very low or it comes in occasional cloudbursts, the loss may have to be calculated on a ten-day or fifteen-day basis instead of the monthly or annual basis.

Table IV. Comparison of Calculated Run-Off with the Actual on Mississippi River for 10 Years Average Data

$R_{10} = P_{10} - x\,T_{10}$ (x for Mississippi = 0.5)

Years 10 years ending	*10 years average rainfall (P) Inches*	*10 years average temperature (T) Degrees F.*	*Calculated run-off $R_1 = P - 0.5T$ Inches*	*Actual run-off R Inches*	*Departure $R_1 - R$ Inches*
1	2	3	4	5	6
1887	31.58	44.8	9.18	8.60	.58
88	31.32	44.2	9.22	8.87	.35
89	30.47	44.2	8.37	8.78	– .41
90	30.14	44.2	8.04	8.54	– .50
91	28.69	44.1	6.64	7.75	–1.11
92	29.01	43.8	7.11	7.57	– .46
93	28.72	43.9	6.77	7.38	– .61
94	27.67	44.2	5.57	7.00	–1.43
95	27.24	44.4	5.04	6.44	–1.40
96	27.84	44.5	5.59	6.23	– .64
97	27.78	44.6	5.48	6.42	– .94
98	27.82	45.0	5.32	5.94	– .62
99	28.49	44.9	6.04	6.14	– .10
1900	28.79	45.1	6.24	6.18	.06
01	28.53	45.1	5.98	6.21	– .23
02	28.58	45.3	5.93	6.01	– .08
03	29.31	45.5	6.56	6.37	.19
04	29.84	45.1	7.29	6.56	.73
05	30.90	45.1	8.35	7.16	1.19
06	30.89	45.2	8.29	7.61	.68
07	31.07	45.0	8.57	7.74	.83
08	31.36	45.1	8.81	8.07	.74
09	31.65	45.1	9.10	8.24	.86
1910	30.19	45.0	7.69	8.06	– .37

Years 10 years ending	*10 years average Rainfall (P) Inches*	*10 years average temperature (T(Degrees F*	*Calculated run off $R_1 = P - 0.5T$ inches*	*Actual run-off R inches*	*Departure $R_1 - R$ inches*
1	2	3	4	5	6
1911	31.22	45.0	8.72	8.08	.64
12	30.47	44.8	8.07	8.08	– .01
13	29.97	45.0	7.47	7.61	– .14
14	30.16	45.2	7.56	7.44	.12
15	30.11	45.3	7.46	7.36	.10
16	29.97	45.1	7.42	7.30	.12
17	29.65	44.9	7.20	7.08	.12
18	29.50	44.8	7.10	6.85	.25
19	29.47	44.9	7.02	6.83	.19
1920	30.53	44.8	8.13	7.11	1.02
21	30.03	45.0	7.53	7.08	.45
22	29.95	45.3	7.30	7.02	.28
23	29.46	45.3	6.81	6.86	– .05
24	29.38	45.0	6.88	6.88	.00
25	28.79	45.0	6.29	6.44	– .15
26	28.77	45.1	6.22	6.14	.08
27	29.15	45.4	6.45	6.26	.19
28	29.33	45.4	6.63	6.48	.15
29	28.75	45.2	6.15	6.44	– .29
1930	28.40	45.4	5.70	6.14	– .44
31	28.31	45.6	5.51	5.95	– .44
32	28.26	45.5	5.51	5.81	– .30
33	28.23	45.6	5.43	5.83	– .40
34	27.86	46.1	4.81	5.54	– .73

The formula on the monthly basis has been checked against seven catchments in U.S.A. and three catchments in India. The annual results based on monthly calculations are given below:

	Name of catchment	*Precipitation inches P*	*Temperature Degrees F. T*	*Calculated loss inches L*	*Calculated run-off inches R_1*	*Actual run-off inches R*	*$R_1 - R$ inches*
1	2	3	4	5	6	7	8
1.	Miami River above Dayton	37.07	52.76	26.28	10.79	11.87	–1.08
2.	Red River above Grand Forks, N. Dakota. . . .	20.29	39.2	18.35	1.94	1.43	0.51
3.	Black River Basin above Neillsville, Wis.	32.02	42.7	21.74	10.28	11.71	–1.43
4.	Rock River Basin above Afton, Wis. . . .	31.69	45.8	22.31	9.38	10.47	–1.09
5.	Skunk River Basin above Augusta, Iowa .	34.01	49.9	25.56	8.45	8.46	–0.01
6.	Mississippi River Basin above Keokuk, Iowa . .	29.67	44.8	22.78	6.89	7.17	-0.28
7.	Pamperang River Basin	42.51	48.83	23.78	18.73	20.02	–1.29
8.	Mahanadi River at Sambalpur . .	56.68	80.07	29.31	27.37	28.33	–0.96
9.	Kosi River above Barakshetra . . .	52.80	47.70	16.85	35.95	37.47	–1.52
10.	Ashni River at Dochi Dam site	57.20	58.10	22.93	34.27	35.80	–1.53

Typical monthly comparison is given in Table II(*a*), II(*b*), II(*c*) and II(*d*) in respect of the Miami River at Dayton for 1907, the Kosi River at Barakshetra (1947), the Mahanadi at Sambalpur (1932) and the Ashni at Dochi Dam site (1947).

The formula based on the year as a unit has been checked against nineteen catchments of which eighteen are in U.S.A. and one in Great Britain see Tables III, IV and V.

In the case of annual run-off the departure of the calculated from the actual may be due to a change in the seasonal distribution, the rainfall occurring at the close of one year so that the partial effect of it is felt during the following year, or due to inadequacy of rainfall

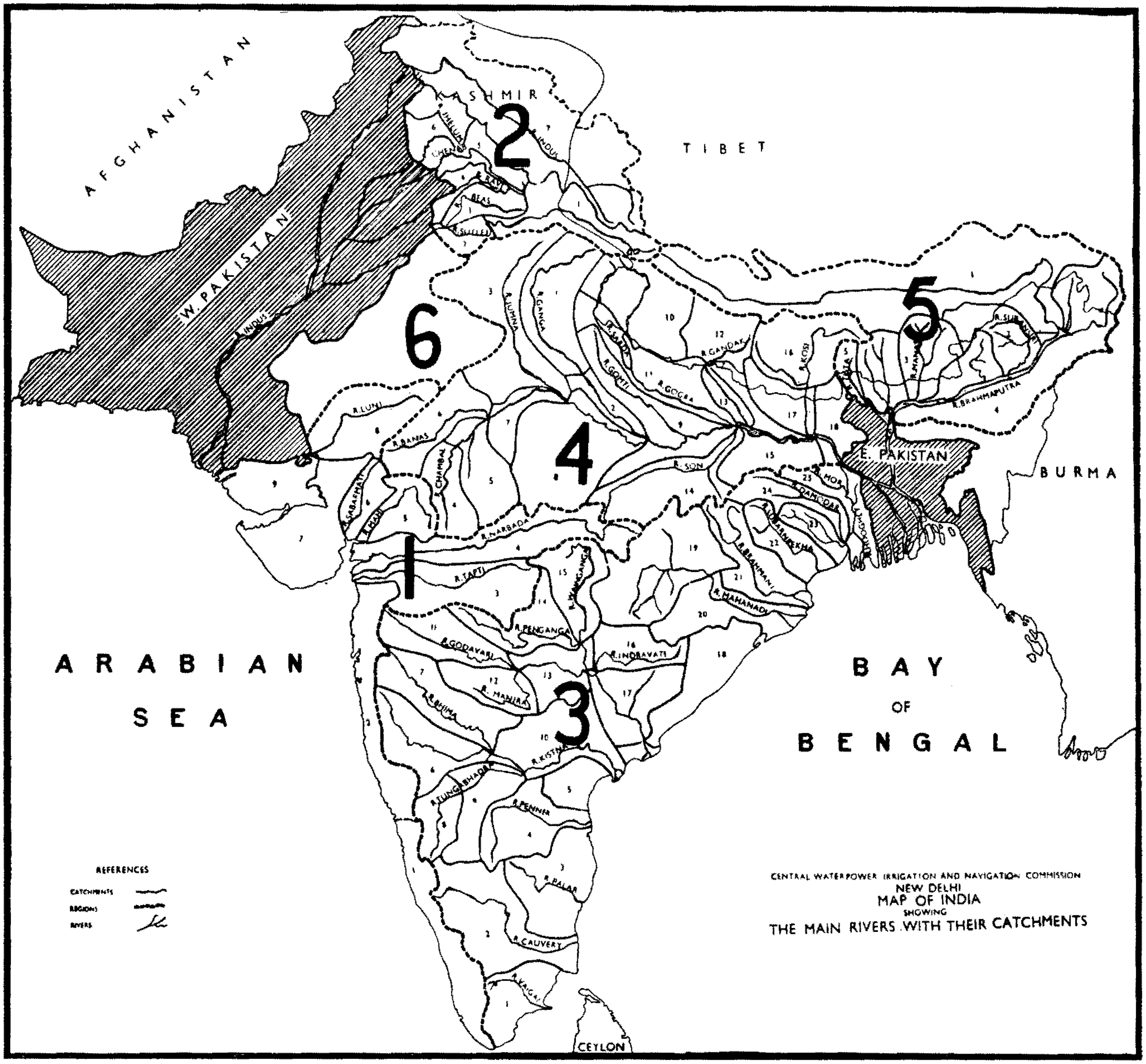


Figure 5

and temperatures, stations and run-off data. The same will apply to monthly departures but taken over the year as a whole these departures will decrease. Similarly the departures in the annual analysis of individual years will diminish or disappear if a number of years are dealt with collectively provided the data is satisfactory and adequate. The greater the number of years taken, the closer will be the agreement. Glacier fed streams will need special treatment.

This paper is presented in the hope that other countries will check their data against the above formulae. If these formulae, (with slight adjustments, if necessary) are, in fact, found to be of universal application, the work of forecasting yields from catchments, where the rainfall data over a considerable number of years exist but very little has been done in the way of river gaugings, will be greatly facilitated. This will be an asset of the utmost importance in preparing projects in new areas as it will be possible within a very short time to get a fairly close approximation of the water supplies available during the year and, with the known trends of rainfall, over a series of years. It is possible that in some cases the temperature data also may not be available in sufficient detail, but the variation in temperature from year to year is relatively small and will not seriously affect the calculations for a first approximation. This method will be of special value in making preliminary forecasts in relatively unknown regions.

WATER RESOURCES OF INDIA

The above formulae have been utilized to make a preliminary forecast of the water yields of the various

Table V. Comparison of Calculated Run-Offs on Miami River Above Dayton, Ohio

$R_A = P_A - x\,T_A$ (x for MIAMI = 0.5)

Year ending Sept. 30	Rainfall P inches	Temperature T Degrees F.	Actual run-off R inches	Calculated $R^1 = P-0.5T$ inches	Departure R - R
1	2	3	4	5	6
1894	30.7	54.7	4.9	3.35	–1.55
95	24.0	53.0	3.7	0.0	–3.70
96	46.2	54.0	8.1	19.20	11.10
97	33.3	53.4	12.8	6.60	–6.20
98	44.3	55.0	14.7	16.80	2.10
99	34.2	53.2	9.7	7.60	–2.10
1900	35.1	54.4	6.6	7.90	1.30
01	30.1	53.4	5.6	3.40	–2.20
02	31.6	51.1	3.8	6.05	2.25
03	37.1	53.6	12.6	10.30	–2.30
04	39.1	49.8	13.1	14.20	1.10
05	38.5	51.5	7.1	12.75	5.65
06	33.2	52.9	9.2	6.75	–2.45
07	43.1	51.9	17.2	17.15	–0.05
08	37.7	53.1	17.7	11.15	–6.55
09	39.3	53.2	13.1	12.70	–0.40
1910	36.3	52.3	15.1	10.15	–4.95
11	39.8	53.7	13.9	12.95	–0.95
12	43.8	50.8	23.1	18.40	–4.70
13	42.9	54.0	24.4	15.90	–8.50
14	32.3	53.3	8.3	5.65	–2.65
15	41.8	52.1	12.1	15.75	3.65
16	39.9	53.2	19.2	13.30	–5.90
17	35.7	51.1	11.4	10.15	–1.25
1918	36.8	50.3	9.4	11.65	2.25
Average:	37.07	52.76	11.87	10.79	–1.08

Columns 1 to 4 computed from "Rainfall and Run off in the Miami Valley," by Ivan E. Houk, Technical Reports, part VIII, 1921.

Table VI. Water Resources of India

	Name of region	Catchment area Sq. miles	Normal rainfall inches (Annual)	Mean temperature degrees F. (Annual)	Loss inches (Annual)	Run-off inches (Annual)	Run-off million acre-ft. (Annual)
1.	Rivers falling into Arabian Sea (excluding the Indus System) . .	189,790	47.95	77.9	23.11	24.84	251.46
2.	Indus Basin in India	136,673	21.86	54.7	13.02	8.84	64.43
3.	Rivers falling into Bay of Bengal, other than Ganga and Brahmaputra systems	467,309	42.77	79.0	29.37	13.40	334.03
4.	Ganga System	376,818	43.76	62.2	24.00	19.76	397.09
5.	Brahmaputra System	195,460	48.11	46.8	18.47	29.64	308.95
6.	Rajputana	64,887	11.48	79.1	11.48	—	—
	TOTAL	1,430,937	41.03	—	23.26	17.77	1,355.96a

a Say 1,356 million acre-ft. (1.87 million cub. ft. throughout the year.)

Table VI(a). Region No. 1. Run-Off of Rivers Falling into Arabian Sea excluding Indus Basin

	Name of river	Catchment area sq. miles	Normal rainfall inches (Annual)	Mean temperature degrees F. (Annual)	Loss inches (Annual)	Run-off inches (Annual)	Run-off million acre-ft. (Annual)
1.	Streams from Cape Comorin to Tadri (excluding Tadri)	21,950	115.49	73.4	36.41	79.08	92.60
2.	Streams from Tadri to Tapti (excluding Tapti)	22,150	104.95	77.3	26.17	78.78	93.07
3.	Tapti	25,000	30.72	80.3	25.17	5.55	7.40
4.	Narbada	33,750	47.54	76.3	25.36	22.18	39.92
5.	Mahi	13,450	32.62	77.3	22.1	10.52	7.55
6.	Sabarmati	8,370	29.89	82.6	21.43	8.46	3.78
7.	Streams of Kathiawar	23,950	20.59	79.4	17.54	3.05	3.90
8.	Luni	24,750	15.20	78.0	15.04	00.16	0.21
9.	Streams of Cutch	16,420	18.84	79.6	15.38	3.46	3.03
	TOTAL for rivers falling into Arabian Sea, excluding Indus Basin	189,790	47.95	77.9	23.11	24.84	251.46

Note: Table VI (*b*) has not been included as detailed data are incomplete, particularly regarding glacier contributions.

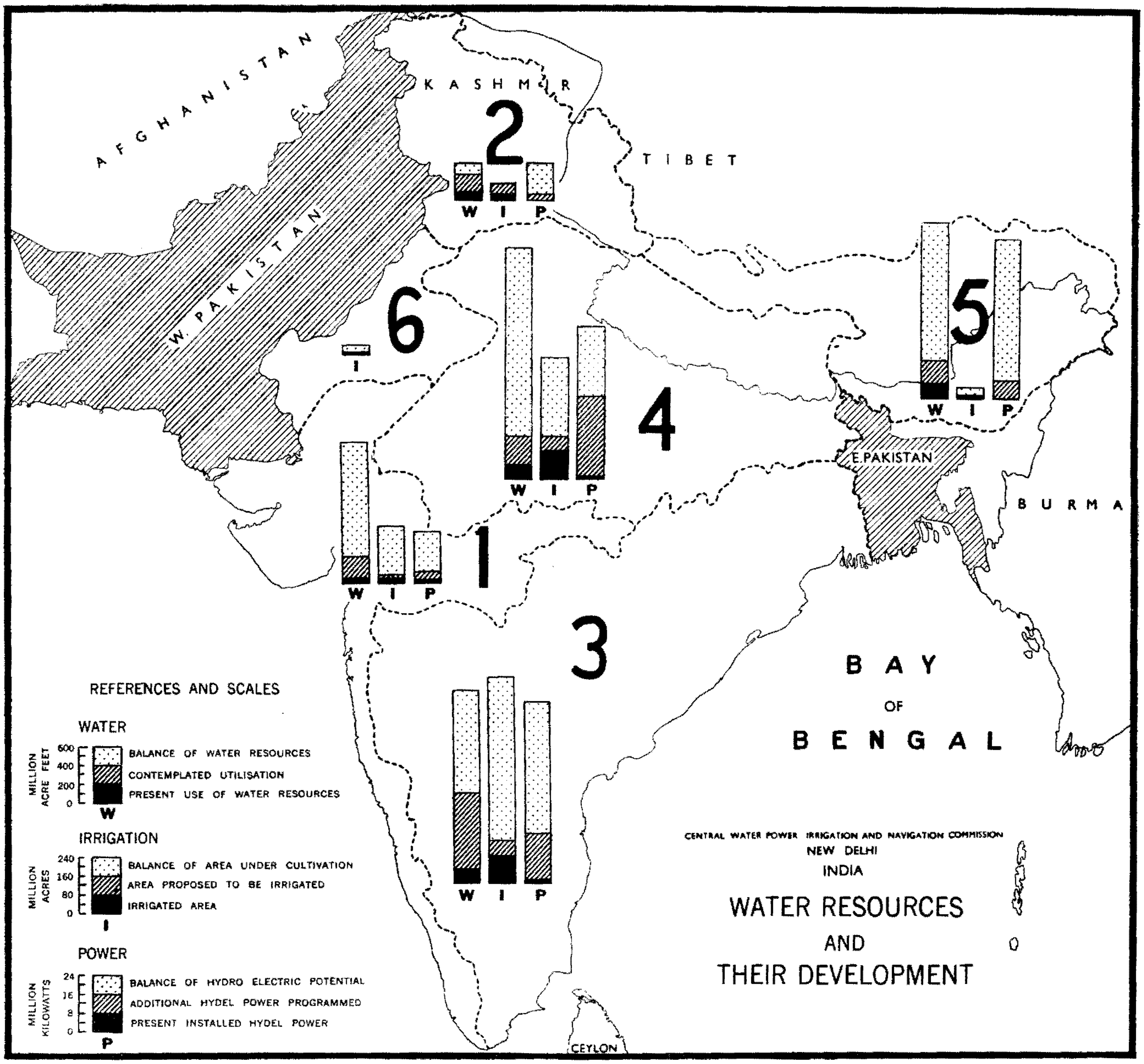


Figure 6

catchments in India. For this purpose India has been divided into six major regions.

Region 1. Rivers falling into Arabian Sea (excluding the Indus System).

Region 2. Indus Basin in India.

Region 3. Rivers falling into Bay of Bengal, other than Ganga and Brahmaputra Systems.

Region 4. Ganga System.

Region 5. Brahmaputra System.

Region 6. Rajputana.

The following table gives, among other features, the mean annual run-off in these regions.

The main regions have been further subdivided into catchments of major rivers and their tributaries. The rainfall, run-off and other data for these subregions are given in Tables VI(*a*), VI(*c*), VI(*d*), VI(*e*) and VI (*f*).

Region	*Catchment area Sq. miles*	*Normal rainfall inches (Annual)*	*Mean temperature Degrees F. (Annual)*	*Loss inches (Annual)*	*Run-off inches (Annual)*	*Run-off million acre-ft. (Annual)*
1.	189,790	47.95	77.9	23.11	24.84	251.46
2.	136,673	21.86	54.7	13.02	8.84	64.43
3.	467,309	42.77	79.0	29.37	13.40	334.03
4.	376,818	43.76	62.2	24.00	19.76	397.09
5.	195,460	48.11	46.8	18.47	29.64	308.95
6.	64,887	11.48	79.1	11.48	—	—
TOTAL:	1,430,937	41.03	—	23.26	17.77	1,355.96*

*Say 1.356 million acre-ft. (1.87 million cusecs through the year).

Table VI(c). Region No. 3. Run-Off of Rivers Falling into Bay of Bengal other than Ganga and Brahmaputra Systems

	Name of river	*Catchment area sq. miles*	*Normal rainfall inches (Annual)*	*Mean temperature degrees F. (Annual)*	*Loss inches (Annual)*	*Run-off inches (Annual)*	*Run-off million acre-ft. (Annual)*
1.	Rivers from Cape Comorin to Cauvery (excluding Cauvery) . .	17,150	35.79	76.2	28.81	6.98	6.38
2.	Cauvery	31,800	38.91	72.7	34.13	4.78	8.10
3.	Rivers between Cauvery and Penner (excluding Penner)	25,000	37.92	81.3	32.16	5.76	7.70
4.	Penner	20,575	26.81	84.5	26.81	—	—
5.	Rivers between Penner and Kistna (excluding Kistna)	9,800	29.68	82.9	27.26	2.42	1.26
6.	Kistna up to Bhima (excluding Bhima)	21,078	34.87	76.4	21.21	13.66	15.36
7.	Bhima	26,511	30.07	78.9	24.93	5.14	7.27
8.	Tungabhadra up to dam site	11,195	39.31	76.5	26.50	12.81	7.65
9.	Tungabhadra from dam site to its confluence with Kistna	15,983	23.98	79.6	23.44	0.54	0.46
10.	Kistna from its confluence with Bhima to its mouth (excluding Bhima & Tungabhadra)	22,933	33.7	81.6	29.06	4.64	5.68
	Total for Kistna River . . . . (Items 6 to 10)	97,700	32.02	78.8	25.03	6.99	36.42
11.	Godavari up to Manjara (excluding Manjara)	21,700	30.70	78.1	25.36	5.34	6.18
12.	Manjara	11,900	34.73	78.9	26.61	8.12	5.15
13.	Between Manjara and Wain-Ganga (excluding Wain-Ganga)	11,700	39.00	80.2	27.77	11.23	7.01
14.	Pen Ganga	19,000	39.07	80.9	27.84	11.23	11.39
15.	Wain Ganga (excluding Pen Ganga)	24,000	49.56	79.2	26.43	23.13	29.61
16.	Indravati	16,000	59.29	77.5	29.30	29.99	25.60
17.	Godavari from its confluence with Wain-Ganga to its mouth	16,700	49.85	79.1	30.96	18.89	16.82
	Total for Godavari River . . . . . (Items 11 to 17)	121,000	43.38	79.1	27.61	15.77	101.76
18.	Rivers between Kistna and Mahanadi (excluding Mahanadi) . . .	27,964	43.50	80.9	34.76	8.74	13.03
19.	Mahanadi up to Hirakud dam site	32,750	56.08	79.6	28.5	27.58	48.20
20.	Mahanadi From Hirakud to mouth.	18,520	59.78	79.1	32.39	27.39	27.05
	Total for Mahanadi River.	51,270	57.36	79.4	29.85	27.51	75.25
21.	Brahmani and Baitarani combined	21,700	58.93	77.9	31.48	27.45	31.80
22.	Subarnarekha and streams from Baitarani to Subarnarekha	13,700	56.28	78.9	33.73	22.55	16.48
23.	Streams between Subarnarekha and Damodar (excluding Damodar) .	8,750	60.15	80.8	35.87	24.28	11.35
24.	Damodar	9,000	55.70	77.8	33.79	21.91	10.50
25.	Hooghly	11,900	61.50	79.1	39.47	22.03	14.00
	GRAND TOTAL	467,309	42.77	79.0	29.37	13.40	334.03

Table VI(d). Region No. 4. Run-Off of Ganga River System in India

	Name of river	Catchment area sq. miles	Normal rainfall inches (Annual)	Mean temperature degrees F. (Annual)	Loss inches (Annual)	Run-off inches (Annual)	Run-off million acre-ft. (Annual)
1.	Ganga up to and including Ram-Ganga	32,300	46.60	74.60	27.64	18.96	32.64
2.	Ganga from Ram-Ganga to Yamuna (excluding Yamuna)	5,500	33.00	78.10	23.64	9.36	2.74
3.	Yamuna up to confluence with Chambal (exclud. Chambal)	42,250	27.66	73.50	22.76	4.90	11.03
4.	Chambal (i) up to Kotah dam site	11,070	33.28	77.60	22.06	11.22	6.62
5.	(ii) between Kotah and Banas (exclud. Banas)	20,750	36.16	77.30	22.24	13.92	15.39
6.	(iii) Banas	18,860	24.71	77.80	20.54	4.17	4.19
7.	(iv) Chambal from Banas to confluence with Yamuna	3,900	27.09	76.40	20.89	6.20	1.29
8.	Yamuna between Chambal and its confluence with Ganga	6,750	40.35	77.80	23.70	16.65	41.49
	Total for Yamuna River	143,580	32.94	76.40	22.50	10.44	80.01
9.	Ganga between Yamuna and confluence with Gogra (excluding Gogra)	32,500	41.56	77.80	25.46	16.10	27.89
10.	Gogra Transhimalayan	30,200	39.97	40.70	12.85	27.12	43.65
11.	Rest of Gogra up to confluence with Ganga	19,210	46.50	77.10	29.15	17.35	17.77
	Total for Gogra River	49,410	42.50	54.90	19.20	23.30	61.42
12.	Gandak Trans-Himalayan	14,500	39.97	40.70	12.85	27.12	20.96
13.	Rest of Gandak up to confluence with Ganga	2,630	49.92	77.80	29.73	20.19	2.83
	Total for Gandak River	17,130	41.46	46.40	15.42	26.04	23.79
14.	Sone	25,550	54.60	78.00	29.08	25.52	34.77
15.	Ganga between Sone and confluence with Kosi (exclud. Kosi).	23,400	49.13	77.90	30.30	18.83	23.48
16.	Kosi up to Barahakshetra dam site.	22,988	77.05	47.70	18.93	58.12	71.21
17.	Kosi between Barahakshetra and confluence with Ganga	10,430	55.60	76.80	33.60	22.00	12.23
	Total for Kosi River	33,418	70.40	56.80	2.60	46.80	83.44
18.	Ganga from Kosi to Pakistan Border.	14,030	71.53	76.50	35.55	35.98	26.91
	GRAND TOTAL	376,818	43.76	62.2	24.00	19.76	397.09

Table VI(e). Region No. 5. Run-Off of Brahmaputra River System in India

	Name of river	Name of tributary	Catchment area sq. miles	Normal rainfall inches (Annual)	Mean temperature degrees F. (Annual)	Loss inches (Annual)	Run-off inches (Annual)	Run-off million acre-ft. (Annual)
1.	Brahmaputra	Trans-Himalayan	131,500	39.97	40.70	12.85	27.12	190.20
		Subansiri	10,700	39.97	40.70	12.85	27.12	15.48
		Manas	14,510	39.97	40.70	12.85	27.12	20.99
		Part of Brahmaputra up to Pakistan Border.	35,000	80.81	72.40	41.95	38.86	72.54
		Tista	3,750	82.77	64.30	34.08	48.69	9.74
		TOTAL	195,460	48.11	46.83	18.47	29.64	308.95

Table VI(f). Region No. 6. Run-Off of Rajputana

	Name of region	Catchment area sq. miles	Normal rainfall inches (Annual)	Mean temperature degrees F. (Annual)	Loss inches (Annual)	Run-off inches (Annual)	Run-off million acre-ft. (Annual)
1.	Rajputana	64,887	11.48	79.09	11.48	—	—

Table VII. Land and Water Resources and Their Utilization

Particulars	Region 1	2	3	4	5	6	Total of six regions
I. LAND (in million acres)							
1. Total area	121.47	87.47	294.18	241.45	125.09	42.02	911.68
2. Uncultivable area	22.00	8.57	86.05	45.68	8.50	2.57	173.37
(*a*) Area under forests	13.82	2.52	39.88	20.51	4.17	0.30	81.20
(*b*) Area not available for cultivation	8.18	6.05	46.17	25.17	4.33	2.27	92.17
3. Cultivable area	49.29	14.23	174.61	108.95	25.00	7.96	380.04
(*a*) Fallow land	5.62	1.46	28.67	11.65	1.79	1.20	50.39
(*b*) Other uncultivated land excluding current fallows	8.17	2.71	32.26	24.22	17.40	1.94	86.70
(*c*) Net area sown	35.50	10.06	113.68	73.08	5.81	4.82	242.95
II. WATER (in million acre-ft.)							
1. Water available	251.46	64.43	334.03	397.09	308.95	—	1,355.96
2. Present use of water							
(*a*) For irrigation	11.15	10.76	22.85	25.86	3.30	—	73.92
(*b*) For power	—	—	1.67	—	—	—	1.67
(*c*) For other purposes	—	—	0.06	—	—	—	0.06
(*d*) Total	11.15	10.76	24.58	25.86	3.30	—	75.65
3. Contemplated utilization under the Seven Year Plan.							
(*a*) For irrigation	15.52	20.79	80.60	26.34	—	—	143.25
(*b*) For power	25.94	7.30	48.86	32.47	36.00	—	150.57
(*c*) For other purposes	0.02	2.75	0.81	0.69	—	—	4.27
(*d*) Total	41.48	24.00[1]	130.27	49.78[1]	36.00	—	281.53
4. Balance of water still remaining unused	198.83	29.67	179.18	321.45	269.65	—	998.78
III. IRRIGATION (in million acres)							
1. Cultivated area	41.12	11.52	142.35	84.73	7.60	6.02	293.34
2. Irrigated area	2.92	4.04	18.60	19.82	0.90	1.11	46.89
3. Area proposed to be irrigated under the Seven Year Plan	2.53	6.61	11.22	9.72	—	—	30.08
IV. POWER (in million kw.)							
Installed capacity	0.250	0.025	0.172	0.050	0.0005	0.005	0.50
Additional capacity programmed under the Seven Year Plan	0.540	0.478	3.191	4.789	1.250	—	10.248
Total hydro-electric potential	3.5	2.5	12.5	10.5	11.0	—	40.00

Remarks:

Region 1. Comprises the catchment areas of all rivers flowing into the Arabian Sea with the exception of the Indus Basin in India.

Region 2. Comprises the catchment area of the Indus Basin in India.

Region 3. Comprises the catchment area of rivers falling into Bay of Bengal, excluding the Ganga and Brahmaputra Systems.

Region 4. Comprises the catchment area of the Ganga River System in India.

Region 5. Comprises the catchment area of the Brahmaputra River System in India.

Region 6. Comprises the area of water-less Rajputana.

[1]The totals in (*d*) do not tally as the same water is to be used for power and irrigation in some cases.

These are first approximations.

Note:—

1. While the statistics of power relate to 1948, other statistics relate to 1944-45.
2. The figures of total hydro-electric potential represent only approximate anticipated figures, as no details have been worked out in this regard.

WATER UTILIZATION

Out of the 1355.96 million acre-ft. of total run-off in India only 75.65 million acre-ft., i.e., 5.6 per cent are being utilized at present for purposes of irrigation and power generation. Under the new Seven-Year Plan, it is proposed to utilize an additional 281.53 million acre-ft., thus leaving a balance of 998.78, i.e., 73.7 per cent. A fair proportion of the latter can be utilized at a later stage. These figures as well as figures of land areas, cultivation, irrigation and power generation are given in Table VII.

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Water: Analysis and Utilization of Data

JAN SMETANA

ABSTRACT

The report gives first the classification of flood discharges. The usual classification considers only the extremes and the arithmetical means. To obtain a perfect classification it is necessary to include also flood frequency. This is possible if we presume that the calculus of probabilities and especially the Laplace Gauss Law is applicable to those phenomena, and consequently mathematical statistics can be used.

The attached chart illustrates graphically the example that explains the method. It contains columnar diagrams of class frequency, summary curves of frequency /S, S_v, S_p/ and final resulting curves /Q, Q_v, Q_p/ that give the number of *n* years in which a certain discharge will most probably be reached or surpassed. S and Q curves are valid if all floods during a year's time are considered; S_v and Q_v curves are valid if vegetative periods are taken into account; S_p and Q_p curves correspond to floods in periods when grass on meadows can be damaged by inundation of water. This report also gives the results of other studies on the size of retention area in reservoirs according to the classification of floods.

The report points out that in Central Europe with its unstable climate we can hardly hope to be able to compute a long-range forecast of floods. Such a forecast would be of great value as a base for planning, for some years or at least some months ahead, the disposal of water stored in reservoirs.

If we use the formula for water energy $N = 7 \times Q_{50\%} \times h$ /kw/ (where $Q_{50\%}$ is the discharge reached or surpassed on 50 per cent of the days in a year, h is absolute head), we find 1,040,000 kw. to be utilizable in Czechoslovakia out of which 223,000 kw. have been already utilized. Our hydro-power stations are designed for $Q_{25\%}$ discharge and that means 31 per cent more kwh.

Czechoslovakia plans canals connecting the Elbe, Oder and Danube rivers, which would realize a European trans-continental waterways network of great international importance.

Our world-known spas, like Karlovy Vary (Carlsbad), Mariánské Lázně (Marienbad), Jáchymov (Joachimstal) in Bohemia, Piešťany and Sliač in Slovakia etc., are most carefully managed and maintained.

We have started to work out a general plan for water economy based on natural science, techniques and economy.

This paper is for international use, therefore I presume that its aim is to provide data and methods which can be useful for other countries also.

Our classification of flood run-off and flood frequency which I am going to give first differs from the German classification which has been used in Central Europe.

The German classification marks:

HQ-maximum discharge in the concerned year;

MHQ-arithmetical means of flood discharge HQ in a series of years;

HHQ-maximum flood discharge in a series of years;

KHQ-maximum flood run-off ever recorded or considered possible.

Our classification of flood run-off includes flood frequency based on statistical analysis. I am going to explain this method in an example.

At a certain location on a river there occurred a number of floods f (=30) in a continuous series of N years (=30). In a descending row we arrange their peak discharges and we also note the months of their occurrence in the following table:

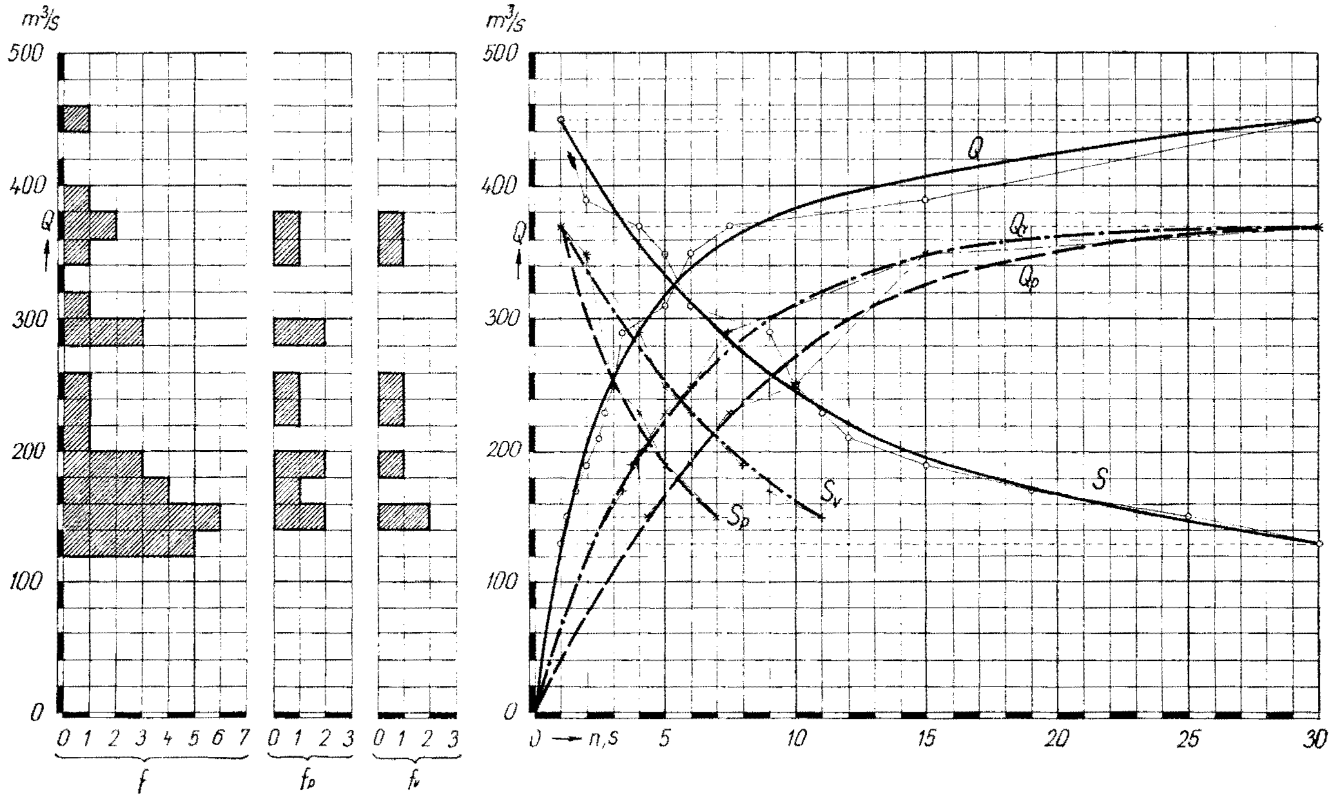
Date of max. month year	*Max. discharge cub. metre per/sec.*	*Date of max. month year*	*Max. discharge cub. metre per/sec.*	*Date of max. month year*	*Max. discharge cub. metre per/sec.*	*Date of max. month year*	*Max. discharge cub. metre per/sec.*
IV. 1900	453	II. 1906	178	X. 1915	284	IX. 1912	142
II. 1909	382	IV. 1924	170	VI. 1926	246	III. 1929	141
VII. 1906	378	I. 1917	168	VII. 1919	222	II. 1922	140
III. 1915	370	I. 1927	166	I. 1922	214	II. 1911	139
V. 1911	360	VIII. 1912	160	V. 1910	200	II. 1900	135
II. 1923	308	III. 1924	158	VI. 1928	200	XII. 1925	131
I. 1920	292	XI. 1906	150	I. 1908	190	II. 1905	130
IV. 1917	290	III. 1909	146				

From this table we compute columnar diagrams (histograms) whose perpendicular axis is divided into a class scale, e.g., each grade being 20 cub. metres per sec. water gauge. The first histogram is computed for all f (=30) floods while the second is derived only from those peak discharges which occurred in the series of years, between 15 April and 31 October, i.e., at the time when fields were under plant cover. There are fy (=11) floods of this kind. The third histogram is computed for floods recorded between 15 May and 15 September, i.e., when meadows were covered with grass that could be damaged if flooded, or crops that might be carried away by water. There are fp (=7) floods of this kind.

The above-mentioned histograms therefore, show class frequency.

This is one of the interesting characteristics of histograms: in our example they show that floods were more frequent in those periods when fields were without plant cover than in a vegetative period, and in the period of vegetation two maximum floods were recorded.

Histograms also show that in water gauging, class grades under 200 cub. metres per sec. are most frequent. This



means that if we take the river's profile at a location of a size sufficient for discharge of 200 cub. metres per sec., then during all f (=30) floods, the river will overflow its banks only 12 times if we take an entire year into account. If we consider only periods of vegetation, the river will overflow its banks only 6 times instead of fv (=11) times. Considering the periods between 15 May and 15 September, we find that instead of fp (=7) floods, the river will overrun its banks only 4 times.

Let us compute summary curves S, S_v and S_p indicating the frequency of measured class grades. For computation of these curves, we presume that deviations from mean values in gauging are distributed as accidental errors in some measuring, i.e., we can use calculus of probabilities and especially the Laplace-Gauss Law. S curves will be continuous and fall between the given points.

This is followed by computation of Q, Q_v and Q_p curves to give probable flood discharge which will occur or that will be exceeded once in n years where $n = \frac{N}{S}$, s being abscissa of S, S_v and S_p curves.

In this example, we derive from the curves that a cross-section capacity of 200 cub. metres per sec. (capacity determined by a centre of 190 cub. metres per sec. class grade) protects the banks against floods during:

30: 13 = 2 years, if we consider yearly periods;

30: 7 = 4 years for periods between 15 April and 31 October;

30: 4 = 7 years considering periods between 15 May and 15 September.

The foregoing classification of floods through the Q curves not only gives the probable repetition in n years of floods, but also enables us to rule out uneconomical water engineering investments.

The longer the series of N years, the more probable are the Q, Q_v and Q_p curves. Some of our gauging stations have been recording for more than a century. Of course Q_{30y} (= years) estimated from such long continuous observations is much closer to the actual discharge than Q_{30y} based on N (= 30) years of observation. We cannot recommend either graphic or mathematical extrapolation of Q curves. In any case, it is possible if we are able to compute maximum discharge which we can take for Q_{100y} by a reliable and verified method or formula.

Having explained our classification of floods it is intelligible and precise to say that we have found naturally formed beds of our rivers in flat land to have a capacity of $Q_{0.5y}$ to $Q_{0.75y}$; our rivers in agricultural districts are regulated and embanked for Q_{2y} discharges; in villages for Q_{50y} to Q_{100y}, according to their importance.

A continuous regulation and embankment of streams is followed by an increase in peak discharges caused by known reasons. If the peak flood discharge which was probably reached or exceeded during n years before regulation was started, is to be reached or exceeded even after regulation was finished in the same number of years, it is necessary to compensate for the effect of the systematic regulation on the increase of flood discharge by retention space in reservoirs. Results of our study show that if we regulate for Q_{2y} cub. metres per sec. capacity, it is necessary to compensate for the whole increase of discharge. For protection against floods, we must reserve a part of the reservoir storage which is about 20 per cent of the total volume of inundations at the concerned part of the river before it was systematically regulated. I call this protective space "compensation protective space".

For more than two years we improved protection against floods by other protective space in reservoirs which I call "improving protective space". On the basis of detailed studies, we compute volumes of total protective spaces, (i.e., improving compensation space) 3 to 5 per cent mean of a yearly run-off, partly according to the volume of inundations of the concerned part of the river, partly according to the numbers of years for which we want to protect the inundation territory of the river.

It is preferable that the protective space in reservoirs with masonry or concrete dams should be above water-level which is of the same height as the crest. This necessitates suitable adjustable sluices located over the crest of the dam. In such a case outflow of the flood-water from the reservoir can be regulated by opening or totally raising the sluices. Thus we avoid the unfavourable results and conditions which would be caused by discharging water through the bottom pipes where the pressure head is great.

For our country, construction of dams is of the utmost importance: we have to utilize water in the broadest range, and at the same time we have to prevent flood damage.

In some cases we do not hesitate to maintain a very high rate of total storage to the mean of yearly run-off.

It would be very favourable to compute long-time forecasts of inflow for economic disposal of water in reservoirs.

Short-time forecasts from rainfall run-off in the drainage areas of reservoirs can be compiled by known methods if the recording service in the upstream drainage area is well equipped. Long-time forecasts are still in the developmental stage.

In this short report, forecasting methods cannot be described. I refer to studies of experts on this subject published in the bulletin of the International Association of Hydrology presented to its Assembly of 1936 in Edinburgh, and of 1939 in Washington, and to my general report presented in Edinburgh in 1936 and published as *Prévision des niveaux d'eaux et des débits des cours d'eau d'Europe.*

At this time we cannot expect that in Central Europe, with a complex climate influenced by many unstable circumstances, a long-time forecast could be worked out that would be of a practical use either for a few years' or even a few months' schedule for disposal of water stored in reservoirs. Although we cannot abandon our attempts at long-range forecasting, we must base our projects on something else. In our country we had two disastrous dry years which followed, one directly after the other, in 1933 and 1934. After we reviewed the past seventy years, we found that these two disastrously dry years represent the greatest demand on reservoir storage from which stream discharge is to be increased during periods of drought. Schedule for water economy based on those two years would most probably be quite sufficient under any circumstances. This would represent a reliable and safe plan, but also a very uneconomical one. It seems better to reserve, in a system of reservoirs, a small number of reservoirs whose storage would be a reserve for such unexpected and exceptional droughts.

Of course utilization of water energy depends also upon the disposal of water in reservoirs.

In order to provide data on water energy, it is essential to state the basis from which they were derived. The World Conference on Energy has been working to make this basis a common one; thereafter all data would be comparable.

I will give data on water energy which can be utilized in our country (or which has been already utilized), based on discharges in the dry year of 1933 and computed for $Q_{50\%}$ (i.e., for that discharge which was either reached or exceeded in half a year's time) from the following formula:

$$N = 7 \times Q_{50\%} \times h. \ /kw./.$$

Coefficient 7 corresponds approximately to the product of $\frac{1000}{102} \times 0.94 \times 0.85 \times 0.90$ where $\frac{1000}{102}$ corresponds to the ratio of kw. and kgm./sec., 0.94 is reduction of the actual head to the usable one, 0.85 is coefficient of turbine usefulness, 0.90 is coefficient of generator usefulness.

From this formula we ascertain the utilizable output in our country—1,040,000 kw., out of which 223,000 kw. has already been utilized.

Detailed study and experience have established that in my country it is useful to install turbines at least for $Q_{25\%}$ cub. metres per sec. where the mean of ratio Q25 per cent: $Q_{50\%} = 1.69$.

The amount of producible kwh. in this case is about 31 per cent more than at the installation for $Q_{50\%}$.

It is also worth mentioning that the Labe (Elbe) River which drains the whole Czech basin, flowing into the North Sea, and the Odra (Oder) River with its source in the mountains in Silesia and its mouth in the Baltic Sea, are to be connected by canals with the most important river, the Danube.

Canalization of the Labe in Bohemia, forming a part of the foregoing navigation project of great international importance, is going to be completed.

A very valuable natural resource which we carefully maintain is our mineral waters. On them are based the world famous spas, for example Karlovy Vary (Carlsbad), Mariánské Lázně, Františkovy Lázně, Jáchymov and Poděbrady in Bohemia, Luhačovice in Moravia, and Piešťany and Sliač in Slovakia.

Water economy and utilization is a very important part of our national economy, and therefore, it must be regulated and utilized systematically and in such a way that the advantages gained by its use in one branch of the national economy does not bring about a disadvantage in some other branch. This is all the more imperative because some of our regions lack natural humidity, and our rivers discharge very little water during dry periods.

For all of these reasons we have started to work out a general plan for water economy based on wide natural, technical and economic research of our water resources and on the analysis of demands of water in industry, power production, agriculture and navigation—and not least for the good health of the people—so that we may reach the optimum synthesis.

The Regime of the Nile and the Use of Forecasts

Y. M. SIMAIKA

ABSTRACT

Owing to the scarcity of rain, the lands of Egypt are entirely dependent on the Nile for their irrigation. During flood the discharge of the river is far in excess of the actual requirements of irrigation and has to be allowed to go to waste into the sea. On the other hand during the low stage the discharge is by no means adequate for the requirements. Hence the two main problems which have always occupied the attention of the irrigation engineer in Egypt are:

1. To provide adequate water during the low stage,

2. To protect the country against high floods.

The importance, therefore, of predicting the supply of the Nile both during the flood and low stages cannot be exaggerated. During flood, precautionary measures must be taken in good time to avert disaster, while in the low stage it is of great importance for the efficient distribution and the operation of the three reservoirs on the Nile (Aswan, Gebel Aulia and Sennar) to prepare a programme for their filling and emptying based on a good forecast.

A short account is given of the various methods of forecasting the flood and low stages, as well as forecasting the Nile flood from meteorological elements.

The periodicity of the Nile flood from the old records of Roda gauge in Cairo is also discussed. The records extend back to 640 A.D.

The Nile is a potential source of large quantities of water-power and mention is made of the hydro-electric power schemes at both Aswan and the outlet of Lake Victoria.

The importance of the Nile to Egypt can hardly be exaggerated. Owing to the scarcity of rain, crops are entirely dependent on irrigation from the river. This has led to extensive studies of the regime of the main stream and its tributaries.

Thousands of years ago, the ancient Egyptians recorded Nile levels on gauges some of which still remain. Records of Roda gauge near Cairo date back to 640 A.D. There is no other series of observations of meteorological phenomenon comparable in length to these Nile records except those derived from the rings of the big California trees, which take us even further.

The Nile which is about 6,500 kilometres or more than 4,000 miles long is the second longest and one of the most remarkable rivers in the world. Its basin covers an area of 2,900,000 square kilometres (1,100,000 square miles) or three-tenths of the area of Europe. Its basin extends from Lat. 4 degrees S to Lat. 31 degrees N and includes a greater variety of climates than that of any other river. It contains Lake Victoria, the largest fresh-water lake in the eastern hemisphere. (See Figure 1).

There are two regions from which the Nile draws the greater part of its water: Abyssinia and the Lake Plateau which includes Uganda and parts of Kenya, Tanganyika and the Belgian Congo.

The Abyssinian tributaries of the Nile are the Blue Nile, Atbara and Sobat, which together produce 84 per cent of the water.

The water from the Lake Plateau comes mainly from Lake Victoria and its tributaries, though a part comes from the Lake Albert system. The total flows down the Bahr el Jebel, through the swamps of the Sudd Region in southern Sudan, where half of it is lost, until it joins the Sobat to form the main stream of the White Nile.

Owing to the effect of the Lakes Victoria and Albert and the swamps, the discharge of the Bahr el Jebel at its junction with the Sobat does not vary much throughout the year.

On the other hand, the Abyssinian tributaries rise regularly every year, beginning in May and reach full flood on their upper waters at the end of August, after which they gradually decline and are at their lowest in March and April. The Blue Nile discharge at its lowest is only about one-fiftieth of what it is when in full flood, while the White Nile at the tail of the swamps before it receives the Sobat varies only about one-sixth during the year.

The White Nile, including the Sobat, contributes from January to June two and one-third times as much as the Blue Nile and Atbara together. (Figure 2).

The Abyssinian tributaries when in flood bring down a great deal of silt which reaches a maximum concentration in Egypt of about 3,600 parts per million. For this reason it has always been the custom to begin to fill the Aswan reservoir some time after the peak of the flood has passed when the silt content has fallen to such an extent that there is no danger of depositing large quantities in the reservoir.

Thus the flood of the Nile is subject to regular variation. During the flood period (August to January) the discharge is far in excess of the actual requirements of irrigation and has to be allowed to go to waste into the sea. High floods have occurred in past years accompanied with serious breaches of the Nile banks causing loss to life and property.

On the other hand, during the low stage (February to July) the discharge of the river is low and by no means adequate for the requirements of irrigation. Hence the two main problems which have always occupied the attention of the irrigation engineer in Egypt are:

1. To provide adequate water during the low stage,
2. To protect the country against high floods.

The importance, therefore, of predicting the supply of the Nile both during the flood and low stages cannot be exaggerated. During flood precautionary measures must be taken in good time to avert disaster, while in the low stage it is of great importance for the efficient distribution and the operation of the three reservoirs (Aswan, Gebel Aulia and Sennar) to prepare a programme of their filling and emptying based on a good forecast.

FORECAST OF THE LOW STAGE

This is based on the fact that when the rains are well over, the river falls steadily and regularly until the rains start again. Thus in January a forecast can be made of the quantity of water which will reach Egypt until the end of June, based entirely on the state of affairs in January. This type of forecast is useful in arranging the programme of water distribution during summer, the emptying of the Aswan and Gebel Aulia reservoirs and particularly in fixing, well in advance of the time of sowing the amount of rice which can be grown. The method is based on correlations of gauges or discharges at the different sites on the Nile and its tributaries. They assume amongst other things a regularity of behaviour and regime at similar stages and conditions of the river, an assumption which is generally true as far as the Nile is concerned. Such correlations are, however, apt to break down during the periods of rapid change such as the early part of the rise of the flood in July. At all times they must be used with care, particularly when the steady period has passed.

Correlations between Malakal (on the White Nile) and Sennar (on the Blue Nile) with Tamaniat, Tamaniat with Atbara (both on the Main Nile) and Atbara with Aswan used in conjunction with time of travel relations between the various stations, are found very useful in giving a very fair forecast of the water reaching Aswan during the summer period.

FORECAST OF THE FLOOD STAGE

At present there is no accurate method of forecasting a high flood until the rain has actually fallen in Abyssinia and then the first warning is given by Roseires gauge, right up the Blue Nile and not far from the Abyssinian mountains, where the river shows the effect of the rainfall by extensive fluctuations, occasionally rising and falling 2 metres in 10 days or even rising 4 metres in a week. In the 620 km. from Roseires to Khartoum these rapid fluctuations are considerably damped but the main features persist.

Let us consider an average year like 1931-1932. Notice the peaks A, B, C and D on the Roseires and Khartoum curves (Figure 3). When we get to Halfa the river Atbara also affects the levels. On the whole it rises similarly to the Blue Nile and often, though not always, a peak on the Blue Nile is accompanied by one on the Atbara, since both streams draw their supplies from Abyssinia and a widespread rain will affect the two. Khashm el Girba gauge on the Atbara, however, is nearer to Halfa than Roseires gauge so a peak on the Atbara arrives at Halfa two or three days before one which started at the same time on the Blue Nile. The Atbara carries much less water than the Blue Nile, but the effect of a peak may be considerable because owing to the shorter journey there is less damping. The peak B at Khashm el Girba happens at the same time as B on the Blue Nile, but it

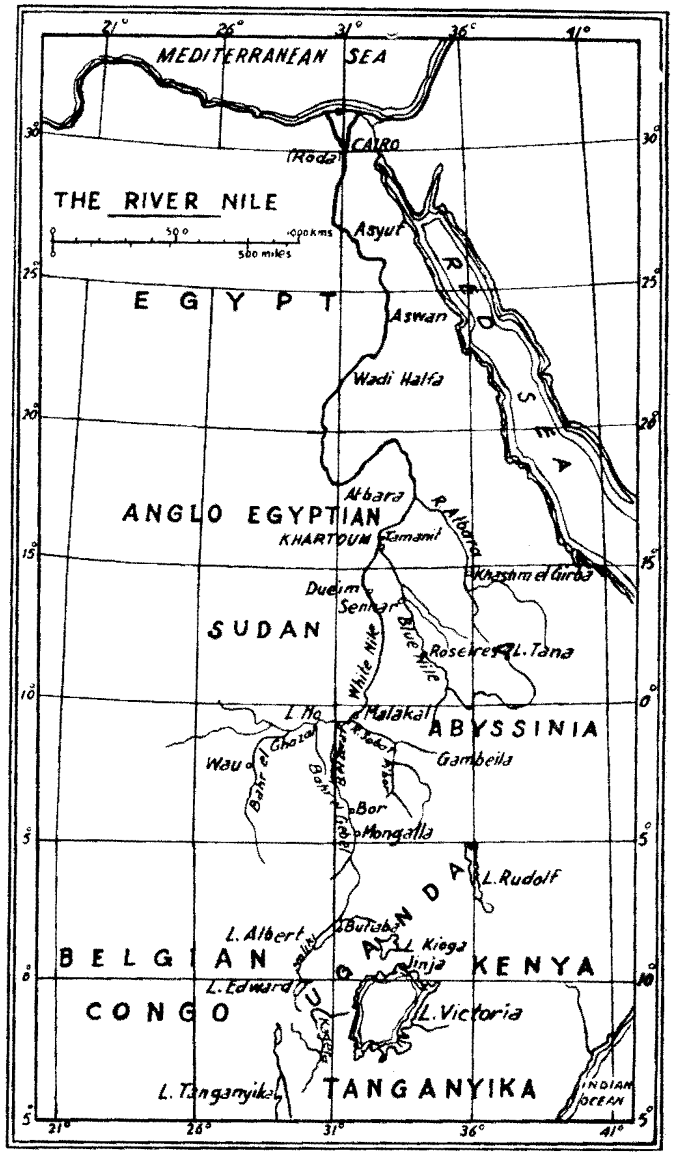


Figure 1

gets to Halfa two or three days before the Blue Nile peak and is responsible for the actual maximum B at Halfa. Peak E on the Atbara does not coincide with anything of importance on the Blue Nile and corresponds to E at Halfa. C at Khartoum, which occurs when the Atbara has fallen, is responsible for C at Halfa.

This analysis illustrates the forecasting of the height of the flood in Egypt from what happens on the Blue Nile and Atbara.

In a high flood, what happens on the tributaries is followed day by day in Cairo with the closest attention, as on the forecast which is made depend the measures to be taken to reduce the danger from a high flood.

Another critical time is when the flood is first beginning to rise and the Aswan reservoir is nearly empty. In a year when the flood is late, the most careful attention is needed in June and July so as to make full use of the reservoir water, and at the same time not have the reservoir empty before the natural river supply is sufficient for the crops. Failure to make full use of the water increases the difficulty of irrigation and some crops suffer, while a mistake in the other direction may lead to serious loss of crops through lack of water, consequently a daily forecast is made based on the quantities of water passing Roseires and Khartoum on the Blue Nile, Malakal on the White Nile, and Khashm el Girba on the Atbara and the water released day by day from Aswan is governed by these forecasts.

FORECASTING THE FLOOD FROM METEOROLOGICAL ELEMENTS

Another kind of forecast which has not up to the present attained sufficient accuracy to be of practical use, is based on the fact that the major features of world weather must be related through the general circulation of the atmosphere and many such relations have been found by Walker, Lyons, Craig, Hurst and other investigators. The Nile flood is one of these major phenomena, and Bliss[1] has found a connexion between the Nile Flood (N), the temperature (D) at Dutch Harbour in Alaska on the borders of the Arctic Circle, the temperature (S) in Samoa in the Pacific Ocean and the pressure (P) at Port Darwin in Northern Australia.

Where (N) is the total Aswan Discharge from July to October,

(D) is the Dutch Harbour mean temperature, March to May,

(S) is the Samoa mean temperature, December to May,

(P) is the Port Darwin mean pressure, March to May,

(D), (S) and (P) represent differences from average divided by the standard deviation.

The equation is:

$$N = -0.40D - 0.23S - 0.30P$$

This means that when the two temperatures and the pressure are high the following Nile flood tends to be low. It is interesting to note that all these places are on the opposite side of the world to the Nile.

The formula fitted very well the observations from which it was constructed, but its success in recent years has not been tested for lack of the data from the Pacific. As a rough measure of its value we may say that the equation accounts for about half the variation of the Nile flood.

Perhaps the great advances in meteorology which have been made as a result of the study of the upper air may ultimately lead to long-range forecasts of the flood which are of practical use as well as being of theoretical importance.

Up till now much valuable information has been collected by the East African Meteorological Service, which has many stations in and near the Lake Plateau basin of the Upper White Nile some of which have been working for about 20 years. When there is a similar development of meteorology in Abyssinia and right across Africa there will be the material for a study of

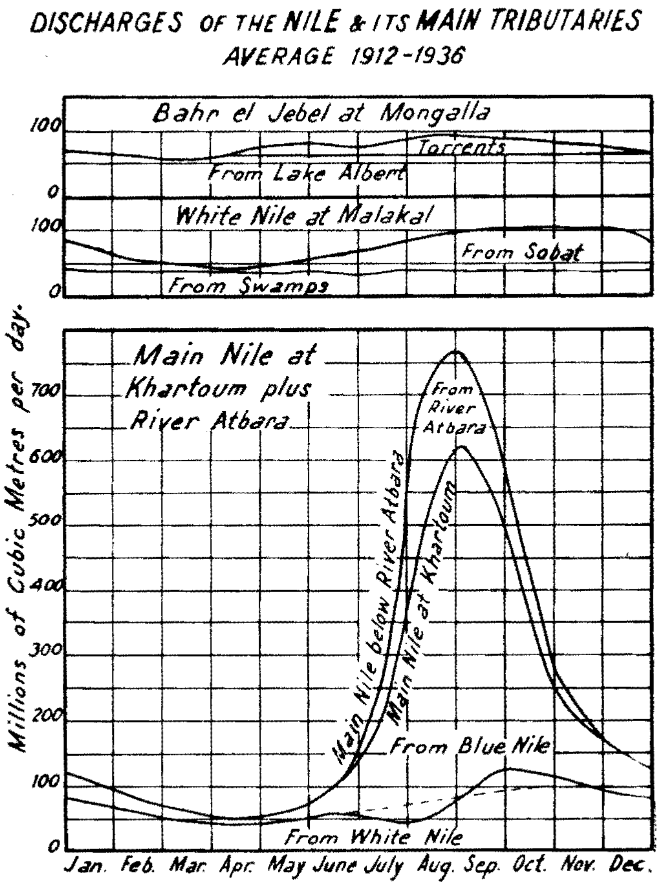


Figure 2

the rains and the general conditions which produce the Nile flood.

While on the subject of forecasting the Nile flood, the question of periodicity may be considered. The old records of levels on the Roda gauge in Cairo have already been mentioned and of these the most complete series give maximum and minimum levels, although with gaps, for about 900 years from 620 to 1520 A.D. Although they contain many sources of error and naturally have not the precision of modern scientific observations, nevertheless, they are probably as reliable as many of the statistics collected today about less well-defined phenomena such as health or social conditions. In spite of uncertainties due to repairs and renewals of the gauge, change of the river channel and vagaries of gauge observers, a good deal of useful information can be extracted from the records.

One use to which they have been put is to estimate the chances of high or low floods. Another is the search for periodicities. With this aim they have been analysed by several people who have found many periods varying from 2 to 240 years. The periodic part is small compared with irregular variations. None of the periods is pronounced enough to be discoverable except by refined and painstaking analysis. A glance at the records when plotted on a fairly large scale shows that there is no period which is directly evident to the eye. It is not a case of Joseph's seven fat and seven lean years, but something much more irregular. The principal feature is the occurrence of fairly

[1] Bliss, "Nile Flood and World Weather", Mem. Roy. Met. Soc., vol. I, no. 5.

long stretches of years when on the whole floods have been high and others when they have been low. Nevertheless a low flood may occur in a high series and high floods in the low series. In the period 1869-1898 floods were high, while 1899-1949 was a period of low floods.

ENERGY SOURCES OF THE NILE

The Nile is a potential source of large quantities of water-power and as Africa develops some of this will be employed. A beginning will be made with the Aswan and Lake Victoria power schemes.

THE HYDRO-ELECTRIC POWER SCHEME AT ASWAN DAM

To avoid the risk of heavy deposition of silt during flood, the rule is to keep the sluices of the Aswan Dam fully open throughout the flood season. Investigations which have been carried on over a number of years have shown, however, that with a head of 8 metres maintained on the dam during the flood, the amount of silt which is likely to be deposited with the lapse of years would be very small. Hence for the purpose of power generation, the lowest head has been fixed at 8 metres, so that the range of variation of the head on the dam would vary from 33 metres when the reservoir is full to 8 metres during flood. Owing to this big range of head, Kaplan or adjustable-blade propeller turbines are being used.

The total installed capacity of the station is 344,000 kw. Under present hydraulic conditions the maximum output will be 260,000 kw. This output, however, lasts about eight months in the year and falls down to 50,000 kw. during flood. Thus there will be a seasonal energy of 210,000 kw. available for eight months of the year and a firm energy of 50,000 kw. available all the year round.

The seasonal energy will be used in the production of 300,000 tons of chemical fertilizers and 90,000 tons of steel, while the firm power would be used for the development of the local industries of Aswan Province.

Arrangements are also being made for the generation of electric power from the various barrages on the Nile at Esna, Naga Hamadi and Asyut. Owing to the small head on these barrages the total output will be about 74,000 kw. falling to 48,000 kw. during flood.

As a result, the fertilizer output will be increased to about 500,000 tons.

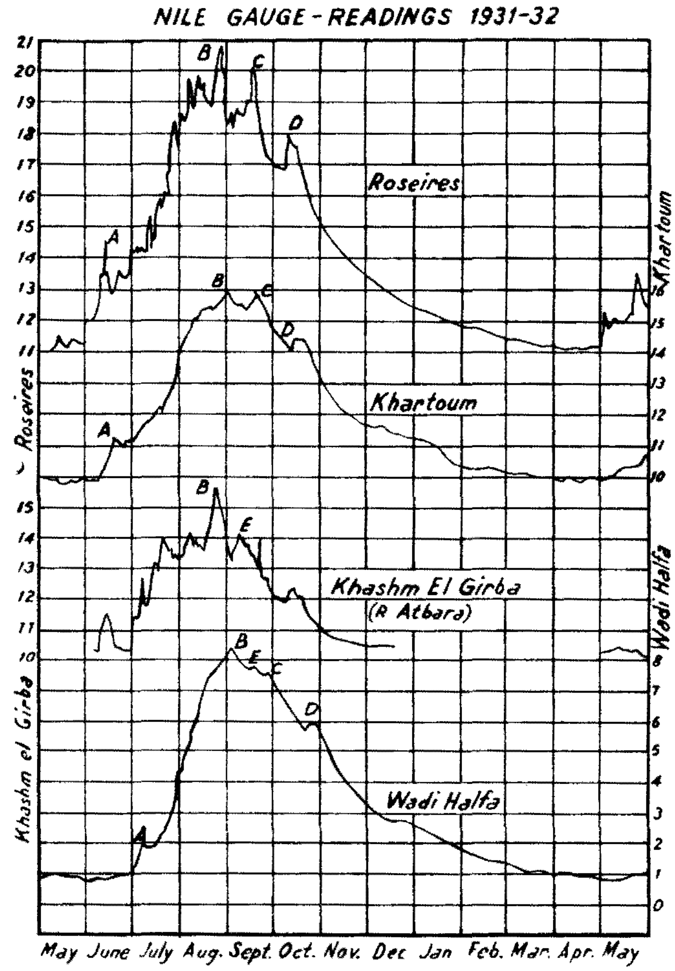


Figure 3

LAKE VICTORIA POWER SCHEME

A joint scheme between Egypt and Uganda for converting Lake Victoria into a reservoir has just been agreed upon. Lake Victoria with a capacity of 200,000 million cub. metres will be the largest reservoir in the world. The water will be used for irrigation in Egypt while use will be made of the 24-metre fall at the Lake's outlet to produce 80,000 kw. for various industries in Uganda.

The Application of the Probability Theory to the Solution of Hydrological Problems

VIKTOR FELBER

ABSTRACT

The author presents two problems of great importance for modern hydraulic engineering, the consumption problem with variable river profiles (stability problem) and the high-water-frequency problem, giving a new concept of these problems by introducing the methods of the probability theory. This concept which is more and more used in applied hydrology means a gradual change of the practice hitherto in use in hydrography. Theory and application of the mathematical means are discussed in concise form, new possibilities of definition are shown, the solutions of other problems are indicated and references are given to research papers, some not yet published, of others and of the author himself.

The stability problem is solved on the basis of a new representation of the water-level collective (*Wasserstandskollektiv*), called time-medians polygon (*Zeit-Schwerlinien-Polygon*), deduced from a water-level time polygon (*Wasserstand-Zeit-Polygon*) by once smoothing it, respectively by correlation of several polygons of medians (*Schwerlinien-Polygone*). The high-water data necessary for the hydrological characterization are concluded from the functions of distribution, of excess probability and recurrence frequency calculated for mixed collectives (*Mischkollektive*).

The requirements of modern hydraulic engineering have set tasks in applied hydrology which, in part, cannot any longer be solved by the means of former classic hydrology. Both experience and theory have shown that in meeting these requirements problems arise which, anticipated rather than recognized at present, can be clarified only by adopting new methods. These problems, manifold as they are, have a common purpose, i.e., to deduce from a great number of observed or measured natural phenomena, certain characteristic values which are determined for a given task, with the highest probability within the range of variations given by their natural causes. Adopting this concept implies the partial abandonment of the usual way of solving hydrological problems. Many of the functions hitherto used and the formulae found by experience can now be supplemented or replaced by the results of statistics. For statistical mathematics, including the theories of correlation and probability, is the only means that allows for a comprehensive evaluation of observations and at the same time yields results obtainable in an economic way. It is an indispensable and self-evident presupposition that the new methods agree with the laws of hydrodynamics and hydraulics.

According to statistical research methods, any task starts by choosing a suitable collective (1) (2)[1]. From the sequence of natural mass phenomena (observations) at least one characteristic or argument (result of observations), given by the formulation of the problem, is introduced into the calculation as a measurable quantity. Some solutions of problems are best described by characteristics of a specific kind. From the given collective then must be deduced by selection one or more collectives consisting of elements suitable for the best characterization.

The application of methods of the probability theory offers numerous new possibilities for the solution of hydrological problems. Some results have been obtained in research works in part not yet published. Two of the results will be presented in this paper in concise form. The first, the consumption problem with variable river profiles (stability problem) is of particular importance for the hydrology of water-power economy, while the second, the high-water-frequency problem, has importance for the hydrology of river construction.

[1]Numbers within parentheses refer to items in the bibliography.

THE CONSUMPTION PROBLEM WITH VARIABLE RIVER PROFILES (STABILITY PROBLEM)

All data concerning water-power economy—as they are recorded for instance in the Austrian water-power register—are based on complete consumption statistics for many years covering as many points (water-gauges) of a river basin as possible. Considering the existence of the regional consumption relation (*Raumabfluss-Beziehung*), there must be a specific interrelation between the characteristic consumption values of the different profiles. This condition is sufficient to prove the correctness of the statistical results. However, it implies another condition, equally necessary though alone not sufficient, that must be satisfied, i.e., the comparability at a given point. That means that at any point the measured quantities of consumption can be co-ordinated to the water-level observations. There is a specific relationship between water-level and consumption only as long as the consumption capacity of the profile is maintained. But the consumption capacity depends on the hydraulic state and the morphological formation of the profile and the adjoining lower river-course. Detritus, suspended and sinking material carried by the river-water, as well as artificial and natural alterations of the river is often the cause of morphological or hydraulic transformations of the river-bed. In general, a consumption capacity constant in time (stability) cannot be assumed, and the relationship between water-level and consumption may change for a longer period, though a specific relationship (consumption curve) will exist for any time-interval of constant stability. Therefore the stability of the water-gauge profile must be examined before plotting the consumption curves. This could be done directly if a sufficient number of accurate consumption measurements were available for all time-intervals with constant stability. This is mostly not the case because the measurements are too few or not comparable owing to distribution over too many years, so that it is impossible to obtain immediately the multiform relationship between water-level and consumption.

The four methods of examining the stability of river-profiles are equivalent as to their scientific basis and differ only in the accuracy of the results (3).

The starting collective is the water-level (W-collective), first because there are always enough observations available, second because the stability changes in the profile (river-section) can be clearly seen from it. For the water-level corresponding to the actual consumption depends in a specific way on the transport capacity of the river-section. The law determining the actual position of the water-level is given by the superposition of the influences of consumption quantity and consumption capacity. Of course, the water-level variations are primarily influenced by the variations of consumption, whereas the change of the consumption capacity determines only the level about which the primary variations occur. Therefore such water-levels are introduced as characteristic of the W-collective as represent a specific consumption type of a given rhythm (for instance summer and winter consumption). Instead of the observed water-levels W mean values, calculated for a half year consumption $\triangle t_i$, Y_i $(1 = 1, 2, \ldots n)$ are therefore introduced as arguments of the W-collective. The consumption rhythm thereby becomes clearly visible. The continual water-level curve is replaced by the water-level time polygon (*Wasserstand-Zeit-Polygon*, Y_i-polygon) as representation of the W-collective.

It is the purpose of the stability examination to fix the bounds between the time-intervals of constant consumption capacity and to give a numerical indication of the change rate of the consumption capacity relative to the consumption state of a chosen time-interval. The limitation of the sections with constant stability gives at the same time the number of the consumption curves for the whole period under examination. The change rate determines the mutual position of the consumption curves.

Water-levels and consumption can also be made comparable by correction of the water-levels, i.e., by taking into account the rate of change. The totality of the corrected water-levels forms the W_r-collective. The connection of the water-levels W_r with the consumption quantities is a specific one as with stable profiles.

Generally it can be seen from the Y_i-polygon when stability changes take place. The calculation of the change rates, however, requires that one know in advance the variation level showing a discontinuity at the time of the stability change. Regular variations allow the calculation of the level as average $\overline{Y}_T$ of all Y_i-values over the period T $(= n \triangle t_i)$. Geometrically it represents a straight line bisecting the Y_i-polygon and lying parallel to the time axis. A step or a transition in the variation level to a new level corresponds to a change of the consumption capacity according as this change occurred suddenly or by degrees.

In case of *one* sudden change the period of examination T is divided into two time sections $\triangle T_K$ and $\triangle T_B$ with the levels $\overline{Y}_K$ and $\overline{Y}_B$. The rate of change of the consumption capacity in the section $\triangle T_K$ relative to $\triangle T_B$ can be defined by

1. $$S_{KB} = \overline{Y}_K - \overline{Y}_B,$$

a term expressed in centimetres of water-level.

Even if the curve has the form of a meander the average must be considered as a median. Therefore the level about which the values of the collective vary can be conceived as a median of a time polygon and calculated correspondingly. There is no restriction as to the form of the polygon. Hence it makes no difference for the determination of the level of variation whether regular or irregular, disturbed or undisturbed sequences of variations occur. In case of irregularities or disturbances the variation level only loses the character of a straight line parallel to the axis and breaks up into elements of the length $\triangle t_i$ varying more or less, according to the magnitude of the irregularities, about a mean level (i.e. about the level $\overline{Y}_T$ of the regular sequence). The variation level itself becomes a time polygon, namely the time-medians polygon (*Zeit-Schwerlinien-Polygon*).

The time-medians polygon corresponds to the time polygon in economic statistics known as "trend", as both represent the level variable in time about which the seasonal differences vary.

For the calculation of the height $\overline{Y}_i$ of the median element representing the i-st half year of consumption, the formula

2. $$\overline{Y}_i = \tfrac{1}{4} (Y_{i-1} + 2\,Y_i + Y_{i+1})$$

was found, if Y_{i-1}, Y_i, and Y_{i+1} denote the heights of the Y_i-polygon in the (i-1)-st, i-st, and (i + 1)-st half year. The time-medians polygon (*Zeit-Schwerlinien-Polygon*, $\overline{Y}_i$-polygon) is obtained therefore by once smoothing the Y_i-polygon. Hence the $\overline{Y}_i$-polygon has a smoother form than the Y_i-polygon, the changes of level thereby becoming better visible. Now the subdivision of the observation period T into sections of equal stability $\triangle T_K$ can be readily performed. Then similar values of $\overline{Y}_i$ are summed up to mean values $\overline{Y}_K$ $(K = 1,2, \ldots . B, \ldots . N)$ and the rates of change S_{KB} determined according to the system of equation 1 (time-medians method).

The calculation of the time-median must not be confounded with a smoothing analysis. While this analysis allows repeated application of formulae of different kind, in obtaining the median only formula 2 can be used and that only once in order to make all discontinuities as clear as possible.

As the change of stability is best visible in periods of low water it is convenient to apply the above procedure to the NW-collective (low-water collective) deduced by selection from the W-collective.

Greater accuracy of calculation is reached by quantitatively introducing a suitable comparative collective (time-medians method with quantitative introduction of a comparative polygon), whereas mere comparison with such a collective (time-medians method with qualitative introduction of a comparative polygon) only extends the aspects of the stability problem.

Assuming that, besides the actually observed water-levels W, the water-levels W_r corresponding to a stable profile were also known, two collectives would be available for the critical examination of the changes of the consumption capacity. The rates of change relative to the b-st half year were then defined by the time polygon

$$3.\quad S_{ib} = (\overline{Y}_i - \overline{Y}_b) - (\overline{Z}_i - \overline{Z}_b)\ (i = 1,2, \ldots\ b, \ldots n)$$

if $\overline{Y}_i$ and $\overline{Z}_i$ denote the median elements of the arguments Y_i, respectively Z_i of the two given collectives. The W_r-collective is unknown. However, it can be defined as consequence of a cause, for instance of a N-collective with the characteristics $\overline{X}_i$. Then a correlative relationship exists between the comparable characteristics of the collectives connected by causality. It could be proved that this relationship in any practical case can be reduced to the linear correlative relation

$$4.\quad \overline{Z}_i - \overline{Z}_b = a\,(\overline{X}_i - \overline{X}_b)\ (i = 1,2, \ldots b, \ldots n)$$

The transformation factor $a = \mathrm{tg}\boldsymbol{\alpha}$ is calculated (as the variations of the water-level about their median must be of the same dimension for all states of stability, the identity

$$5.\quad \overline{y}_i\,(= Y_i - \overline{Y}_i) = \overline{z}_i\,(= Z_i - \overline{Z}_i)\ (i = 1,2, \ldots b, \ldots n)$$

is therefore justified) by the formula of the correlation theory

$$6.\qquad \mathrm{tg}2\,\boldsymbol{\alpha} = \frac{2\sum\limits_{i=1}^{n} \overline{x}_i\,\overline{y}_i}{\sum\limits_{i=1}^{n} \overline{x}_i\,\overline{x}_i - \sum\limits_{i=1}^{n} \overline{y}_i\,\overline{y}_i}$$

if x_i represents the variations of the characteristics of the comparative collective about their median. Hence the system of equations

$$7.\quad S_{ib} = (\overline{Y}_i - \overline{Y}_b) - a\,(\overline{X}_i - \overline{X}_b)\ (i = 1,2, \ldots b, \ldots n)$$

corresponds to the time polygon (equation 3).

By summing up similar values S_{ib} to mean values $\overline{S}_K$ $(K = 1,2, \ldots B, \ldots N)$ the rates of change relative to the time-interval $\triangle\,T_B$ can be calculated by

$$8.\qquad S_{KB} = \overline{S}_K - \overline{S}_B\ (K = 1,2, \ldots B, \ldots N)$$

with greater accuracy than by means of the equation 1 system.

As comparative collective any collective connected with the W-collective by causality may be chosen: the precipitation in the catchment area, the consumption in a neighbouring profile, or the water-level in a stable river-section.

Adequate correction of the comparative polygon leads to a method of the highest accuracy for calculating the stability changes (time-medians method with quantitative introduction of a corrected comparative polygon). This procedure, however, has no practical importance considering the extensive calculations involved.

THE HIGH-WATER FREQUENCY PROBLEM

High-water in the hydrological sense is a consumption phenomenon with a consumption quantity not falling below a value that corresponds to the naturally available water quantity of the river regime, the consumption quantities themselves rapidly changing with time. According to the probability theory it can be concluded that all consumption phenomena of this sort can be comprehended as elements of a new collective "high-water" by a suitable selection from the collective "consumption".

According as economic-technical decisions on river regulations or investigations on the size of reservoirs are in question, the peak consumption HQ or the total quantity M of the high-water is introduced as characteristic of the high-water collective.

In the sense of the probability theory a collective is characterized by the relationship between its characteristics and the number (absolute frequency) of the members associated with these characteristics. This relationship is called distribution function. The collective "high-water" therefore can be described either by the distribution curve of the peak values of consumption HQ or by the total quantity M.

The exact calculation of a distribution function presupposes that it can be described analytically by the Gaussian exponential law. But collectives of biological or other objects existing in nature do not show normal distribution.

Fechner (1) succeeded in transforming the asymmetric distribution of different natural mass phenomena into normal ones by introducing the logarithms of the characteristics. In the case of hydrological collectives even this procedure is in itself not sufficient for obtaining normal distribution functions. For this reason the first attempts of applying the methods of the probability theory to hydrology did not lead to satisfactory results (5, 6, 7, 8).

Theoretical investigations (9) have shown the type of a mass phenomenon to be manifest as mean value of the arguments. Therefore a density maximum corresponds to any species within a class. Statistical masses comprising several species of characteristics are called mixed collectives (*Mischkollektive*). Their distribution curves possess several density maxima. Mixed collectives always then occur if the complex of causes or the complex of conditions placed between origin and effect of the mass phenomenon change. Such changes have always to be expected in hydrological collectives. Therefore they are mixed collectives.

After the mathematical bases had been found (10, 11) it was natural to investigate hydrological mass observations with the aid of the theory of mixed collectives. At first this was done for the consumption (12) and subsequently for the mass phenomena precipitation, sub-soil water and high water (13, 14). Thereby collectives consisting of two, three and even more parts resulted. In particular all former high-water investigations led to mixed collectives of three parts (*dreiteilige Mischkollektive*).

The example given here to demonstrate the theory and application of this procedure is taken from the numerous high-water investigations of the author. In this example the logarithms of the high-water peak values

$$9.\qquad x = \log HQ$$

are introduced as arguments. The distribution function of a partial collective K is then given by the Gaussian exponential law

$$10.\qquad V_K\,(x) = A_K \exp\left[-\frac{1}{2\,\sigma_K{}^2}(x - a_K)^2\right]$$

where $\exp z = e$

the importance of which is generally known. The partial collective K appears to be completely described when the average of the arguments a_K, the standard deviation σ_K and the density maximum A_K are known.

Practically, the collective is divided into classes of the eligible but constant length $\triangle x_i$ ($i = 1,2, \ldots \ldots \lambda$). By counting the arguments of the i-st class the number (absolute class frequency) N_i is found. It is convenient, however, to put in its place the relative class frequency

11. $$n_i = \frac{100\, N_i}{\sum\limits_{i=1}^{2} N_i} \quad (i = 1,2, \ldots \ldots \lambda)$$

where λ denotes the number of classes. By plotting the n_i over every interval i as parallel to the argument axis the graduated polygon (*Stufenpolygon*) of frequencies is formed (Figure 1a), representing the basis for obtaining the general distribution function which can be written as the sum of the normal distribution.

12. $$V(x) = \sum_{K=1}^{\nu} V_K(x) \quad (K = 1,2, \ldots \nu)$$

if ν denotes the number of the partial collectives. A mixed collective consisting of ν parts is therefore completely described if the three constants of the ν partial collectives, i.e., $3\,\nu$ quantities, are given numerically. The theoretical idea underlying the calculation of these quantities is principally based on the transformation of the distribution curves of the K partial collectives by a suitable function into straight lines. In practice this is done by plotting in the middles of the intervals of the graduated polygon (*Stufenpolygon*) the values

13. $$y_{Ki} = \sqrt{\log \frac{A_K}{n_i}} \; (i = 1,2, \ldots \gamma, K = 1,2, \ldots \nu)$$

as ordinates, taken postive in the ascent of the frequency polygon and negative in the descent, and by connecting these points by the compensation lines

14. $$y_K = \beta_K (x_K - a_K) \quad (K = 1,2, \ldots \nu)$$

(Figure 1b). The intersections of the compensation lines with the argument axis yield the argument averages a_K and the differences $(x_K - a_K)$ for $y_k = 0.467$ and the standard deviation σ_K. The density maxima A_k, necessary for the calculation of the equation 13 system are unknown and therefore must be estimated in advance. Generally the determination of the averages and of the standard deviation of the partial collectives requires one or more repetitions of the procedure. A satisfactory result is given and the calculation finished when the surface of the distribution curve

15. $$F = \sum_{K=1}^{\nu} F_K = \sqrt{2\pi} \sum_{K=1}^{\nu} \sigma_K A_K \qquad (K = 1,2, \ldots \ldots \nu)$$

and the surface of the graduated polygon (*Stufenpolygon*) with the class length $\triangle x$

16. $$F^1 = 100 \triangle x$$

have the same size. The difficulties of calculation increa e with the number of partial collectives. In any case the two boundary distributions are the starting point.

The distribution function equation 11 may be calculated numerically, as the $3\,\nu$ characteristic values of the mixed collective (*Mischkollektiv*) are known by now, with the aid of tables (2, 15) from which the density values for any arguments x can be taken directly (Figure 1a). Because of the quick convergence of the Gaussian density function it is sufficient to calculate it for a finite range of arguments only. For normal distributions 99.7 per cent of all possible observations are contained within the interval. Therefore the probability for an observation being greater than $a_K + 3\sigma_K$ amounts to 0.15 per cent only. The same holds true for arguments $\leq (a_K - 3\sigma_K)$. For this reason the author makes the practical range of variation of every partial collective equal to the sixfold standard deviation $6\sigma_K$. From this assumption follows easily a definition of the peak consumption RHHQ for the highest water to be expected. RHHQ is that peak quantum which is surpassed with the probability of 0.15 per cent only. It can be read off directly from the distribution function as argument

17. $$\log \text{RHHQ} = o_\nu = a_\nu + 3\,\sigma_\nu$$

at the upper limit σ_ν of the right boundary collective.

The sum function for mixed collectives is defined by

18. $$S(x) = \sum_{K=1}^{\nu} \frac{F_K}{F} \Phi(u_K) \quad (K = 1,2, \ldots \ldots \nu)$$

The factors $\frac{F_K}{F}$ represent the surface ratio between the total collective and its parts. The special values of the function Φ for the (transformed) arguments

19. $$u_K = \frac{x - a_K}{\sigma_K} \quad (K = 1,2, \ldots \ldots \nu)$$

are contained in tables (2, 15). The function of the excess probability

20. $$W(x) = 1 - S(x)$$

can therefore be calculated immediately (Figure 1c).

It is usual in river-construction hydrology to indicate the peak quantum reached, respectively exceeded, once in

21. $$p = \frac{1}{\overline{W}(x)}$$

years. The peak quantum of the recurrence frequency p is called p years high-water. The probability $\overline{W}(x)$ is deduced from a collective of N elements representing the result of observations of $\overline{N}$ years. The probabilities $\overline{W}(x)$ and $W(x)$ are therefore connected by the formula

22. $$\overline{W}(x) = \frac{N}{\overline{N}} W(x)$$

Hence the recurrence frequency is given by the equation of functions resembling a hyberbola

23. $$p = \frac{1}{\overline{W}(x)} = \frac{\overline{N}}{N} \frac{1}{W(x)}$$

according to the character of the probability function W (x), it quickly approaches the boundary values (Figure 1d).

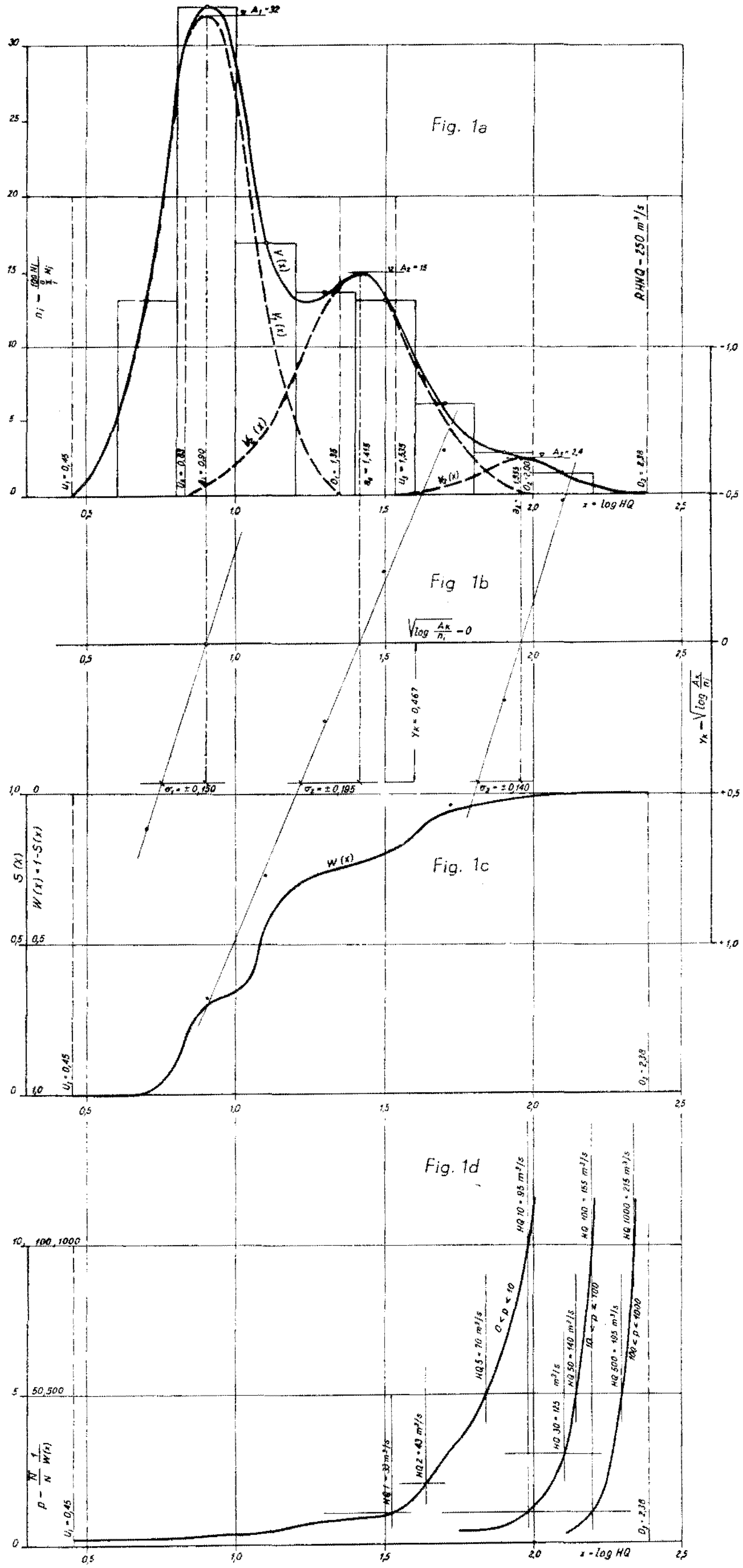


Fig. 1a
Fig 1b
Fig. 1c
Fig. 1d
RHHQ = 250 m³/s
z = log HQ
W (x)
σ₁ = ± 0,150
σ₂ = ± 0,195
σ₃ = ± 0,140
y_K = 0,467
u₁ = 0,45
o₃ = 2,38
HQ 10 = 95 m³/s
HQ 100 = 155 m³/s
HQ 1000 = 215 m³/s
HQ 5 = 70 m³/s
HQ 2 = 43 m³/s
HQ 500 = 195 m³/s
0 < p < 10
10 < p < 100
100 < p < 1000
z = log HQ

Finally it may be mentioned that in calculating the quantities of an economic extension of discharge reservoirs, investigations have been made on the most probable form of high-water waves (14). The problem was solved by means of an operation in probability theory known as "connexion" (*Verbindung*) (2), which thereby for the first time was applied to mixed collectives.

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Summary of Discussion

The CHAIRMAN declared the meeting open and announced that the agenda had been amended to enable other sections also to use the lecture lantern. The first statements to be made would, therefore, be those which were to be illustrated by lantern slides, namely those by Mr. Schaefer and Mr. Orr on induced precipitation.

Mr. V. J. SCHAEFER, in introducing his paper on "The Economic Aspects of Meteorology", told the meeting of the research carried out and the results obtained in experimental meteorology by the research laboratories of the General Electric Company in collaboration with the meteorological services of the Army Signal Corps and the Office of Naval, Military and Air Research of the United States of America.

He then showed about forty slides illustrating the different aspects of the experiments made, the types of clouds used, methods of cloud-seeding etc. He pointed out that the research laboratories of the General Electric Company had concentrated mainly on a study of the phenomenon of precipitation rather than on the eventual application of the methods evolved.

In conclusion, he said that he was convinced that the work so far done in that new branch of science opened up great possibilities. Many years would have to be devoted to the study of these meteorological phenomena before any really useful results could be obtained. Similar research was being carried out on parallel lines in other countries especially in Canada, Australia, South Africa and France. He hoped that the scientists of the entire world would pool their new discoveries for the benefit of humanity. The United Nations Scientific Conference on the Conservation and Utilization of Resources was the first official step towards that indispensable world co-operation. The success of his work would depend to a large extent on the co-operation he received.

Mr. ORR presented the paper he had prepared with the assistance of Mr. Pettit and Mr. Fraser on "Canadian Experiments on Induced Precipitation".

The Canadian studies were more practical than those undertaken by Mr. Schaefer's group. Their purpose was to find a means of applying the methods of induced precipitation to agriculture, forestry and water-power.

He also illustrated his paper with lantern slides of photographs and statistical tables showing the results of the fifty-nine experiments carried out in Canada and the twenty in Australia.

Although the Canadian experiments had been mainly concerned with the possibility of inducing rainfall by applying cloud-seeding methods, the data obtained were as yet insufficient to allow a quantitative assessment of the results which might be expected. It could be said, however, that that new technique opened up enormous possibilities to the science of meteorology.

The CHAIRMAN opened the general debate on the two papers on induced precipitation which had just been presented.

Mr. M. BERNARD explained why the United States Weather Bureau was not participating in the experiments described by Mr. Schaefer. It was quite common in the United States for the initiative, in scientific research, to be taken by private industry, while federal bodies acted as critics and judges. That in no way meant that the Weather Bureau was not following with deep interest the work undertaken, or that it rejected the conclusions to which that work had led, but owing to its wide experience in meteorology it was wary of being over-optimistic with regard to a field as yet unexplored.

The United States Weather Bureau concentrated mainly on improving existing methods of weather forecasting; its research services, however, did not overlook the new avenues opened to meteorology by Mr. Schaefer and other scientists of the world, and hoped that they would be able, in the near future, to submit the concrete results of their work.

Mr. McLintock was very interested in the information furnished by Mr. Schaefer on the use of silver iodide in cloud-seeding; he wished to know whether that product was the only one, apart from "dry ice", to be used in experiments.

Mr. V. J. Schaefer replied that silver iodide was, in actual fact, the only substance which had been particularly effective, owing to its crystalline structure which resembled that of ice; that did not however mean that that substance was the only one in existence, but merely that it was the only one so far known. Various natural and artificial substances had been studied during the research which had been undertaken with a view to determining the storm-producing factor and to find a substance which could replace silver iodide. That was how it had been discovered that certain silicates could be used as sublimation agents; but they were effective only at temperatures below −12 degrees C—while quartz was only effective at a temperature of −25 degrees C—in addition to which large pieces of silicate had to be used. There was, for the moment, no substitute for silver iodide.

Mr. Irmay asked what had been the greatest quantity of rain obtained thus far through induced precipitation.

Mr. V. J. Schaefer recalled that the experiments made by his group were mainly on the study of cloud modification; they had, therefore, been made only on a very small scale and were intended to bring about light snow rather than rainfalls. It appeared, however, from reports on experiments made in South Africa, Australia and Canada that the heaviest precipitation obtained was about 2/10 of an inch.

Mr. Hubbert asked for information on the possibility of cloud-seeding by shelling from the ground.

Mr. V. J. Schaefer recalled that the question had been considered; the press had reported on certain experiments attempted in Spain with the aid of rockets. He did not think that method very practical as no useful results could be obtained at an altitude of less than 20,000 ft. Moreover, the possible danger from falling shell fragments should not be overlooked.

He did not think that that method was of any interest for the time being.

Mr. W. R. Nelson asked whether it was possible to recognize visually clouds which were suitable for artificial precipitation or whether it was necessary to make preliminary chemical experiments in order to ensure the ultimate success of the operation.

Mr. V. J. Schaefer replied that, generally speaking, it was fairly easy to recognize the cloud formations which could be used. In general they appeared as rather hard surface clouds which were above freezing level and which dissipated as they rose in the atmosphere. If a cumulus reached high altitudes without subsiding, it most likely contained snow. However, the difference was not always so clear. For that reason the research carried on currently was also concerned with discovering an optic or electronic means of differentiating between ice and water. So far it had not been successful.

Mr. Goldschmidt stated that according to Mr. Schaefer's paper it appeared that it was possible to stabilize clouds. The question arose whether the altitude of stabilized clouds could be modified in order to use the winds to shift them about in space.

Mr. V. J. Schaefer emphasized the importance of that question to which his group was devoting much attention. He pointed out that nature worked in exactly that manner. Blizzards were often caused by the fact that snow-laden clouds descended and came up against cumulus clouds.

However, in order to be able to change the altitude of clouds, it was necessary as a preliminary to determine the process of their shifting and to study the effects of over-seeding or underseeding. It had already been established that if a cloud was overseeded the snow particles did not fall, while if it was underseeded the cloud became laden with large snow flakes which fell rapidly. The future would reveal the possibilities and their limits in that field.

Mr. Schaefer called attention to an important phenomenon which occurred in certain parts of the world where large cumulus clouds at altitudes in which the temperature was below −39 degrees changed into cirrus clouds which could spread over hundreds of miles. The presence of those masses prevented the formation of new cumulus clouds and it seemed very desirable to find a way of eliminating them.

All those problems were being studied and their solution was a question of time.

Mr. Pritchard remarked that as yet there was no indication of the possibility of producing self-perpetuating storms. Did Mr. Schaefer hope that a method for creating such storms could be perfected?

Mr. V. J. Schaefer replied that in the course of an experiment carried out at Albuquerque (New Mexico) the preceding winter, there had been reason to hope that such a storm had in effect been created. The proof, however, was not conclusive. It seemed reasonable to believe that as methods of seeding and increasing the heat caused by precipitation were perfected it would be possible to act not only on the seeded cloud but also on the neighbouring clouds thus setting off a chain reaction comparable to that of self-perpetuating storms. For the moment, however, no concrete result had been obtained. The best method was to continue the intensive study of natural storms.

Mr. Paulsen, at the Chairman's request, read the abstract of his paper on "Current Concepts in Appraisal of Water Resources".

Mr. S. Buchan emphasized that, in the United States, the Water Resources Division, U.S. Geological Survey, directed the studies undertaken on the appraisal of water resources and had played a considerable part in disseminating knowledge in that field throughout the world. He stressed Mr. Paulsen's statement that a good knowledge of the water resources of a region was an indispensable requisite for wise planning and successful operation of the resources of the region. Too frequently water resources were considered inexhaustible.

He also noted that Mr. Paulsen had stressed the action which might be undertaken to improve the quantity and the quality of water resources.

He went on to criticize the division of the appraisal of water resources along three lines: surface-water investigations which required civil engineers ground-water investigations which required geologists and quality of water investigations which required chemists. In his opinion, geologists should contribute to the first and third investigations as well as to the second. Indeed, surface water and ground-water were not different and the composition of water was determined by the ground over which it flowed.

He regretted, moreover, that Mr. Paulsen had not explained in greater detail the possibility of applying recent progress in chemical and physical science to the methods and equipment used.

He wondered finally whether the methods designed to increase the supply of water, particularly by artificial recharge of ground-water reservoirs, had been successful.

Mr. Paulsen endorsed Mr. Buchan's remarks. It might be said that an accurate appraisal of water resources would involve three stages: a general inquiry on all existing sources; then the establishment of a network of observation stations; finally, more detailed study in particular regions combining all the available techniques.

In conclusion, he stated that the United States Geological Survey was very desirous of developing all the techniques necessary for the adequate appraisal of both surface and groundwater resources and in so far as practicable was directing its research to that end. The Geological Survey had been associated with several projects in which the artificial recharge of ground-waters was successful.

Mr. S. Buchan, at the Chairman's request, presented his paper on "The Conservation of Ground-Water in Britain".

Mr. Brennan remarked that in the United States the problem of storing and releasing flood water was very important. In certain arid regions of the United States, reservoirs constructed for flood control could be utilized to recharge downstream ground-water basins, by proper regulation of reservoir releases. He wished to know whether the problem of utilization of water in correlation with flood control also arose in the United Kingdom.

Mr. S. Buchan replied that the rainfall and the nature of the rivers was very different in the United Kingdom, where the problem of floods was not acute; water was not used for recharge. It had often been asked why flood water should not be kept in impounding reservoirs, but it had always been extremely difficult to decide exactly when the reservoirs should be filled and when they should be discharged. He hoped to gather useful data on that point in the United States.

Mr. McLintock explained that a project for the construction of reservoirs up-river from London to regularize the flow of the Thames was being studied currently.

He wished to know what procedures were used in the United States for the recharge of aquifers.

Mr. Wing asked what legal provision existed in the United Kingdom to prevent the boring of wells in districts where abstraction was excessive. In the United States there were very few laws regulating the utilization of ground-water.

Mr. S. Buchan replied that in the London area excessive abstraction had resulted in a lowering of water-levels to 300 ft. below sea-level in 1938, which had induced a flow of brackish water. The number of wells in use had been reduced by enemy action during the war which had permitted a return to a normal situation. When the new law came into force after the war in 1945, the first regulatory measures had been for that area. The boring of new wells, the enlargement of existing wells and the development of pumping operations had been made subject to authorization.

In other areas permission to bore new wells was only granted after enquiry and when it was established that abstraction of water would not be prejudicial to the area. Observation wells enabled the water-level to be measured constantly.

Indeed, according to the 1945 law, the owner of a piece of land was no longer the owner of the ground-water; he could only use it if that utilization was not prejudicial to his neighbours.

Mr. Le Van asked what measures were taken against water pollution. In the case of abandoned wells, were there any legal requirements to seal them against possible pollution of the aquifer? What legal measures existed to protect ground water against pollution by chemical wastes from manufacturing processes where conservation measures required ground-water to be returned after use?

Mr. S. Buchan explained that there was no obligation to seal up abandoned wells. But the pollution of surface or ground-water was an offence and a person could be obliged to seal up a well if it had been polluted. Similarly, proceedings could be taken against any person or any establishment contaminating water used for domestic consumption by emptying into it chemically polluted water.

Mr. S. B. Morris pointed out that in Southern California there was so far no regulation limiting excessive abstraction of water. Nevertheless, a recent sentence of the Supreme Court of California had limited the abstraction of water from a reservoir threatened with exhaustion as a result of excessive abstraction.

The Chairman requested Mr. Morris to present the paper on "Methodology of the Austrian Waterpower Register", prepared by Mr. Lernhardt, who had not been able to attend the Conference.

Mr. S. B. Morris stated that the paper contained interesting details concerning the methods according to which the new Austrian Waterpower Register, which had been begun in 1946, was prepared. It should be noted, in particular, how moderate the costs of preparing the Register were.

He pointed out that there were similar publications in the United States, especially those of the Weather Bureau and the Geological Survey. A law of 1928 made it compulsory for the Corps of Engineers to make reports on large rivers. Those reports were so detailed that some of them had been used as a basis for surveys which had contributed to the accomplishments of the Tennessee Valley Authority. Lastly, the National Resources Planning Board had been publishing since 1938 studies on the development and utilization of rivers; likewise, the Water Resources Branch of the Geological Survey, the U.S. Corps of Engineers, the Bureau of Reclamation and various institutions were also preparing various studies, reports and constructive plans.

Mr. Lernhardt's paper admirably emphasized the progress made in Austria in that field.

Mr. Wing noted with especial interest the efforts, described in the paper, which the Austrian Government had made to fill existing gaps in the continuity of the information collected.

It was certain that for a period of a quarter of a century, for example, the information which had been collected lacked uniformity; serious inaccuracies were due to the shifting of observation stations and to changes in methods of registration. Personal experience in connexion with a great number of stations had enabled Mr. Wing to establish that such changes occurred every five years approximately.

The information gathered must therefore be thoroughly checked before being published. Unfortunately, it did not seem that such a prudent practice was followed in most countries, especially in the United States, where some publications did not mention the shifting of stations.

Mr. Paulsen fully agreed with Mr. Wing on the need for giving the information collected real and lasting value, so that the data assembled would constitute comparable amounts.

As for the shifting of observation stations and changes in methods of registration, they were made only when inevitable and necessary. The problems introduced had not passed unnoticed by the United States Geological Survey and, except perhaps in some summary reports by non-Federal agencies, such changes were always properly explained and recorded in the annual water-supply papers of the Geological Survey.

Mr. M. Bernard pointed out, in answer to Mr. Wing's criticism, the need for considering the time element, which was a fundamental factor when it was a question of publishing data to be used as a basis for estimates and plans. Exaggerated care to furnish only unquestionably correct data might delay publication of such a survey indefinitely. The wise thing was to make information which could be reasonably considered as acceptable available to the users as soon as possible, subject to subsequent correction.

It was true that stations were sometimes shifted, but that fact could not pass unnoticed by the services responsible for the survey, and currently applied techniques made it possible to correct registrations, so that relatively uniform data could be obtained. Such uniformity was even greater in the case of information furnished by stations for observing precipitation, the data of which was reasonably comparable over a period of approximately forty years.

Mr. S. B. Morris pointed out that the problem which had arisen in Austria was, according to Mr. Lernhardt's paper, to bridge the gap resulting from the fact that no data had been published since 1920. The loose-leaf folder system which had been adopted was especially practical in that respect, for it made it possible to make any necessary additions and corrections in the register during publication.

The Chairman requested Mr. Irmay to present the paper on "Dew Observations and Their Significance", prepared by Mr. Duvdevani, who had been unable to attend the Conference.

Mr. Irmay explained that Mr. Duvdevani's paper described the optical method of dew observation which had been invented by the author and applied since 1943 by the Meteorological Service in Israel. The paper presented some interesting conclusions concerning the influence of the nature and tillage of the soil on condensation of dew and the influence of the latter on plants. Lastly, it explained the importance of that phenomenon for a semi-arid country like the Negeb where the dew was an important source of water supply for the vegetation.

In view of the lateness of the hour the meeting adjourned at that point. The discussion of Mr. Duvdevani's paper was resumed at the following meeting, on Monday, 22 August.

Mr. M. Bernard pointed out that in the United States there were certain exceptionally dry regions where no use had so far been made of dew. He asked Mr. Irmay in which regions it would be possible to use it.

Mr. Irmay replied that the question of utilizing dew was still under study. Vegetation had been noted in certain regions of the Negeb where there was a heavy dewfall; it had been deduced that that vegetation depended upon dew for its growth. Those observations might be of some interest for certain exceptionally dry regions in the United States.

He pointed out that at certain places in the Sahara the French authorities utilized dew as a source of water. He drew attention to a work published twenty-five years ago, on the existence of reservoirs, constructed in prehistoric times in the south of Denmark to collect dew; the author of the work suggested that that method might be used in the desert regions of the Near East. For the time being those suggestions were only theoretical. The method suggested by Mr. Duvdevani might be one way of putting them into practice.

Mr. Goldschmidt asked whether Mr. Irmay was aware of the existence in southern England of any reservoirs to collect dew.

Mr. Irmay replied that he was not a specialist on the question and was not in possession of the necessary information to reply.

At the Chairman's request, Mr. Bernard introduced Mr. Richards' paper on "Estimation of Flood Run-Off", which he summarized.

Mr. Irmay stated that Mr. Richards' paper was based on his book "Flood Estimation and Control". His mathematical developments were based on the Chezy formula: $V = C\sqrt{dS}$, where V equalled the velocity of flow, d the depth of the sheet of water and S, the slope of the ground. Mr. Woodruff of the University of Missouri had carried out extremely interesting experiments on the run-off from artificially controlled rainfall. He had found that V was proportional to the depth and not to the square root of the depth as in the Chezy formula. Mr. Irmay would like to know how that affected Mr. Richards' results.[1]

The CHAIRMAN stated that Mr. Richards would certainly have an opportunity of replying to that question later, since it would be included in the official report of the meeting.

Mr. AUBERT in introducing the paper by Mr. Coutagne on "Classification of Hydrological Studies and of the Estimates Derived from Them", explained that Mr. Coutagne had not included any new data in his paper. He had merely attempted to define the terms used and to classify possible hydrological studies. Many studies, based on very different points of view, had been carried out on the yield of watercourses and it was therefore difficult to classify and compare them. Mr. Coutagne proposed that a logical system of classification should be adopted which would facilitate comparison between those studies and thus enable some progress to be made in river hydrology.

Mr. Coutagne's study consisted of two parts: the classification of hydrological studies, the principal elements of which Mr. Aubert summarized briefly, and the application of hydrological studies to yield estimation. The latter part was extremely important.

Mr. M. BERNARD read the abstract of his paper on "Water Supply and Flood Forecasting".

Mr. KATHPALIA pointed out that Mr. Bernard divided the United States into two zones. In the zone where the average precipitation was more than twenty inches, the amount of surface water was normally in excess of the requirements of the population. In India, however, even in those regions where the precipitation was as high as forty inches, irrigation was necessary. He wished to know what combination of conditions made an annual precipitation of approximately twenty-five inches sufficient for the needs of the population in certain areas of the United States.

In connexion with the irregular distribution of rainfall in the United States, he asked if any relationship had been found to exist between the duration of storms and their extent.

Lastly, with regard to estimates of water resources in the western United States, he noted that the rate at which water would be released from the snow pack during the summer and autumn had yet to be forecast. He wondered whether any attempt had been made to establish the relationship between the temperature during the period of precipitation and the consequent stream flow.

Turning to some of Mr. Bernard's other statements, he stressed the importance of the interdependence of resources and the necessity for establishing all-purpose development programmes for river basins.

The lack of basic data, which hindered the drawing up of plans, was not, as Mr. Bernard had suggested, a purely American characteristic; the same could be said of the under-developed countries.

Finally, Mr. Kathpalia noted Mr. Bernard's emphasis on the value of yield statistics. He thought that pending complete yield statistics all countries should collect data utilizing precipitation statistics and other meteorological statistics, as Mr. Bernard suggested. From the mass of data thus collected it would be possible to deduce some simple correlations of universal application; the estimated water yield could subsequently be checked by actual observations when the latter had been collected.

Mr. M. BERNARD admitted that he had given too general a picture of the American climate. It was true, however, that east of the 20-in. isohyet of average annual precipitation, the rainfall was sufficiently regular to render irrigation unnecessary. There were, of course, certain exceptions.

It was clear from the analysis of storms in the United States that the relation between their intensity, their length and their extent did not vary much from one region to another within the country.

Finally, Mr. Bernard stated that a relationship had actually been established between the temperature during periods of precipitation and the yield of water. That ratio, however, could as yet be determined only on an experimental basis and its use was restricted to short-term estimates. Too little was known about the melting of snow to allow of a more reliable ratio being established.

At the CHAIRMAN's request, Mr. WING read the abstract of the paper by Mr. Khosla on "Forecasting Water Yield, Flood Run-Off, Flood Frequency and Power Potential".

He pointed out that in forecasting water yield the author of the paper had taken as his basis data relating to temperature. In forecasting water yield it was possible to adopt several points of view: some people took as their basis the theory of probability, others meteorology and others, including the author of the paper, data relating to temperature. That was why it was essential to classify and combine the different points of view, as Mr. Coutagne had emphasized in his study. An attempt must be made in hydrology to separate the basic factors from factors which were fundamentally of little importance if a final definition of a limited number of basic factors was to be achieved. Data relating to temperature were certainly included in that number.

Mr. IRMAY pointed out that Mr. Khosla's study rested on the hypothesis that the run-off was equal to the difference between precipitation and losses due to evaporation and transpiration. Mr. Khosla had omitted, however, to take ground-water into account.

Mr. F. C. RODRIGUEZ stressed that in the Philippines the question of seepage was a basic one in forecasting yield. A great part of the rainfall was lost because it seeped into the ground-water and thence into the sea.

[1]In reply to Mr. Irmay, Mr. Richards wrote: "I do not consider that Mr. Woodruff's experiments suggest any modification in my formula or methods. The water running off a catchment virtually does so through a network of small channels to the discharge of which the Chezy formula would be applicable."

Mr. WING replied that Mr. Khosla's study dealt with surface-water only. The forecast which he had made did not concern ground-water. His formula had been successfully verified in numerous regions and in most cases the margin of error had not exceeded 15 per cent.

Mr. M. BERNARD, who was invited to present Mr. Smetana's paper on "Water: Analysis and Utilization of Data", said that he was not able to discuss it critically. He would merely point out that Mr. Smetana was a member of the Hydrological Institute and President of the International Geodetical and Geophysical Union, a fact which illustrated the close relationship between the two subjects, as did the fact that another international association, the International Association of Meteorology, also dealt with the same problems.

Mr. WING recalled that forecasting was carried out in Europe by the method of probabilities. According to Mr. Bernard, no really satisfactory technique had been worked out, and so the statistical method could not be relied upon, since the periods of observation which had provided the data upon which statistics were based were too short. If that were so, Mr. Wing wondered how long an observation period would be necessary to furnish reliable data, and what Mr. Bernard meant by satisfactory statistical data.

Mr. M. BERNARD explained that for short-range forecasting, the only line that could be drawn was between what was possible and what was not.

Observation periods of from twenty-five to thirty years could be considered to furnish relatively adequate statistical data; statistics based on eight to ten years' observation would not be so reliable.

Mr. WING remarked that if the margin of error, which was 33 per cent for statistics covering ten years, was as high as 20 per cent for statistics of twenty-five to thirty years, the latter could hardly be considered to provide adequate data.

Mr. M. BERNARD pointed out that the length of the period of observation was only one of the factors to be considered; many others were involved. Thus, for forecasts of water supplies in the western part of the United States, three factors were taken into consideration and errors in forecasting were thus between 15 and 20 per cent.

Mr. Bernard read a summary of Mr. Simaika's paper on "The Regime of the Nile and the Use of Forecasts".

Mr. GOLDSCHMIDT thought that the very interesting correlation between meteorological conditions which Mr. Simaika mentioned in his paper should be emphasized. He wondered whether correlation was also observed on the other side of the world.

Mr. M. BERNARD said that similar examples of correlation existed; he recalled the extremely interesting findings made ten years before in South Africa.

Existing knowledge of the subject recognized the influence of atmospheric pressure. The phenomenon of "atmospheric waves" might perhaps provide a solution for the problem. Its study would probably be facilitated by a fuller knowledge of the stratosphere, and some of the yet unsolved mysteries might be cleared up.

The CHAIRMAN announced that Mr. Felber was unable in person to present his paper on "The Application of Probability Theory to the Solution of Hydrological Problems". The paper did not call for any comment.

Water Supply and Pollution Problems

22 August 1949

Chairman:

Roberto PACHECO, Adviser, Permanent Delegation of Bolivia to the United Nations

Contributed Papers:

Utilization of Surface, Underground and Sea Water
Abel WOLMAN, The Johns Hopkins University, Baltimore, Maryland, U.S.A.

Artificial Ground Water Supplies in Sweden
O. Victor E. JANSA, Consulting Engineer, *Vattenbyggnadsbyrån*, Stockholm, Sweden

Water Storage in the Negeb
S. IRMAY, Hydraulics Laboratory, Hebrew Institute of Technology, Haifa, Israel

Control and Utilization of Polluted Waters
Ernest W. STEEL, Consulting Engineer, *Instituto Nacional de Obras Sanitarias*, Caracas, Venezuela

Desalinization of Brackish Water
K. S. SPIEGLER, Research Chemist, Weismann Institute, Rehovoth, Israel

Control and Utilization of Polluted Waters
Jan ZAVADIL, Professor of High Technical Teaching, Brno, Czechoslovakia

Biological Purification of Settled Sewage in Shallow Ponds
Magnus WENNSTRÖM, Consulting Engineer, *Vattenbyggnadsbyrån*, Malmö, Sweden

Summary of Discussion:

Discussants:

Messrs. LE VAN, DWORSKY, RAUSHENBUSH, JUDA, S. BUCHAN, EL SAMNY, DE SANTA MARIA, RINGERS, IRMAY, PAPANICOLAOU, GOLDSCHMIDT, GORMAN

Programme Officer:

Mr. A. E. GOLDSCHMIDT

Utilization of Surface, Underground and Sea Water

ABEL WOLMAN

ABSTRACT

Someone[1] has said that "water is more precious than gold and more explosive than dynamite". Because it gives life, it must be guarded, conserved and beneficially used—and at times it has been fought over with weapons legal or lethal. Where it is scarce, it must not be wasted or abused, where it is rampant, it must be curbed. Where it is defiled, it must be cleansed.

Modern technology and experience have taught us that all of these beneficent values may be obtained only through quantitative knowledge of these resources, through the balance of uses, through the equilibrium of equities of geography and of politics, through the evolution of sound fiscal programmes and through continuing research.

Unilateral actions within the single regions of one country or within a single country of a larger region must perpetuate conflicting claims and postpone mutually beneficial developments.

Examples of water-resource developments have been listed in the United States, in Siam, in the Netherlands and in India. Each illustrates deficiencies in basic hydrologic data, in development analyses, in multiple use, and in delayed project accomplishment.

Even the answer to where the waters are and their volume, is still lacking. The prerequisite to any plan, namely the inventory of resources, is yet to be quantitatively presented. The United Nations might serve to stimulate countries toward this first corrective, so that intelligent programming might proceed at an accelerated rate.

The task of reviewing the uses and the development of surface and underground water resources on a world-wide basis would be an impossible one even without the limitations of time and published space. The day may arrive when the United Nations may find it profitable to initiate an undertaking in which the water resources of the world would be reviewed and analysed in such a form as their economic and human functions warrant. Until such an enterprise is instituted, however, the most that can be done for the purposes of the present conference is to illustrate by example the origins, uses and developments that are characteristic of several selected countries. Even when such a selection is made it is disheartening to find how incomplete is the actual knowledge on this major resource of the world.

For example, data on the volumes and rates of flow of the six great streams of the world are most inadequate, even though the degree of inadequacy varies from the reasonably satisfactory data available on the Mississippi, to the many missing links necessary for comprehensive analysis in the case of the Amazon, the Plata Parana, the Congo, the Yangtze, and the Ganges.

When this list is extended to the somewhat smaller and less well-known rivers, the inventory becomes less and less satisfactory, and consequently development programmes bog down even for discussion purposes. Willcocks and Craig many years ago phrased the importance of basic hydrologic data most neatly, in the following words:

"It must not be imagined for a single instant that these long lists of figures are dead things. In the hands of competent and originally minded engineers they have within them as great a potency of life as the fabled dragon's teeth, and when sown up and down, may chance to spring up armed men. Without them no grasp can ever be had of the behaviour of the Upper Nile and its tributaries."

[1]Elton K. McQuery, Executive Secretary to the Governor of Colorado, *State Government*, January 1949, p. 11.

Perhaps one of the most important contributions which this particular paper may make to the conference is to emphasize once more the great dividends which would ensue if an international group were to elaborate the hydrologic data for the major surface and underground waters of the world. The existence of such basic hydrologic data, coupled as they might ultimately become, with co-ordinate data on land characteristics, would inevitably lead to the delineation of development programmes. These programmes in turn would confront the international statesman with the challenge of spending at least part of the money resources of the world on water development, bringing major fruits to the people of the world, far more important than equal amounts of money spent for military or other competitive purposes.

The present paper, therefore, will restrict itself to the presentation of simple pictures of the resources available and in some instances developed in certain countries of the world. By such illustrations the reader may discover the richness of the resources and the vastness of the engineering, economic and human challenges for the future. Largely because the author's ignorance is less with respect to the resources of his own country, it is chosen as the first example. This choice does not carry the implication that the development programmes of the United States exceed in magnitude or in concept the projects of other countries. It is merely a good place to begin the listing of illustrations.

UNITED STATES OF AMERICA

The uses to which water may be put, whether of surface or underground origin, cover the familiar functions of potable water supply, industrial water, irrigation, power, dilution of wastes, navigation, fish life, wild life and recreation. In recent years all of these multiple-purpose uses have come into play in the planning and in the execution of projects.

Although not all of the reservoir systems of the United States are multiple-purpose reservoirs, no inconsiderable number of them now are designed and operated for such purposes. In 1940, for example, the major reservoirs in the United States, of 20,000 acre-ft. capacity and over, aggregated in capacity approximately 150 million acre-ft., of which somewhat over 50 per cent was for multiple use. Irrigation and power, each approximately the same in total volumes, accounted for another third of the total reservoir space. Multiple use, irrigation and power, therefore, accounted for over 90 per cent of the storage capacity in the major surface reservoirs of the United States.

Since 1910, this impounded capacity has risen from approximately 20 million to well over 150 million acre-ft., or more than sevenfold in a period of a third of a century.

Although municipal water-supply storage represents a relatively small part of this total, approximately between 4 and 5 per cent, this use, of course, is the maximum for which any country must prepare.

On the basis of the census of 1940, Hoyt estimates that the total storage listed is equivalent to about 1.1 acre-ft. *per capita*. Sutherland, some ten years previously, had reported that Canada, relatively sparsely populated, had 2.9 acre-ft. *per capita;* New South Wales and Victoria, in which irrigation is extensively practised, 0.80, and South Africa, only 0.075 acre-ft. *per capita*. It is not surprising, of course, that artificial storage capacity reflects the stage of development of the individual countries, as well as the highly variable amount and nature of distribution of the annual rainfall.

For public water-supply purposes, namely for potable, sanitary and industrial purposes, there are between 13,000 and 14,000 organized water-supply systems in the United States, which distribute something of the order of 12,500 million tons of water annually, or about 10,000 million gallons per day. The total capital investment in systems for this purpose is over $5,000 million ranging in *per capita* costs from $40 to $100 and upwards, depending upon the size of the community served as well as the distance to the source of supply and the amount of treatment required.

The average city uses about 133 gallons of water per day per person. It has been estimated that at least 20 million customers are served, representing something in excess of 85 million people. Inasmuch as the American population is distinctly plumbing-minded, it is not surprising that its *per capita* water use is perhaps the highest in the world. This experience, of course, does not mean that similar *per capita* uses are indicated for all countries of the world, although it is clear that sanitary facilities can only make their way in many parts of the world through the introduction of public water-supply systems.

In a recent survey (Schroepfer, *et al.*) of some 400 selected water-supply systems, approximately 8 per cent were privately owned, the remainder were under public ownership and operation. It is of equal significance to note that, of some 446 instances, the sources of supply in 30 per cent were from wells, indicating that a relatively high proportion of water-supply systems are dependent upon underground waters for daily usage.

In 1940, 5,372 water-treatment plants of all types were producing in the United States somewhat over 7,000 million gallons of surface water a day.

Chlorine treatment of water (first used in 1908) was practised in 4,590 systems; softening in 547; iron or manganese removal in 598. More than 1,400 plants added some type of treatment intended to improve the taste or odour of the supply.

The results of these comprehensive installations in American cities may be best measured by the fact that typhoid fever now accounts for less than 1.0 death per hundred thousand persons. At the turn of the century, nearly 200 deaths occurred annually from water-borne disease for each one that occurs today. The accomplishment is one of which the modern water-supply engineer should be proud.

From the standpoint of size, however, the great developments in the United States are, as has already been pointed out, primarily for irrigation, power and flood control. It should be emphasized, however, that in many instances the water used for irrigation purposes is from underground, even though such underground resources are frequently replenished by surface storage releases. In the central valley of California, for example, no less than 40,000 individual wells tap the underground water channels. One of the great problems of this area lies in the fact that the water-level in most of these wells has been dropping steadily since 1930 because of overdraft. The wells vary from 30 ft. to over 2,500 ft. in depth. In this valley over 75 per cent of all irrigation water is essentially from groundwater. Many areas of the western portion of the country are similarly dependent upon underground water drafts, almost invariably declining in static levels and increasingly supported by surface-water reservoir releases.

The draft of underground water in virtually all metropolitan areas of the country is excessive, primarily because public regulation of such overdrafts is distinguished more by its absence than by its universality. Some states it is true, such as New Mexico, Utah, Idaho and others, do exercise such limiting control, but for the most part controls are late in being instituted and still relatively sparse in application.

Use of reclaimed sewages

The professional worker in water-supply fields has not neglected the possibility of reclaiming water from the spent sewage discharges of communities. In spite of this interest, however, the number of full-scale plants practising the reclamation of sewage for industrial water-supply purposes is still small in the United States and virtually unknown, except for irrigation purposes, in most other countries of the world. Sewage effluents are being used at 135 locations in eighteen states in the United States. Agriculture accounts for 124 of these places.

In the United States some nine installations aggregating a total of less than 50 million gallons per day are now in use for industrial wastes. The largest of these installations, of course, is the industrial water-plant, built and operated by the Bethlehem Steel Company at Sparrows Point, Maryland. This plant uses the treated sewage plant effluent of the City of Baltimore as its source for industrial water. This effluent is processed by alum coagulation and settling and by chlorination. The water produced has the following characteristics:

1. Chlorides below 175 ppm.
2. pH between 6.8 and 7.0.
3. Hardness below 50 ppm.
4. Suspended matter below 25 ppm.
5. Low bacterial content.

The company has the option of taking up to 100 million gallons a day from the City plant. At this writing, it is taking in the neighbourhood of 35 to 40 million gallons per day, perhaps the largest sewage-reclamation plant for industrial water in the world. The cost of so reclaiming the sewage-plant effluent is 1.73 cents per thousand gallons, exclusive of fixed charges.

This practice might profitably be extended under careful design and control in many parts of the world, where industrial water particularly is at a premium. It offers an important means of conservation of a natural resource, which should not be continuously discharged to the sea after it has served its purpose for the water carriage of sewage from municipalities.

Sea-water utilization

The use of sea-water, by proper conversion, for fresh-water supplies has been an intriguing prospect for centuries. If such water might be rendered suitable for drinking, boiler feed or general use, at a reasonable price, it would solve the problem of fresh-water supply in many areas of the world.

Progress in this direction has been surprisingly great in the course of the past ten years. Salt water may now be conditioned with reasonable economy for the following special conditions:

1. Aboard sea-going vessels.
2. On-shore installations or at military outposts on islands where fresh water is at a premium,
3. On-shore installations for producing steam and power, and
4. For boiler feed water installations for central stations.

The cost of producing such water has been progressively pushed downward for all of these purposes and interest has been further renewed in these programmes by the suggestion that the heat required for distillation purposes might be developed from nuclear fission operations. With respect to the latter sources of heat it is reasonable to conclude that the use of atomic energy to displace more orthodox fuels is some years off. Where fuel is at a premium, such as for naval vessels or other ships at sea, or in remote places where other fuels are unavailable, this source of energy may become practicable as time goes on.

It is important to point out, however, that the development of newer processes for evaporation of sea-water are reducing the costs in this field to the point where they are not too strikingly prohibitive.

Until recently most large-scale commercial equipment for the distillation of sea-water rested upon steam-fired single-effect or multiple-effect evaporators. During the Second World War, however, the development of the vapour-compression distillation unit has placed it in a competitive position for sea-water distillation plants.

Over the years the development from single-effect evaporator to the vapour-compression type has resulted in a large reduction of the heat required per unit of water produced. It is stated, for example, that the old oil-fired boiler with single effect evaporators produced 0.655 lb. of water per 1,000 B.T.U. Diesel-oil driven vapour-compression evaporators may produce in excess of 10 lb. of water for the same heat energy of 1,000 B.T.U. It is now possible, for example, to produce 1,000 gallons of make-up water by distillation at a total cost of less than 50 cents, in comparison with previous costs of two to three times this amount.

These processes produce a pyrogen-free, disinfected, distilled water, with a negligible content of total dissolved solids and gases. The future may produce even more satisfactory and more economical techniques for sea water evaporation. The procedures, however, are still reserved for relatively special purposes and at the moment are not competitive with most fresh-water sources.

BRITISH COLUMBIA

In striking contrast with most situations is the legislative programme and activity in British Columbia, a province fortunate in the legislation covering the use of its water resources. For well over three-quarters of a century this province has had some form of legislative control over water and for one-half of a century has covered the use of waters in the most minute details. Even as far back as 1912 its legislation was considered to be one of the most effective laws upon the subject in existence.

At the 1946 World Power Conference, the Dominion Water and Power Bureau stated that the British Columbia system "both in its legislative foundation and its administrative procedure has reached a high degree of perfection".

The fundamental principles upon which this system is founded are that water in the streams is a public asset and that no prescriptive or riparian right should be permitted to interfere with its beneficial use. Its law has been tested in the courts and has stood the test of time. It is interesting that no legal action over water rights has occurred in the province for nearly the last 30 years, a record which alone should call the attention of this form of legislation to the interested water practitioner.

THE NETHERLANDS

Through force of circumstances the water resources of the Netherlands are at a premium. They are under careful control, they are equally carefully husbanded and they have developed, particularly for waters from underground, a highly specialized programme for conservation and use. Of somewhat over seventy cities all have community water-supply systems. Of the rural communities a major portion also have public distribution of water.

Of the 428 units thus supplying water, 136 take water from the dunes, 243 from underground water outside of the dunes and 49 from surface sources.

The *per capita* water use in these countries is relatively low. In 1927, for example, for 4.6 million people, the average *per capita* use per day was about 25 gallons. In Rotterdam it approached an average of some 30 gallons per day, perhaps the largest unit use of the municipalities of that time.

In 1946, with a population of about 9,300,000 the problem of supplying water was becoming increasingly difficult. Provisions of fresh and potable water still required constant attention, even though the ground-water investigations dated as far back as 1853 in the case of the dunes south of Haarlem for the City of Amsterdam.

The execution in recent years of a great many public works, such as canals, locks, tunnels and reclamation works, especially in those areas where fresh and brackish ground-waters occur together, have constituted a danger with regard to the limited volumes of fresh water. These problems have many resemblances to those in the lower Florida section of the United States and in the lower Jordan River Valley area of the Middle East.

The reclamation of new "polders", such as those from the former Zyder Zee, has to be considered in relation to the quantity and quality of seepage water to be expected.

The kind of close collaboration developed in this country between the investigators in waterworks practice and those charged with the planning and execution of general public works, as well as with agricultural experts, should give a very profitable lesson to most other countries in the world whose water, land and general development programmes are, as is invariably the case, closely interlocked. The surface and underground water studies carried out in these countries will be invaluable sources of information adaptable with adjustment to almost all other countries of the world.

SIAM

This country is chosen as an example for review primarily because it represents a significant and interesting geographical setting. It has an area of about 220,000 square miles with a population of approximately 18 million. It is dependent primarily upon surface streams for rather extensive irrigation purposes. Within its region, fluctuations in rainfall from a figure of 200 inches annually in Burma to about 50 inches at Bangkok represent the nature of the problem with which the country is confronted.

Its growing season for its staple crop of rice, May to November, often occurs in the season of insufficient rainfall.

The country, therefore, has developed extensive modern irrigation works originally outlined by Sir Thomas Ward at the turn of the present century. The first irrigation project was started in 1915 with practically all of the irrigation systems designed for gravity flow. Further storage programmes are projected on the Chao Phya River, with an average flow of approximately 211,000 cub. ft. per second and an average minimum flow of about 1,760 cub. ft. per second. The completion of this project will permit the production of two rice crops annually in favourable seasons. At the moment approximately 8,800,000 acres are devoted to rice culture. This acreage will probably be increased with the new development proposed to something more than 10 million acres.

INDIA

India has vast resources in water, so far almost completely unconserved, in spite of the fact that it probably has the largest acreage of land in the world under irrigation. It has been stated that the mean run-off of the waters of the rivers of India is of the order of 2,300,000 cub. ft. per second. The mean annual utilization of water for agricultural and other purposes is approximately 133,000 cub. ft. per second, or less than 6 per cent of the available water wealth of that massive country. Over 94 per cent of this liquid gold runs to waste to the sea.

In addition, a vast underground reservoir of water is available of which only about 30,000 cub. ft. per second are being utilized at present.

The country, like almost every other country in the world, including the United States of America, suffers either from too much water with disastrous floods or too little water with equally disastrous droughts. Here, as almost everywhere else, the conservation and equalization of flow for productive purposes offers a major challenge. A very substantial part of the waters running to waste can be put to beneficial use and will increase by many times the total quantity of water now being utilized for irrigation, domestic water and power generation.

India at present irrigates 70 million acres of land, probably equal to the combined irrigated area in all of the other countries of the world. Their officials state that there is enough additional water in the rivers of India to irrigate many times that area, if suitable lands are available and irrigation is otherwise feasible. They naturally point out what an amazing difference such increases in irrigated areas would make to the food position of India and of the world.

In spite of the immense water resources and their strategic location, India develops somewhat less than 500,000 kw. of hydro-electric power. Calculations indicate that their potential water-power would be in the neighbourhood of 30 to 40 million kw. Here, as in other countries of the world, a wise utilization and husbanding of these vast potential resources in water might easily revolutionize their economies. The Government of India, aware of these potentialities, has set up a Central Waterways, Irrigation and Navigation Commission for the purpose of ascertaining India's water potential, surface and underground, and preparing and pressing forward schemes for its control, conservation and utilization, such as the Damodar Valley project, the Mahanadi Valley project, the Kosi and Tista projects, and others. The Brahmaputra, the largest of India's rivers, still remains to be studied, although its valley is one of the great potential industrial areas of the Far East.

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Artificial Ground Water Supplies in Sweden

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ABSTRACT

Artificial recharge of ground-water supplies is carried out at a considerable number of Swedish municipal waterworks. On account of the quality of Swedish surface-water, pre-treatment of the raw water by rapid sand filtration has been found necessary at most plants. After such treatment of the raw water the infiltration periods will generally be six months or more.

The aim is to have the infiltration basins located at a level as high above the ground-water level as possible in order to get the water to percolate through the greatest possible volume of air-filled ground, such ground being considered to have a biochemical effect.

The biochemical effect of the ground can be increased by blowing air into the ground.

In order to obtain a perfect purification of the surface-water by infiltration it is considered that the horizontal distance between the infiltration basins and the wells should be at least 800 ft. If the permeable ground consists of fine sand this distance may be reduced to 500 ft.

At present about 300,000 persons, i.e., about 10 per cent of the total population of the Swedish towns, are supplied with artifical ground-water. It is to be expected that within the next decade this figure will increase to about 15 per cent.

The first experiments with artificial ground-water seem to have been carried out in 1810 in Glasgow, Scotland, where a filter gallery was built beneath the Clyde. A few years later similar experiments were made in France, where Toulouse was the first city to be provided with water by "natural filtration". Here exfiltration basins were excavated in sand and gravel near the Garonne, and it was assumed that the water drawn from the basins mainly consisted of water that had percolated from the river through the ground to the basins. In many cases those plants turned out to be a failure because of clogging of the river-beds and algae growths in the basins. Later on it was claimed in England that the current of the stream was able to remove the deposits from the bed of the river opposite the basins or galleries. Later on the idea of producing artificial ground-water was further developed in Germany and the United States, where the natural filters of Des Moines are the most noteworthy.

In the United States the artificial recharge of ground-water seems to have been accomplished mostly by passing water from streams or lakes over the surface of the ground, in ditches or basins, this method being commonly known as water-spreading. Gradually the improvement of well-construction methods and the introduction of superior pumping equipment have considerably increased the possibilities of artificial ground-water recharge.

The idea of effective pre-treatment of the surface-water before infiltration appears to have been originally put forth and plainly explained by the distinguished Swedish engineer, J. G. Richert, who emphasized that the infiltrated water at the entrance into the ground must be a thoroughly filtrated surface-water of the same purity as a good drinking water and that the water in the ground must pass a stretch of considerable length. Such a treatment will result in a perfectly pure, colourless and crystal-clear water of almost constant temperature and refreshing taste. "The surface-water has been refined into ground-water". Moreover the artificial ground-water is in some cases superior to the natural ground-water in regard to the content of mineral matter, which as a rule will be considerably less in the artificial water. Richert's opinion that the infiltrated water already at the entrance into the natural ground must be of high purity was based on the observation that even a slightly turbid water will gradually penetrate and clog the pores of the ground and eventually spoil its purifying capacities. This clogging effect has been particularly distinctive at certain American waterworks, where the ground-water is recharged through wells and great difficulties have arisen through progressively diminishing capacities.

O. E. Meinzer has classified the methods of artificially increasing the recharge thus: (1) indirect methods, by which increased recharge is accomplished by locating wells as close as practicable to the areas of rejected recharge or natural discharge; and (2) direct methods, by which water from a surface source is conveyed to points from which it percolates into a body of ground-water. The direct method may be subdivided into (*a*) recharge by surface application; and (*b*) recharge through wells. The indirect method has been applied at a few Swedish waterworks, but it has generally failed because of progressive clogging of the ground. The direct method with recharge through wells has been tried at one Swedish plant only, viz., at the waterworks in Gothenburg. Though the water was pre-treated by slow sand-filtration the recharge wells soon became clogged and had to be abandoned. On the other hand the direct method, with recharge by surface application, has been applied at several Swedish waterworks and, with one exception only, rendered the most satisfactory results.

In the Scandinavian countries the ground-water prospects are generally quite unfavourable on account of the glacial periods, during which practically all the sedimentary formations, such as sandstones, limestones and sand and gravel deposits, were torn up and carried away, being finally deposited in the Baltic and on the plains of northern Germany. On at least two different occasions great portions of the land were sunk below the surface of the sea and again raised above sea-level. In those parts of the land the unassorted moraine deposits from the melting ice have been worked upon by the sea and partly covered by marine clay. There are vast areas where the ground above the igneous rock consists of nothing but moraine beds or clay. Those deposits are almost impermeable and generally worthless as a source for municipal water supplies. The glacial streams flowing under the ice, however, have formed a special kind of gravel deposits which have been left as elongated ridges, or eskers, all over Sweden. The eskers, not seldom having a length of more than 100 miles, consist of pure gravel and sand and are often embedded in impervious clay, hence forming excellent natural ground-water conduits. From a hydrological point of view the eskers are the most important sources of ground-water in Sweden and they have been utilized to a great extent for supplying water to municipal waterworks. Unfortunately the natural ground-water capacities of the eskers are limited and consequently many towns originally supplied with ground-water have been forced to provide an additional surface water supply. In many cases, however, it has been possible to increase the ground-water capacities in a sufficient degree by artificial recharge. The possibilities and the value of this method are far from being exhausted or even understood.

The pioneer ground-water recharge plant in Sweden was designed by Richert for the waterworks of Gothenburg. The plant was constructed in 1897 to 1898 and has ever since been in constant operation and rendered the most valuable service. The plant consists of two infiltration basins having a total area of 1.38 acres. The basins are arranged as ordinary slow sand-filters, the filter beds resting on the levelled natural ground, which consists of glacial sand deposits. The raw water is drawn from the river Göta Älv and the capacity of the plant is 4.0 million gallons per day. The artificial ground-water is pumped from tube wells, the distance from the infiltration basins to the wells varying from 700 to 3,000 ft. Though the river water is heavily polluted the quality of the ground-water, drawn from the tube wells, has always been perfect.

In conformity to the principles laid down by Richert two additional plants for artificial ground-water recharge were erected at Sala in 1903 and at Örebro in 1918. The Örebro plant differs from the Gothenburg plant in that the raw water is first treated in a slow sand-filter plant and then conveyed to the infiltration basins, which are formed as ditches.

At Sala, which is a very small plant, the bottom layers of the infiltration basins are located a few feet, only, above the ground-water level, the distance between the basins and the pumping wells being only about 500 ft. The raw water has a very high content of organic matter and is highly coloured. The plant was operated satisfactorily for thirty-five years. In 1938 the colour of the water drawn from the wells began to increase and after a few years only the colour was more than 50 parts per million platinum standard. It was found that the natural sand layers were completely penetrated by organic matter and for some time the plant had to be abandoned. A plant for coagulation and rapid water sand-filtration of the raw water was then erected and the surplus of chemically treated water was used for an attempt to wash out the organic matter from the ground in order to revive its purifying capacity. This experiment was entirely successful and the infiltration plant is now used as a valuable conditioning plant for the chemically treated water.

At Örebro the infiltration ditches are located about 30 ft. above the ground-water level, the distance from the point of infiltration to the pumping wells varying from 600 ft. to 1,200 ft. The raw water, which is drawn from the Svartå river, is highly polluted by organic matter, but the artificial ground-water at the wells has always been perfect, colourless and free from bacteria, taste and odor. The plant has recently been enlarged to a capacity of 4 million gallons per day.

Notwithstanding the excellent results obtained at the above-mentioned ground-water plants, the method of artificial ground-water recharge was for a long time not utilized to any considerable extent. Next followed four plants at Luleå in 1932 (1.0 million gallons per day), Eksjö in 1936 (0.6 million gallons per day), and Hälsingborg in 1937 (4 million gallons per day) and Katrineholm in 1938 (1.3 million gallons per day). The water-supply plant at Luleå at first comprised a series of tube wells sunk in glacial sand layers alongside the river Lule Älv a few miles from its mouth at the Baltic. After a few years the water delivered by the wells became saline and, naturally, it was thought that the salinity was caused by infiltration of sea-water. It could, however, be proved that no sea-water could penetrate from the sea to the ground-water-bearing layers and that the salt originated from fossil salt deposits hidden below the bed of the river and drawn to the wells by the lowering of the ground-water level. An infiltration basin was built on the river slope 700 ft. from the wells and river water, pretreated in a rapid sand-filter plant, was infiltrated in the basin. By infiltration in excess of the quantity pumped from the wells the fossil salt in a short time was forced back into the depth and in about two months the salinity of the water delivered to the town was reduced from 1,250 parts per million to 75 parts per million. The quality of the water is now perfect and in the next few years the capacity of the infiltration plant will be increased to 3 million gallons per day.

During the Second World War the population of most of the towns of Sweden increased considerably and, as a consequence, also the demand for water, especially in the industrial centres. Among these towns Karlskoga (30,000 inhabitants), Kristinehamn (17,000), Eskilstuna (51,000), and Västerås (54,000) were previously supplied with natural ground-water pumped from wells in eskers located in the vicinity of the towns. At Eskilstuna, however, the capacity of the ground-water works was very small and therefore the main quantity of the water was supplied from the River Hyndevadsån and purified in a slow sand-filtration plant.

When, on account of the growing water consumption, the waterworks of the above-mentioned towns had to be extended, it was proposed by the author that the possibility of increasing the ground-water flow by artificial recharge should be investigated and the sinking of observation wells, test pumpings and infiltration experiments were started. It was found that at all these four places the conditions for applying the artificial recharge method were very promising and definite plans were promptly prepared. At the beginning of 1949 the ground-water recharge plants at Karlskoga, Eskilstuna and Kristinehamn were completed and the extension of the waterworks at Västerås is expected to be accomplished in 1951. In a similar manner an artificial recharge ground-water plant will be substituted for the existing surface water-supply of Karlstad (34,000 inhabitants). As will be shown below these new plants involve some new ideas.

At each of the new plants the raw water is drawn from rivers or lakes. The waters are usually slightly turbid and have quite high contents of organic matter. As a consequence the colour will vary between 20 and 100 platinum scale. It may be mentioned that these surface waters sometimes contain a considerable amount of organic iron compounds. During the summer the waters often are rich in algae. The composition of the raw water necessitates rapid sand-filtration before infiltration. At the preliminary infiltration experiments at Eskilstuna unfiltered river water was pumped to a temporary infiltration basin. In the most unfavourable conditions the filter bed of this basin became clogged after three days' run only, and the average filtration period was about two weeks. After the introduction of rapid sand-filtration the filtration period of the infiltration basins have lasted for six months or more. Another reason for the pre-treatment of the raw water is that during the winter the infiltration basins must run without interruption lest the filter-bed freeze and cause almost insurmountable trouble. Experience has shown that no freezing trouble will occur as long as the infiltration runs continually.

The infiltration basins are square or rectangular in shape, excavated on the top of the eskers with the surface 40 to 60 ft. above the natural ground-water level. Thanks to this great height of percolation the air-filled gravel layers act as a kind of trickling filter and the decreasing oxygen content of the percolating water indicates an oxidizing process. At times the content of organic matter in the infiltrated water is so great that the original content of oxygen in the water is insufficient for a complete biochemical break-down thereof. It is therefore to be feared that the ground layers below the infiltration basins will gradually be mixed with undecomposed organic substances. In this way the pores of the ground may be clogged and the quality of the ground-water deteriorated by mixing with reduction products from the accumulated organic matter, if anaerobic decomposition should occur. It may, however, be possible to increase the oxygen content of the percolating water to a sufficient degree by blowing air into the ground at a great depth below the infiltration basins. This new method has been proposed for the above-mentioned ground-water recharge plants.

At Karlskoga the quantity of organic matter, carried into the ground by the infiltrated water, will amount to about 600,000 lb. per year. It is evident that the consequences of such a considerable load on the natural purifying capacity of the ground may be fatal and a comprehensive programme for a continual investigation of the changes in the ground-water bearing layers has been prepared, the results of which will be very interesting.

The temperature-equalizing effect of the ground at the infiltration of surface water is very great. It would be ideal if the time for the passage of the water through the ground could be extended to six months. The water infiltrated during the winter would then be regained at the height of the summer and vice versa. In most cases, however, the time of passage through the ground is much shorter than six months, which ideal time is expected to be obtained at one plant only, viz., at Karlstad. Even if the time of passage is one or two months only, the variations of the temperature of the water pumped from the wells will be small.

At Karlstad a large field of drifting sand will be used for artificial production of ground-water. The raw water will be pumped from Lake Vänern to a rapid sand-filter plant and the pre-treated water will be infiltrated in rectangular basins, spread over a front about 5,000 ft. long. Tube wells will be arranged along each side of the infiltration basins, at a distance of about 500 ft. from the basins. Ten-inch tube wells with very fine strainers will be used, the calculated average capacity of each well being 0.4 to 0.6 million gallons per day. The ultimate total capacity of the plant will be 10 million gallons per day.

A number of other Swedish towns are now considering projects for artificial recharge of their existing ground-water supplies, among which may be mentioned Södertälje (24,000 inhabitants), Söderhamn (11,000 inhabitants), Hudiksvall (9,000 inhabitants), Hässleholm (10,000 inhabitants) and Nyköping (18,000 inhabitants).

Water Storage in the Negeb

S. IRMAY

ABSTRACT

The Negeb is the southern arid part of Israel; it consists of a fertile coastal strip and the western plain, and of a barren central hilly desert and Wadi Araba. The rainfall is very scanty, mostly below 250 mm., humidity is low, evaporation is high and dews are heavy. The soil in the western Negeb is a wind-borne loess of varying depth on a limestone substratum. Underground water is rare and mostly saline. The development of the Negeb requires the importation of water for irrigation from the north and adequate soil conservation techniques, and eventually underground water storage. This will make possible the irrigation of an area of some 350,000 dunams, while the other 2 million dunams of cultivable land will be dry-farmed. Numerous small and medium-sized reservoirs are necessary in order to supply sudden demand during hot spells, to store up week-end surpluses, and to conserve and regulate the supply to meet local demands.

As most of the western Negeb is loess and loess-soil on limestone substratum, heavy percolation losses are envisaged. Some experience has been gathered from a reservoir on Wadi Auja.

The author has been asked by the Scientific Council and the Ministry of Agriculture of Israel to carry out research work in order to propose methods for the construction of low-cost storage reservoirs in the loess of the Negeb. He has travelled through the United States for that purpose and summed up the different methods (removal of loess; mechanical compaction; silting; chemical treatment; earth, cement, bituminous, and resin linings) that might be eventually applied. Before a decision can be made as to the best method, a survey of the Negeb soils is required in order to determine the amount of clay minerals and their type.

GENERAL OBSERVATIONS

The Negeb is the name given to the southern arid part of the State of Israel. It has the shape of a wedge whose apex lies at Elath on the Gulf of Aqaba. The base is an approximate west-east line drawn from Gaza through Beersheba to Sodom (Dead Sea), to the south of the Judaean highlands. Its eastern Transjordan frontier is Wadi Araba. Its western Egyptian border runs along the Sinai Desert and the coast of Gaza.

The area of the Negeb is about 12,200 sq.km. or 45 per cent of the area of Mandatory Palestine. Now it forms more than half the total area of Israel. Four distinct zones may be recognized:

1. The coastal strip, from Gaza to Rafa, 700 sq.km. in area and 10 km. to 15 km. in width, is covered mostly by moving sand dunes, with some loessial loams and steppe soil on its fringe.

2. The western Negeb, between Beersheba and Auja, 2,700 sq.km. in area, is a level, slightly undulating plain or plateau, some 50 to 300 metres above sea level. It merges gradually into the Sinai Desert. It is mostly covered by a typical wind-borne loess soil or a limestone substratum. The loess assumes a more loamy character towards the west and north.

Duststorms which transform daylight into darkness are frequent. A characteristic feature are the large dry wadis; occasionally, after irregular heavy winter rainfalls in the Judaean hills, these wadis convey swollen masses of water rushing for a short period towards the Mediterranean or the Dead Sea.

3. The central Negeb. These are the eastern and southern hills and deserts, better described by the biblical name of wilderness. The area is some 200 to 900 metres high and is divided into a series of north-east to south-west ridges. The ridges correspond with anticlinal and monoclinal structures in the strata. When the crest has disappeared by erosion, large cirques have been formed with steep inward facing cliffs (Wadi Hathira, Wadi Hadhira, Wadi Raman). The numerous wadis draining towards Wadi Araba indicate the passage at times of considerable quantities of water. The top soil is usually very shallow. The usual topography is rough and stony in limestone, especially in hard Eocene, gentle and smooth with plenty of flint debris in the Senonian and Lower Eocene chalks and marls.

4. Wadi Araba, from Sodom to Elath, 800 sq.km. in area and 170 km. in length, is a low flat valley, the southern part of the great Jordan Valley and the Dead Sea rift valley. The water shed is 280 metres above sea-level (the Dead Sea is some 395 metres below sea-level). Its central part is filled with alluvium and the margins are characterized by the alluvial fans and the wide gravel beds of the numerous tributary wadis. There are some sand dunes on its eastern fringe.

CLIMATE

Geographically, Israel is in the sub-tropical zone, yet, though a small country, it has a variety of climatic zones.

The coastal plain and the highlands have a typical Mediterranean climate, resembling that of Southern California. There are two well-demarcated seasons. The summer, from May to October, is entirely without rainfall, except for heavy night dews, and is rather hot. The soil is parched to 40 degrees C and more, and its organic matter is destroyed. Clay soil forms numerous cracks to a depth of several metres. The winter, from November to April, is mild, without frost but with occasional heavy rainfalls. Violent rainstorms of a cloudburst type often sweep the loose shallow soil from the hill slopes down into the wadis. The dry wadis are transformed into muddy, swollen torrents, which transport both water and soil into the Mediterranean or the Dead Sea.

The Jordan Valley and the Negeb are of the arid type, as their average yearly rainfall is usually below 250 mm. Their Lang factor (i.e. yearly rainfall in millimetres divided by average temperature in degrees C throughout the rainy season) is below 15.

The climate of the Negeb is far from being uniform. The name Negeb means "dry, arid" in Hebrew. If one travel from north to south, the average rainfall decreases from 400 mm. at Faluja to 225 mm. at Beersheba and 25 mm. at Elath or Aqaba. Enthusiastic archeologists have attributed to the Negeb a history of abundant population, which it has probably never supported. In spite of the numerous ruins, there were never more than one or two large towns at the same time, and these towns lived mostly from the caravan trade. The total population has never exceeded some tens of thousands. By unceasing effort the desert had to be beaten back. House cisterns, terraces, dams and reservoirs captured the scanty rainfall and wells were dug into the subsoil. Even this civilization has been wiped out by the roaming Bedouin and his two companions, the camel and the goat. It is no wonder, then, that the Negeb has supported hitherto only some 50,000 people, most of them nomads. During rainy seasons some barley was raised in the northern loess areas.

The climates of the four zones are as follows:

1. The coastal strip has a mild and uniform climate, resembling that of Tel Aviv. At Gaza the average maximum day temperature in August is 31 degrees C and the minimum night temperature is 20 degrees C, or 11 degrees C daily range. The average minimum in January is 8 degrees C. Relative humidity is high throughout the year, the average being 69 per cent. Dew is scanty and evaporation low; the average daily Piche evaporation rate at Gaza is only 5 mm. This comparative stability is due largely to the alternation of wind currents. In the summer, winds come chiefly from the west to north-west and bring moist and cool air from the Mediterranean. In the winter, the winds blow from the desert towards the sea. Superimposed upon that seasonal regime there is a cool and moist western breeze by day and a dry land wind at night. During transitions, especially in spring and fall, the dry and hot hamsin wind blowing from the desert harms the crops and discourages man and beast. Humidity may fall below 10 per cent and evaporation is very high. The rainfall decreases from 450 mm. at Majdal in the north to 200 mm. at Rafa.

2. The western Negeb has an ordinary continental climate, resembling that of Afula, Jezreel Valley. By day the average maximum temperature in August is 35 degrees C and the night minimum is 17.5 degrees C, or 17.5 degrees C daily range. In January the minimum is 5.5 degrees C. Humidity decreases further from the sea, especially by day; the yearly average is 59 per cent, 49 per cent in June and 72 per cent in January. Evaporation increases, however; 7.9 mm. is the average daily Piche, 11.2 mm. in July and 4.4 mm. in January. The nights are mostly cool, humid, quiet and bright throughout the year. Dews are very frequent. Dr. Ashbel assumes that they account for some 200 mm. of precipitation. Frost is not uncommon; at Beersheba a temperature of —5 degrees C has been recorded. The yearly rainfall varies from 400 mm. at Faluja in the north, to 225 mm. at Beersheba in the centre and 100 mm. at Auja in the south.

3. Central Negeb, composed of hills and deserts, has a continental climate resembling that of Jerusalem. The daily and yearly fluctuations of temperature resemble those of the western Negeb. The higher the hills the lower is the temperature and the higher is the rainfall. Frost is not unusual on winter nights. Unfortunately this is as yet unexplored country and sufficient rainfall and humidity data are not available.

4. Wadi Araba has an extremely arid and continental climate. The average maximum temperature is 40 degrees C in summer during the day at Sodom or Elath, and the minimum at night is 25 degrees C. The daily range is then 15 degrees C. The minimum in winter is 9 degrees C. The highest temperature ever recorded at Sodom is 49 degrees C. Humidity is very low; 37 per cent is the yearly average at Elath, 25 per cent in August and 49 per cent in January. The evaporation rate is among the highest in the world, owing also to the steady winds: 15 mm. is the daily average at Elath, 21 mm. in summer and 9 mm. in winter. Rainfall is sporadic and scanty ranging from 60 mm. at Sodom to 24 mm. at Elath.

It should be borne in mind that the average value of rainfall is often misleading. At Beersheba a single 24-hour rainfall was 64 mm. (30 per cent of the yearly average), at Sodom 56 mm. (100 per cent), at Aqaba 70 mm. (280 per cent).

The climate of the Negeb is not worse than in other parts of Israel, if Wadi Araba is excepted. But rainy days are fewer in number: from 30 to 35 days in the north, 10 to 20 days in the hills and 5 days in Wadi Araba.

GEOLOGY

The oldest formations are cretaceous near Beersheba. There is some hard Turonian limestone and Campanian-Maastrichtian chalk, breccious flint and phosphatic limestone. Then follows the Danian and soft Eocene limestone, some Oligocene quartzitic chalky marl and hard limestone. Miocene is represented by marl outcrops and Pliocene by sandstones and marls. Pleistocene consists of gravel on the slopes and the older dunes of the coastal strip, often covered by dark brown loamy soils. The chief soil-forming rocks are limestone and sandstone.

HYDROLOGY

The heavy rainfalls on the Judaean hills and highlands drain mostly into the Negeb. The wadis, which are dry in summer, are occasionally filled with muddy, swollen masses of water, which sometimes cause great devastation. The wadis often become very large. Wadi Saba is some 150 metres wide near Beersheba; Wadi Gaza is over 250 metres wide near Gaza. Nevertheless, as the Negeb usually has less than 200 mm. of rainfall, the run-off coefficient of the vast drainage areas is very low, less than 5 per cent.

Most of the rainwater percolates into the porous subsoil or evaporates into the air. The few existing borings show that the water table is very deep and that the water is saline. A shallow well near Beersheba contains over 500 parts per million of chlorides. A deeper boring between Beersheba and Gaza contains some 3,500 parts per million of chlorides and 7,650 parts per million of total salts. The majority of water occurrences consist of shallow wells in the Eocene chalks and chalky limestones and some waterholes in the gravelly beds of wadis. At Auja two wells obtain their saline and contaminated water from wadi gravels and yield 20 cub. metres per hour each. The spring Ein Hafira yields 10 cub. metres per hour and Ein Hosb 4.3 cub. metres per hour.

The prospects of finding water by deep boreholes are not good in view of the low rainfall, the structural complexity of the area and the predominance of limestones and chalks. The low rainfall cannot leach out the salts from the rock strata, which explains the high salinity of ground-waters.

IRRIGATION OF THE NEGEB

Plant crops require light, heat, water and nutrients. The Negeb has plenty of light, heat and inorganic nutrients. It has insufficient water and organic matter. It must therefore be irrigated and receive nitrogenous fertilizers. Since the local water resources are insufficient, it is necessary to bring water from other regions.

The principal water resources are as follows:

1. Rainfall in the Negeb itself, supplemented by heavy night dews. Though very unreliable, it should not be disregarded. Underground water storage, soil conservation, terracing and contour ploughing methods should be applied in order to reduce run-off and soil erosion. These are the methods of dry-farming.

2. Underground water pumped in the sand dunes of the coastal plain. There are some 65 million cub. metres available for irrigation, by pumping the water from wells and deep borings. Most of it will irrigate the coastal plain areas. Now part of it is diverted for the irrigation of the few settlements in the western Negeb. The water is pumped and delivered through long pipes and discharged into small pools and reservoirs situated at high places.

3. Storage of winter storm waters in the western wadis. The Jordan Valley Authority contemplates a scheme for the irrigation of the western Negeb by storage and recovery of winter flood waters from all the principal wadis draining into the Mediterranean. This supply will then be conveyed to the Negeb through a main canal running north-south. Dams and reservoirs will be constructed on the following wadis in southern Israel:

Wadi	*Annual Storage (million cubic metres)*	*Type of dam*
Natut	12	rock-fill
Musrara	15	rock and earth-fill
Sarar	25	(?) also underground storage
Ajjur	15	earth and rock-fill
Zeita	8	earth-fill
Hasi	6	earth-fill
Raml	70	earth-fill
Sharia	8	earth-fill
Saba (Shenek)	30-50	earth-fill
Khalasa	10	earth-fill (optional)
Saba (upper)	15-25	earth-fill (optional)
Mishash	5	rock-fill (optional)

One of the main difficulties in building dams on wadis is the securing of an ample supply of water during the summer for construction purposes. Earth-fill dams require the addition of water, so that the earth is compacted at optimum moisture content in order to obtain maximum density. Rock-fill dams require a considerable amount of water in order to secure the greatest stability and prevent or minimize subsequent settlement. Both earth and rock-fill dams have to be constructed in dry weather. Water should then be brought from afar.

Another difficulty is the silting up of reservoirs, because of the heavy soil erosion. This may be reduced by terracing, afforestation, soil conservation practices and the construction of small check-dams upstream.

The cultivable lands of the Negeb are mainly situated in the western Negeb. There rainfall is relatively higher, the loess soil more fertile and water resources are nearer. Yet the amount of water available for irrigation is considerably less than the cultivable lands require.

In the western Negeb there are some $2\frac{1}{4}$ million dunams[1] of cultivable lands, and in Wadi Araba some further 250,000 dunams. The water requirement estimates in the Negeb are based on local experience and on effective heat (i.e., annual accumulation in day degrees and the maximum daily temperatures above the freezing point of water). The Jordan Valley Authority thus arrives at about 1,000 cub. metres per dunam per year for irrigation by flooding or furrows. A more conservative estimate based on irrigation by sprinkling is about 700 cub. metres per dunam per year.

The irrigation of all cultivable lands in the Negeb would thus require the enormous amount of some 2,000 million cub. metres per year. Therefore, only first-class lands near the water resources would be irrigated, while the rest of the cultivable lands would be developed by dry-farming methods.

The Jordan Valley Authority foresees the irrigation of some 160,000 dunams in the northern Negeb and some 80,000 dunams in the southern Negeb, or a total of 240,000 dunams with a total water consumption of 240 million cub. metres.

If sprinkling irrigation is to be employed, the total irrigated area in the Negeb will amount to some 350,000 dunams—enough to support an agricultural population of at least 60,000, since a family of four is supposed to subsist on 25 irrigated dunams.

The water for irrigation would be taken from the main canal or laterals. The general distribution system will consist of a network of lined canals or steel pipes. The local distribution system will be comprise mostly of closed pipes. Booster pumps may be installed for irrigation by sprinkling. Throughout the project local ponds or reservoirs would be constructed in order to:

1. Supply sudden demand for additional water during hot spells, e.g., dry khamsin winds.

2. Store up week-end surpluses of water when irrigation is not ordinarily done.

3. Conserve and regulate the supply to meet local demands, as long canal systems require many hours, even days, to regulate the flow. On the other hand, if demand is suddenly reduced because of heavy rains, and no storage

[1]One dunam is about 1/4 acre; 1,000 cub. metres per dunam are about $3\frac{1}{4}$ acre-ft. per acre.

capacity is available, all the canal flow would be wasted before the main supply is cut off.

The reservoirs should be located on high ground in order to permit irrigation by sprinkling and flow by gravity, at least.

LOESS SOIL IN THE WESTERN NEGEB

The western Negeb, which is by far the most promising part of the region, is covered by a layer of loess or loess-like soil of varying thickness, usually 3 to 5 metres but sometimes 15 and even 30 metres. The loess merges gradually into loamy soil towards the north and west. Further to the west there are moving sand dunes.

Loess is defined as an unconsolidated or weakly consolidated deposit of calcareous fine earth materials; silt is dominant throughout with a lesser content of very fine sand or clay. The texture of each deposit is homogeneous. The mineral composition is variable, as it depends on the source of the loess materials, but it usually consists of 60 to 80 per cent quartz grains, 10 to 20 per cent feldspar and other minerals and 8 to 15 per cent clay. There are always sufficient calcium and magnesium carbonates which attach themselves to the silt grains and cause effervescence in diluted cold hydrochloric acid. The aeolian origin of loess is regarded as a defining feature. The source of loess is usually an arid desert or a semi-arid steppe, where adequate winds blowing from one direction predominently raise dust storms and dusty whirlwinds. In other regions where the wind quietens, the heavy sand grains settle first and form the loose blown sands; the lighter yellowish silt grains settle further under the action of rain or dew and form true loess deposits. This explains the fine texture and fine porous and permeable structure of loess, without any horizontal strata. The carbonate binder gives it some cohesion, so that dry loess may form steep walls. On the other hand, it forms a slurry when put into water. Capillary rise in loess may be 10 metres and more.

Loess is a living soil throughout its depth. Even if the upper soil is removed, it could be put to tillage at once. It contains potassium, phosphorus and other materials required for plant growth. Because of the small size of the grains, it yields their elements to water solution more readily than sand soil. This explains its high fertility, which is its most valuable property for mankind. The principal wheat-producing regions of the world coincide roughly with the areas of this "golden earth" of agriculture: the Ukraine, the lower Volga, Central Asia, China, North Africa, Argentina, United States (Kansas, Nebraska, Illinois, Iowa, Dakota, Ohio, Oklahoma, Texas etc.). True loess, or primary loess, is mother-rock on which loess soils or secondary loess have been developed. The latter consist of sands, sandy loams and clayey loams formed by weathering, biological action and redeposition by water which has leached out lime and decomposed the feldspars; the soil has become more plastic, less permeable, and has more of a single-grained structure. It is less good for agriculture but better for storage of water. Sometimes in river beds the loess soils contain small stones.

The Negeb loess probably contains not less than 15 per cent clay, as may be surmised from its high moisture content (5 to 7 per cent), its plasticity and the cracking of its exposed surface. The following table gives the chemical composition (in per cent by dry weight) of two typical loess-surface soils, one from Muharraka, the other from Beersheba (the latter contained 20 per cent stones and pebbles, which had to be discarded).

Material	*Muharraka*	*Beersheba*
SiO_2	57.5	48.5
$Fe_2O_3+Al_2O_3$	14.5	16.5
CaO	12.2	16.0
Na_2O+K_2O	3.7	4.5
$SiO_2/(Al_2O_3+Fe_2O_3)$	4.0	3.0
H_2O (at 105°C)	5.1	7.1

The high silica sesquioxide ratio shows that it is possible to render the loess more impervious by applying sodium salts; by base exchange the soil calcium ions are displaced by sodium ions and the soil is peptised or deflocculated.

This is verified by experience. Where there are sodium salt efflorescences on the surface, the soil becomes compacted, smooth and hard, so that vehicles may easily move over it, without sinking into the soft loose loess.

At Revivim settlement a low dam was constructed on Wadi Asluj and the flood-waters were diverted to an earth reservoir. The dam was once destroyed by the flood. Then the 20,000 cub. metres reservoir was treated with sodium chloride and the percolation losses decreased from 300 mm. to 30 mm. per day. In order further to decrease the losses, the reservoir was lined with an asphalt sheet mixed-in-place, about 4 cm. thick after compaction and containing some 225 kg. asphalt per cub. metre. As long as the reservoir was filled with water at a depth of 3.5 metres there was no leakage. When the water-level dropped, the asphalt sheet cracked and it had to be repaired several times.

IMPERMEABILIZATION OF EARTH RESERVOIRS IN LOESS SOIL

The irrigation of the Negeb will probably be a more costly project than in less arid regions. The average water-rate throughout Israel is U.S. $ 0.009 per cub. metre (Jordan Valley Authority, at pre-war prices). Numerous small-sized and medium-sized reservoirs are required for peak-consumption, and for daily and weekly storage. Their capacity may vary from 10,000 to hundreds of thousands of cub. metres, and the depth of water from 3 to 25 metres. Larger reservoirs are required for the storage of flood-waters, mostly in adequate wadis or valleys. In all these cases it is necessary to decrease all water losses by conveyance, evaporation, seepage and waste.

Conveyance losses, which in earth canals can exceed 50 per cent, may be decreased by employing steel pipes, reinforced concrete pipes or canals with concrete, bituminous and earth linings.

Waste of water may be decreased by good irrigation technique, sprinklers, efficient organization and control.

Evaporation losses may be considerable, probably over 6 mm. per day. These are usually outside human control. Very small reservoirs may be covered by roofs or thin shells. Narrow reservoirs may be protected by artificial wind screens on the wind side. Trees are less efficient, as they transpire water and their roots may damage the dams. A promising method is underground water storage, especially if there is an impervious underground basin filled with permeable rocks, sand or gravel. Such a dam has been contemplated on Wadi Saba near Beersheba. The water impounded may be stored by wells or galleries. The practicability of the method depends on the character of the underlying limestones and the possibility of grouting fissures.

Prevention of seepage is the best method; however, seepage through the bottom of the reservoir is more important in larger reservoirs whereas seepage through dams is more important in the smaller ones.

It is not proposed to enter here into the details of dam construction. In earth-fill dams the loess is removed and its structure destroyed. It then consists of silt containing some clay. Water is added almost up to optimum moisture content and the soil is compacted to maximum density in horizontal 15 to 20 cm. layers by means of heavy equipment (sheepfoot-rollers). The Russians employed loess for the impermeabilization of the Dnieprostroy Dam. In China some 1,600 km. of earth channels in loess areas have lasted for four hundred years.

As some experience has been obtained on the subject of decreasing the seepage in canals, the various methods will be mentioned. In the first place it should be borne in mind that it is not sufficient for a soil to be impervious when it is under water or when the moisture content is constant. A soil should be stable as well, i.e., it should not swell when water is in excess, or shrink when it dries, otherwise the cracked soil resembles a sieve.

The mechanical properties of loess are conditioned by its structure, texture, amount of clay, chemical character of the clay mineral, their base exchange capacity and exchange actions. If the clay minerals are of the montmorillonite type, the soil has widely varying properties such as swelling, and high base exchange capacity, i.e., it absorbs and holds much water, especially when bulked or undisturbed. This is the reason why some loess soils are not permanently affected by compaction, as they are subject to radical changes of moisture and temperature. On the Volga-Don Canal the porosity of loess decreased from 40 to 30 per cent in 18 months.

Canals and reservoirs may be rendered impervious by several methods: (1) No treatment; (2) removal of loess; (3) mechanical compaction; (4) silting; (5) linings; (6) chemical treatment.

1. If the reservoir is left to itself, it will generally seal itself after a certain period because of the settling of fine particles and biological activity of micro-organisms. Most fishponds in Israel thus became practically impervious. Cracking when dry is not eliminated. This method is probably unsuitable for the Negeb.

2. Removal of loess until solid rock is reached is a method requiring a relatively non-deep loess deposit on a practically impervious rock. The limestones are very treacherous, yet this method cannot be discarded.

3. Mechanical treatment by compaction after moistening at optimum moisture content has proved its value in Israel, yet it does not prevent shrinkage of the soil when it dries. This method renders the soil dense and less permeable, but does not stabilize it, unless the compacted soil is covered with some protective layer.

4. Silting is the deposit of a layer of silt by hydraulic or other methods. This method was employed on the Vale Project, State of Oregon.

5. With respect to lining, different types of imported substances may be employed.

(*a*) *Earth*

(i) Loose clay earth lining. Clay is dumped on the bottom and slopes without consolidation. Sand or gravel added to the clay reduces shrinkage.

(ii) Compacted earth lining at optimum moisture content. The earth imported should contain much clay and little lime. This lining cracks and does not eliminate weeds. This method was applied for the All American Canal, Imperial Valley, California.

(iii) Bentonite lining. Bentonite is a montmorillonite clay formed by weathering of lava tuffs and ashes. It swells rapidly, so that cracks are not dangerous. It is often employed in the United States.

(*b*) *Bituminous linings*

Bitumen is an impervious material, but it does not stabilize the soil. Soil stabilization should be obtained by a well graded mineral skeleton. Eventually adhesive-promoting agents should be added to the soil in order to render it water-repellent and oil-absorbent. As asphalts are attacked by certain bacteria and disrupted by weeds, some bactericides and weedkillers should be employed.

(i) Hot-mix asphaltic concrete lining well graded. It is rather heavy, 5 cm. thick. The cost is $ 1.20 per square metre. Some 25 km. of canals have been thus lined since 1947 in the United States.

(ii) Buried asphalt membrane. This most promising method was developed by the U.S. Bureau of Reclamation, Denver, Colorado. It consists of a thin asphaltic membrane (5 mm. to 8 mm.) formed by a single spray application and covered by some 30 cm. to 60 cm. of loose soil. The membrane is tough, does not flow at ordinary temperatures, and remains plastic even below the freezing point. It is very cheap ($ 0.40 per square metre) and requires simple implements. The slopes may vary from 1: 1½ in stable soils to 1: 2 in poor ones. There are two types: the semi-blown asphalt cement and the catalytically blown. This asphalt does not allow growth of weeds.

(iii) Prime and prime-membrane linings. Liquid asphalt (cutback) is applied to the soil, the liquid being absorbed by the treated soil (prime lining), or an asphaltic membrane is applied for a wearing course (prime-membrane lining).

(iv) Prefabricated asphaltic surfacings and membranes placed over or in canvas, paper, asbestos etc.

(v) Petroleum grouting, such as the Shellperm process of the Shell Development Company.

Here micro-emulsions of asphalt are injected into the soil.

(vi) Pneumatically applied asphalts. Either rapid-curing cutbacks or medium-breaking asphalt emulsions are placed in a manner similar to portland cement shotcrete.

(vii) Cold mixes are made with asphalts which are fluid or capable of being placed at ordinary temperatures. The last methods have been applied only on small areas.

(*c*) *Portland cement linings*

Portland cement is produced in Israel and is easily available.

(i) Soil-cement linings have been tried in the United States. They require thorough compaction.

(ii) Gunite blown over chicken wire on loess. This method has been employed at Iowa Falls for a swimming pool.

(iii) Reinforced concrete. This is a good method, but very expensive. It may be employed for very small reservoirs or for drinking water.

(iv) Concrete or pre-cast concrete blocks. Good only on stable soils and low heads.

(*d*) *Soil-resin linings*

The loess may be mixed with a vinsol or positive resin where it then becomes stabilized.

(*e*) *Other linings, such as bricks, tiles, and plastic membranes.*

6. The chemical treatment of loess depends essentially on the amount of clay materials, their chemical composition and base exchange capacity.

(*a*) If the soil contains montmorillonite clay in sufficient amounts, it may be treated by sodium salts.

(i) Soil petrification by the addition of sodium silicate and calcium chloride is employed at Denver, Colorado, for foundations.

(ii) Sodium chloride, especially when the silica/sesquioxide ratio exceeds 3, has been successfully employed at Daganya, Jordan Valley, and at Revivim, in Negeb loess soil. The percolation losses decreased from 300 to 30 mm. per day. The calcium chloride formed should be leached out. Water containing lime or magnesium might destroy that action.

(iii) Soda ash may be employed as well. Soda ash may eventually be added to bentonite linings, if the pH is below 8.5.

(iv) In the USSR sodium fluoride has been employed. The advantage of this method is that insoluble calcium fluoride is formed, so that the reaction is irreversible.

(v) Large organic cations called Armacs, which are by-products of the canned-meat industry, have been proposed for the stabilization of soils. Other organic catalysts have been successfully employed.

(vi) The presence of potassium, ammonium, or amine ions tends to reduce swelling of soils.

(*b*) If the loess does not contain montmorillonite clay minerals, bentonite or some other fat clay should be added. If the amount of clay is high, the soil should be treated by the addition of lime, calcium or magnesium chloride. The last mentioned salts are very hygroscopic and tend to maintain a constant moisture content in the soil.

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Control and Utilization of Polluted Waters

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ABSTRACT

Stream pollution by sewage and industrial wastes affects cities, manufacturers, agriculturists, property owners, fish-life and recreation. Fundamental needs for correction are application of scientific knowledge already available, overcoming of legal restrictions on co-operative action and understanding of problem by public and lawmakers.

Many existing anti-pollution laws are unreasonable and ignore following important considerations :

1. **A stream is an asset to a region and should be used to the best interests of that region.**
2. **Every stream has a self-purification capacity that it is uneconomical to disregard.**
3. **Wastes should not be treated to a greater extent than the self-purification capacity of a stream necessitates.**
4. **Sanitary engineers have sufficient knowledge of stream pollution and recovery to predict the amount of pollution a stream can care for without undesirable effects.**
5. **Plants for treating sewage, industrial wastes and public water-supplies can be designed to fit into any scheme of stream improvement and use.**

Proper organization for control is important. State anti-stream pollution boards with power to make and enforce regulations are making some progress. A recent law passed by the United States Congress should encourage further improvement. Boards which have authority over a whole river-basin are desirable in densely populated industrial regions.

The numerous interests and considerations involved in stream pollution are important to national, local and individual welfare. Water is necessary in proper amount and quality for city water supplies, for irrigation and other rural uses and for supplying industries. Streams are also the natural drains of a region and must receive city sewage from cities and waste water from industries. They tend, therefore, to become sewers carrying organic matters in large or small amounts. If the amounts are great enough fish life will be adversely affected, and perhaps the stream may become so offensive to sight and smell that people living near it may be seriously inconvenienced. Less apparent but more dangerous may be bacterial contamination of the water. This will endanger water supplies, make bathing unsafe and contaminate shell-fish grown at the mouth of the river.

It will be seen that fundamental needs enter the picture. Cities must obtain water, frequently from streams, and dispose of it as sewage at minimum cost. Industry's needs are the same. Agriculturists and food producers in general wish enough water of good quality. A large proportion of the public wishes to indulge in such sports as fishing, bathing, boating and hunting in and over public waters. Certain communities and individual property-owners may have just complaints against odours caused by sewage or wastes produced by a city or industry located upstream. Frequently, too, pollution is discharged into a stream in one governmental area but the troubles appear in a different governmental jurisdiction.

A complicated problem usually requires complicated methods of solution and this one is no exception. The sciences of biology, chemistry and engineering must be applied in research, investigation, and prescription of remedies. Legal restrictions that prevent concerted action must be overcome. Probably the most important requirement is an understanding on the part of the people and their lawmakers of the necessity for co-operative action between all actual and potential users of a stream, whether they wish to use it for water supply, disposal of wastes or recreation.

Although stream pollution has been discussed, denounced and legislated against for many years, pollution has steadily increased, at least in the United States. The United States Public Health Service reports that in 1948 approximately 40 per cent of the sewage of 71 million people was being discharged untreated directly into streams. The industrial wastes entering streams were estimated as equivalent to a population of 55 million to 60 million people. Probably a similar situation exists in other industrialized countries with their attendant urbanization. It appears, therefore, that the sooner the problem is faced the easier will be the solution.

In the United States many laws have been passed by the states in the hope of securing stream protection. Frequently such laws merely forbade the pollution of streams to the extent that nuisances or dangers might occur. No scientific definition of pollution was given and what might constitute an adequate remedy for a violation was highly uncertain. The laws were difficult to enforce, especially against cities, and in many cases protection against pollution was obtainable only by filing of civil suits for damages.

This unsatisfactory condition was responsible for many poorly conceived attempts to improve matters by the passage of new laws, or the advocation of a wide variety of new laws. The aim of many such attempts was the restoration of polluted streams to an original state of purity that conceivably might have existed before their banks were inhabited. On the other hand, powerful interests were frequently active in opposition to all anti-pollution measures to the end that they would be unhampered in polluting streams without restraint.

These two opposed objectives are equally unreasonable and ignore a number of important considerations. They are:

1. A stream is an asset to a region and as such should be used to the best interests of that region taken as a whole.

2. Every stream has a self-purification capacity which it is uneconomical to disregard.

3. No industry or city should be required to treat its wastes to a greater extent than the self-purification capacity of the stream makes necessary.

4. Sanitary engineers have acquired sufficient knowledge of stream pollution and recovery so that predictions can be made as to the amount of pollution which a given stream can care for without undesirable conditions arising or detriment to fish-life.

5. Sewage and waste treatment plants can be designed to eliminate polluting material to any extent required by an anti-pollution programme. Water treatment plants can be designed to cope with any reasonable bacterial loads placed upon them.

Complete understanding of stream pollution and self-purification requires considerable study of technical treatises (1)[1]. For the purposes of this paper, however, a very brief description of pollution, the process of recovery and methods of study that are used should suffice.

When sewage or industrial wastes are discharged into water containing dissolved oxygen, unstable organic matters are oxidized into simpler compounds through the action of aerobic bacteria. Should the dissolved oxygen be all used, thereafter oxygen is taken from nitrites and nitrates, if any are present. If the oxygen demand is not yet satisfied anaerobic bacteria will become dominant and oxygen will be derived in part from sulfates and other compounds, with the release of hydrogen sulfide and other odorous gases. In other words, an unsatisfied oxygen demand with no dissolved oxygen present ordinarily means odours.

The amount of oxygen demand unsatisfied is obtained from the biochemical oxygen demand test. This important test was developed some thirty years ago (2) and further studied in relation to the de-oxygenation and reaeration of streams by investigators of the United States Public Health Service (3). It is now a standardized test (4) and usually, in American writing, is termed the B.O.D. It is expressed as parts per million, or as pounds, exerted over a period of days, ordinarily five, at a standard temperature, generally 20 degrees C.

The rate of satisfaction of B.O.D. depends upon the remaining demand and the water temperature, higher temperatures resulting in higher rates. When sewage is discharged into a stream the B.O.D. is satisfied at the expense of the dissolved oxygen content. This is called de-oxygenation. Simultaneously oxygen will be dissolved from the atmosphere at the surface of the stream. This is called reaeration. If the diluting water is large in amount, the B.O.D. of the mixture of stream-water and sewage may be so low that the reaeration rate may exceed the de-oxygenation rate. Then there will be little effect upon the oxygen content of the water. If the reverse is true, the dissolved oxygen content will decrease until the reaeration rate first equals the rate of de-oxygenation and then exceeds it. In other words, if the dissolved oxygen content of a stream is plotted as a curve against time of flow in days below a point of pollution the curve will drop and then rise toward the oxygen saturation point. This curve is known as the oxygen sag (5). The curve, for a time, may show a zero oxygen content and during this period anaerobic conditions will result, with the previously mentioned bad effects.

The oxygen sag was first studied by the United States Public Health Service (3) and further discussed by Phelps (1) and Fair (5). There are some complications which may have to be considered. Additional pollution or diluting water may enter the stream below the first point of pollution; but these conditions can be allowed for. Another complication is the deposition of organic solids on the bottom of the stream where conditions favourable to sedimentation occur. These deposits make demands upon the oxygen content of the water in a special manner. Benthal decomposition, as it was designated by Fair (6), has been studied by him and his associates so that approximations can be made as to its effect upon the overlying water.

The oxygen sag would be of little practical use if it were not possible to apply it quantitatively. Fortunately this can be done, through a combination of theoretical knowledge and data obtained from a study of the stream.

Reaeration proceeds at a rate dependent upon water temperature, the existing B.O.D. and such characteristics of the stream as depth, velocity, presence of rapids, etc., (1, 2). The reaeration rate may be expressed as an equation including a reaeration coefficient dependent upon the stream characteristics just mentioned. Coefficients have been investigated (1) and further amplified to what is called a self-purification coefficient by Fair (5) and Thomas (7).

The rate of satisfaction of B.O.D. can also be expressed as an equation in terms of temperature and time. By combining the equations of reaeration and de-oxygenation and using the coefficients appropriate to the stream, the equation of the oxygen sag curve will be obtained for that stream.

The coefficient of reaeration is obtained in the following manner. Water samples are collected at various points downstream where the times of flow below the point of pollution are known. These are tested for B.O.D. and dissolved oxygen and, of course, the water temperature must be known. These quantities are substituted in the oxygen sag curve equation and the coefficient of reaeration is computed. The coefficient should be obtained during a critical period, which is that of low flow and high temperature. It is, however, possible to deduce a coefficient for other stages of a stream when it has been obtained for a few.

[1]Numbers within parentheses refer to items in the bibliography.

So far only the effect of putrescible organic matter has been discussed. Bacterial contamination and self-purification are important and have been studied (8) so that it is possible to predict the bacterial load that will be placed upon a water treatment plant in warm or cool weather. This information is also applicable to the availability of the water for bathing purposes or for growing of shell-fish.

Other aids are available in a study of streams. The amount of organic matter contributed to sewage by a person per day is fairly constant and has been determined in terms of B.O.D. (1). This is useful in evaluating the effect upon a stream of an increase in population. The strength of industrial wastes can be obtained in terms of B.O.D. and then transferred into a population equivalent. For example, the sewage of a city with an actual population of 100,000, but with many industries, may have a population equivalent of 250,000.

The bacterial load placed upon a stream by sewage can be predicted (8) with sufficient accuracy from the population and the reduction effected by sewage treatment can be estimated.

By use of the above information it is possible to predict the adverse effect upon the dissolved oxygen content of a stream that will result from an increase in sewage discharge or establishment of new industries. Conversely, it permits the estimation of an increase in dissolved oxygen in a stream when sewage treatment is applied or improved, or industrial wastes are reduced in amount or treated. Also bacterial loads and their variations can be estimated and water treatment correlated with said loads so that a safe water will always be produced. Furthermore, these data are applicable not only to the whole river but also to any reach. In fact we now have all that is needed for a scientific approach to control of stream pollution. A stream can be classified as to local needs or as to needs of the region it serves. Thereafter, by proper planning and control of the discharge of sewage and industrial wastes, that is, the extent of treatment in most cases, the desired stream condition can be maintained.

Classification of streams may be according to use of the stream, with appropriate requirements as to content of dissolved oxygen and bacteria. Probably inflexible categories should not be used although there is a temptation to use them. At one end of the scale the river condition might be required to be that which will permit bathing without danger and use for water supplies with standard or even sub-standard treatment. Still higher requirements might be applied where a stream enters an impounding reservoir for a water-supply which is only chlorinated. At the other end of the classification scale would be a dissolved oxygen content which merely assures that no odour nuisance will result. An oxygen content might be permitted that presents some danger of temporary local nuisances, if the points of possible nuisances are located in uninhabited or factory areas where odorous or unsightly conditions would be of no consequence.

Stream classification has been advocated in the United States of late. Several state pollution boards are authorized to classify streams as well as to prescribe standards of water quality. It is safe to say that classification will soon become a usual procedure in stream improvement campaigns. A recent application of the principle is the improvement of the Androscoggin River in Maine. This river has been highly polluted by paper-mill wastes. The courts of Maine, after hearing expert testimony, ordered three mills to lagoon their waste sulphite liquids during periods when the dissolved oxygen content of the river is in any danger of falling below 4 parts per million at a certain point. Continuous observation and chemical control are also specified (9). This is an important decision in the United States for it implies that the courts recognize the possibility of correlating scientifically the relationship between pollutional loads on streams and their self-purification powers.

A survey of the present attempts to control stream pollution in the United States indicates a confused situation and, though progress can be reported in some states, nowhere is it completely satisfactory. The existing laws are in some cases difficult to enforce. Others merely state the required quality of effluents of sewage-treatment plants, usually too high and with no regard to conditions in the receiving streams.

The best control agencies organized so far in the United States are the stream pollution boards or commissions. They are usually empowered to make administrative regulations as to stream quality, to classify streams and to issue orders to cities and industries to abate violations of laws or regulations. Unfortunately the lawmakers who authorize such organizations never make adequate funds available for their proper functioning. Generally inspections and investigations must be made by the sanitary engineers of the state health department who are already overburdened with other duties. Consequently we usually see the efforts of the engineers almost entirely confined to meeting emergencies, such as the killing of fish in some portion of a river, perhaps due to faulty handling or treatment of an industrial waste, or appearance of odors in another river caused by faulty operation of a sewage treatment plant. Such work is important but it is merely the repair of defences rather than the more constructive work of building new and adequate ones.

Difficult problems can be expected. Consider two cities located along a river. The upper one causes some pollution in the stream but no nuisances or other difficulties are to be noted by the non-scientific observer. The lower city adds its pollutional load and the sum of the two causes trouble, although either one alone would not. This would be a situation difficult for the citizens of either city to understand and certainly the upstream city would be slow to see the need for spending money to remedy matters. On the other hand, should the upstream city reduce its pollutional load by expensive sewage treatment the lower city would thereby escape the necessity of heavy expenditures. Similar situations may and do exist with regard to industries.

The obvious answer to the problem stated is consideration of the river and its tributaries as a unit in the control of pollution. The control organization should be a board with representation of the interests concerned, ordinarily the various political subdivisions in the river-basin, industry and the state or other higher government. The state pollution board, if there is one, obviously should be represented. The local board should have a staff of engineers, chemists and biologists to make investigations and recommendations. Funds for investigation might be derived in part from the higher government and in part from local sources. Funds required for treatment of sewage and wastes should be raised locally. They can be based on the load placed upon the stream in terms of population equivalent and all such collections could be placed in a common fund to care for the cost of new treatment plants and their operation. The advantages of such a scheme are obvious. The degree of treatment of sewage and industrial wastes can be prescribed with regard to stream conditions and the economics of the region. With proper administration and use of the technical knowledge previously mentioned no city or industry will pay more than its own share of the cost of keeping the stream in good condition.

It is admitted that there will be difficulties in introducing and carrying on the scheme outlined. A vast amount of investigation by well qualified technical personnel will be required. There will be the usual distrust and objections to a new governmental authority. Also the stream may run through several States or countries with the accompanying legal difficulties.

Industries will present a number of problems. Those located in cities and which discharge their wastes into city sewers may make agreements with the city rather than with the river control authority. That is, the authority would collect its charges from the city on the basis of the sewage arriving at the sewage treatment plant. For industries located outside of cities different procedures would have to be adopted. This problem is complicated by the fact that the best methods of treating certain industrial wastes have not yet been ascertained. Obviously each industry should be encouraged to improve its processes so that waste is decreased in amount and concentration and to develop its own methods of treating the unavoidable wastes.

So far little progress has been made in the United States in establishing pollution control on a river-wide basis, although England has its river authorities which are regional in nature. The accomplishments in the Ruhr River Valley of Germany under the direction of Imhoff (10) are well known to sanitary engineers as an application of controlled self-purification in a small river of an important industrial area. Times of flow in the Ruhr River were increased by construction of dams thus augmenting the self-purification powers of the river to the extent that the highly polluted water can be used for municipal purposes, after collection in infiltration galleries, chlorination and use of activated carbon. The total amount of river water used for domestic and industrial purposes along its course far exceeds its dry-weather flow. Incidentally the dams and reservoirs provide power and recreation.

Recently, in the United States, there has been a movement toward formation of inter-state compacts, notably in New England, in the Ohio River Valley, the Potomac River Basin and the Delaware River Valley. These have as their objects the setting of minimum standards of stream-water quality and the making of recommendations based on the welfare of a large region. While these are undoubtedly useful it must not be overlooked that better streams can only be obtained by acceptance of the responsibility for making improvements where pollution originates, whether it be produced by such public entities as cities and state institutions or by private industry.

The attitude of industry lately toward the stream pollution problem has been encouraging. It shows an ever-increasing tendency to assume its responsibilities by carrying on research that will reduce the amounts of undesirable wastes and to discover better methods of treating the unavoidable ones. This has been done to best effect by associations formed by certain industries, as the paper manufacturers, textile manufacturers and others. They have developed methods of investigation (11) and have collected much existing information regarding treatment of industrial wastes (12). It is obvious that industry itself is, in many instances, better qualified to solve its industrial waste problems than is a governmental authority, the latter then should only specify the results to be obtained by the waste treatment.

A proposed programme for the Merrimack River Valley District in Massachusetts deserves mention (13). The Merrimack is a medium-sized river with many industrial cities on its banks. The sewered population is about 258,000 but the pollution load in terms of B.O.D. has a population equivalent of 2,356,000. Bacterial pollution is also high. The dissolved oxygen content of the stream at critical periods is very low and will be lower in the future unless improvements are made. Comprehensive studies were made of the reaeration characteristics of the stream with the result that it was possible to recommend plants to provide various degrees of sewage and waste treatment that will insure satisfactory conditions in the river. In order to keep the coliform bacterial count to acceptable limits for bathing and recreational use chlorination of all sewage treatment plant effluents would be required.

The proposed allocation of costs and responsibilities for the above scheme is interesting. The District would assume the obligation of treating all sewage and wastes now being discharged into the river or that will be discharged in the future. The District would provide intercepting sewers where necessary and may require sewage of one city to flow through the sewers of another, but expenses so incurred will be paid by the District. The cost of sewers and certain units of the treatment plants depends upon the quantity of the sewage and industrial wastes. The cost of secondary treatment is determined primarily by the B.O.D. of the sewage and wastes, while the cost of sludge disposal is determined primarily by the amount of suspended solids in the sewage and wastes. The proportion of annual treatment costs for each of the above factors was ascertained and these would be assessed against each city on the basis of 0.19 lb. of B.O.D. and 0.25 lb. of suspended solids per person per day. Industrial wastes would be surveyed by the District staff and B.O.D. and suspended solids estimated for assessment of costs. The annual costs would be assessed against cities and industries in proportion to the amounts produced and their B.O.D. and suspended solids contents. It was estimated that of an annual cost of $777,023 about 58 per cent would be assessed against manufacturers and 42 per cent against municipalities. This scheme was rejected by the voters of the District late in 1948. It is therefore at least temporarily postponed.

It is to be expected that stream conditions in the United States will be improved in the next few years as the result of passage by Congress in 1948 of Public Law 845. Its primary purpose is to help the states in control of pollution and the United States Public Health Service is the administrative agency. Control of interstate waters to prevent dangers to health and welfare is established. Co-operative activities, interstate compacts and uniform state anti-pollution laws are to be encouraged. Information as to pollution and its prevention, methods of treating industrial wastes, results of surveys and investigations are to be collected and disseminated to interested parties. Money is made available to further research by the United States Public Health Service and grants will be made to the states for investigations and surveys related to control of pollution by industrial wastes. Grants will be made available for surveys, designs and preparation of plans for approved projects for reduction of stream pollution to the amount of \$20,000 or one-third of the cost, whichever amount is the smaller. Also interest-bearing loans will be made for the construction of treatment works to the amount of one-third the cost or \$250,000 whichever is the smaller.[1]

To the conservationist and the sanitary engineer the immediate future in the field of stream improvement looks promising. The public is evincing an intelligent interest in conserving this important resource and the lawmakers are yielding to the pressure, after first receiving and heeding engineering advice as to the laws required. Science has had the remedies available for two decades and now should have an increasing opportunity to apply them.

[1]Editor's note : While these moneys were authorized by Public Law 845, as late as July 1951, no expenditures had been made.

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Desalinization of Brackish Waters

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High salinity of water may be of different origin. Passage of water through marine formations and contamination by sea-water are common causes of high salinity. Purification of brackish water is of particular importance in arid and semi-arid regions. It is sometimes possible to collect and utilize the scarce water resources of these regions before they are likely to undergo contamination. However, there is often no alternative to a brackish water-supply.

The nature and concentration of dissolved salts vary between wide limits. Waters are considered brackish if they contain more than 1,000 parts per million (p.p.m.) of dissolved solids, the main constituent of which is usually sodium chloride, followed by the chlorides, sulphates and bicarbonates of calcium and magnesium. Table 1 shows typical analyses of brackish waters found in Israel.

Table 1. Chemical Analyses of Typical Brackish Waters Found in Israel

(Parts per million)

	Asi Spring (1)[1] *(near Beisan)*	*Kurdani Spring (near Haifa)*	*Beerot Yizhak Well (Negeb)*
Chloride, Cl^-	916	600	955
Sulphate, $SO_4^{=}$	113	91	398
Bicarbonate, HCO_3^-	334	390	458
Calcium	186	116	32
Magnesium	71	68	55
Sodium	434	322	843

These waters are unfit for drinking and most industrial and agricultural uses. According to U.S. Public Health standards a potable water-supply should preferably contain less than 500 p.p.m., and only in exceptional cases up to 1,000 p.p.m., total dissolved solids. In agriculture, the permissible limits of salinity depend on the crop, the nature of the salts, the soil and the climate. Some crops, e.g., date palms and cotton, stand high salinity under favourable conditions. Irrigation waters containing less than 700 p.p.m. total dissolved solids are suitable for most plants under most conditions, those containing 700

[1]Numbers within parentheses refer to items in the bibliography.

to 2,000 p.p.m. are harmful to the more sensitive crops, while those containing more than 2,000 p.p.m. are unsatisfactory.

Sodium percentages larger than 75 equivalent-per cent of the total solids injure the physical condition of the soil (2).

While in certain cases the addition of inorganic fertilizers counteracts the harmful action of sodium chloride, on the whole only its elimination makes saline water fit for irrigation purposes. Desalinization of water for drinking and household is being carried out by various methods; so far no method has been considered sufficiently economical for irrigation (3).

REMOVAL OF WATER FROM DISSOLVED SOLIDS

Distillation is probably the most economical method for desalinization of sea-water. Roughly one ton of hydrocarbon fuel is required for the distillation of ten tons of sea-water in a single-effect evaporator, while in multiple-effect apparatus, fuel requirements decrease roughly inversely with the number of effects.

Compression distillation involves, adiabatic recompression of the vapour from the boiling liquid, thereby raising its temperature and pressure, and then the use of the vapour to boil more liquid. The method was used during the war to provide distilled drinking water from sea-water. The fuel economy is stated to be about 175 tons distilled water per ton of fuel; the method would, therefore, be equivalent to the performance of a 15-effect evaporator (4).

The use of solar energy for distillation of brackish water is possible in simple equipment. Solar radiation heats the water in a pan covered by a structure of glass or a transparent plastic, similar in shape to a hotbed. The vapours condense on the glass and the condensate is collected (5). Yields depend on meteorological conditions. In Rehovoth, Israel, at about 32 degrees latitude, the yields are 8 to 10 litres per day and per square metre of pan area in summer (6).

REMOVAL OF SOLIDS FROM WATER

All these distillation methods can be characterized as the removal of the water from the dissolved solids. Chemical demineralization by ion exchangers implies the removal of the solids from the water, viz., by adsorption. In the following a brief summary of the theory of this method is presented, followed by data on its application to the partial demineralization of moderately brackish waters.

Ion exchangers are natural, modified natural or synthetic insoluble substances capable of exchange adsorption of ions. If saline water is passed through a bed of cation exchanger in its hydrogen form, the exchanger adsorbs the metal ions, releasing hydrogen ions instead. Thus the salts in the water are converted to acids. If the acid solution is now passed through a bed of anion exchanger in its hydroxyl form, the acids are adsorbed (or alternatively, the acid radicals exchanged for hydroxyl ions).

When the exchangers are saturated with metals and acids, respectively, they must be regenerated. Commonly dilute solutions of sulphuric acid are used for regeneration of cation exchangers and solutions of caustic soda or soda ash for anion exchangers. For moderately brackish water the length of a period between two successive regenerations is usually several hours, and the flow rate is about 20 volumes of water per volume of resin and per hour.

The exchange reaction on a cation exchanger involving sodium and hydrogen may be written as

$$Na^+ + HR = NaR + H^+$$

where R designates the insoluble, structurally bound anionic part of the exchanger (7, 8). The thermodynamic equilibrium constant K for this reaction is defined by:

$$K = \frac{a_{H^+} \cdot a_{NaR}}{a_{Na^+} \cdot a_{HR}} = \frac{C_{H^+} \cdot C_{NaR}}{C_{Na^+} \cdot C_{HR}} \cdot \frac{\gamma_{H^+} \cdot \gamma_{NaR}}{\gamma_{Na^+} \cdot \gamma_{HR}}$$

$$= \frac{C_{H^+} \cdot C_{NaR}}{C_{Na^+} \cdot C_{HR}} \cdot F_{Na^+}$$

where a_{Na^+}, a_{H^+} are the respective activities in aqueous solution of the ions Na^+ and H^+, a_{NaR} and a_{HR} the activities of the sodium salt of the cation exchanger and its hydrogen form respectively, γ the activity coefficients and C the concentrations (given usually in milli-equivalents per cubic centimetre of solution and resin, respectively).

In terms of mole fractions the mass-action equation can be written as

$$\frac{{}_{Na}X_R}{1 - {}_{Na}X_R} = \frac{{}_{Na}X_S}{1 - {}_{Na}X_S} \cdot \frac{K}{F_{Na}}$$

where

$${}_{Na}X_R = C_{NaR} \,/\, C_R,$$

$${}_{Na}X_R = C_{Na^+} \,/\, C_S,$$

C_R the total molar exchange capacity of the exchanger (varying with commercial exchange resins between 0.5—2.5 milli-equivalents per cc, corresponding to 12–58 mg. sodium per cc.)

and

C_S the total molar concentration of the solution. For the exchange between hydrogen and calcium or other divalent ions the mass equation, expressed in terms of molar ratios is the following:

$$\frac{{}_{Ca}X_R}{(1 - 2\,{}_{Ca}X_R)} = \frac{K_{Ca}}{F_{Ca}} \cdot \frac{C_R}{C_S} \cdot \frac{{}_{Ca}X_S}{(1 - 2\,{}_{Ca}X_S)^2}$$

where

$$F_{Ca} = \frac{Y^2{}_{H^+} \cdot Y_{CaR}}{Y_{Ca^{++}} \cdot Y^2{}_{HR}}$$

and K_{Ca} the equilibrium constant for the calcium-hydrogen exchange.

Fig. 1 shows a plot of $2\,{}_{Ca}X_R$ versus $2\,{}_{Ca}X_S$ for various values of $K_{Ca}\,C_R \,/\, C_S$ assuming F_{Ca} to equal unity. The product of K_{Ca} and C_R representing a characteristic

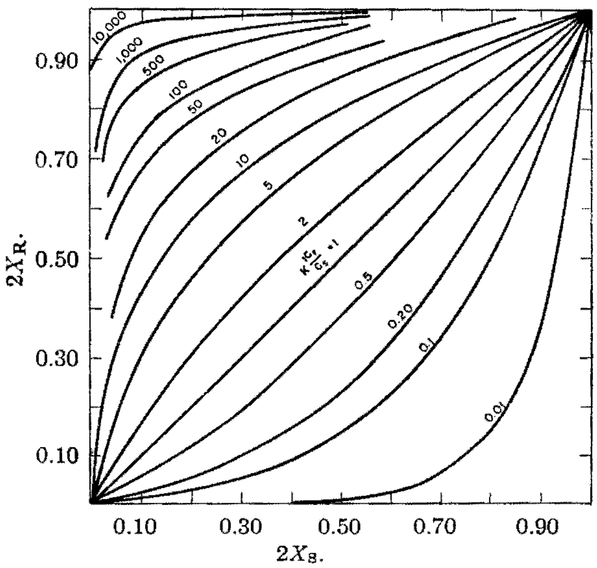

Figure 1. Plot of $2_{Na}\times_R$ vs. $2_{Na}\times_S$.

constant of the resin, the equilibrium curve depends even in dilute solution on the total equivalent concentration C_S of the solution, while in the case of the sodium-hydrogen exchange it does not depend directly on C_S, but only on the ratio of the activity coefficients $\gamma_{H^+} \mid \gamma_{Ha+}$ which varies only slightly with C_S. For a given ratio $_{Ca}X_R$ of calcium to hydrogen on the exchanger, the ratio $_{Ca}X_S$ in solution is the higher, the higher the total molar concentration of the solution; in other words, the selectivity of the exchanger for a divalent over a monovalent ion increases with dilution (9), while exchangers containing quaternary hydroxyde groups are strong bases.

Adsorption of free bases and acids by regenerated cation and anion exchangers decreases with the strength of the dissolved bases and acids and the acidic and basic strength of the exchanger, respectively. Thus carbonic acid is only partly adsorbed by weakly basic anion exchangers. Weakly acid cation exchangers convert a lower percentage of salts to acids, but a smaller excess of regenerating acid is required to reconvert them to the hydrogen form. This is important for the economical aspect of the process.

The equilibrium data thus determine selectivity and efficiency for different conditions and help in the choice of suitable resins for a given application.

The rate of ion exchange reactions determines the maximum flow rates permissible for a given application.

In determining the kinetics of the reaction (e.g., sodium-hydrogen exchange) the following steps have to be considered :

1. Diffusion of sodium ion through the solution to the adsorbent particles;

2. Diffusion of sodium ion through the adsorbent particle;

3. Chemical exchange between sodium ion and hydrogen linked to the reacting resin radical;

4. Diffusion of hydrogen ion out of the interior of the exchanger;

5. Diffusion of hydrogen away from the particle (10).

In dilute solutions the exchange velocities were found to satisfy a second-order rate equation (11). This might be explained by assuming either chemical reaction (step 3) or diffusion through a boundary consisting of a liquid film (steps 1, 5) to determine the rate of exchange.

For some resins at least, there is strong evidence for the latter assumption. In more concentrated solutions (more than about 0.1 molar), diffusion in and through the adsorbent particle determines the rate. Variation of rate constants among the cations is correlated to their diffusion rates.

Thermodynamic equilibrium and kinetic data provide the basis for the theory of column performance. The action of a resin bed exchanging ions with a solution passing through it may be compared to other "percolation" processes, e.g., heat transfer between a gas flowing through a bed of granular solid. Exchange in flowing systems is far more effective than equilibrium contact, for instead of an equilibrium state involving usually incomplete exchange, we may consider flow in the column as a succession of a very large number of incomplete exchange processes occurring in very thin layers. If a solution of sodium salt flows down a cation exchanger column in its hydrogen form, practically the whole of the sodium is adsorbed at the top of the column, yielding an effluent containing only acid. However, with the passage of increasing quantities of solution the sodium band broadens until it reaches the bottom of the column when the sodium concentration in the effluent rises steeply (break-through point).

For a given resin, solution and flow rate, the concentration of sodium in the liquid and resin depend on the time after the entry of the solution into the column, and on the depth from the input end.

The basic differential equation for this process, describing the change of concentration of resin and solution with time and depth, has been solved for several simple cases (12) and verified by chemical analysis of the column effluent and also by the use of radio-active tracers (13, 14).

While this work has been most valuable in promoting the understanding of column action, the calculations become rather involved if an initial concentration gradient exists in the column, and if several ions are being adsorbed, as is the case in partial demineralization. Experimental evaluation of column performance is then less time-consuming than calculation.

While demineralization research has aimed mainly at the production of completely demineralized water, complete removal of salts is neither necessary nor desirable in demineralization of water for municipal and agricultural use. By sacrificing completeness of conversion, a certain economy in regenerant chemicals, which usually account for more than half of the treatment costs (see below), can be achieved.

Regeneration of anion exchangers saturated with volatile acids by means of steam is stated to be possible (15), yet does not appear to be applied on a major scale and demineralization installations still rely on acid and alkali regenerants. To make large-scale ion exchange demineralization an economic proposition, economy of chemicals is essential. Theoretically, about one U.S. ton of both sulphuric acid (66 degrees Be) and soda ash are necessary to reduce the salinity of 1,000 cub. metres by 1,000 p.p.m. as sodium chloride. At present New York prices this corresponds to chemical costs of 4 to 5 cents per cub. metre. If burnt lime is substituted for soda ash, the theoretical requirement is 0.6 U.S. tons of the technical product corresponding to chemical costs of only 2 to 2.5 cents per cub. metre (including the acid). To achieve complete demineralization, using a strongly acid cation exchanger and a weakly basic anion exchanger, acid requirements are 200 to 300 per cent higher and alkali requirements 40 to 80 per cent higher than theoretical.

In partial demineralization, on the other hand, almost theoretical efficiency of the acid regenerant can be achieved by maintaining the acid flow in the regeneration stage in a direction opposite to the water-flow in purification; the exchanger is only partially regenerated, regeneration being stopped as soon as excess acid appears in the spent regenerant (16).

Figure 2 illustrates the difference in effectiveness of sodium ion removal in parallel and counter-current flow. The points on the curves were obtained by passing a dilute solution of sodium chloride in downflow over a resin column containing an average of 35 per cent of the regenerated form RH, having the segment rich in hydrogen at the top in the case of parallel flow (curve A) and at the bottom in counter-current flow (curve B). Parallel flow reduced the sodium concentration so little that it was of no practical value. In counter-current flow, the sodium concentration was reduced materially at the beginning, then increased gradually. When enough sodium chloride solution had passed through the bed to exhaust the partially regenerated resin, the over-all exchange had reached one-third of the sodium present at the beginning.

In practice partial demineralization can be carried out at high regenerant efficiency by passing the brackish water through two or more pairs of columns.

If calcium is present in considerable proportion, pre-softening of the solution, or treatment of the cation exchanger with sodium chloride solution prior to regeneration, is necessary. This procedure introduces sodium chloride or lime into the cost sheet. In plants near the seashore, treated sea-water may be used instead of salt solution.

The progress of demineralization of a synthetic brackish water similar to Asi Spring water (about 2,000 p.p.m. total dissolved solids) is shown in Figure 3. In a pilot plant of a capacity of 20 cub. metres per day, 7.5 cub. metres were treated. There was a base exchange pre-softener containing Dowex 30 in the sodium form, two pairs of columns in series each containing a Dowex-30 column regenerated previously to the extent of about 35 per cent by sulphuric acid, and an Amberlite 1R-4B column regenerated nearly completely by a solution of soda ash.

This was one of a series of cycles in which acid regenerant consumption was only 10 to 20 per cent higher, and soda ash consumption only 30 to 60 per cent higher than the theoretical figures (17).

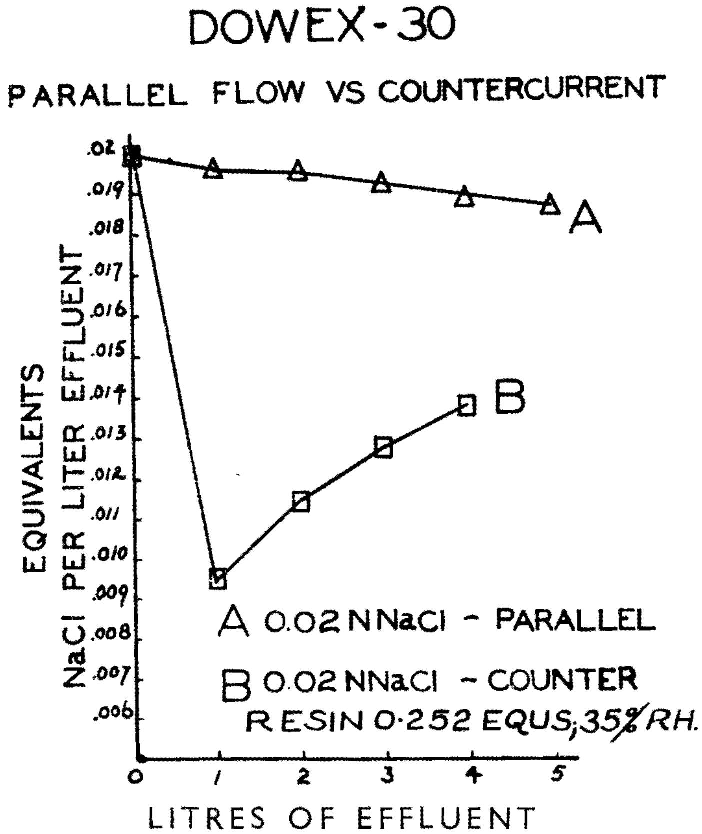

Figure 2

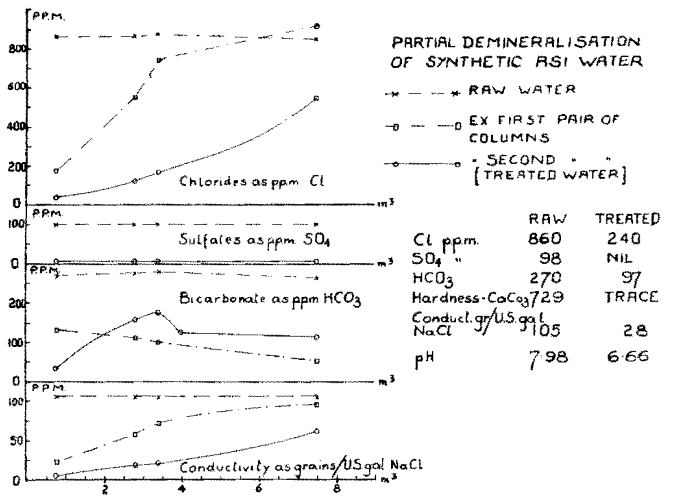

Figure 3

Regeneration of the anion exchanger by lime water is possible, but unless bicarbonates are removed previously, precipitation of calcium carbonate in the bed occurs and causes mechanical difficulties. In terms of alkali equivalents, lime is about five times cheaper than soda ash; but equipment for lime regeneration is more bulky than for soda ash or caustic regeneration.

Attrition of cation exchangers is estimated at several per cent per year. Anion exchangers are much less stable.

The capacity of the resins usually drops considerably during the first cycles; later on, the decrease is only gradual. With resins of good quality, the cost of resin-replacement is estimated at one to two U.S. cents per cub. metre of water treated.

In the process of partial demineralization just described the spent cation exchanger regenerant is a dilute solution of sodium sulphate containing only small amounts of contaminants. Recovery of sodium sulphate by evaporation is economical only if a cheap source of energy is available. In arid regions solar evaporation might solve the problem.

In principle, recovery of regenerant acid and alkali from sodium sulphate is possible by electrolysis or a modified Le Blanc process but this might prove economical only where cheap current or coal are available and the amount of sodium sulphate warrants construction of additional plants.

To give a random example: Chemical costs for the partial demineralization of Kurdani water (Table 1) from about 1,500 p.p.m. total dissolved solids to 500 p.p.m. should amount to about 5 cents (in f.o.b. New York prices) per cub. metre to which must be added one to two cents for attrition of resins. Pre-softening is to be carried out by purified sea-water. If half of the theoretical amount of sodium sulphate could be recovered as pure product, this would represent a value of nearly 3 cents per cub. metre of water (not including recovery costs). For the time being, sodium sulphate recovery is still in the experimental stage and it remains to be seen whether and under which circumstances it is economical.

The profitability of ion exchange demineralization decreases with the salinity of the raw water, as regenerant requirements and rinse water requirements increase approximately proportionally with the salinity and in inverse proportion to the length of the period between two successive regenerations. For highly saline waters and particularly for sea-water, distillation is preferable. At the present stage, partial demineralization by ion exchange should prove economical for the treatment of moderately brackish waters for urban and industrial use. Thus while no panacea for the utilization of brackish waters, partial demineralization is a valuable tool for the utilization of water resources hitherto considered useless.

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Control and Utilization of Polluted Waters

JAN ZAVADIL

ABSTRACT

The growth in populations, the concentration of industry and the rise in water use and waste has been accompanied by an increase in the pollution of both running and stagnant surface waters especially in the more populous areas.

With the development of natural science the testing of the quality of water has followed investigation into its quantity. In view of the variety of properties of water, as well as the demands upon it, no single factor has yet been found which would characterize the quality of water. The tracing of oxygen had the widest significance. It is necessary (as for example, in geoponics) to secure more intensive international co-operation. The same applies to the treatment and purification of water.

The practical aim is to utilize waste water. As regards town sewage and similar waste water, it is necessary to revert once more to irrigation. If the quality of water is not suitable there is need of treatment, perhaps preliminary purification, and always for constant control. The treated waste water even if it has to be pumped and carried in pipes should be added to the relatively pure water from reservoirs. Progress in processes and construction methods make it possible to find economic justification for undertakings that formerly could not be carried out.

Water is a natural treasure of special character. It is found in the form of steam, liquid, snow and ice. It is found in the air, on the surface of the earth and under its crust. Water can pass from each state to the other two, and back again. As it does so, changes in quantity take place, dictated by place and time. Water is for the most part made use of, and then it returns into further circulation, frequently deteriorated in quality. An important point is the possibility of using it over and over again.

Pure water exists solely in the form of steam. It is polluted by natural influences or, predominantly, by the action of man. Even rainfall contains, together with absorbed gases, certain other substances. In the years 1883—1884 a royal commission in London found that the evaporation of rainwater was 26.4 to 80 mg. per litre. Webel ascertained in 1900 that at Ploty in the south-west of Soviet Russia the quantity of bound nitrogen which got into the soil from rainwater amounted altogether to 3.9 kg. per hectare, and in the following year to 5.2 kg. per hectare. Rocek at Brno (in December 1921 and January 1922) even detected some scores of micro-organic germs in one cub. cm. of snow water.

The pollution of surface water is governed by a decisive element. Rainwater flowing continually on the surface becomes polluted by substances washed from the fields and from places of human habitation. The portion of rainwater absorbed by infiltration is ridded of the coarse ingredients of the wash. Water issuing through pores is as a rule pure, and more or less hard, and possibly becomes turbid as the result of chemical changes. Water issuing through fissures is similar to pure water in so far as the fissures are filled with sand; if they are not, it approaches the character of karst water which is a transitional form of water running on the surface. (A special category is formed by mineral waters, which pollute a stream by concentrated disembouchement even if the quality of the water has undergone no great change by the bath.)

Waste waters are polluted artificially. According to the urgency of the purpose for which they are required we divide them as follows: for personal and recreational use; agricultural, including fishing; industrial; exploitation of power; and navigation.

Each type of utilization has different effects.

Pollution is mechanical (sediment or deposit), physical (hardening), chemical (for example, acidity), bacteriological (large quantity of micro-organisms), biological (unfavourable to flora and fauna). As regards requirements there arise esthetic faults (sight, smell), and also defects adverse to health. The most serious are in the waste water from human habitations and from industries.

The capacity of water to purify itself (the settling, granulation and decomposition of matter, especially organic) depends on atmospheric conditions, on the place in which the water is concentrated (on the size of the surface, the depth, distribution, fall etc.), and becomes weaker and weaker as a counter-effect to advancing deterioration.

The control of the quality of water is based on: the progress made by the natural sciences and special study; the demand for quality, and on the consequences of the consumption of water.

Man for long judged water instinctively. Scientific development is also reflected in the analysis of water, in which sphere suitable working processes have been perfected. This concerns, for example, research into turbidity. The determining of p H has become a general practice. In 1912, English chemists introduced the ascertainment of the biological consumption of oxygen. It is obvious what significance attaches to the invention of the microscope.

The number of germs is still being determined; the coliform group serves as indicators of the presence of disease-breeding micro-organisms. In biological research regard is paid to important societies without losing sight of their adaptability. The Commission for Ensuring Purity of Water attached to the State Research Council in Czechoslovakia has just issued a "Draft of Uniform Methods for the Testing of Surface and Waste Waters". Of importance is the possibility of mutual comparison of results.

Every test contributes in a certain manner to the characterization and thus to the classification of waters according to quality. For example, the State Hydrological Institute in Prague (B and Z Cyrus) analysed polluted water and characterized it in detail:

1. Catharobia—spring water;

2. Oligosaprobia—pure water in areas little affected by human habitation;

3. β mezosaprobia—pure water without any coarser artificial influences;

4. α mezosaprobia—dubious water, sometimes polluted by nature and under the influence of a concentration of dwellings and partially also of industry;

5. β polysaprobia—water tainted, mainly by the concentration of industrial waste;

6. Hypersaprobia—dangerous water, mainly concentration of waste water from industry;

7. Antisaprobia—water pernicious by reason of matter which destroys all life in the water.

According to the manner of use and required quality of surface water we arrive at the classification given by Fair:

A. Drinking water (after chlorination);

B. For baths;

C. For pisciculture;

D. For common technical purposes and irrigation.

Details of opinion are at present lacking. There is, for example, no agreement on the precise requirements for drinking water. Views differ as regards water for household use and as to the quality of water for bathing. In industry it is also a question of fundamental attitude. For example, the Commission for Purity of Water in Czechoslovakia has just recently set up committees for waste water: (1) for mines and gas-works; (2) foundries and the metalworking industry; (3) the chemical industry, including glassmaking and ceramics; (4) the textile industry; (5) the cellulose and paper industry; (6) the leather industry; (7) the sugar industry; (8) the yeast branch; and (9) the provisions branch. In each of these cases specific and different demands are made on water.

In the individual branches of production more than one type of water use exists (for example, drinking water and water for personal uses; for filling boilers; for cooling, condensing and cleaning purposes; for industrial processes; and as parts of the product). The result is varying forms of pollution.

In England, with the great industrial expansion, numerous complaints about waste water arose as early as the middle of the past century. It was first of all necessary to have recourse to legislation and to research. Efforts were always made, according to the particular development, to express the directives in figures. In Bohemia and Moravia-Silesia, a water law was promulgated in the year 1870 which was designed to ensure that neither public nor private interests would be harmed by water pollution. As was the case in Germany, every case was judged on its merits. All depended on the instructions for official supervision. The towns frequently pointed to their lack of funds to prevent the harm they were causing. The same was the case with the industrial concerns.

The demand that water should be discharged in the same quality in which it was received would seem to be a just one. The case is not isolated, however, in which water must be treated before industrial use can be made of it. In waste water there are usually substances which may be used as raw materials in some factories (fibres etc.), while in others they are mere ballast.

In order that natural water shall not be polluted beyond a reasonable limit, everything that causes taint is destroyed, eliminated or utilized in the form of waste. Waste water under purification is regarded as a dispersal system. In each case it is determined what kinds of waste water suitably unite. Appropriate equipment is used to collect the various matter contained in the water (grating, sieves, nets or traps for sand, fats or sediment; apparatus for flaking; slow, rapid and special filters; filters with special interiors; biological filters, disinfection and perhaps infiltration). The manner in which the purifying of waste water is carried out depends upon the character of the water, its relation to natural water and the purposes for which it is required.

Rakings from exhaust water (3 litres per person per annum) are destroyed or otherwise made harmless. Sand (12 litres per person per annum) is used under paving-stones or for filling up holes. Oils and fats are worked up (into soap). The sludge (from town and other sewers) is made into compost by rotting and thickening (50 litres per person per annum, on second sedimentation more than 50 litres) and is artificially converted into a manure through co-ordination of its nutritive matter, and may be inoculated and added to surface water for irrigation. In the rotting process heating gas is secured (3 cub. metres *per capita* per annum).

Tests in Brno gave the following yields expressed in kilogrammes per 1,000 kg.:

	N	P_2O_5	K_2O	*Organic matter*	*Ash*
Dry sludge/I.sediment .	8.92	3.49	1.34	154.7	145.3
Stable manure	6.0	6.10	7.56	242.8	57.1

The proportion of mineral matter to organic matter in the fresh sludge is 1: 2.85.

An effort is being made (Dr. Jonás) suitably to inoculate waste water that is rich in organic matter (from yeast factories, from the diffusion and the pressing of beet in sugar factories etc.) and after fermentation to extract the valuable feeding stuff. The mineral dregs and dregs resulting from the addition of precipitants can be used according to their nature. The membraneous layers formed in special filters (for example, in paper mills) together with the matter secured with them, can be used as raw material. In the case of dregs from a rapid filter, the main thing is to prevent their causing difficulty.

After surveying the matter which is obtained in the process of purifying water, questions still arise:

What are we to discharge into the waste water and what (such as ash etc.) can be more suitably taken elsewhere?

To what extent can waste water (in industry) be used again and to what extent is it recommended to elaborate a process with a smaller consumption of water?

How to use waste water containing polluting matter?

According to the urgency of requirements, it is necessary to revert as far as possible to agricultural utilization of waste and exhaust water: in biological fishponds, and in irrigation work.

In biological fishponds (according to Hofer) the water is saturated by oxygen on the surface. A vertical circulation of the water takes place under the influence of heat. The freshness of the water is improved by new supplies. The dilution is given as fivefold. A six-days retention of the water in the pond is reckoned with. In every case a test is made of the extent to which the given degree of dilution proves satisfactory, or if it is necessary to combine an adjustment of the wash water to make the result attained satisfactory. It is decided, for example, which elements of mechanical purification to use when the diluting water is appropriately warm, if it is specially rich in oxygen, and so on. The influx of diluting water is regulated. The inflow is observed. Wash (from 1,000 to 1,500 inhabitants) is best distributed at the rate of 100 litres per person and day to a pond of half a hectare the sides of which are in the proportion of 2: 3, and the depth 0.3 to 1 metre. The micro-organisms decomposing organic matter serve as food for higher organisms. The final product is carp (1,000) showing a growth of 300 kg., or if waste water be used, 500 kg. per hectare (value kcs. 25 per kg.) at 80 per cent, that is 400 kg. of fish meat of 625,000 calories. In the case of ducks, on the average 300 birds per hectare can be fed. Advantageous categories of ponds are those that have their own breeds chosen with due regard to the given conditions. The carrying out of ground work and the inflow of water by mechanical means facilitates the establishment of the fishponds.

Figure 1 illustrates an alternative solution (proposed in a competition, by Zavadil) for Brno and the whole system of fish culture. In this alternative scheme irrigation is proposed. The main pond for two-year carp and one-year carp covers 73.6 hectares, including the others, 83.0 hectares. Provision is made for enlarging the ponds. The dilution water from a river is supplied from a reservoir, that is, it is indeed clarified but aerated and warmed by superficial supply.

Irrigation by waste water was known, for example, in ancient Athens. More recently in England (1865) a royal commission recommended the purification of waste water by means of irrigation, even if this method does not always benefit the farmers. In the seventies of the last century a French commission regarded irrigation as the most effective method where the soil is sufficiently per-

PLAN FOR THE SEWAGE PURIFYING PLANT AT BRNO.

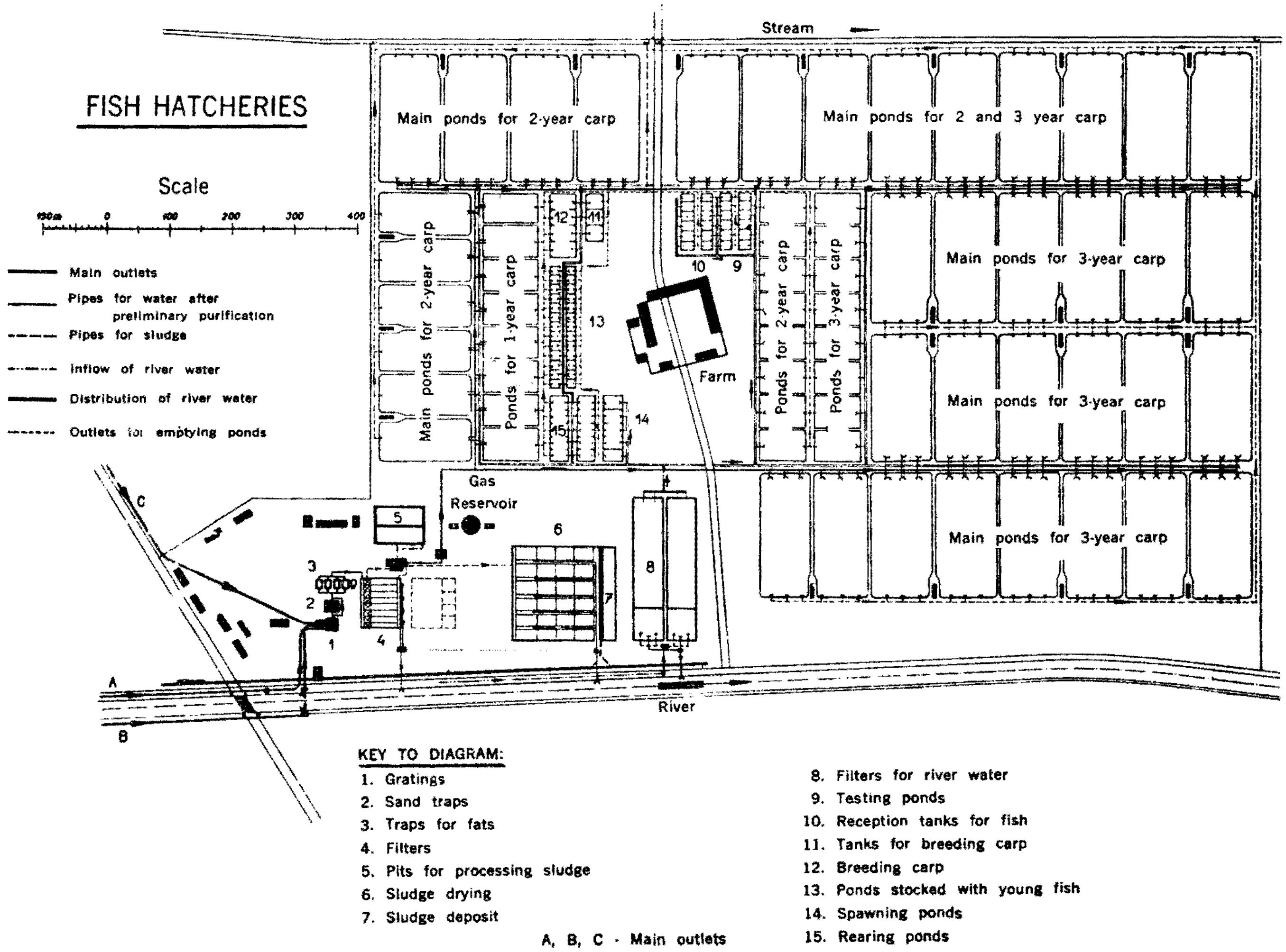

Figure 1

meable. In Bohemia and Moravia-Silesia after the abolition of the last stages of serfdom (1848) much was expected of irrigation in general. The water law, however, gave more support to drainage. Water for irrigation can only be got from reservoirs in a clarified state, that is, surface water, and therefore it is essential to improve it by treated and controllable waste water.

According to researches in land improvement made in Czechoslovakia, irrigation by means of liquid manure diluted at a ratio of 1: 10 proved its efficacy even in the case of an annual precipitation of over 1,000 mm. By the addition of waste water cleansed of floating and easily settled matter to the irrigation water at a tested ratio, the formation of humus in the soil is encouraged, and feeds young growth (for example, in meadows). The stable manure thus obtained can fertilize fields at least five times larger in extent, and thus increase the crops on other areas.

A general scheme of irrigation by Prague sewage water (Zavadil) envisages a mechanical purifying plant 13.62 km. beyond Prague. The supply pipe has a diameter of 2 metres. From the angle of gravitation it dominates an area of 5,700 hectares at the confluence of the Vltava and the Elbe. Beyond these rivers exist other suitable areas. The soil is sandy and suffers from floods, so that it is necessary to protect it with dykes. This restricts infiltration which must be replaced by irrigation. The region is one of the dryest in Bohemia (average annual precipitation 525 mm.).

The quantity of sewer water is much larger than the water brought in by the main water-supply system. Numerous industrial concerns have their own water-supplies (giving, it is estimated, 200 litres per person per day for a population of 1 million). Many of the streets are still surfaced with road metal. Tests show 1.385 milligrammes per litre, according to Imhoff 31.305 milligrammes per litre at 100 litres per person per day. For dilution the water of the Vltava supplemented by water from a reservoir above Prague is used. Observation of the process makes it possible to determine how many and what nutritives must be added to make the conditions as favourable as possible for vegetation. At the same time care must be taken not to overburden the soil either with water or matter.

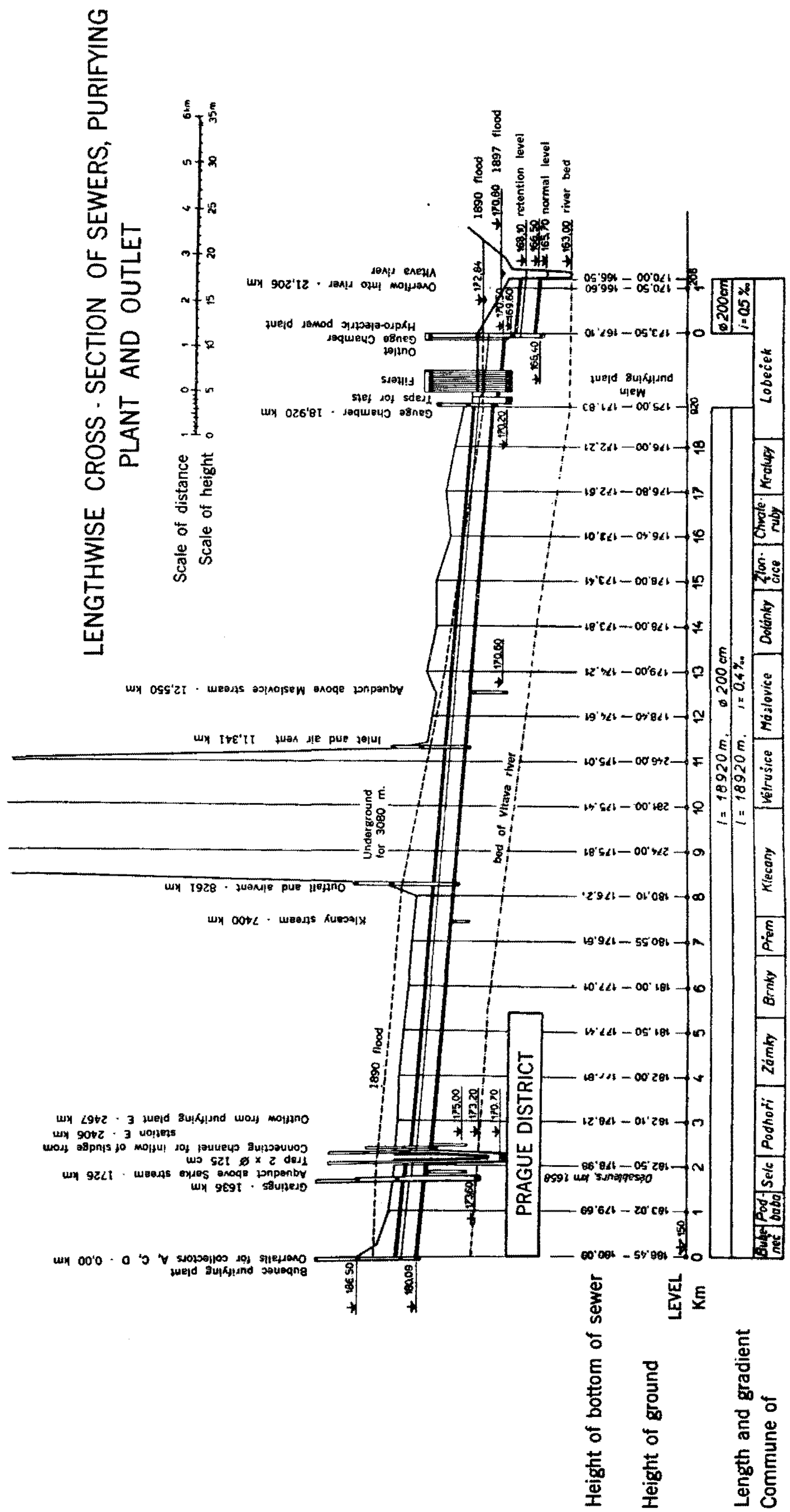
LENGTHWISE CROSS-SECTION OF SEWERS, PURIFYING PLANT AND OUTLET
Scale of distance
Scale of height
Height of bottom of sewer
Height of ground
LEVEL Km
Length and gradient
Commune of
PRAGUE DISTRICT
Bubenec purifying plant
Overfalls for collectors A, C, D - 0,00 km
Gratings - 1636 km
Aqueduct above Sarka stream - 1726 km
Trap 2 x Ø 125 cm
Connecting channel for inflow of sludge from station E - 2406 km
Outflow from purifying plant E - 2467 km
Désableurs, km 1658
1890 flood
Klecany stream - 7400 km
Outfall and airvent - 8261 km
Underground for 3080 m.
bed of Vltava river
Inlet and air vent 11,341 km
Aqueduct above Maslovice stream - 12,550 km
Gauge Chamber - 18,920 km
Traps for fats
Filters
Main purifying plant
Outlet
Gauge Chamber
Hydro-electric power plant
Overflow into river - 21,206 km
Vltava river
1897 flood
retention level
normal level
river bed
l = 18920 m, ø 200 cm
l = 18920 m, i = 0,4‰
ø 200 cm
i = 0,5‰
Bubenec
Pod-baba
Sele
Podhoří
Zámky
Brnky
Přem
Klecany
Větrušice
Máslovice
Dolánky
Zlončice
Chvatěruby
Kralupy
Lobeček

Figure 2

A steady inflow of 0.11 sec./hectare means an annual 3.154 cub. metres or 315.4 mm. per hectare. In the case of 100 litres per head per day this means undiluted wash from 86.4 head of population (average content of nitrogen 100 grammes, phosphor acids 25 grammes, and potash 75 grammes) per cub. metre. Irrigation by means of biologically purified, well-aerated water means a supply of moisture without nutrition and an unfavourable lixiviation of the soil.

Tests at Brno give the following result:

	Evapo-ration	*Gross*	*Colloid and precipit.*	*All*	*Inorganic all gross*	*Colloidal & precipit.*	*All*	*Organic all gross*	*Colloid and precipit.*
Milligrammes per litre	1447	658	789	808	334	474	638	324	314

In 1932 the value of fertilizer matter was fixed in this country at kcs. 80 per person per annum.

Irrigation is envisaged of seeded meadow for one-third of the area under treatment. The second part (improvement by humus) may have a vegetable crop with irrigation along the furrows or spraying by pure water. The third part may be sown with subsidiary crops.

At temperatures under 6 degrees C irrigation is purely mechanical, its effect ceases when the water freezes. But no better results can be expected from any other methods of biological purification not protected from a drop in temperature. It is necessary to consider how long water can be allowed to accumulate.

If under normal conditions 40 quintals of hay are obtained, in the case of irrigation, if treated and controlled waste water is utilized, a crop of 80 quintals per hectare (value kcs. 150 per quintal) can be secured. Reckoning 31 kg. of starch units from 100 kg. of hay, and 3.7 calories from 1 gramme of starch, this gives us 9,176,000 calories.

For a comparison of the utilization of waste water for fishponds and for irrigation it is necessary to take into consideration the competition presented by sea fish, the permeability of the soil, the greater adaptability of vegetation, the greater quantity of vegetable matter and the variety of uses to which it can be put. Outlay on construction and on working will in both cases be substantially reduced with mechanization. Local conditions will show where suitable areas for irrigation are lacking, and where it is necessary to establish biological fishponds.

The smaller the mineral resources of a country the greater the importance attaching to an annually repeated production of organic matter, for which use is found on all sides. By the use of waste water more soil is made available to replace that which is being reduced by the erection of various kinds of buildings.

Biological Purification of Settled Sewage in Shallow Ponds

MAGNUS WENNSTRÖM

ABSTRACT

At a treatment plant at Källby for the sewage from the city of Lund in Sweden, which has about 32,700 inhabitants, a settled sewage with a 5-day B.O.D. averaging 158 p.p.m.[1] is made to pass through a series of 2-ft.-deep ponds, which have areas of 1.28, 1.11, 1.04 and 3.90 acres. About 530,000 US gallons per day pass through the pond system. The estimated detention period is about 8.5 days, and the sewage is kept on the move by means of 1 kw. circulation pumps with a lift of only about 5 inches so that on the average the sewage passes through every pond about six times before it is discharged into the next pond. The city of Lund is situated at a latitude of 55°42″ N, has an average temperature of 73 degrees C, and a total annual precipitation of 24.2 in. Evaporation losses are assumed to be about 15.7 inches per year.

The three ponds first arranged were started in April 1934 and the fourth one in October 1939. It seems probable that by dividing the pond system into several different units we gain the best conditions of life for the bacteria and other organisms of the lowest forms, as well as for zoo-plankton of still higher forms, the further we get towards the outlet of the pond system. Besides bacteria and flagellates, especially active organisms that may be mentioned are *Urostyla weissei Stein*, *Epiphanes senta (Müller)* and *Daphnia magna Straus*, the latter systematically cultivated on the site.

The operating results are as follows :

	Raw sewage	*Inlet to pond I*	*Outlet from pond I*	*II*	*III*	*IV*
B.O.D. p.p.m.	(243)	158	95	66	58	20
B.coli per ml		100,000	40,000	20,000	20,000	30
Total detention time in the pond system days			1.15	2.70	3.75	8.50
Number of re-circulations			6.5	5.8	6.0	5.0

DESCRIPTION OF THE PLANT

The sewage passes through a primary settling tank with a detention period of about 5 hours in dry weather and half an hour when it is raining.

The embankments of the ponds are 3 to 5 ft. high, covered with grass and entirely built up of materials available on the site.

To be able to make effective use of the whole pond-surface all the ponds have distributing arrangements at their inlet and outlet ends. The final distribution of the water takes place on its passage through a plank-piling, in which there is a row of holes which allow the water to pass with a head of a few millimetres and in this way a very even distribution of water over the whole inlet and outlet ends is ensured.

The water has to pass every pond about six times on an average before it is discharged into the next pond. The water which is to be returned from the outlet-end to the inlet-end by re-circulation passes through re-circulation pipes. In pond I the re-circulation pipe consists of a wooden channel about 24 × 28 in. and in the other ponds of concrete pipe-lines of 2 ft. in diameter.

The circulation pumps, driven by 1 kw. motors, are propeller pumps having a diameter of about 16 in. Their heads vary between 4.5 and 5.9 in. and their capacity between 39.5 and 30.5 gallons per second. They are placed in the centre of pump-pits built up of concrete pipes 5 ft. in diameter. In a dividing layer of the pit there is a circular hole for the impeller. In the "lower storey" the settled water or the water coming from the previous pond runs out and mixes with the water from the re-circulation pipe-line.

The mixture is improved by the passage of the water through the pump-wheel, and from the "top storey" the water passes on to the distributing devices to continue its way through the pond.

VOLUME AND COMPOSITION OF THE SEWAGE

During ordinary week-days the daily flow of water to Källby is at present about 1,610,000 gallons of sewage and about 247,000 gallons of subsoil water.

One-tenth of the water brought to the ponds is measured in a tipping bucket gauge. With very small variations the load of water during the last one and a half years has been 530,000 gallons per day, and it has also been possible to keep the flow to the oxidation ponds comparatively constant during the hours of the day and night.

Below it is assumed that the sedimentation undergone by the sewage before it flows into the oxidation ponds reduces the B.O.D. of the water by about 35 per cent. The B.O.D. of the settled sewage has been determined at 158 p.p.m. as a daily average for the week-days Monday to Friday. Ignoring any differences there may be between these and other days of the week, the daily B.O.D. load of the oxidation ponds has been calculated at 700 lb. The analyses, about 180, were made during the period August 1944—October 1948.

During the period May 1943—April 1949 the settled sewage was analysed to determine its content of potassium, nitrogen and phosphorus. Water samples were taken at 9 and 11 a.m. and 3 p.m. and mixed before analysis. Altogether 109 analyses were performed with the following results expressed in p.p.m.:

$K_2O = 30.9 \pm 6.7 \quad N = 40.6 \pm 12.8 \quad P_2O_5 = 6.3 \pm 3.7$

Fermentation tests in glucose broth have shown the number of thermostable coli-form bacteria in the settled sewage to be 100 million, 200 million and 20 million per litre (mean value and upper and lower quartile values). The examinations were made on twenty-three occasions during the period April 1947—September 1948.

[1] Biochemical oxygen demand averaging 158 parts per million.

THE PURIFYING EFFECT OF THE POND-SYSTEM

Sporadic chemical investigations of the ponds have been made since 1935 and more thorough ones were made during the period October 1947—October 1948. Water samples were as a rule taken at 1, 2 and 3 p.m. and analysed separately. Fourteen complete series of investigations were made. They comprise: B.O.D., pH, $KMnO_4$ consumption, dissolved oxygen, H_2S, water temperature, chlorides, alkalinity and conductivity.

The water discharged from pond IV has a B.O.D. with a mean annual value of about 20 p.p.m. If we start from the inlet value during a dry period, 158 p.p.m., the B.O.D. reduction in the whole pond-system will be 605 pounds per day. Thus the purifying effect calculated on the B.O.D. of the settled sewage would be about 87 per cent. Calculated in comparison with the non-treated sewage the decrease of the B.O.D. will be 985 pounds per day, which corresponds to a total purifying effect of about 92 per cent. These results have been reached with a pond-surface area of 1 acre per 1,350 of contributory population. With a pond-surface area of 1 acre per 2,700 persons a total purifying effect of 76 per cent has been obtained, and with a pond-surface area of 1 acre per 8,100 persons the final result has been about 61 per cent.

The distribution of the analytical results will be clear from the following figures (mean value and upper and lower quartile values).

	Raw sewage	*Inlet I*	*Outlet from pond I*	*II*	*III*	*IV*
			104	108	82	44
B.O.D. p.p.m.	(243)	158	95	66	58	20
			78	42	29	12
B.O.D. per cent	100	65	39	27	24	8

By heavy loading of the ponds we have always tried to make the actual oxygen absorption as great as possible. As a rule hydrogen sulphide has been present in very small quantities only. The ponds have—as far as known—never spread any unpleasant odour, and indeed no appreciable odour at all, except in their immediate neighbourhood. The variation of pH has been very slight, with a mean value varying between 7.7 and 7.8 and the lowest observed value 7.5.

The effluent from pond IV has invariably been of extremely good quality, clear and free from odour, in summer-time rich in crustaceans and rotifers and during certain periods also in green algae, which have not had time to be destroyed by the higher organisms just mentioned. A purifying plant operating in this way pays a "licence fee" to the watercourse previously polluted, by delivering to it large quantities of first-class food for fishes.

The bacteriological effect of the pond-system may be seen from the following figures. The settled sewage was bacteriologically examined on twenty-three occasions in the period April 1947—September 1948. The discharge

	Gelatin bacteria	*Agar bacteria*	*Congo-agar bacteria*		*Glucose fermenting coli-bacteria*
	(20° C, per ml.)	(37° C, per ml.)	(37° C, per 10 ml.)	(45° C, per 10 ml.)	(45° C, per litre.)
Inlet	7,000,000 [2] 3,500,000 1,800,000	1,400,000 700,000 320,000	2.000,000 1,350,000 150,000	1,500,000 900,000 120,000	200,000,000 100,000,000 20,000,000
Outlet I	7,200,000 2,100,000 500,000	650,000 330,000 180,000	1,300,000 875,000 500,000	950,000 550,000 300,000	200,000,000 40,000,000 20,000,000
Outlet II	2,500,000 1,000,000 500,000	630,000 320,000 130,000	600,000 200,000 160,000	450,000 210,000 110,000	40,000,000 20,000,000 5,000,000
Outlet III	2,000,000 600,000 200,000	310,000 75,000 37,000	400,000 150,000 80,000	250,000 80,000 40,000	20,000,000 20,000,000 4,000,000
Outlet IV	70,000 17,000 6,000	10,000 4,000 2,000	1,200 400 100	600 200 100	200,000 30,000 2,000
Per cent reduction [3]	99.51	99.43	99.97	99.98	99.97

from the different ponds was examined at least eighteen times in the same period.

As regards nutritive salts in the water only a few determinations have so far been made for the outlet end. There seems to be some reduction in phosphorus and potassium and a considerable reduction in nitrogen.

THE AGENTS IN THE PURIFYING PROCESS

General

The air temperature, length of day, hours of sunshine, wind and precipitation, vital rhythm of the micro-organisms and composition of their communities, movements of water in the ponds, rain falling on the pond-surfaces, infiltration, evaporation, depth of ponds, and the orientation of the ponds in relation to the prevailing winds are examples of the circumstances that with great probability may each have an influence on the purifying process.

For the periods preceding the sampling days and corresponding in length to the time required for the water to flow through the whole pond-system (about 8.5 days), some of the above conditions are known and efforts are now being made to distinguish at least to some extent, the parts played by the different factors. The prospects of doing this will be increased after some new treatment plants of the same type planned by the author have been started. In summer-time there occurs a decrease in the B.O.D. reduction, which is probably due to the oxygen requirement of the dead plankton killed in connexion with the analyses.

Re-circulation

During October 1947—February 1948 additional aeration was arranged in pond I and during the same time the water of the pond was circulated five times on an average. In the period March 1948—October 1948 no additional aeration was made and the water was circulated 6.5 times. In the first-mentioned period the B.O.D. of the effluent of this pond was decreased to about 83 p.p.m.[4] and in the latter period to 87 p.p.m. The difference is insignificant and a comparison between the costs and the efficiency of the two different methods may be made.

In the first period the B.O.D. decreased by 158—83 = 75 p.p.m., i.e., in all 330 lb. O_2/d, and in the second period by 158 — 87 = 71 p.p.m., i.e., 315 lb. O_2/d in all. If the latter quantity is divided by acres of "effective pond-area", that is the real pond-area multiplied by the number of re-circulations, the result will be $\frac{315}{6.5 \times 1.28} = 38$ lb. O_2 per effective acre. The "effective pond-area" during the first period was $5 \times 1.28 = 6.4$ acres. The oxygen absorption in the surface-layers of the pond may then be supposed to have been $6.4 \times 38 = 243$ lb. O_2/d. The difference between the result reached in reality, 330 lb. O_2/d, and the last mentioned amount is 87 lb. O_2/d, which is practically the same result as the effect of the aerator mentioned by the constructor, that is 95 lb. O_2/d. Taking into consideration what is stated above, the result might be taken as indicating that the season can only have an insignificant effect on the purifying process in pond I.

During the first period 1.608 kw. was delivered to the aerator and 0.875 kw. to the pump motor. During the second period the fan motor of the aerator was not in operation and the pump motor received the same power as before. With combined re-circulation and aeration the cost of oxidation was $\frac{2.483 \times 24}{330} = 0.18$ kwh. per lb. of O_2 and with only re-circulation $\frac{0.875 \times 24}{315} = 0.07$ kwh. per lb. of O_2.

The micro-organisms

No mathematical scale for the relative contribution of the different agents of the purification processes can as yet be given. During the time April 1948—March 1949

[2]Mean value and upper and lower quartile values.
[3]Calculated on the mean values: Inlet I—Outlet IV.

[4]Arithmetical mean.

the ponds were biologically explored on eighteen occasions. On these occasions 152 different species were identified.

During the time from 1 October to 1 March the unicelled animal organisms, the protozoa, predominate. During the rest of the year, in addition to these, there are multi-celled organisms of various kinds. The rotifers are particularly well represented and certain crustaceans are sometimes to be found in large quantities.

Daphnia magna Straus, which from the beginning has been systematically cultivated at the place is mainly to be found in pond IV. The same is the case as regards the rotifers, of which the following may be especially mentioned: *Epiphanes senta (Müller)*, *Brachionus rubens Ehrenb. Rotaria rotatoria (Pallas)*, and *Cephalodella catellina (Müller)*.

Among the protozoa identified the following may be especially mentioned. In ponds I, II and III, *Urostyla weissei Stein* is abundant during the greater part of the year with the exception of June to August. *Vorticella microstoma Ehrenb.* has been found in all the ponds, but more so in No. IV and with a decreasing frequency in the direction of the inlet of the pond-system. Its frequency is highest April to November. *Glauchoma scintillans Ehrenb.* is to be found in the whole system of ponds with a more even frequency in the first three ponds and most plentiful during January to April. *Paramecium putrinum Clap & Lachm.* is to be found in all the ponds during the whole year but with a somewhat decreasing frequency in August to November. *Paramecium aurelia Ehrenb.* is also generally found but is most plentiful in pond IV from May to October. *Vorticella campanula Ehrenb.* is practically only to be observed in pond IV, with its highest occurrence from November to January.

Euplotes patella (Müller) Ehrenb., too, is practically only present in pond IV during November and December.

Astylozoon faurei Kahl is also to be found in pond IV and occurs there in December and January.

In ponds I, II and III there is an especially great multitude of bacteria, blue-green algae and colourless as well as coloured flagellates. The frequency of these organisms has as yet only been subjected to certain preliminary investigations. No doubt they all have their tasks to fulfil in the breaking-down process. But there the oxygen-producing green flagellate *Spondylomorum quaternarium Ehrenb.* and many different species of *Euglena* may be especially mentioned. They are all to be found in enormous quantities, the former mainly in ponds I and II and the latter in II, III and IV.

Costs

A heavily loaded biological filter of a size corresponding to that of this pond-system (about 10,000 persons) may at today's prices[5] be estimated as costing about \$40,000. An activated sludge plant may cost about \$67,000. A pond system of the type described above will on flat ground that is sufficiently firm cost about \$20,000 exclusive of the ground and requires power of about 4 kw.

Operating experience

The experience gained with the plant may be summed up as follows:

1. Large surfaces of water and shallow depth provide the best possibilities for oxidation from the atmosphere and good life conditions for oxygen-producing algae.

2. It seems probable that, by dividing the pond system into several units with different standard of the water, well-mixed in every pond, we gain the best life-conditions for the bacteria and other organisms of the lowest forms as well as for zoo-plankton of still higher forms, the further we get towards the outlet of the pond-system. The lowest organisms, the bacteria, the flagellates and the blue-green algae, which perform the hard work of the purifying process, operate with comparatively great rapidity. Because of this, pond I ought to be the smallest one. The higher forms work more slowly and for this reason the size of the ponds ought to be increased in the direction of the outlet. During the warm season the oxygen-producing algae become abundant in the ponds situated in the middle, and in the last pond they feed the enormous quantities of rotifers and of naturalized Daphnids sometimes to be found there. The Daphnids, as first-class food for fish, may be discharged into the river, there to fulfil their destinies in still higher forms of life. The Daphnids which die in the ponds form a very good sediment that has no tendency to ferment, which would probably have been the case with a product consisting of dead green algae.

3. As the direct oxidation which takes place on the surface of the water is directly proportional to the momentary lack of oxygen, it is important that the most "oxygen-hungry" water is always at or close to the surface. To a certain extent this is attained by the re-circulating pumping, which ensures a very effective mixing of the water before every new passage over the pond. The re-circulation pumping ought to be so arranged that the oxidizing process reaches a relative balance in the same length of time as it takes the volume of the water to pass through the pond. An even distribution of the water-flow over the whole breadth of the pond is particularly important.

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[5]In Sweden.

Summary of Discussion

Mr. LE VAN summarized Mr. Wolman's paper on "The Utilization of Surface, Underground and Sea Water", and stressed the general inadequacy of statistical data and the unsuitability of regulations particularly in the United States.

Mr. DWORSKY drew attention to the importance of maintaining a high standard of purity of water and of the atmosphere. Cholera and other epidemics were rife in the East. Water-supplies should be improved not only in quantity but also in quality.

The principal facts, as also the methods which should be used, were of course well known. That was evident in the United States, where mortality from typhoid fever had dropped to 0.2 per one hundred thousand. In many other countries, however, the known methods had yet to be widely placed into use.

The importance of action in that sphere could not be minimized, for to safeguard the health of the individual was to assure a greater output from manpower.

Mr. RAUSHENBUSH thought that Mr. Wolman had submitted a document of importance, which opened the way to numerous questions. He would like to ask four questions.

Firstly, he wished to know how the estimated cost of fifty cents for 1,000 gallons for distilling sea-water had been arrived at; he wondered whether that was a reasonable price or whether it could be reduced. It seemed a reasonable price for drinking water but not for irrigation.

Secondly, he would like to know whether the cost of reclaiming "polders" in the Netherlands, estimated by Dr. Blake at $500 per hectare, was not too high to make the operation worth while.

Thirdly, he wished to know whether the figures quoted for India were quite accurate and whether that country's available water-supplies would really be sufficient to irrigate a larger area.

Finally, he wondered whether the regulations applied in British Columbia should be advocated for less developed countries. He hoped that Mr. Wolman, who was not present, would be afforded on opportunity to give replies to these questions so that they might be included in the Conference Proceedings.[1]

Mr. JUDA said that the plans considered for Los Angeles had indicated that sea-water could be distilled at approximately $ 1.00 to $ 1.25 per thousand gallons.

Mr. S. BUCHAN stated that experiments made in the London area in purifying sea-water had shown that the estimated cost of distilling would be approximately $1.00 per thousand gallons.

Mr. EL SAMNY agreed that the situation could undoubtedly be improved in India, since only surface-water was used there at the moment; dams would have to be built, however, since all the land not under irrigation but suitable for it was higher than the surface-water.

Mr. DE SANTA MARIA recognized the extreme importance of the question of the purification of water. Colombia had been working on that problem for some time past, but the cost of plants was a factor which that country, whose means were infinitely lower than those of the United States, could not overlook. It had been possible to make comparisons with four installations in the United States and several in the United Kingdom, which had shown that Colombia could introduce water purification by much less costly methods than those used in the United States: chlorination, use of ammonium chloride and sand filtration.

Mr. DWORSKY agreed, in regard to the question of cost, that it was customary in the United States usually to use much mechanical equipment; it was often forgotten that the same results could be obtained by much simpler means.

Mr. RINGERS asked Mr. Raushenbush to clarify his question regarding the reclamation of "polders" in the Netherlands.

Mr. RAUSHENBUSH referred to a passage in Mr. Wolman's paper on the importance attached in the Netherlands to the question of water-supply, especially after the draining of new lands. Those observations had reminded him of certain comments made by Mr. Black and published in the United States Press, to the effect that the cost of drainage in the Netherlands would be greater than the value of the land thus obtained. He wondered whether Mr. Ringers could throw any light on that question.

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[1]In reply to Mr. Raushenbush's questions, Mr. Wolman wrote:

"I am much interested in the questions raised by Mr. Raushenbush. The figure of fifty cents for 1,000 gallons for distilling sea-water represents the operation and maintenance costs for small compressor distillation units. If to this figure the interest and amortization charges for the installation are added, the probable cost would be in the neighbourhood of $1.50 per 1,000 gallons. The amortization is figured over a fifteen-year period.

"With present developments under way, the total fixed operation and maintenance costs can be reduced to approximately $1.00 per 1,000 gallons. There is also the possibility for the future of recovering chemicals and commercially significant minerals from the by-product brines, since these are two to three times as concentrated as ocean water.

"As the size of compression distillation plants increases, the efficiency is improved and heat conservation is likewise improved. With larger installations, the total cost per 1,000 gallons, covering fixed charges and operation and maintenance, probably will approach fifty cents per 1,000 gallons.

"The cost of reclaiming 'polders' in the Netherlands, estimated by Dr. Blake at $500 per hectare, may not be too high in those countries where arable land is at a great premium.

"The figures quoted for India's available water resources come from official governmental publications. I see no reason why these figures should not be reasonably accurate.

"The regulations referred to in British Columbia were given as examples of intelligent governmental control. How they should be applied in all countries, developed and undeveloped, would in every instance depend upon the local governmental situation. They were not suggested for blanket application throughout the world."

Mr. RINGERS said that it would be difficult to make an exact assessment of the real cost of the draining operations carried out in the Netherlands. It was estimated that the cost of draining the Zuyder Zee had amounted to $ 1,000 per hectare, or $ 400 per acre, which was not excessive in view of the high price of land in the Netherlands.

In regard to the water-supply to the "polders" thus reclaimed, it should be pointed out that, as a result of the draining of the Zuyder Zee, the Rhine had formed a lake in the middle of that region and thus provided the necessary water. In view of the fact that the Rhine flowed through highly industrialized regions, the Netherlands had of course to make sure that it was not polluted by the influx of industrial waste before entering Netherlands territory. That was a question which should not be overlooked when the peace treaties were signed.

In conclusion, he said that Mr. Wolman had been perfectly right to stress that water was scarce in the Netherlands. Owing to the structure of the soil that country was obliged to procure the water it needed either from the dune area or from rivers.

Mr. LE VAN, referring to reclamation and the treatment of the sewage, remarked that that operation would make it possible to recover large quantities of mineral substances which, as things were, were lost.

The CHAIRMAN asked Mr. Buchan to present Mr. Jansa's paper on "Artificial Ground Water Supplies in Sweden".

Mr. S. BUCHAN gave a brief summary of Mr. Jansa's paper. He drew attention to the various methods by which attempts had been made in Sweden to recharge ground-water supplies artificially, stressing that the only really satisfactory method among them was that whereby surface sources (rivers) were directly drawn upon. Raw water, after initial treatment, (coagulation by alum and quick filtering through sand) ran through infiltration basins into artificial wells, after being purified by passing through successive sand and gravel beds.

He mentioned the height of the beds through which the water had to pass to be sufficiently purified. He then enumerated the principal plants in Sweden where that work was done, and mentioned some of the obstacles which had been encountered owing to the saturation of the sand and gravel beds through waste, organic substances, salts etc. and the way in which those obstacles had been overcome.

He also described some of the methods which it was proposed to use to improve the results obtained, particularly that of blowing air into the soil well below the level of the infiltration basins during filtration, to increase the oxygen content of the water. In conclusion, he emphasized that much was expected of that method in Sweden, which had very little ground-water, all it had being in the small "eskers" area.

The CHAIRMAN requested Mr. Irmay to present his paper on "Water Storage in the Negeb".

Mr. IRMAY read the abstract which appeared at the beginning of the document and which dealt with the need to establish reservoirs in the Negeb. He pointed out the difficulties of such an undertaking owing to the predominating climatic and geological conditions.

In reply to a question by Mr. PAPANICOLAOU, Mr. IRMAY stated that the average annual discharge of the Jordan was 1,000 million cub. metres, as far as the visible flow was concerned. It was estimated that the underground flow had a discharge which was equally great; its waters, however, flowed into the Dead Sea, where they were lost in evaporation. He added that the waters of the Jordan near the mouth were saline.

Mr. PAPANICOLAOU wished to know the discharge per second of the Jordan.

Mr. IRMAY remarked that since measurements and experiments had not started until recently, he could give only an approximate figure. The minimum discharge near Tiberias was some 10 cub. metres per second; the maximum discharge near Allenby Bridge was 660 cub. metres per second. He pointed out that the wadis which flowed into the Jordan and which were torrential in character could reach a discharge in the neighbourhood of 200 cub. metres per second after storms. Lake Huleh and Lake Tiberias acted as equalization reservoirs. Consequently it was more important to know the average annual discharge of the Jordan than to know the discharge per second at a given point.

The CHAIRMAN asked Mr. Dworsky to present Mr. Steel's paper on "The Control and Utilization of Polluted Waters".

Mr. DWORSKY summarized briefly the principal points discussed in Mr. Steel's paper: the importance of the problem of stream pollution, which affected cities as well as manufacturers, agriculturists, property owners, fish life and public recreation; the complexity of that problem, the solution of which required the co-operation of scientists, engineers, manufacturers and lawmakers; the importance of the scientific knowledge already acquired on that subject, especially on the capacity of streams for self-purification which made it possible to predict stream pollution accurately and to control it; the need to establish pollution control in the United States on a river-wide basis; examination of the progress already made in the United States, chiefly in the administrative field (formation of inter-state compacts), the efforts on the part of manufacturers, the significance of the proposed programme for the Merrimack River Valley District, a noteworthy feature of which was the equitable division of costs between the manufacturers and the municipalities, and the importance of the National Water Pollution Control Act (Public Law 845) which was passed by Congress in 1948.

Mr. GOLDSCHMIDT emphasized that the problem of stream pollution was becoming more serious with the development of industry and was extending to areas where it had hitherto been unknown. He regretted that most of the methods suggested in the various papers were directed towards remedying pollution where it existed rather than preventing it where it had not yet occurred. In his opinion it was not enough to provide curative methods, it was equally necessary to stress preventive methods.

Mr. GORMAN, of the Public Health Service of the United States, considered that the attitude recently adopted by the manufacturers in regard to pollution control was quite encouraging. He drew attention in particular to the case of one industrial plant in which no new process could be put into effect until the laboratory of the factory had perfected a method of handling the wastes resulting from that new process.

Mr. Dworsky thought that the problem of dealing with industrial wastes concerned not only the question of pollution control but was in reality linked to the much broader question of the conservation and utilization of resources. Indeed the losses resulting from sewage and industrial waste discharge were considerable. The total figure for the United States was not known but a few examples would suffice to show the magnitude of the problem. For example, forty-seven mining concerns in the State of Pennsylvania had begun to treat anthracite silts, which furnished a very high-grade coal. The profits realized were so great that the concerns in question had ordered heavy machinery in order to recover the silts accumulated on the river bed, where up to that time the wastes had been discharged. In the same way a small American factory, which had been compelled by the local authorities to stop discharging its wastes into a neighbouring stream, was now making a profit owing to the recovery of 4,000 gallons of low-grade ether per year. Some kinds of recovery projects might seem unnecessarily costly and useless in countries rich in resources, but it must be realized that man could not continue indefinitely to waste the natural resources.

Mr. Irmay pointed out that the Institute of Technology at Haifa had for two years been studying the problem of sewage reclamation to provide for agricultural needs. It had been calculated that sewage was capable of furnishing annually 54,000 lb. of nitrogen, 13,000 lb. of phosphate and 6,000 lb. of potassium. Sewage, however, did not constitute merely a source of fertilizer. Properly treated it could also supply water to the arid or semi-arid regions of Israel. Finally, treatment of sewage would also make it possible to put an end to the pollution not of the rivers, of which there were very few in Israel, but of the coastal waters.

Mr. Raushenbush, referring to the section of Mr. Steel's paper which dealt with pollution control, wondered whether the method which Mr. Steel appeared to advocate, namely, the equitable division of costs between the municipalities and the manufacturers concerned, was necessarily the best in every case. He wondered whether the other experts had any suggestions to offer on the subjects.

Mr. Dworsky stated that the method described by Mr. Steel in his paper had not yet been applied; it was merely a plan.

According to the terms of the Federal law already mentioned, American experts would study the question of combating pollution and the purification of water for the country as a whole and would draw up a number of programmes which would take into consideration the various uses of the water. It was a question of a comprehensive study which would require a fair amount of time and which seemed to correspond to that envisaged by Mr. Steel in his paper.

Mr. Juda introduced Mr. Spiegler's paper on "Desalinization of Brackish Waters". He added that at that time the question had not received the attention it deserved. The problem was that of perfecting an economical method of desalinizing brackish waters at low cost. There were two principal methods which, after various experiments, were being considered in industry in Israel. The first of those methods, that of distillation by evaporation, made it possible to desalinate water at a cost of approximately 1 to 2 dollars per thousand gallons, according to the fuel used, the cost of the process remaining the same whatever the salt content of the water. The ion-exchange process, on the contrary, varied in cost according to the salt content, in the following proportions: it cost from 18 to 23 cents per thousand gallons, if the salt content was approximately 500 parts per million; 28 cents, if the salt content was 1,000 parts per million; 45 cents, if the salt content was approximately 2,000 parts per million. In the large factories, however, where lime was used as a regenerant, the cost might be considerably less. It should be noted, moreover, that if the ion-exchange process was accompanied by a treatment of wastes which made it possible to recover a part of the minerals, the cost of the process was diminished still further.

The Chairman drew the attention of those present to two further papers which had been prepared for the meeting and were available to participants. These were the paper by Mr. J. Zavadil on "Control and Utilization of Polluted Waters" and the paper by Mr. M. Wennström on "Biological Purification of Settled Sewage in Shallow Ponds".

The Chairman thanked the experts for the information and suggestions which they had given during the meeting. He stressed the tremendous importance of the exchange of views which had just taken place.

Comprehensive River Basin Development — A Symposium

23 August 1949

Chairman:

Gilbert WHITE, President, Haverford College, Haverford, Pennsylvania, U.S.A.

Contributed Papers:

Comprehensive Planning for River Basin Development
H. VARLET, *Ingénieur en Chef des Ponts et Chaussées, Directeur de l'Electricité et du Gaz au Ministère de l'Industrie et du Commerce*, Paris, France, and
J. AUBERT, *Professeur à l'Ecole Nationale des Ponts et Chaussées; Président de la Cie Française de Navigation Rhénane*, Paris, France

River Development in the Central Valley of California
Richard L. BOKE, Regional Director, United States Bureau of Reclamation, Sacramento, California, U.S.A.

The Snowy River Scheme in Relation to Utilization of Australia's Water Resources
A. S. BROWN, Director-General of Post-War Reconstruction, Canberra, Australia

Economic Utilization and Development of the Water Resources of the Euphrates and Tigris
Vahé J. SEVIAN, Engineer-in-charge of Hydraulic Section, Directorate General of Irrigation, Baghdad, Iraq

Water Supply in the Agricultural Areas of Western Australia
T. LANGFORD-SMITH, Regional Planning Division, Department of Post-War Reconstruction, Canberra, Australia

Experience in the Integrated Development of a River Basin—Excerpt from An Economic Report on the Conservation and Utilization of the Natural Resources of Iran
H. PIRNIA, Director-General of the Ministry of Finance, Iran

Summary of Discussion:

Discussants:

Messrs. AUBERT, MENHINICK, EL SAMNY, BOKE, LE VAN, GARCÍA QUINTERO, IRMAY, HAMID, F. C. RODRÍGUEZ, PAPANICOLAOU, RINGERS, EYSVOOGEL, STROME, HANNUM, FINK, M. BERNARD, DWORSKY, KALINSKI, DYKES, DE VRIES, VAN BLOMMESTEIN

Programme Officer:

Mr. A. E. GOLDSCHMIDT

Comprehensive Planning for River Basin Development[1]

H. VARLET and J. AUBERT

ABSTRACT

A number of objectives have to be reconciled when a plan for comprehensive river-basin development is being prepared. These objectives will be studied in the following order: flood control, sanitation, navigation, power production, irrigation, domestic and industrial requirements, fish-life and wild-life protection. The study will reveal a number of cases in which these objectives coincide or are in conflict.

The apportionment of installation costs and operating income and expenditure will then be examined, as an introduction to the study of the principles determining the place to be assigned to each of these objectives in the over-all plan.

The last part of the paper deals with the structure of organizations entrusted with comprehensive river-basin development.

INTRODUCTION

Many factors must be taken into account in preparing a scheme for comprehensive river-basin development.

The various objectives may be listed as follows:

(*a*) Flood control,
(*b*) Sanitation,
(*c*) Navigation,
(*d*) Power production,
(*e*) Irrigation,
(*f*) Domestic requirements,
(*g*) Industrial requirements,
(*h*) Fish protection,
(*i*) Wild-life protection.

The reconciliation of these various objectives, which is vital, has two distinct aspects. They may be reconciled either in the planning and building of the structures, or in their subsequent operation.

It is advisable to start by examining the various points of view in order to determine the way in which each of them coincides or conflicts with the others.

The facts ascertained in this first examination will have to be used in the subsequent studies: data required for comprehensive planning; principles involved in estimating costs and apportioning them between the various objectives; determination of annual revenue; calculation and apportionment of operating costs; place to be assigned to each objective in the over-all plan; and operation of water-control structures.

The last part of our paper will deal with some administrative features of the types of organization which may be entrusted with comprehensive river-basin development.

OBJECTIVES, METHODS AND RECIPROCAL EFFECTS

Atmospheric precipitations are intermittent, but this feature is only partly reflected in the yield of watercourses. Our ancestors were undoubtedly struck by this phenomenon when they considered the matter thousands of years ago. In regions such as Egypt, where water is the main source of natural wealth, they even deified the rivers whose permanent flow through arid regions in a completely dry climate seemed to savour of the miraculous.

We now know how the natural regularization of yield is produced: it is a result of temporary retention of water on the surface or in the subsoil. Hence it is the variations in the yield of watercourses which cause us concern because they prevent us from making full use of the watercourses.

Man can achieve a certain degree of flood control by imitating the methods of nature. The essential method therefore consists in the construction or use of reservoirs.

Regularization of the yield of watercourses is, moreover, only one particular aspect of the very general process by which civilized man attempts to adapt to any needs which may arise the assets provided by nature in each successive season.

(*a*) *Flood control* consists in a special application of the general principles set forth above.

In the high valleys of watercourses where dams of great height can be built to store hundreds, thousands and even tens of thousands of millions of cubic metres, the flooding of land for the dam basin gives rise, especially in long-civilized countries, to human problems.

The canalization of a watercourse by means of more or less movable dams creates reservoirs of another kind which may also be of use in flood control.

The use of reservoirs for flood-water control has been particularly developed in the United States of America. For certain coastal rivers in the Eastern States it is proposed to build reservoirs capable of storing approximately one-half of the volume of the annual precipitation.

In the management of the Tennessee the proportion of the annual precipitation stored in the high valleys is 10 per cent, and the proportion which can be stored in the upper parts of the canal reaches is also 10 per cent.

In certain special cases, considering the capacity of the existing reservoirs and the height of the flood-protection dykes, flooding cannot always be avoided.

In such cases it is advisable to cut one's losses and allow limited flooding in order to protect other areas liable to flooding.

This was why the Mississippi Commission arranged for a certain number of natural or artificial channels in addition to the river bed for the run-off of water at flood periods. Clearly such flooding is adverse to the agricultural use of the flooded areas, but it is undoubtedly in the general agricultural interest of the valley. The use of such measures entails administrative and financial organization which the inhabitants concerned will not be easily persuaded to accept.

[1]Original Text: French.

The reservoirs also have the effect of decreasing erosion and hence the conveyance of solid matter.

(*b*) *Sanitation:* In their natural state some rivers divide into a large number of channels forming an inextricable and constantly-shifting network. The existence of stagnant channels through which the river has more or less ceased to flow at low-water or even mean-water periods, and of the swamps which usually accompany them, is troublesome from the sanitary point of view.

In certain areas the elimination of mosquitoes is of paramount importance and can be achieved only if the swamps are drained and the water concentrated in a single permanent channel.

(*c*) *Navigation:* The need for a minimum water-level for navigation is another reason for concentrating the river-water in a single channel. This operation is always the first stage in river control and was introduced on the Rhine as early as the beginning of the nineteenth century.

There are now very few wandering rivers in Western Europe; however, the Rhône in the Southern Jura is one of them.

This concentration in a single channel is often accompanied by a shortening of the river which may seriously endanger flood control.

The town of Szegedin was completely destroyed in 1879 by a flood aggravated by the straightening and shortening of the course of the Tisza, a tributary of the Danube.

The concentration of water in a single channel may also have important effects on the longitudinal section of a river and particularly on its longitudinal section at low water. If the river flows in a flat region, the lowering of the low-water level by, say, one metre may result in an almost identical lowering of the level of the water table in the adjacent areas. As these effects may be felt over a very wide belt of territory, the agricultural interests involved may be considerable. This is the case in the valley of the Elbe in Germany, and is the reason why the engineers have forbidden dredging operations in the river-bed.

When it is desired to make a river navigable, the concentration of the river water in a single channel is not considered sufficient, and free flow control or canalization is also introduced.

Clearly in free flow control care must be taken to see that the structures (concave dykes and groins) do not adversely affect the flood-water level. Care is also taken to maintain a low-water level high enough to meet agricultural requirements.

The low-water level is always raised several metres when a river is canalized by the construction of a number of more or less movable dams.

In valleys of the Elbe type this raising of level may have adverse effects on agriculture, but it is possible to counter these by placing drainage canals on both banks of the river, in accordance with the usual practice where artificial navigation canals run between embankments.

For example, when the Kachlet Dam was built on the Danube the river was embanked, and it flows above the surrounding plain for several kilometres. Seepage through the dykes is collected by drainage canals.

The construction of canal dams is, as we will see, favourable to the production of power.

Apart from natural watercourses, navigation also takes place in artificial canals, and their water-supply is a difficult problem.

For this reason storage dams are sometimes constructed, as they are desirable for flood control and for most other water requirements.

We will devote a special section to problems connected with their operation.

(*d*) *Power production.* Hydro-power installations require falls and hence the construction of dams. As we have indicated, this method therefore produces structures similar to or identical with those built for navigation.

From the hydro-power standpoint the operation of making a fall, or a drop in level, may be distinguished from the operation of storage which enables the water to be used at seasons other than those in which there is natural flow.

Although there may be no conflict in the building of the structures, a study of their operation will bring out certain divergencies.

There is an increasing tendency in construction to make high falls for the production of power. We consider that this concentration of the total gradient of a watercourse at a small number of points is also desirable for navigation.

For instance, the navigable waterway of the upper Rhône will have a fall of 65 metres at the Génissiat Dam. Passage through the dam will be effected by means of a flight of locks or a ship-canal lift and will be easier than if the fall of 65 metres were distributed over several dams sited at intervals.

It should be pointed out that the construction of storage dams enables the total production of power to be increased by preventing losses of water.

(*e*) *Irrigation.* The irrigation of land under cultivation is desirable when the local rainfall is insufficient or too irregular.

In practice irrigation and its indispensable adjunct, drainage, almost always enable agricultural yields to be increased, even in the so-called temperate climates.

If the climate is very dry, some types of soil which without irrigation are completely arid are capable when irrigated of producing several harvests each year. Irrigation then produces its maximum results.

In arid regions such as Egypt that part of the river yield which finally flows into the sea is regarded as a loss which should be avoided in the future. There is, indeed, no doubt that improved control of the Nile yield would enable a larger area to be irrigated and would provide additional food for the rapidly-increasing population of Egypt.

Hence in irrigation perhaps more than in any other activity, water should be regarded as a natural source of wealth to be conserved and used under the best possible conditions.

Moreover, the development of irrigation leads to the construction of storage reservoirs, the need for which has been indicated above in connexion with other techniques.

As operating problems will be considered later in this paper, we will for the moment deal only with certain facts.

When a watercourse is canalized, its yield is always sufficient to ensure the operation of the locks. There is therefore no conflict of interest between navigation and irrigation.

This is not true if a watercourse has not been canalized. For instance, the movable dam at Sansanding on the Niger (in the French Sudan) was constructed mainly for irrigation purposes. In accordance with the original plan, which is to be carried out in successive stages, the maximum water intake of the irrigation canals is to be 800 cub. metres per second (to be distributed over 1 million hectares), representing the total yield available during the period under review. It is clear that a yield of that volume accompanied by a suitable concentration of the Niger water would allow a certain amount of navigation on the river below the Sansanding Dam at that period of the year.

Such conflicts of interest may generally be resolved by the construction of reservoirs.

In this connexion we would cite another example which has been selected not for its size but for its historical interest.

Louis XIV gave Riquet (the constructor of the Midi Canal, Southern France) a concession for the sole use of the waters of the Sort (a tributary of the Tarn). The owners of property along the Sort did not contest the validity of the King's decision but complained that the river was completely dried up at certain periods.

The floods of the Sort are very large and sudden and consequently the construction of a storage reservoir would meet the interests of all concerned.

(*f*) *Domestic requirements*. One of the essential conditions to be complied with is the avoidance of water pollution, a problem which was discussed at the previous meeting.

Leaving aside pollution, we would note that water drawn off from a river for domestic requirements is generally returned to the river a short distance below the point of intake. Thus, the water drawn off from the Seine and Marne for requirements in the Paris urban area is returned either at the same level in the downstream section of the Suresnes reach or at a slightly lower level (3 metres lower) in the next reach.

In exceptional cases water for domestic requirements may come from another basin. Thus the piping of water from the Avre (Normandy) by the city of Paris some fifty years ago involved the city in the payment of heavy damages to the riparian proprietors.

Similarly, it is proposed to catch part of the Loire water from the water tables bordering on the river and pipe it to Paris. The pumped water is very pure owing to its filtration through the sand. This plan can be carried out only if an equal, indeed an appreciably greater, quantity of water is taken from the flood yield of the Loire, stored in reservoirs and returned at the appropriate seasons. These same reservoirs will also serve to reduce the Loire floods, which constitute a serious threat to the riverain proprietors.

(*g*) *Industrial requirements*. Water may be taken from rivers for various industrial requirements, but we propose to deal only with water drawn off by riverside factories.

Large volumes of water up to or exceeding 10 cub. metres per second are drawn off by plants generating electricity by steam. After the water has passed through the plant's condensers and the temperature has been raised, it is returned to the river a short distance downstream. In such cases there is no pollution, but in summer the rise in temperature may have adverse effects on public sanitation and may also lead to the disappearance of part of the stock of fish.

On the other hand, during the hard winters, when there were ice-floes on the Seine and Marne and a number of ice-jams had formed above the town, it was noted that the heating of the water by the effluent pumped out of the plants in the Paris area melted all the ice-floes as they passed through Paris.

In other cases the drawing-off of water for industrial requirements raises pollution problems.

(*h*) *Fish conservation*. During the spawning season certain kinds of fish move up the watercourses and must be allowed to cross the dams in order to run upstream to regions where the water is increasingly oxygenated. Water with a high oxygen content is essential for the spawning of certain kinds of fish.

In many watercourses in Western Europe this migration of fish upstream does not appear to result in the conservation of very large stocks, but it should nevertheless be considered. The question is always studied in France when new dams are constructed, and the solution often consists in the building of fish ladders. At the Kembs Dam on the Rhine, where the fall reaches some 12 metres at certain periods of the year, fish lifts have been built.

On the other hand, the migration of salmon is extremely important on the rivers in the western United States, and warrants considerable expenditure. One of the original methods consists in catching all the reproductive fish below a dam. All are killed and used for various purposes, and the hard and soft roes are used for the intensive rearing of fry. The individuals are thus eliminated in order to ensure the survival of the species!

(*i*) *Wild-life conservation*. Wild-life conservation is chiefly important on very large rivers, which owing to their size are beyond the normal scope of river-basin development.

Nevertheless, in medium-sized and even small watercourses the concentration of the water in a single bed both for sanitation and navigation has the effect of eliminating the conditions of habitat favourable to certain types of wild-life. The areas thus reclaimed are generally of use for agricultural purposes, and consequently it may be said that wild-life conservation may be opposed at the same time to sanitation, navigation and the agricultural use of the water.

As an example of this last conflict of interests, the proposed drainage of the water of the Camargue (the name given to the delta of the Rhône) in order to bring part of the area under cultivation, might be unfavourable to the bird population, which includes a number of rare and interesting species such as the scarlet ibis.

We have not attempted to make a complete study of the coinciding and conflicting interests of the various objectives of river-basin development but only to list a certain number as examples.

RECONCILIATION OF THE VARIOUS OBJECTIVES

(1) *Data required for planning of comprehensive river-basin development.*

The principal data are morphological and hydrological.

A full knowledge of the topography of the basin and also of the nature of the watercourse bed itself is essential. Knowledge of the bed is acquired by soundings either by pole or with a lead, or by ultrasonic soundings, the most rapid and practical method, for which several types of apparatus have now been perfected.

From the hydrological standpoint it is necessary to have statistical data covering as long a period as possible. These relate to rainfall and to the levels and yields at various periods at given points on the principal watercourse and its tributaries.

These general data must, of course, be supplemented by special studies of the various techniques. Thus, a sound irrigation and drainage plan can be drawn up only by engineers who have a thorough agricultural knowledge of the area.

(2) *Principles involved in estimating costs and apportioning them between the various objectives.*

When the working plan has been drawn up in all its aspects, the cost is theoretically easy to estimate.

The main uncertainties result from the inevitable gaps in the knowledge of the soil in which the foundations of the structures are to be sited, and also—at certain periods and in certain countries—from instability of the currency.

The apportionment of the various costs between the various objectives is a more difficult problem.

If the whole of the work is carried out and the costs borne by a single organization (e.g., the Tennessee Valley Authority, or TVA), this apportionment is made principally for the sake of clarity. A study of the various financial statements which can thus be drawn up is a valuable basis for similar decisions which the responsible authority may take regarding the management of other river-basins.

When several organizations have to finance the works jointly, apportionment is even more necessary, because it will form the logical basis for an allocation of the costs.

However, experience shows that the State, under whose auspices the management is carried out, is not always interested in a logical apportionment, as certain objectives which are considered more remunerative may be subjected to additional charges in the nature of a tax levied for a particular purpose.

As a concrete example, in Switzerland the Federal Water Supply Department has imposed certain obligations on companies which have been granted concessions for hydro-power developments. Both on the Aar and on the section of the Rhine between Lake Constance and Basle the concessionaires have been systematically obliged to build a lock entrance or even a whole lock.

When the structures are used simultaneously for separate purposes, the apportionment of the costs between those purposes must admittedly be to some extent arbitrary.

For instance, let us consider the management of the section of the Rhône upstream from Lyons for navigation and for power production, and in particular the section of about 120 km. between the lower pond of the Seyssel Dam and the upper pond of the Jons Dam.

The development of this part of the river will involve the installation of plant generating 400,000 kw. and producing 2,000 million kwh. a year.

As regards navigation, it is proposed to provide for the movement and two-way passage at all points of barges of 1,350 tons burden and approximate length 85 metres, breadth 11 metres and draft 2 metres.

The development for both these purposes will involve an expenditure of 72,000 million francs.

If the development were solely for the purpose of power production, the expenditure would amount to 65,500 million francs. On the other hand, if the development were solely for navigation, the expenditure would amount to 45,000 million francs.

We consider that in a development for both purposes at least 6,500 million and at most 45,000 million francs would be chargeable to navigation, but the choice of one or other of these two figures or of an intermediate figure is a matter for agreement. We would add that the determination of the annual profits of operation, which are dealt with later in this paper, might serve as a basis for reasonable agreement.

(3) *Determination of annual revenue.*

The determination of annual revenue may be relatively simple for certain objectives.

As regards the production of power, a value may be assigned to the various types of kwh. produced annually. This value is at least equal to the selling price but in certain cases may be greater. For instance, the TVA allocated a certain amount of power to riparian proprietors on the Tennessee at prices lower than those which would have been charged by a purely commercial organization.

It is more difficult to set a value on the benefits accruing from the creation or improvement of a navigable waterway, as goods transported on navigable waterways could generally be conveyed by rail or road transport at an extra charge which it is difficult to determine in each case. However, the reduction in freight charges and the volume of traffic provide a good indication of the profits accruing from a river development. The longer the period covered the greater is the accuracy of this indication.

Let us take, for instance, the canalization of the lower Seine between Paris and Rouen. In 1840 freight charges were from 12 to 15 francs per ton for goods conveyed between these two towns. In 1910, seventy years later and with a monetary unit corresponding to the same weight of gold, freight charges were approximately

2 francs downstream and 3.25 francs upstream. The total annual traffic in 1910 appears to have varied from 5 to 10 million tons for the various sections of the whole run between Paris and Rouen.

As regards irrigation, assessment of the benefits is most simple when uncultivated land is converted into intensively cultivated land.

In the south of France an irrigated hectare is reckoned capable of producing 15 tons of fodder, the quantity of water used for irrigation being approximately 16,000 cub. metres per hectare per year.

It is clear that a calculation based on these facts produces a far higher figure for the benefits accruing from irrigation than one based on the price charged for water supplied to users. This means that the public authorities give certain benefits free of charge to the users.

It is sometimes possible to evaluate the benefits accruing from the satisfaction of domestic and industrial water requirements and from fish and wild-life conservation by using methods similar to those which we have given as examples.

(4) *Calculation and apportionment of operating costs*

The apportionment of annual operating costs for maintenance of the structures gives rise to the same difficulties as does the correct allocation of installation costs.

On the other hand, the distribution of personnel costs is often easier. In many cases separate personnel are engaged on power production, lock operation and irrigation canal operation. However, the wages of personnel operating the dams remain to be apportioned.

(5) *Place to be assigned to each objective in the over-all plan*

Owing to the conflicting interests which we have indicated above, not all the various objectives can be fully attained, and compromises will have to be made.

Generally speaking, we consider that the best method is to seek to obtain the maximum annual revenue.

Let us consider, for example, the development now under construction at Donzére-Mondragon on the Rhône, where the annual production of kwh. is valued at 2,000 million francs.

If a volume of 16,000 cub. metres of water (the amount required for the irrigation of one hectare for one year) is drawn off above the dam for irrigation requirements, the result will be an annual loss of 800 kwh. (for a fall of approximately 25 metres).

The price paid by the proprietor of the irrigated hectare will be less than the selling price of the 800 kwh. which could have been produced with the same water, but the value in terms of power of the 15 tons of fodder produced will certainly be greater than 800 kwh. Obviously the 15 tons of fodder would in one year feed a number of draught animals able to do more work than 800 kwh.

If the value in terms of power were the only consideration, the conclusion would be that in cases such as that of Donzére-Mondragon, irrigation should be given priority over power production. Moreover, the agricultural possibilities in the lower valley of the Rhône are strictly limited not only by the topography of the area but also by the shortage of labour.

Human considerations, which cannot easily be taken into account in the calculations, may compel one to give absolute priority to certain uses of water. This is particularly true in hot dry countries where irrigation is indispensable to the life of the inhabitants.

(6) *Operation of water-control structures*

This consists in the operation of the dams.

In view of what has been said above, it is hardly necessary to dwell upon the conflicts which may exist between the wish to continue to impound or store water and the wish to allow it to flow.

Two further examples however will clarify this idea.

In order to diminish flood-water, a reservoir must be kept empty as long as rains may be expected. If, on the other hand, the main concern is to increase the low-water yield of a watercourse for navigation (as, for example, by the Fort Peck Dam on the Missouri), it is essential that the reservoir be filled before the period when large precipitations may no longer occur.

If a reservoir is constructed for the production of hydropower in a power-station at the foot of a dam and also for irrigation downstream, there is a further conflict of interests in the choice of the best period for emptying the reservoir. For irrigation must be emptied in summer, whereas from the power point of view it is better to pass the water through the turbines in winter, when in some countries kilowatt-hours are in shorter supply.

Hence the emptying of a lake (and, more generally speaking, the operation of a dam) must be effected in accordance with a plan in which the various interests are reconciled as far as possible.

The preparation of such a plan is complicated, even when power production is the sole objective. However, by taking into account the various values of power at different periods and the values of precipitation observed over as long a period as possible, one can draw up the plan which would have been of the maximum benefit in the past. That plan will be put into effect in the future subject to periodical modifications dictated by observations made in future years.

The plan will determine the volume of water to be discharged in accordance with the date and the water level in the reservoir.

It is much more difficult to prepare such a plan when the objectives in view are numerous, and in some cases it will be necessary to rely on common sense.

A careful attempt to achieve the maximum profit is, however, feasible—as in the case which we have just considered—if the various objectives can be weighed against one another (the best method being the evaluation in terms of money of the various possibilities).

The problems involved have been studied in detail by contemporary French hydraulic engineers. "*Les Réserves et la régularisation de l'avenir*", by Pierre Massé (Hermann et Cie, Paris 1946), may be consulted with profit.

TYPES OF ORGANIZATION TO BE ENTRUSTED WITH COMPREHENSIVE RIVER-BASIN DEVELOPMENT

One method, which has the merit of being straightforward, consists in entrusting comprehensive management to a special organization.

This was done by the Government of the United States of America for the Tennessee development when it gave the TVA important administrative powers and practically unlimited financial resources. The TVA was able to prepare and carry out its plan for development without being dependent on the authorities which are elsewhere responsible for the control of hydro power production, irrigation and management of navigable waterways on behalf of the various States or the Federal Administration. Thus the TVA is in no way dependent on the Reclamation Service or the Corps of Military Engineers which have carried out the management of all the navigable waterways in the United States of America.

Moreover, the TVA has not used pressure against private persons but has educated the interests concerned by means of practical demonstrations so as to encourage them to co-operate freely with it.

There is no doubt of the excellent results obtained by the TVA, but widespread use of that method obviously presents serious difficulties. Thus, even in the United States of America its application was considered but rejected, at least temporarily, for the development of the Missouri.

Nevertheless, when giving a single organization a comprehensive task of development it is possible to adopt the opposite solution to the American one and to withhold from the organization any power beyond those given by the ordinary law.

This was the solution adopted for the *Compagnie Nationale du Rhône* (C.N.R.) founded in 1933.

The C.N.R. was given a general task of river development for the three purposes of navigation, power production and irrigation (flood control could well have been a fourth purpose), and had to proceed in the same way as an ordinary company to which a concession is granted.

It was subjected to numerous and complicated formalities by the various Ministries concerned, in particular by several directorates of the Ministry of Finance, by the Navigable Waterways Directorate of the Ministry of Public Works, by the Electricity Directorate now attached to the Ministry of Commerce and Industry, and by the Directorate of Rural Engineering of the Ministry of Agriculture.

These facts explain why, apart from the war, the carrying out of a scheme such as the Génissiat Power Station has taken a fairly long time. That time was prolonged by the conviction of the whole French electrical industry between 1933 and 1937 or 1938 that there was a permanent over-production of kilowatt-hours in France.

These two examples, the TVA and the C.N.R., appear to us to be two extreme solutions between which less rigid formulae may be found.

For example, the Netherlands Government agreed to delegate some of its rule-making powers to certain joint management companies formed in Holland (for very different and more limited objectives, including the building of toll bridges). Thus those companies have been free to fix charges payable by the public. In return for that delegation the boards of directors of the companies include a number of officials representing the various Ministries concerned.

The C.N.R. has not been relieved of any of the statutory requirements through the presence of similar officials, whose advice has almost always been followed by the board of directors.

We readily acknowledge that it is always difficult to lay down conditions for a system of exemption, but we consider that, when a single organization is entrusted with the comprehensive development of a river basin, it must of necessity be accorded certain powers of its own and its relations with the various authorities which existed before its creation must be clearly defined and simplified as far as possible. Such authorities must, of course, be represented in the new organization.

When the comprehensive planning of river-basin development is entrusted to all the services concerned and not to a single organization, execution is normally more difficult and slower owing to the numerous amicable agreements which have to be made. The machinery for reaching decisions between several independent and powerful authorities without invoking the legislature still remains to be discovered.

River Development in the Central Valley of California

RICHARD L. BOKE

ABSTRACT

The Federal Bureau of Reclamation's Central Valley Project is charged with the task of multiple-purpose development on two main rivers in a highly cultivated, 500-mile long fertile valley in the heart of California. The far-flung system of dams, canals, power-plants and other works now nearing completion, and requiring the closest co-ordination in operation, will help remedy a seasonal and geographical maladjustment of irrigable land and water resources. The legally repayable costs of these initial works, costing $ 440 million, will be financed through revenues from the sale of water and power, under an allocation of costs that throws the major burden on power revenues. Ultimate development of all the land and water resources of the valley, as planned by the Bureau, will cost about $ 3,000 million at today's prices.

Challenging as are the engineering difficulties of river-basin development, management faces even more perplexing problems as to policy. This will be true until national policy as to objectives of valley development is more clearly charted. Must each unit of a valley programme stand economically on its own contribution to the public wealth, or shall the test of feasibility be applied to the complete basin programme? If a river-basin is worth developing as a public enterprise, is it not worth developing fully under the obligation to see that no resource is wasted?

tion and operation extending from the releases of water and power at Shasta Dam in the north to the southern tip of the Friant-Kern Canal, where the last farmer and the last town may get their irrigation or municipal water, and eventually their power. These works will provide over 2 million acre-ft. of water for use in Central Valley. They will be instrumental in bringing some 500,000 acres of new land into production as well as providing a supplemental supply to an equal number now dependent upon vanishing ground-water supplies. They also perform an important function in the delta, the area lying between the San Joaquin and the Sacramento Rivers, where these rivers join to run into the sea, in controlling salt-water intrusion from the ocean—an intrusion that has threatened to destroy tens of thousands of acres of some of the most productive land in the world.

As massive as is this $400 million, 450-mile network, it is only the beginning of full valley development and river control. It represents the basic foundation for what is known as the Bureau of Reclamation's Comprehensive Basin Plan for the Central Valley. That plan includes a total of 38 reservoirs, whose water would develop nearly 3 million acres of not now irrigated land as well as supplying municipal and industrial water urgently needed, both in the valley and in the large municipalities in the San Francisco Bay area. Of the 38 reservoirs, 21 would be used also for flood control. They have been so planned and co-ordinated with the existing and proposed levees and flood control reservoirs as to provide complete flood protection for the Central Valley. Conditions here are unusually favourable for the use of reservoirs for both flood control and irrigation since, by reason of the irrigation draft during the long rainless summer, the reservoirs are empty or partly empty at the beginning of the rainy season in November or December. Rain-floods arising from precipitation in the valleys and foothills are therefore easily controlled. Precipitation in the headwaters of most of the streams is in the form of snow which does not start to melt until about March or April, at which time all danger of rain-floods is past. The snow run-off is also usually adequate to fill the reservoirs for the irrigation season, particularly since reservoir operations can safely be predicated on snow surveys. The power-plants which would be included in a number of these multiple-purpose reservoirs as well as in smaller upstream plants would annually produce more than 8,000 million kwh. of power. Of this, 2,500 million would be needed for project pumping, the rest for further commercial and industrial development throughout California. Equally important, these plants will, where necessary, furnish financial aid to the irrigation features of the dams, canals and pumping plants. Present reclamation law provides no other subsidy to irrigation other than interest-free money for irrigation features.

In addition to the 38 reservoirs and the attendant power-plants, the plan contains a system of transfer canals, transmission lines and pumping plants that would tie together all of the water and power features of the entire river-basin. They would be the means of getting additional surplus waters from north to south, and power from generating plants to project pumping plants and commercial load centres.

Most important to the project's planning and operation, both physical and financial, is the concept of co-ordination. In this case, through integration, the whole is greater than the sum of all its parts. The combination of dams, reservoirs and canals operated as a unit will produce more water to irrigate more lands than will the totality of dams and reservoirs operated separately. Also the power plants of this system will produce more power operated as a unit than if operated separately. This is another way of saying two things: one, that the financial returns from these works will be greater (and, therefore, the return of the public moneys greater) through carefully co-ordinated planning, construction and operation of these works; and two, that a full development and use of the valley waters, power supplies and other resources can be obtained only through a single central plan and single integrated operation. What is needed, and what the Bureau of Reclamation proposes for the Central Valley, is to extend the concept of the multiple-purpose dam (which is now the accepted unit with its many functions and duties) to the concept of a multiple-purpose basin plan into which geographically separated dams, canals, power-plants and other works become both physically and financially part of what is essentially a single structure, even though the diverse parts of this structure spread over 500 miles of valley and mountain. We know that only through doing this can we take full physical advantage of the natural resources of the valley. We know also that only through utilization of such a comprehensive plan can such a development be financed and the costs repaid by the direct beneficiaries of the project, the water and power users.

Under present legislation, or under any probable modifications of that legislation that might be enacted in the near future, it is perfectly clear that a basin plan for the Central Valley is feasible only if the more profitable elements of the plan contribute to the less profitable. This will be accomplished by the deposit of the revenues from all operations into a common pool, and the payment, where necessary, for the various features of development out of that pool. To achieve this, it is probable that the type of cost allocation used in the Central Valley project will be extended to the Basin Plan, though undoubtedly the approach will be modified as experience dictates and to meet new problems which arise in bringing together financially this more complex structure of added physical plant.

The method of cost allocation being applied in the initial features of the Central Valley Project is really a combination of two because there seem, upon examination, to be two methods for which a reasonable claim to validity exists in application to the problems of the Central Valley Project. The first is the alternative justification method which has been widely used in the past. The second is the proportionate use method, modified to provide recognition of such priorities as navigation and flood control governing the operation of joint facilities, and to insure that in the case of each function the cost allocated thereto should be the least of the following three: (1) appropriate cost under the present project, (2) the cost of attaining the same purpose by an alternative single-purpose means, and (3) the value of the benefits.

There is no space here to go into great detail in describing cost allocations. The most significant results, both for the Central Valley Project and as they may be projected into the basin plan, are these: this cost allocation, after $49,527,000 has been charged to navigation and flood control as non-reimbursable benefits, allotted approximately $200 million to irrigation and a little over $100 million to commercial power. In contrast to the amount allocated to these repayable functions, irrigation, under our scheme of allocation and repayment, will repay through water revenues only $55 million out of the $200 million, while commercial power will repay not only the $100 million allocated to it, but an additional $123 million. This $123 million, together with surplus payments from municipal water amounting to $20 million, will repay the costs of irrigation structures which water users are unable to repay. The total repayment of the project under this arrangement would be accomplished approximately by the year 2009. The allocation here is most significant in demonstrating, in a general way, the kind of application such an allocation and repayment schedule would have in the basin plan of development in which single-purpose upstream power plants would contribute to the building of canals 200 miles distant and often with no direct physical connexion. It is a certainty that within the framework of present thinking, unless the pooling of revenues along these lines is accomplished, the water resources and therefore the lands of California cannot be fully developed. Present legislation does not give either an adequate base to achieve physical pooling of the units of the basin plan or this financial pooling essential for economic feasibility. Both the public and the legislator must understand these needs if the full development of the Central Valley is to be attained.

There has been implicit here an assumption that if a river-basin is worth developing at all as a public enterprise, it is worth developing fully and that in a very real sense the objective of river-basin planning is complete utilization of watershed resources. I suggest that the public test of economic feasibility is a test to be applied to the complete programme and not to each of the analytically-separable parts. Obviously this is not a settled question of philosophy or policy. Public ventures such as the Central Valley Project inhabit a twilight zone between social vision and hard-boiled accountancy. Economists can point out that some features of the Central Valley Project may cost more than they contribute directly to the public wealth and that it is economically inefficient to tax a profitable feature to subsidize a romantic conception of completeness. The obligation to see that no resource is wasted is a self-imposed obligation and may not meet the standards of rationality which cost accounting imposes.

It must be readily conceded that river-basin plans must meet a general test of economic feasibility. The engineer and the planner have no licence to pursue at public expense ends which are only technical and aesthetic. The monetary calculation of costs and benefits, though a crude criterion, is nevertheless an important one. National resource development is approaching a position in democratic policy where it may claim the same degree of immunity from accountancy that public education and public health enjoy. A reasonable extension of the concept of the democratic right to an opportunity for self-development may some day put economic opportunity on a par with educational opportunity. That day has not yet arrived and the benefits of resource development must still be measured against its economic costs.

Judgment can be based on a single test: if on reasonable economic criteria the complete development of a river-basin is feasible, it is the task of social policy to determine whether only the more profitable features should be undertaken. If there is any lesson to be learned from an attempt to understand the complex interdependence of the natural resources of river-basins, it is that there exists a kind of organic unity which persistently suggests that the proper object of planning, development and administration is the total potentiality of the river-basin.

The Snowy River Scheme in Relation to Utilization of Australia's Water Resources

A. S. BROWN

ABSTRACT

The development of Australia's resources is limited by its water resources and its power supply. The Snowy River scheme is a plan to divert the waters of the Snowy River near its source in the Australian Alps for the purposes of hydro-electric power generation and irrigation. The potential installed capacity of the scheme is 1,720,000 kw. with an output of 6,650 million kwh. (more than two-thirds of the total output of the Tennessee Valley Authority).

Investigations into the best use of the waters of the Snowy River were narrowed down to two main alternatives, namely diversion into the Murrumbidgee or the Murray River. Diversion into the Murray River had the advantage that more electric power could be generated than if the river were diverted to the Murrumbidgee, and was, at the same time, much less costly. A question of some importance was whether, after the power had been generated, the water could be used to equal advantage for irrigation purposes in either river.

In considering the two alternatives, further proposals based on the river Tumut provided a solution from which has been evolved a scheme that provides for the generation of more power than either of the two original proposals provided. By diverting the Snowy River inland the additional water can be used for irrigation instead of flowing unused into the sea.

In May 1949 the Government of the Commonwealth of Australia brought down legislation to establish the "Snowy Mountains Hydro-electric Authority", which is to implement the plans for diversion of the waters of the Snowy and Tooma Rivers near their source in the Australian Alps (south-eastern New South Wales, see Figure 1) for the purposes of hydro-electric power-generation and irrigation development. A conservative estimate of the potential installed capacity of the scheme is 1,720,000 kw. with an average annual output of 6,650 million kilowatt-hours. This is a little more than two-thirds of the total output of the Tennessee Valley Authority. The additional plant will double the present installed capacity in Australia of all power producing plants.

Australia, in spite of its large area of almost 3 million square miles has a population of only 7½ million persons (1947 census) or 2½ persons per square mile. This low population-density has led at times to serious misconceptions of Australia's population-carrying capacity which has often been grossly overestimated. More than one-third of Australia has an average annual rainfall of less than 10 inches and is consequently almost uninhabited. The arid nature of the central and western areas of Australia due to low rainfall is one of the major limitations to Australian development. Half of the remainder of the continent has an average rainfall of less than 20 inches per annum and usually a high rate of evaporation, and is therefore too dry for close agricultural settlement.

The most highly-developed and closely-settled parts of Australia are the east coast and south-eastern corner. Even in the east coast, which receives the higher rainfall, the best use of the waters cannot be made because many rivers which rise in the Great Dividing Range, roughly parallel to and close to the east coast, flow through short courses direct to the Pacific Ocean with the result that a substantial proportion of their water is wasted. West of the Great Dividing Range there is only one large river system, the Murray-Darling, draining a basin extending from southern Queensland and New South Wales and Victoria into South Australia. Further large-scale irrigation development in Australia must be limited to areas where sufficient water and suitable soil conditions are found. Only a few such areas remain undeveloped. It is possible, however, to make use of the waters of the Snowy River for irrigation purposes by diverting its flow into one or more of the streams constituting the Murray-Darling system and this is what will be done by the present scheme.

The use of water for production of hydro-electric power is possible in a few areas only, the important ones being in Tasmania, the Australian Alps and New England (New South Wales). As it is normally more economical to produce power from water than power from coal, it is natural to expect that the major remaining sources should be developed to assist in producing power. Australia, hitherto an agricultural country, has in the war and post-war period greatly expanded her secondary industries and they will continue to expand. The demand for electric power has doubled in the last ten years and is rapidly growing. Although there are large deposits of coal in New South Wales and Queensland production is well below existing demand.

Australia's development, therefore, very largely depends on, and is limited by, its water resources and its power supply. The Snowy River, which is fed from Australia's best snow country is a potential source of hydro-electric power. Although a relatively short river, its annual run-off is 1,700,000 acre-ft. but nearly all of its water is lost as it flows out to the sea through an area which could not be irrigated on any large scale. In fact, with the exception of an agricultural area near the coast, very little use is at present made of its waters. For many years it has been recognized that the Snowy River was a most valuable but wasted asset and many proposals have been put forward for schemes which aim to divert the flow of the river westwards into rivers such as the Murray or the Murrumbidgee, where the water could be used for irrigation purposes. At the same time, since the river rises in Australia's highest mountains, hydro-electric power could be produced and supplied to either Melbourne or Sydney, or used for development of the inland.

The Snowy River, which is about 300 miles long, rises on the slopes of Mount Kosciusko and flows almost due south to the sea. (See Figure 1). In the upper part of the river it flows through deep rugged country for about 30 miles until it opens into a plain about six miles long and three miles wide just before it reaches Jindabyne. Above Jindabyne, the catchment area is about 700 square miles, the catchment having a length north and south of 54 miles and an average width of about 12 to 13 miles being nowhere wider than 23 miles. If a dam is placed at the downstream end of the plain a natural reservoir is formed, the top water-level of which will be at 3,000 ft. above sea-level. The total catchment of the whole Snowy is 5,210 square miles and from "very exhaustive examination of the stream-flow records of the Snowy River at the gauging station of the proposed Jindabyne dam site, and also at the Jarrahmond gauging station in Victoria, it has been concluded that the average flow of the Snowy River at Jindabyne would be about 50 per cent of the total run-off from the whole of the catchment area of the Snowy River under natural flow conditions".

All the proposals concerned with the Snowy are based on this dam at Jindabyne and they all contemplate the diversion of all the water that it is practicable to divert at this point. On the above estimate the quantity or water diverted will be roughly half the flow of the Snowy, and this should not cause any serious disadvantage to the people living near the mouth of the river around Orbost.

THE MURRUMBIDGEE SCHEME

This scheme involves a dam at Jindabyne (see Figure 2) 198 ft. high and with a storage capacity of 647,000 acre-ft.; a tunnel from the north-east side of the Jindabyne dam running 22½ miles easterly to Bridle Creek, a tributary of the Murrumbidgee; a flume or race from Bridle Creek to the Murrumbidgee—a distance of 4¾ miles; a power-station (21,000 kw.) at the Murrumbidgee; and a dam on the Murrumbidgee at Billilingera 184 ft. high with a capacity of 1,143,000 acre-ft. A second power-station with an installed capacity of 25,000 kw. would also be provided to use the waters released from Billilingera Reservoir.

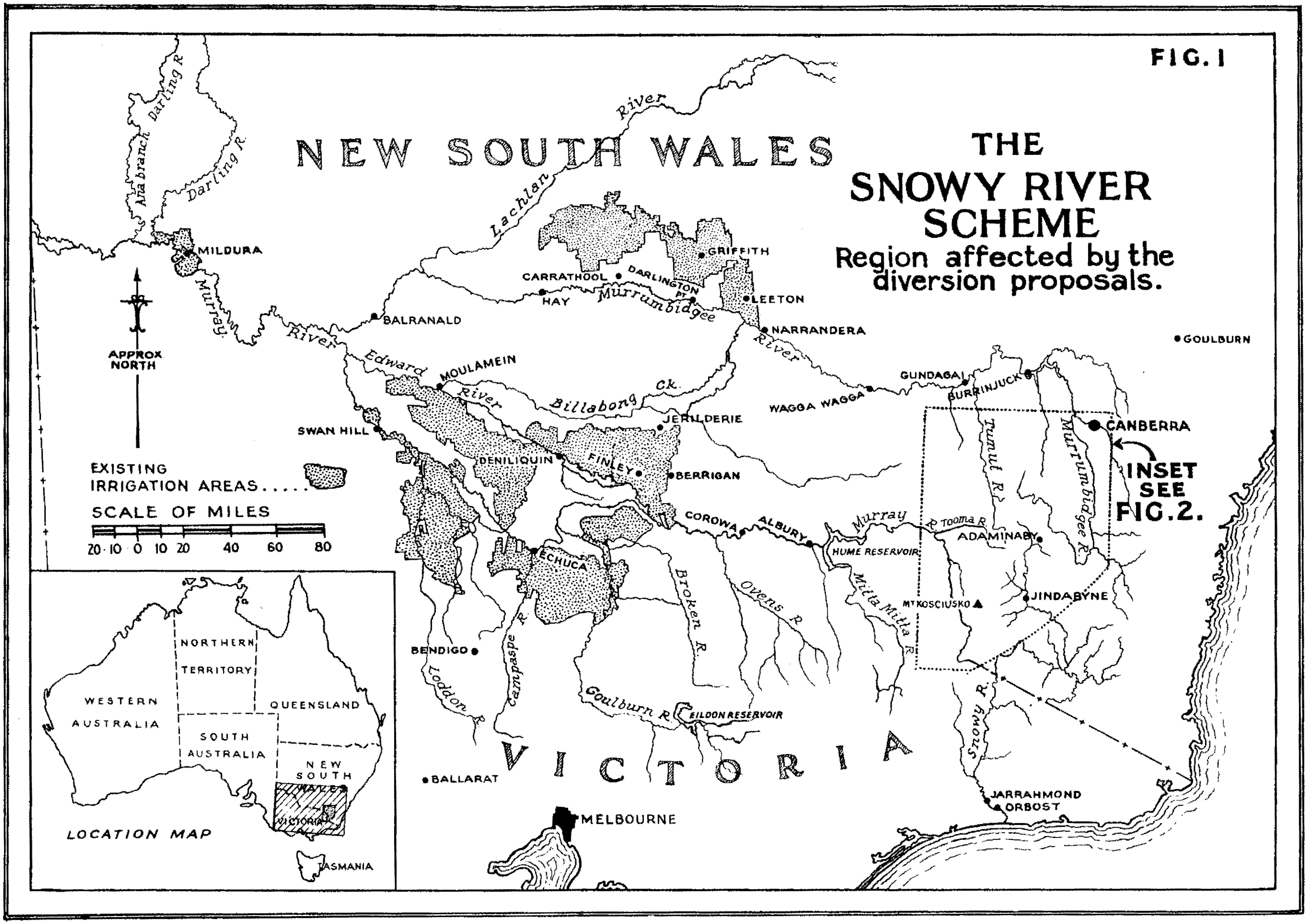
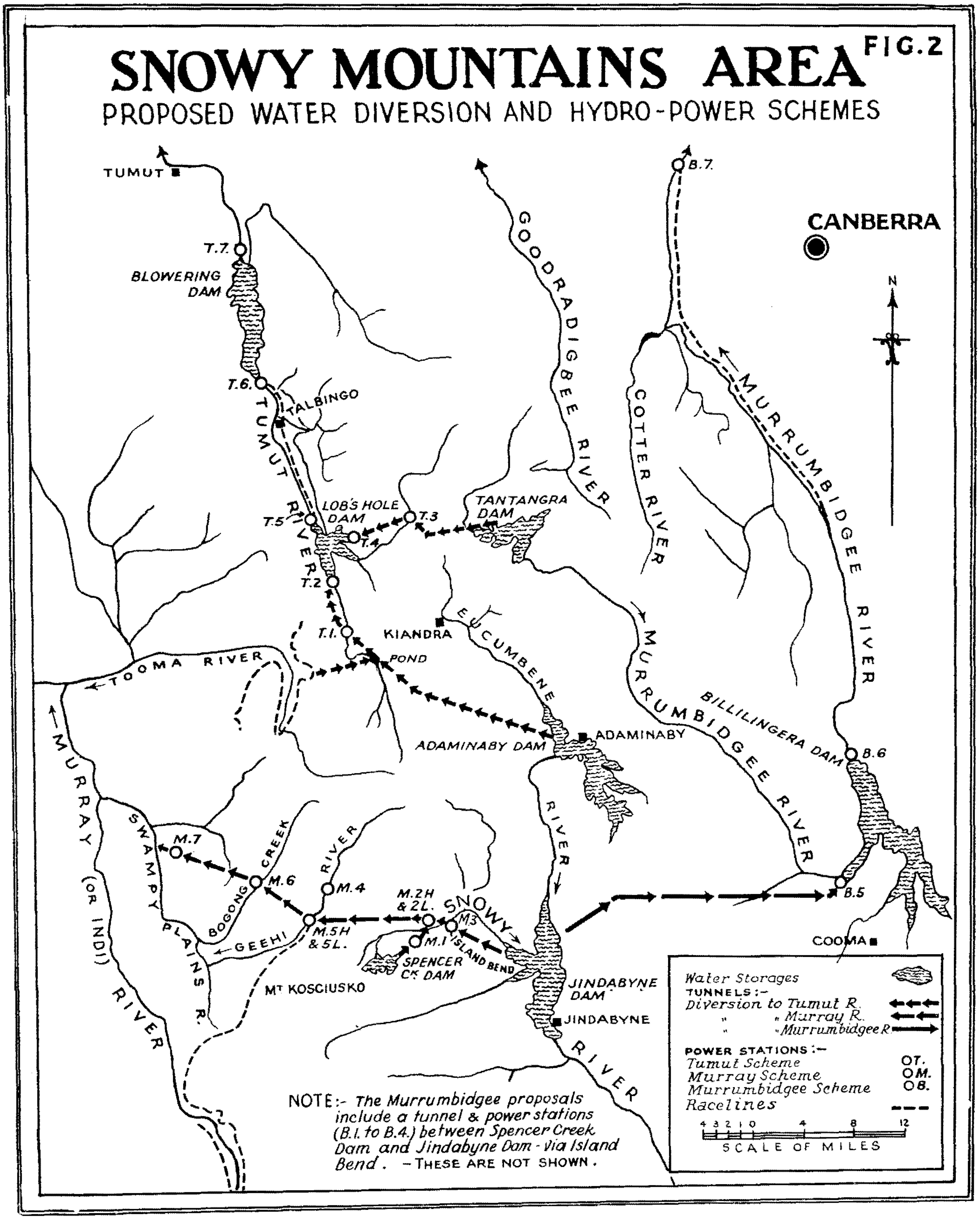


FIG. I
THE
SNOWY RIVER
SCHEME
Region affected by the diversion proposals.
NEW SOUTH WALES
VICTORIA
APPROX NORTH
EXISTING IRRIGATION AREAS .....
SCALE OF MILES
20 10 0 10 20 40 60 80
LOCATION MAP
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
INSET SEE FIG. 2.
MILDURA
BALRANALD
CARRATHOOL
HAY
DARLINGTON PT.
GRIFFITH
LEETON
NARRANDERA
GOULBURN
GUNDAGAI
BURRINJUCK
CANBERRA
WAGGA WAGGA
JERILDERIE
MOULAMEIN
SWAN HILL
DENILIQUIN
FINLEY
BERRIGAN
COROWA
ALBURY
HUME RESERVOIR
ADAMINABY
JINDABYNE
MT KOSCIUSKO
ECHUCA
BENDIGO
BALLARAT
EILDON RESERVOIR
JARRAHMOND
ORBOST
MELBOURNE
Darling R.
Ana branch
Lachlan River
Murrumbidgee River
Murray River
Edward River
Billabong Ck.
Tumut R.
Tooma R.
Snowy R.
Mitta Mitta R.
Ovens R.
Broken R.
Goulburn R.
Campaspe R.
Loddon R.


SNOWY MOUNTAINS AREA
FIG.2
PROPOSED WATER DIVERSION AND HYDRO-POWER SCHEMES
TUMUT
B.7.
CANBERRA
N
T.7.
BLOWERING DAM
GOODRADIGBEE RIVER
T.6.
TALBINGO
TUMUT RIVER
COTTER RIVER
MURRUMBIDGEE RIVER
LOB'S HOLE DAM
T.5
T.3
T.4
TANTANGRA DAM
T.2
T.1.
KIANDRA
POND
EUCUMBENE
TOOMA RIVER
MURRUMBIDGEE RIVER
BILLILINGERA DAM
B.6
ADAMINABY
ADAMINABY DAM
MURRAY (OR INDI) RIVER
SWAMPY PLAINS R.
M.7
BOGONG CREEK
M.6
RIVER
M.4
M.2H & 2L.
SNOWY
M.3
B.5
M.5H & 5L.
GEEHI
M.1
ISLAND BEND
SPENCER CK. DAM
COOMA
MT KOSCIUSKO
JINDABYNE DAM
JINDABYNE
RIVER
Water Storages
TUNNELS :-
Diversion to Tumut R.
" " Murray R.
" " Murrumbidgee R.
POWER STATIONS :-
Tumut Scheme OT.
Murray Scheme OM.
Murrumbidgee Scheme OB.
Racelines
4 3 2 1 0 4 8 12
SCALE OF MILES
NOTE:- The Murrumbidgee proposals include a tunnel & power stations (B.1. to B.4.) between Spencer Creek Dam and Jindabyne Dam - Via Island Bend. - THESE ARE NOT SHOWN.

The first power-station would have a high load-factor, that is, it would be in operation for the greater part of the time because water could pass through it and be stored by the Billilingera dam. The other station would be intermittent in operation because it could be used to develop power only when water was being drawn out of the river, primarily for irrigation purposes. There is at present a power-station at Burrinjuck, lower down the river, and the extra water in the river would enable some further development of power there—about 4,000 kw. Further investigation since the scheme was first outlined has resulted in some improvements, for example, the tunnel has been extended to the Murrumbidgee Valley, but otherwise the scheme remains basically unchanged. For the improved scheme, the output is 75,000 kw. of power at varying load factors and 1,015,000 acre-ft. of water for irrigation (835,000 from the Snowy and the balance from the further regulation of the Murrumbidgee).

THE MURRAY SCHEME

In its essence, the Murray scheme is the same as the Murrumbidgee. This scheme requires the dam at Jindabyne and a tunnel going westward instead of eastward and in the same way there is a power-station at the end of the tunnel. The tunnel is about 30 miles long. In each case, the tunnel is kept practically flat and then there is a sudden fall at the end. It is this fall in the water flowing through the tunnel that develops the hydro-electric power.

The important difference between the schemes is that whereas the total fall from Jindabyne to the Murrumbidgee beyond Bridle Creek is about 500 ft., the fall from Jindabyne to Swampy Plains River (Murray) is about 2,000 ft. So, from this fact alone, you would expect about four times the amount of power to be developed by this scheme as by the Murrumbidgee diversion because the fall (or head as it is usually called) is four times as great. The obvious difference, then, is that in place of the 75,000 kw. for the Murrumbidgee scheme, the basic quantity of power developed by the Murray scheme is about 300,000 kw.

But there is another important difference. The rainfall in the area west of the Snowy Mountains is a good deal greater than it is to the east, and this Murray tunnel passes under some quite large rivers—first the upper portion of the Snowy near Island Bend, then the Geehi, the Bogong and the Khancoban Back Creeks. The engineers have taken advantage of this fact to develop more power. At Island Bend in the Snowy, about 7 miles as the crow flies upstream of the Jindabyne outlet, the tunnel passes below the bed of the Snowy at a depth of about 1,000 ft. If a shaft is sunk and the water allowed to fall down this shaft instead of falling slowly down the river into the dam and then back along the tunnel, additional power can be developed at this point. Thus we have the No. 3 power-station located underground. Similarly, the tunnel passes below the Geehi River and another power-station, No. 5L, is planned there.

A third difference is this. It is possible to develop a substantial quantity of power by the use of the waters of the Geehi and Indi at a high level. This can be done more economically in combination with the Murray proposal than in combination with the Murrumbidgee. Reference will be made later to this aspect of the proposal.

COMPARISON OF SCHEMES

It is difficult to compare the over-all effects of the two schemes. In terms of total installed capacity and cost per kwh., the estimates are as follows: For the low-level Murrumbidgee development, that is Stations Nos. 5, 6 and 7—No. 5 at the tunnel outlet, 75,000 kw.; No. 6 at Billilingera, 25,000 kw. and No. 7, not yet mentioned but planned in the Australian Capital Territory three miles above the Molonglo Junction, 72,000 kw.—the total installed capacity will be 172,000 kw. with a load factor[1] of 60 per cent. The Hydro-electric Committee appraises the firm output of these three installations at 147,000 kw. For the Murray scheme the Committee gives the figure of 620,000 kw. as a comparable figure for the output of Stations Nos. 6 and 7 at Bogong Creek and Swampy Plains. The respective capital costs are £32.2 million for the Murrumbidgee and £23.4 million for the Murray, i.e., £187 per kw. of firm power for the Murrumbidgee and £38 for the Murray. The Committee gives a figure of £72 per kw. as the cost of installation of equivalent steam stations, that is, stations using coal. It is plain that if the proposals are considered as power propositions, the Murray scheme is greatly superior to the Murrumbidgee. It produces about four times the amount of power at about one-fifth of the cost per unit of power. The Murray scheme would be recommended as a power project because it produces power at half the cost (roughly) that power can be produced from coal, whilst in the Murrumbidgee scheme the cost per unit would be more than twice the amount produced from coal. Of course, I am referring only to the low-level development at this stage but this would take something in the order of ten to fifteen years to construct.

UPPER DEVELOPMENT

Some attention has been given to the development of power at a higher level than Jindabyne dam. These developments are in a large measure common to the two schemes although there are some variations in layout.

Murrumbidgee scheme		*Murray scheme*	
Station	*Kw.*	*Station*	*Kw.*
No. 1	50,000	No. 1	92,000
No. 2	68,000	No. 2H	22,000
No. 3	70,000	No. 2L	42,000
No. 4	180,000	No. 3 (Is. Bend)	190,000
Total	368,000	Total	346,000

In the various committees' reports they roughly correspond to Stage 2. They would add about 450,000 kw. to the Murrumbidgee proposal and about 480,000 kw. to the Murray proposal. In essence the scheme is based on a dam at Spencer Creek, which is nearly as high as the

[1]Load factor is the expression of the ratio which the number of kilowatt hours (energy) actually supplied during a given period bears to the number of units which would have been supplied had the maximum demand been sustained throughout that period.

Chalet on Mt. Kosciusko at an elevation of 5,833 ft. The latter is 2,833 ft. above the level of the Jindabyne dam, and the fall occurs within 18 miles. It is proposed to develop power at each of four stations in each scheme (see table on previous page).

This high-level development is a very costly part of both schemes. The Spencer Creek dam, with a water level at 5,833 ft. would need a retaining wall 173 ft. high which would itself cost £10.6 million. If the wall were to be taken up another 30 ft. it would cost a further £3 million.

The second upper development is the Geehi and Indi development mentioned earlier. The Geehi is a tributary of the Murray which falls from 5,000 ft. to 3,000 ft. in about three miles. Provision has therefore been made in the Murray scheme for two power-stations on the Geehi—Nos. 4 and 5. These two power-stations in themselves will provide 113,000 kw. of installed capacity but they are expected to operate at a low load factor (29 per cent). Provision has also been made to bring into the Geehi by means of race-lines water that would otherwise flow into the Upper Murray or Indi River. After this water is brought into the Geehi it can be dropped down a shaft into the main tunnel in the Murray scheme and this of course enables a further quantity of power to be developed. In one sense this Geehi and Indi scheme is an independent scheme and can be considered independently of the two schemes but there are very substantial advantages in combining it with the Murray scheme. The Hydro-electric Sub-Committee reported:

"Without the main Snowy-Murray tunnel the advantage of being able to use the Jindabyne storage is lost. To enable independent developments to meet power demands at any time they would have to carry their own storages. In the case of the Geehi it appears to be possible to obtain enough storage at Windy Creek and on the Geehi River to make a scheme practicable. The scheme for the Murray, however, would require more storage than can be economically provided".

TUMUT PROPOSALS

While considering these proposals the Committee's attention was directed to the River Tumut (see Figure 2). In a distance of about 17 miles, as the crow flies, from the junction with Happy Jack's Creek to Lob's Hole there is a fall of about 2,000 ft. The Tumut is a tributary of the Murrumbidgee joining the main stream near Gundagai, but it is a difficult river to regulate for either power or irrigation requirements. The main difficulty has always been to find a storage site at a high level to enable the stream to be regulated for power purposes. The Eucumbene Valley has provided a solution. Immediately south of Adaminaby is a storage basin comparable with that of Jindabyne. Here a million acre-ft. of storage can be obtained relatively cheaply. The top water level in a dam at Adaminaby would be 700 ft. higher than the dam at Jindabyne, i.e. 3,700 ft. instead of 3,000 ft. It is obvious then that there will be advantages in passing as much water as possible down the Tumut. This involves the following works: first a dam on the Eucumbene at Adaminaby, then a tunnel from the dam across to the Tumut (16 miles) and a small pond on the Tumut. As there is also a good fall between the Upper Murrumbidgee itself and the Tumut, the proposal is to put a dam on the upper Murrumbidgee at the Gulf (Tantangra) and another tunnel of about 14 miles from the Upper Murrumbidgee to Lob's Hole. This would also pick up the water from the upper reaches of the Yarrangobilly River. Both these tunnels would bring water westward into the Tumut. It is possible also to bring water from the upper part of the Tooma eastwards, by means of a tunnel of about five miles, into the Tumut at the same point where the tunnel from the Adaminaby dam joins the Tumut. There would be five power stations at various points down the Tumut and two power-stations between the Upper Murrumbidgee and the Tumut, making a total of seven. Finally, a dam is needed lower down the Tumut to enable the water to be stored for irrigation. Thus the scheme, so far as the Tumut is concerned, consists of four large dams and a pond, and four diversion tunnels and seven power-stations connected by appropriate tunnels or canals. One of the tunnels, the tunnel between the Adaminaby dam, the pond on the Tumut, and the Tooma tunnel, calls for special attention; it is the key to the whole scheme because it is to be so constructed that water can be made to flow either from the dam into the Tumut or from the Tumut into the dam, depending on the level of water in the pond and in the dam.

As the water from the Eucumbene is taken from the pond above the Jindabyne dam, as much water cannot be diverted into the Tumut as could be diverted at Jindabyne; in fact, one can divert only 235,000 acre-ft. about a quarter of the quantity. From the Tooma, which is a tributary of the Murray, one can likewise divert a little over a third of the quantity originally proposed for diversion from the Snowy, or 330,000 acre-ft. There has thus been added to the Murrumbidgee through the Tumut river nearly two-thirds of the amount of water that would have been available from the Snowy alone. Furthermore, the provision of the large storage at Adaminaby would enable additional regulation of the Tumut apart from the effect of any series of dams on the Murrumbidgee-Tumut itself.

The net result of the diversion and the regulation is to make available approximately 640,000 acre-ft. for irrigation in the Murrumbidgee valley.

It is regarded as necessary, however, to replace in the Murray a quantity of water equivalent to that which would be taken from the Tooma to the Tumut—330,000 acre-ft. This would be done by means of a tunnel at a higher level than in the Murray scheme, i.e., it would be brought in at Island Bend rather than at Jindabyne. If this is done (and all parties have agreed that it should be done), then two-thirds of the Snowy water would be used—a little over one-quarter into the Tumut and hence the Murrumbidgee, and a little over a third into the Murray to replace the Tooma waters. What is then to be done with the final third?

THE SCHEME ADOPTED

Two alternative proposals were considered. One was to put the Snowy water into the Murrumbidgee by constructing the tunnel and other works contemplated for the original Murrumbidgee scheme but which under the Tumut scheme would not need to be built. The

	Snowy-Murray (Tumut excluded)	*Snowy-Murrumbidgee-Murray (Tumut excluded)*	*Tumut*	*Snowy-Murray-Tumut (Recommended proposal)*	*Snowy-Murrumbidgee-Murray-Tumut*
Maximum firm capacity (kw.)	1,600,000	1,220,000	1,020,000	2,620,000	2,240,000
	£	£	£	£	£
Capital cost excluding transmission	64,000,000	85,000,000	61,000,000	125,000,000	146,000,000
Cost per kw. of firm capacity	40	70	60	48	65
Annual charges	3,200,000	4,100,000	2,900,000	6,100,000	7,000,000
Annual value of power	9,200,000	7,300,000	2,900,000	15,400,000	13,500,000
Annual saving	6,000,000	3,200,000	3,300,000	9,300,000	6,500,000
Cost of transmission	63,000,000	47,000,000	37,000,000	100,000,000	84,000,000
Total cost including transmission	127,000,000	132,000,000	98,000,000	225,000,000	230,000,000

Note: It should be noted that these figures were those adopted by the Committee in their second report of June, 1947, as a result of further investigation and analysis, and therefore differ from some of those quoted earlier in the paper. In particular, attention is drawn to the increased figure for the maximum firm capacity, namely 2,620,000 kw. instead of 1,720,000 kw.

other proposal was to put the water into the Murray by an extension and modification of the tunnel which would have to be built to replace the Tooma waters. Comparative estimates indicated that by diversion to the Murray of the balance of the waters 380,000 kw. or 17 per cent more firm power could be obtained than in the case of the diversion to the Murrumbidgee. Furthermore the cost of this power would be only £40 per kw. as against £70 in the case of the diversion to the Murrumbidgee because of the cheaper capital cost of the Murray scheme. It was also shown that the water diverted to the Murray could be effectively used in the Murray Valley. In view of the overwhelming advantages, the Committee recommended that the final third of the Snowy water be diverted to the Murray and this was subsequently endorsed by the Governments concerned.

The following table sets out the capacities and costs for each of the proposals investigated.

The next consideration was the apportionment of the water made available from the Snowy River scheme finally recommended as between the States of New South Wales and Victoria for irrigation and other purposes.

Although the primary purpose of the principal storages proposed (at Adaminaby on the Eucumbene, at Tatangra on the Upper Murrumbidgee, at Lob's Hole on the Tumut) is for the generation of hydro-electricity, their effect will be to provide additional regulation of the Tumut and Murrumbidgee Rivers so that a considerable amount of the flow of these streams which is at present not used because of lack of regulation will become available for irrigation in the Murrumbidgee in addition to the waters added from the Snowy and Tooma. To regulate the flow for irrigation purposes, a dam downstream from the hydro-electric storages will need to be provided on the Tumut at Blowering with a capacity of 800,000 acre-ft. Similarly on the Upper Murray, a storage of 1,500,000 acre-ft. will perform the same function. The average additional irrigation water made available annually in the Murrumbidgee and Murray Valleys would be approximately as shown in the following table. It

	To Murrumbidgee		*To Murray*		
	Amount directly diverted from Snowy	*Additional Amount due to regulation of Tumut and Murrumbidgee*	*Amount directly diverted from Snowy*	*Additional Amount due to regulation of Murray*	*Totals*
To:	Acre-ft.	Acre-ft.	Acre-ft.	Acre-ft.	Acre-ft.
N.S.W.	565,500	835,000	300,000	150,000	1,850,000
Victoria	—	—	100,000	150,000	250,000
TOTAL	1,400,000		700,000		2,100,000

will be noted that of the total additional water of 2,100,000 acre-ft. which would be made available for irrigation, 965,000 acre-ft. would come from the Snowy River and the balance of water now unregulated in the Tumut, the Murrumbidgee and Upper Murray Rivers.

Economic Utilization and Development of the Water Resources of the Euphrates and Tigris

VAHÉ J. SEVIAN

ABSTRACT

The restoration of fertility to vast areas of desert land, the generation of power for new industries, the electrification of rural centres, the development of economic and social institutions, depend on the effective conservation and judicious utilization of the water resources of the Euphrates and Tigris rivers.

The difficulties inherent in a basin divided among four States with differing peoples, customs and aims, and the absence of co-ordinated plans of action, render arduous the planning of a multiple-purpose programme, the magnitude and scope of which vary for each country concerned.

Water is an asset which should be conserved when it is not required, and when released, should be used to its fullest possibilities for productive projects. Some principles appropriate to the Euphrates-Tigris basin are stated. Action is outlined for regulating the flows by building reservoirs and conveying the waters under control to arable land. The outline is descriptive and indicates what boldness in planning and execution could bestow in wealth and prosperity when water is used and re-used for various purposes.

Agricultural production will increase, rural life will be stabilized, and economic conditions will improve as control of the rivers become more and more effective. Greater mechanization of agriculture will overcome the shortage of manpower and prevent its wastage. Navigation throughout the entire basin will become of great importance as development progresses and will require, in addition to the present southern outlet at the Persian Gulf, a new outlet to the Mediterranean.

Broad principles are cited as a basis of agreement between the four interested parties, for the co-ordinated planning, execution and operation of the multiple purpose programme of development.

INTRODUCTION

In the regions forming the watershed of the twin rivers, Euphrates and Tigris, water is one of the principal resources. Their economic utilization and development—a problem so far greatly neglected—could play an important role for the betterment of the community within, and to some extent outside of, the basin. This could be achieved by making the best possible use of the water from the time of its precipitation until it reaches the sea, although it is a question whether all the water should be allowed to reach the sea.

What are the potential benefits that could be derived from this system of rivers, the basins of which are intersected by political boundaries? On the one hand, consideration of the entire basin as one physical unit under one management would facilitate the planning, execution and operation of multiple-purpose development programmes, and on the other hand co-ordination of action between the interested nations[1] would be essential for the successful utilization of the water resources.

Turkey, holding the headwaters, has great industrial possibilities, and hence requires power. Agriculture also makes an important demand upon water, mostly for summer crops and gardens. The needs of navigation are not significant at present, but might become so when the basin will have been fully developed. The question of flood control, however, does not arise.

Syria needs water mainly for agricultural development. Navigation along the Euphrates comes next. Floods though of no great consequence would be eliminated with the execution of power projects on the Euphrates in Turkey and the creation of a reservoir in northern Syria.

In Iran, agricultural development is of first importance and could be greatly furthered with the impounding in appropriate reservoirs of the waters of the last two tributaries of the Tigris. Floods would thus be eliminated. Navigation, which is possible in the last tributary, can be improved and extended. Hydro-electric power might be used in place of thermo-electric based on oil when the electrification of the region later stimulates demand, and thus more oil could be released for export.

Iraq would be the main beneficiary of the water resources of the twin rivers. Reservoirs holding all surplus waters at appropriate sites would render the delta of the rivers immune from danger of floods and droughts. Huge expanses of arid lands amounting to millions of hectares would be benefited and present conditions in agricultural districts improved with the released water. Navigation will be facilitated and extended. Industries would be created, based on agricultural raw materials and other products and water-power. An economic structure would be built and the social standard of the people raised. What would be added in wealth and prosperity to the basin would far surpass the nation's past grandeur as depicted in history.

This paper deals mainly with the development of those regions in Iraq served by the twin rivers and their tributaries. Some account is also given of similar possibilities[2] within the same valley in neighbouring countries.

PRINCIPLES

In arid countries agricultural development schemes depend for success on the constancy of the water-supplies although the nature of the crops and climatic conditions etc., permit some variation in supply. When water is lacking, remedial means have to be adopted by obtaining

[1]Four countries share, with a varied interest and interdependence, the basin of the twin rivers. They are Turkey, Syria, Iran and Iraq.

[2]The proposals and views expressed are personal, they do not reflect those of the official department concerned.

a flow regulated by storage reservoirs. The control and beneficial utilization of available water thus become dependent on the capacity of the reservoirs in relation to the flow and on their efficient operation.

Economic considerations make it essential to prepare a comprehensive, large-scale development programme covering the entire basin, and to execute it over a definite number of years, while discarding proposals which do not aim at direct and immediate agricultural and industrial returns. Consideration should therefore be given not to a single-purpose plan for flood relief or navigation etc., but only to a multiple-purpose, interdependent programme whereby benefits to agriculture and industry could also be attained.

Difficulties, inherent in basins intersected by political boundaries, necessitate understanding between contributors to and beneficiaries of the water resources, if these are to be conserved and utilized for multiple purposes. There must be agreement and co-ordinated action on the planning, execution and operation of all activities concerned with multiple-purpose development possibilities.

It is important to consider ultimate potentialities; each proposal advanced should unquestionably form an integral part of the main, comprehensive programme aiming at full utilization of the water resources. Planning and execution of works should be based on this principle, and the cost of adapting short-term programmes to future planned conditions should be kept at a minimum.

The development of available arable land in the coming years requires that the total disposable flow and underground water should reach the various plains at the most suitable sites and levels. Consequently, the water allowed to flow past any point along a river should be restricted, whenever possible, to the amount required for agriculture first of all, plus the amount required for other needs downstream of the given point. Supplies over these requirements should be retained and conserved in appropriate reservoirs, open or underground, and released as demand necessitates.

Though considerations of efficient operation will limit reservoirs to requisite sizes, they should be sufficiently capacious to store water in excess of normal requirements in order to compensate seasonal and annual fluctuations and to provide, if possible, for enhanced utilization of the waters when the cyclic variation is on the rising trend.

With a view to increasing the disposable water-supply beyond that furnished by the normal flow of the rivers, a programme of afforestation and soil conservation should be adopted and means should concurrently be found (1) to enforce a policy of strict economy in the use of water, (2) to harness springs and underground water, (3) to render suitable and harmless for re-use for agricultural purpose all unsuitable flowing or drainage waters, and (4) to bring water from beyond the hydrographic crest of the basin.

The choice of reservoir sites particularly for the Tigris system of rivers, depends upon the various combined objectives to be realized; preference should therefore be given to those sites which afford possibilities for (1) conserving water with the least losses, (2) creating a chain of reservoirs to bring excess water from one basin to remedy deficiency in another, (3) commanding areas as great in expanse as possible, (4) retaining silt in some instances outside the main reservoirs, and (5) generating the maximum amount of power to be applied to (*a*) the manufacture of fertilizers to replace the silt retained in reservoirs and to enhance productivity, (*b*) various industries, particularly those based on industrial crops, (*c*) rural and urban electrification, (*d*) other requirements.

Based on these principles and conforming to conditions prevailing in the basin of the twin rivers, a multiple-purpose programme of development, when carried into operation, will produce the greatest benefits from the available water resources.

PROPOSALS FOR THE CONSERVATION AND UTILIZATION OF WATER RESOURCES[3]

The proposals outlined below might be considered as basic to a comprehensive programme for the full conservation and utilization of the hydraulic wealth of the twin rivers. The map (Figure 1) gives a rough idea of the agricultural possibilities, particularly in Iraq where their magnitude is impressive.

Euphrates valley

Irrigation water in Turkey is restricted by the nature of the country and climatic conditions, and is available only for summer crops and gardens and for shorter periods than is the case in the middle and lower basins of the river. Various small projects for power and irrigation have been considered, and some have been completed, for scattered plains and valleys[4]. An important project for a hydro-electric station will give some 400,000 kw. with the damming of the Euphrates at Keban just below the confluence of the Kara Su and Murat Su, the headwaters of the river. This prospective reservoir site together with others at suitable places might afford control of the river for the benefit of Syria and Iraq, while the power potential would remain with Turkey.

In Syria the valleys of the Euphrates and the Khabur present good possibilities for early development. One project aims at the development of a strip of land extending along the Euphrates from Turkey to Iraq and provides for (1) a reservoir at Yusuf Pasha with a capacity of 1,500 million cub. metres of water (1.2 million acre-ft.), and (2) irrigation canals parallel to the Euphrates which would draw off water upstream of barrages built across the river at suitable sites, or alternatively for the irrigation of this strip of land by means of pumps installed along the river.

On the upper Khabur, irrigation canals would distribute water to certain parts of these fertile lands[5]. In the lower Khabur a network of canals would water lands principally on its left bank. Damming the Khabur at Marcada would create a reservoir of 800 million cub. metres (650,000

[3]Except when specifically stated, the proposals made here are without exception the results of the author's personal studies. Some were communicated years ago, others are disclosed for the first time. The views expressed are personal, they do not reflect those of the Department concerned.

[4]The principal plains are: Erzerum, Erzinjan on the Kara Su, Karaköse, Malazkirt, Mush on the Murat Su., Malatya on the Tohma Su.

[5]Mention is made later for supplementing water-supplies for this fertile region from sources beyond the watershed of the Euphrates.

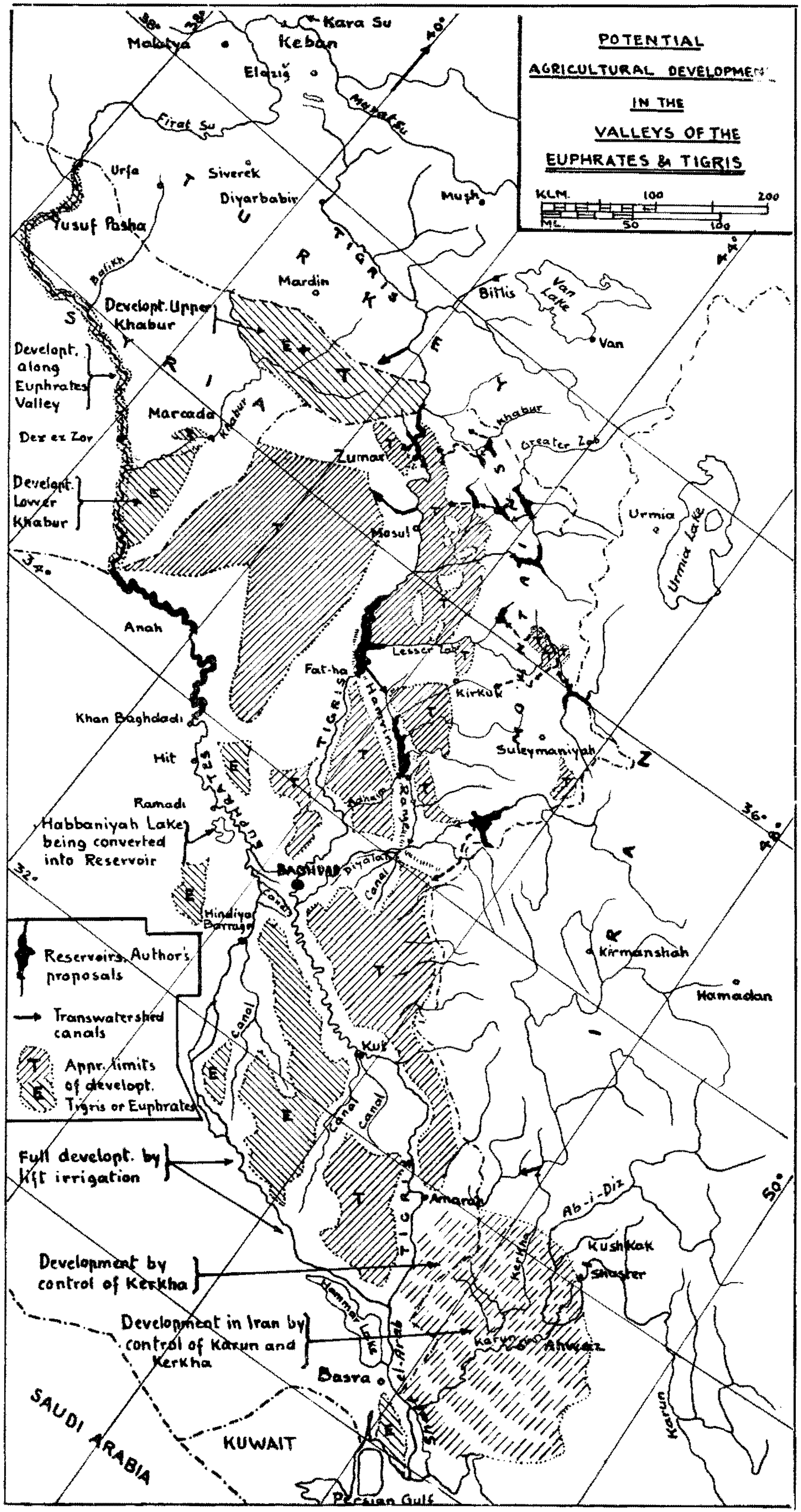

POTENTIAL
AGRICULTURAL DEVELOPMENT
IN THE
VALLEYS OF THE
EUPHRATES & TIGRIS
KLM.
100
200
Ml.
50
100
Reservoirs, Author's proposals
Transwatershed canals
Appr. limits of developt. Tigris or Euphrates
Kara Su
Keban
Malatya
Elazig
Murat Su
Firat Su
Urfa
Siverek
Diyarbakir
Mush
Yusuf Pasha
Mardin
Bitlis
Van Lake
Van
Balikh
Developt. Upper Khabur
Developt. along Euphrates Valley
Marcada
Khabur
Der ez Zor
Greater Zab
Zumar
Developt. Lower Khabur
Mosul
Urmia
Urmia Lake
Anah
Lesser Zab
Fat-ha
Kirkuk
Hamrin
Khan Baghdadi
Suleymaniyah
Hit
Ramadi
Adhaim
Habbaniyah Lake being converted into Reservoir
Baghdad
Diyala
Hindiya Barrage
Kirmanshah
Hamadan
Kut
Canal
Full developt. by lift irrigation
Amarah
Ab-i-Diz
Development by control of Kerkha
Kush Kok
Shuster
Kerkha
Development in Iran by control of Karun and Kerkha
Hammar Lake
Karun
Ahwaz
Basra
Shatt el-Arab
SAUDI ARABIA
KUWAIT
Persian Gulf

Figure 1

acre-ft.). These projects were studied in some detail years ago by responsible agencies[6].

With respect to the conservation of the flowing waters[7], Iraq offers the greatest opportunity for development. Because of the nature of the country, the valley of the Euphrates from the Syrian border to its delta at Hit affords few possibilities of development. On the other hand there are two suitable sites for reservoirs along this stretch: west of Anah and north of Khan Baghdadi, with respective capacities of 6,500 and 10,000 million cub. metres (5.25 and 8 million acre-ft.) at ultimate stages. With these two reservoirs (reduced in size as more capacities are made available elsewhere in the valley), the control of the river will be absolute and there will be complete development of the valley down to the Persian Gulf.

Shaded parts (E) on the accompanying map denote development areas of about one and two million hectares in Syria and Iraq, respectively (2.5 and 5.0 million acres).

Tigris valley

From a bend on the Tigris some 75 kilometres upstream at the Turco-Iraqi frontier, a trans-watershed canal-tunnel will bring a supplementary water-supply from the Tigris to the great and fertile area, lying mostly in Syria, of the upper Khabur in the Euphrates basin[8]. A low dam on the Tigris at a suitable site will regulate the flow and provide the necessary power for lifting the water.

In the northern districts of Iraq, west of the Tigris, vast arid lands could be developed for agriculture if water is raised by pumps. A suggested reservoir site near Zumar holding 5,000 million cub. metres (4 million acre-ft.) and provided with supplementary power from two additional sites further downstream, will provide water and power for the development of this region.

On the left bank of the Tigris, a chain of interconnected reservoirs will bring water and power from two different groups of affluents to the lands in the triangle formed by the Tigris and the Greater Zab.

The irrigation of the cultivable lands between the two Zabs and the Tigris, could be assured by the construction of two reservoirs, one on the Greater Zab and the other on a small affluent of the Lesser Zab which would be filled from sources beyond its own catchment basin.

A well-sited reservoir on the Lesser Zab would provide water for the summer cultivation of three small plains in its upper reaches and serve vast arable lands south of the river.

The regions mentioned are within the humid and semi-arid zones, hence winter cultivation requires supplemental water in years of deficient rainfall.

In the head reaches of the delta falling within the arid zone, nature has provided suitable sites for the conservation of the water and its ultimate conveyance to the land. The Hamrin range of hills crosses the country diagonally, providing three gorges where the river and two of its tributaries debouch. Damming the Tigris at Fat-ha will give a storage possibility of 20,000 million cub. metres (16 million acre-ft.). A hundred kilometres south-east, the river Adhaim could be controlled by a reservoir of about 5,000 million cub. metres (4 million acre-ft.). The second tributary, the Diyalah, can be mastered preferably at a site upstream of the gorge in the Hamrin range, where there is a storage possibility of some 7,000 million cub. metres (5.75 million acre-ft.). Their ultimate capacities—which are not necessarily required—may vary greatly with the role expected from them and their interconnexions with the reservoirs in the upper regions of the basin.

A large canal would connect the reservoir above Fat-ha to the reservoir on the Adhaim and a short trans-watershed canal would connect the latter to the Diyalah reservoir. These reservoirs would achieve complete control over the Tigris system of rivers and permit excess water from one basin to remedy the deficiences of a neighbouring one.

The waters released from these reservoirs and conveyed by the principal canals and the main stem of the river, would allow full development of the middle and lower basins. Shaded areas (T) totalling some 6 million hectares (15 million acres), now arid and devoid of water, would be developed and Iraq would prosper while conditions in the areas presently cultivated would be greatly improved.

In the south-eastern regions of Iraq, constantly flooded by the Tigris and the Kerkha, as well as further east across the Iranian border, great agricultural potentialities could be realized with the control of the Kerkha, the Karun and the latter's affluent, the Ab-i-Diz. Proposals have been made[9] for some control and use of the Karun's water, but to effect efficient control of the three rivers, bolder schemes for the construction of reservoirs at appropriate sites become essential. Beneficial use can be made by Iraq of part of Kerkha's controlled flow when conveyed by a trans-watershed canal.

In the upper tributaries of the Tigris in Iran, the possibilities for development are small and are confined by the physical nature of the country to scattered valleys and plains. But in the south the suggested control of the three rivers will permit (1) agricultural development of some 2 million hectares (5 million acres) in Iran, (2) elimination of floods, and (3) improvement in navigation.

The control of the Tigris and of its southern tributaries should respect the existing or required regime between the fresh water of the rivers and the tidal action in the Shatt-el-Arab—the Tigris and Euphrates estuary. This is

[6] *Régie des Études hydrauliques.*

[7] For the Euphrates, Iraq has one scheme for the conservation and use of its water. The proposal was made about forty years ago by Sir William Willcocks (*The Irrigation of Mesopotamia*, London, E. and F. N. Spon, Ltd.) for using a depression (Habbaniyah Lake) for flood control and storage. Its capacity is small (2,500 million cub. metres or 2 million acre-ft.) when compared to requirements for adequate control of a river with flows varying from 10,200 to 37,060 million cub. metres per year (8.3 to 30.0 million acre-ft. per year). Works started at various periods since 1912 are scheduled for completion by 1951.

[8] See footnote 5.

[9] Report on irrigation schemes in this area by Mr. Van Roggen (prior to 1908); "Report on the River Karun Irrigation Scheme" by Major W. R. Morton, R.E., on special duty to Arabistan (Proceedings of the Foreign Department, June 1908); Preliminary Report on the Kushkak Dam Project by Major Geoffry M. Binnie (1943).

essential for the millions of date trees growing in this region.

The above is a general view of the development possibilities of the valley of the twin rivers. Table I lists the prospective reservoir sites, selected on principles outlined earlier in this paper.

Table 1. List of Selected Prospective Reservoirs for the Development of the Basins of the Euphrates and the Tigris

Sites	*Capacities*[a] 1,000 *million cub. metres*	*Acre-ft.*	*Elevation*[b] *Metres*	*Feet*	*Purposes*[c]
EUPHRATES :					
Keban in Turkey					P.[d]
Yusuf Pasha in Syria	1.5	1.2			I.N.P.[d]
Marcada	0.8	0.6			I.[d]
Anah in Iraq	6.5	5.2	175	574	I.F.P.
Khan Baghdadi	10.2	8.2	137	450	I.F.P.
Habbaniyah	2.5	2.0	50	165	F.I.[d]
TIGRIS :					
75 km. from Iraq in Turkey	1.?	0.8?	425?		P.I.
Zumar in Iraq	5.0	4.0	335	1100	P.I.F.
Triangle	1.5	1.2	855	2800	S.I.
Between	0.1	0.1	670	2200	S.I.
Tigris and	1.4	1.1	610	2000	S.I.
Greater Zab	0.3	0.2	550	1800	S.I.
Greater Zab (upper)	4.5	3.6	670	2200	S.I.
Greater Zab (lower)	5.3	4.2	460	1510	I.
Lesser Zab (upper)	2.5	2.0	760	2500	S.I.
Lesser Zab (affluent)	2.2	2.0	640	2100	S.I.
Fat-ha	20.0	16.0	175	575	I.F.P.
Adhaim	5.0	4.0	150	500	I.F.P.
Diyalah	7.3	5.9	300	980	I.F.P.
Kerkha in Iran					I.F.
Ab-i-Diz					I.F.
Karun					I.F.P.N.

[a] Ultimate capacities are given, which are not necessarily required. The capacities of the reservoirs could be reduced in relation to their expected interconnexions with other reservoirs in the basin.
[b] Elevations are from sea level.
[c] Multiple-purpose: P for power, I for irrigation; F for flood control; N for navigation; S for storage of water during winter season for use during summer season.
[d] Proposals made by agencies other than the author of this paper.

AGRICULTURAL RESOURCES IN RELATION TO WATER RESOURCES

Water, land and man can play a great role for mankind by developing natural resources left latent or allowed to go waste. For the full utilization of the water resources of the twin rivers, scientists and men of action must join in formulating and executing policy. To the scientists is entrusted the task of fulfilling the varied improvements and benefits that can be drawn from this potential source of wealth. These resources, inherently renewable, will bring prosperity, comfort and happiness to the peoples of the basin, when judiciously utilized. An attempt is made to show the salient results that can be achieved.

The Euphrates and the Tigris obtain their main water-supplies from sources outside Iraq. During certain periods of the year, the water flowing in some streams is unfit for use in cultivation. Commingling of these supplies with the normal but controlled flows of the main rivers, adding at a later date suitable water (or unsuitable water which has been made fit for purposes of cultivation) conveyed from basins beyond the *divertium aquarum* of the twin rivers, harnessing underground water, and adopting a policy of economic use of water—all these measures will gradually extend to, and increase the agricultural benefits of, almost all the arable land within the basin.

The proportionate distribution of the arable lands of the entire basin is roughly shown in figure 2, and table 2 gives the approximate figures.

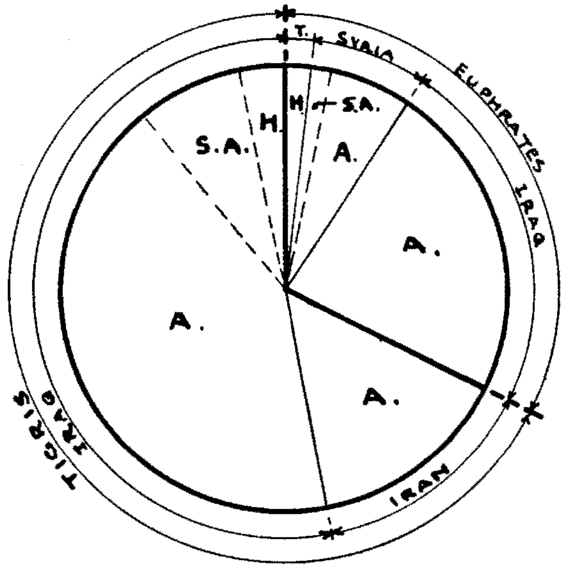


Figure 2. Proportionate distribution of total arable lands within the basins of the Euphrates and Tigris.

T. = Turkey ; H. = Humid Zone ; S.A. = Semi-Arid Zone ; A. = Arid Zone.

Table 2. Cultivable and Cultivated Lands in the Basins of the Euphrates and the Tigris[a]

In thousands of hectares[b]

Countries	*Humid zone*[c]	*Semi-arid zone*[d]	*Arid zone*[e]	*Total*
EUPHRATES:				
Turkey	300	—	—	300
Syria	—	200	800	1,000
Iraq[f]	—	—	3,200[g]	3,200
Iran	—	—	—	Nil
Total	300	200	4,000	4,500
TIGRIS:				
Turkey	—	—	—	Small
Syria	—	—	—	Very small
Iraq[f]	400	1,100	6,000[g]	7,500
Iran	—	—	2,000	2,000
Total	400	1,100	8,000	9,500
Totals for both basins	700	1,300	12,000	14,000

[a] A great number of small plains and valleys (cultivated or cultivable) are not included in the table.
[b] One hectare equals about 2.5 acres.
[c] Humid zone covers regions where rainfall is over 500 mm. (20 in.) per year.
[d] Semi-arid zone covers regions where rainfall varies between 500 and 200 mm. (20 and 8 in.) per year.
[e] Arid zone covers regions where rainfall is below 200 mm. (8 in.) per year.
[f] Figures of irrigated areas in countries other than Iraq are not entered in the above table. They are small when compared to total figures.
[g] Some 2,500,000 hectares (6,250,000 acres) are already irrigated on the rotation system which leaves 50 per cent fallow annually. The Euphrates and Tigris share roughly half and half in this figure. The areas actually under irrigation are in turn divided in about the same proportion between irrigation by flow and irrigation by lift.

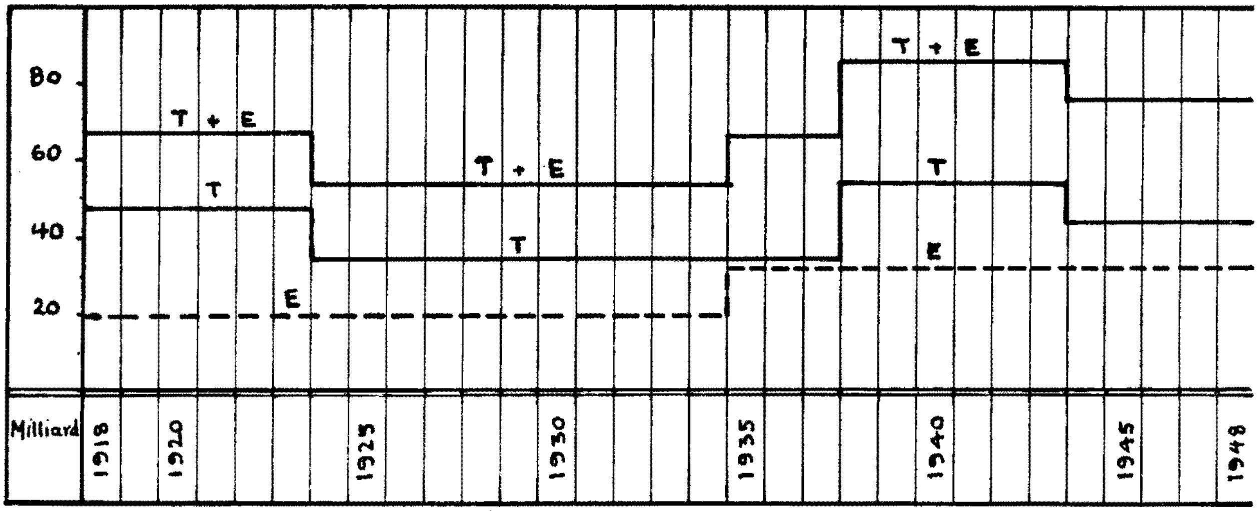


Figure 3. Flows of the Euphrates (E) and Tigris (T) for past years if they were regularized by reservoirs. 1 milliard equals 1,000 million cub. metres or 810,700 acre-ft.

Both rivers are well supplied with water, though with the seasonal and cyclic variations characteristic of rivers. The figures in table 3 are representative of data spread over a period of thirty years.

Table 3. Euphrates and Tigris Rivers: Mean, Minimum and Maximum Flows

	Euphrates at Hit		*Tigris and Diyalah below Baghdad*	
Mean yearly flow:				
1,000 million cub. metres.	25.4	1918-1948	42.3	1918-1948
Million acre-ft.	20.6		34.3	
Min. yearly flow:				
1,000 million cub. metres.	10.2	1930	15.2	1930
Million acre-ft.	8.3		12.3	
Max. yearly flow:				
1,000 million cub. metres.	37.0	1948	55.1	1946
Million acre-ft.	30.0		44.7	

The variation in the flow of the rivers is to be controlled and rendered uniform by means of reservoirs compensating years of lean and ample supplies. Cyclic variations when on the rising trend could be used for the benefit of agriculture, without any immoderate increase in the capacities of the reservoirs, thus realizing greater possibilities in the various fields of development, and particularly possibilities for flood control.

Appendix A gives year by year from 1918 onwards (1) the variation in the flow of the Euphrates and Tigris, (2) their mean flows for past years and (3) the mass curves of their flows from 1918 to 1948.

The total annual disposable discharges of the two rivers as ultimately regulated by reservoirs, are shown in figure 3. Some 8,500 and 7,500 million cub. metres (6.9 and 6.1 million acre-ft.) are now used annually for winter and summer crops, respectively. Thus there is still great scope for irrigation as the demand for water in the coming years increases as a result of the development programme, which will in itself tend to conserve water-supplies formerly lost in marshes and in the sea.

In the middle and lower basins of the twin rivers, rainfall below the isohyet of 200 mm. (8 in.) per year, though advantageously concentrated during the period of winter cultivation, is insufficient for the crops.

In the semi-arid regions between the isohyet of 200 and 500 mm. (8 and 20 in.) per year—i.e., where boundaries fluctuate with the intensity of rainfall—the need of winter crops[10] for perennial water decreases as rainfall increases. In humid districts above the isohyet of 500 mm. (20 in.) per year, rainfall is sufficient for winter cultivation. In these last two zones, irrigation water is required for summer crops[11] only, except that some water is needed in semi-arid regions during periods of deficient rainfall.

If rural life and the rural economy is to be stable, there must unquestionably be available, in spite of the annual and cyclic variations in river flow, great, permanent areas for winter cultivation. For a thousand years winter cultivation has followed the system of irrigation which leaves 50 per cent of the land fallow annually. The system also applies with some exceptions to summer crops. Among the reasons for this system of rotation are the great amount of arable land. The shortage of labour, the lack of fertilizers and, to some extent, the scarcity of water during critical periods of demand. Although disposable water may be conserved in coming years, it appears likely that this rotational system will be maintained and that the water left over from the winter cultivation will be stored and used for summer crops after allowing for losses and for other requirements.

What do the controlled water-supplies of the two rivers represent in agricultural products? How many men could obtain sustenance if the water were available? Succinct replies can be given to these questions. Over 8 million

[10]Wheat and barley are the principal crops with linseed, vetch and beans coming next (November to April).

[11]Cotton, sesame, millet, green gram etc., (April to September), as well as vegetables and fruits.

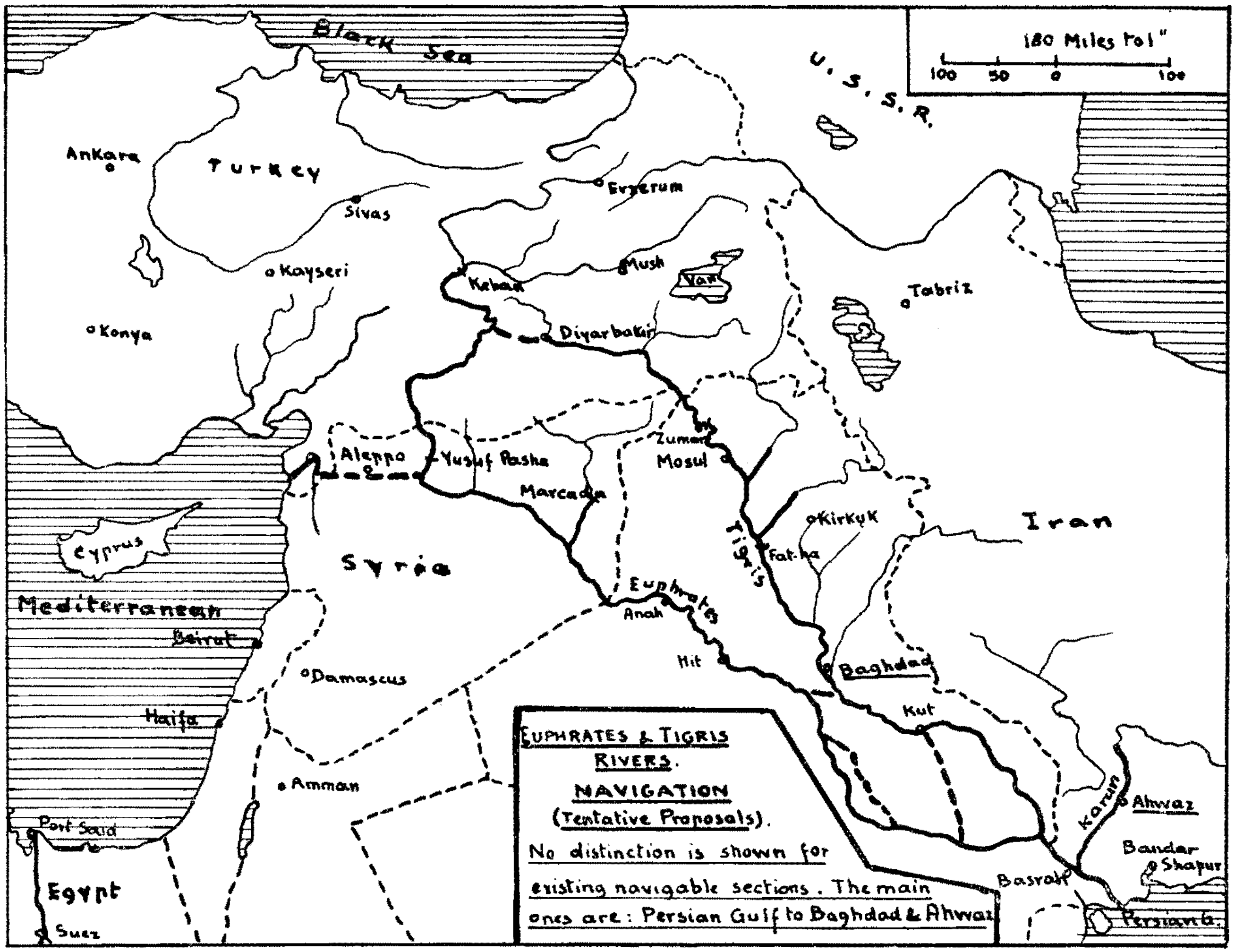


Figure 4

tons of wheat and barley could be obtained annually in the basin, in addition to some 1.5 million tons of varied summer crops[12]. These rough and tentative figures are based on the present low yields[13]. Improvements in agriculture and irrigation, thanks to perfected and scientific methods, will undoubtedly increase, perhaps even double, the figures given above. A population of over 40 million would find sustenance in a healthy environment of improvement and progress. Moreover, development in many other fields, as for instance in farming, vegetable and fruit growing, live-stock breeding etc., would increase the wealth of the basin. Industrial crops and by-products would afford new opportunities for light and other industries, based on power obtained from the controlled water. Activities would also be added in the fields of transportation, electrification and general welfare.

[12]In regions where rainfall is deficient, one cub. metre of water per second is required during six months to irrigate 2,200 hectares (5,500 acres) of winter crops. This represents a depth of 68 cm. (27 in.) of water. The diversity of summer crops makes the problem more complex. An area of about 700 hectares (1,750 acres) could be given one cub. metre per second or a depth of 2.00 metres of water. Exceptions should be made for less demand in cooler regions in the north and more demand for rice-fields.

[13]1.2 tons per hectare.

Migration from the presently well-populated rural and urban centres would provide much agricultural and skilled labour for areas under progressive development. Nomadic tribes would also settle. In view of the labour requirements of the regions undergoing methodic developments and in the interest of their agricultural stability, a systematic programme should be worked out for many years, and should take into consideration the trend toward population increase, the sparsity of rural settlement and the use of labour-saving machinery which would raise output per hectare and per man.

On the basis of a minimum density of 35–40 inhabitants per square kilometre of agricultural land (90 to 100 per square mile), the full development of Iraq could absorb about 4 million inhabitants. The 1947 census gave for the country a total of 4,800,000 (rural and urban). Assuming the present rural population to be 2,500,000[14] and adding some 250,000 from nomadic tribes, one can anticipate theoretically the possible labour supply for about 8 million

[14]The total for settled and tribal rural population in Iraq was 2,246,000 in 1930. See *An Inquiry into Land Tenure and Related Questions. Proposals for Initiation of Reform* by Sir Ernest Dowson, printed by the Garden City Press, Ltd., Letchworth England.

hectares (20 million acres) of arid land. The remaining 3 million hectares (7,500,000 acres) of arable lands would be developed as the population grows and as extensive mechanization is introduced. Activities in other fields will also need additional hands, though this question is not raised here.

FLOOD CONTROL—NAVIGATION—POWER

The elimination of floods by the retention in reservoirs of all surplus waters is next in importance to the agricultural development of the lower basins. The steady release of water would generate power for industries and electrification and, facilitate extension throughout the basin of commercial waterways to suitable markets and outlets. Other sources of wealth will be created, too. The possibilities are briefly outlined below.

Flood control

Of the four countries of the basin of the twin rivers, Iraq is the most threatened by floods. From the latitude of a little above Baghdad to the Persian Gulf, great areas along the two rivers, though protected by dykes, are liable to flood. Damage, mostly affecting winter crops, is generally localized but is sometimes heavy. The control of the rivers by the retention of the water in reservoirs with requisite capacities would totally eliminate flood from the basin. The flood season coincides with the period when demand upon water for the crops is heaviest. Part of the flood-water would be used immediately and the remainder retained for later use. During the last 30 years when continuous records have been kept, proper operation of the proposed reservoirs would have required total storage capacities totalling 20,000 and 28,000 million cub. metres (16 and 23 million acre-ft.) for the Euphrates and Tigris, respectively, in order to equalize the run-off. And if in spite of such storage capacity an overflow should occur during an exceptional future year, it could always be safely conveyed to the sea.

Navigation

Extension of transportation would follow the general trend of the basins' development. Rivers as well as networks of canals would cover the regions in need of commercial arteries. Outlets to the seas—to the Mediterranean and Persian Gulf—will take on importance when the main troughs of both rivers carry millions of tons of agricultural and other products for export. The Persian Gulf has been used throughout history, but the Mediterranean outlet will require engineering work which is, however, within the possibility of execution when economic conditions warrant.

	Km.	*Miles*
Euphrates from Keban (Turkey) to Qurnah (junction with the Tigris in southern Iraq)	2,260	875
Tigris from Diyarbakir to Qurnah	1,630	630
Shatt-el-Arab (estuary of the twin rivers, used by ocean-going vessels)	180	70
Karun river from Khurramshahr on the Shatt-el-Arab to Ahwaz	180	70
Junction canal upper Tigris to Euphrates	80	30
Outlet canal, Euphrates to Mediterranean Sea	205	80

Note: Steam navigation is carried on over the Tigris from Baghdad to the Persian Gulf (850 km. or 330 miles) and on the Karun from Khurramshahr to Ahwaz.

Reservoir regulation would ensure effective navigation by providing suitable channel depths which would vary for rivers and canals. Only for the Mediterranean outlet will the needed water be diverted away from the basin. Water used for navigation elsewhere in the basin would in several instances be collected in reservoirs downstream and re-used for power, irrigation and navigation, as well. The map (Figure 4) illustrates the tentative proposals for navigation while figures for the main rivers—already partly navigable—are tabulated in the previous columm:

Power

Oil is another of the riches possessed by Iraq and Iran in the Tigris basin. Thermo-electric power could be based on oil, but with the harnessing of the rivers, hydro-electric power would release for export. Oil that might eventually be required for industries.

The main power stations would be placed along the Euphrates and the Tigris. They carry sufficient water to maintain a uniform flow and have sufficient head for the generation of constant and big power. Some of the reservoirs (see table 1), storing water during winter for use during summer months would also provide power, as well as a great number of sites which could be utilized later for smaller power.

A grid system would ensure better utilization and transmission of the generated power to practically the whole basin. Approximate potentials of the power-generating sites on the main rivers only are tabulated[15], but they give an idea of the energy resources of a basin now devoid of electricity.

	Kw.
Euphrates:	
Keban in Turkey (power only)	400,000
Anah in Iraq	175,000
Khan Baghdadi	275,000
Hit (power only)	125,000
Tigris:	
K. 75 from Iraq in Turkey	75,000
Zumar group in Iraq	400,000
Gayara (power only)	200,000
Fat-ha	275,000

To what end should this power be utilized? Fertilizers should have priority. In one or two instances water could be used to irrigate huge expanses of land, by lifting it well above its present levels. Light and other industries based on industrial crops, and rural electrification of the entire valley should follow, while urban requirements could be filled later.

PROPOSALS FOR MANAGEMENT: SOME LEGAL AND FINANCIAL ASPECTS OF THE DEVELOPMENT OF THE WATER RESOURCES

The basin of the twin rivers is divided among four countries. The Euphrates rises entirely in Turkey and flows through Syria and Iraq. The Tigris obtains its waters from Turkey, Iran and Iraq, but after leaving Turkey it flows only through Iraq. Turkey and Iran hold the headwaters of the northern tributaries whereas the southern tributaries are entirely in Iran.

[15]With the exception of Keban, all other sites are the proposals of the author of this paper.

The four countries, whether contributors or not, are all beneficiaries of the water resources to a different degree. Interdependent utilization of the water cannot apply to every stream, although the interchange of supplies from one basin to another is realizable in several instances.

To avoid dispute it is essential that the four countries act in concert for the conservation and utilization of the water. All parties are entitled to use the water, but each should refrain from any unilateral action which might cause damage to others[16]. The territorial sovereignty of a contributing country or of a country through which the water flows, should not confer the right to use and dispose of the water within the territory to whatever extent and manner is desired, if such action causes appreciable injury to the other riparian States. Similarly the policy of "vested right" should not be admitted in favour of a country where the flowing waters have been needlessly wasted from time immemorial. The benefits accruing from the full utilization of the water resources should be planned for the basin as a whole, with preference given to agricultural development, since power, flood control and navigation projects are developed concurrently with agricultural development. Water should be used according to the needs agreed upon and the rights conferred upon each individual State by an equitable apportionment of this resource.

The existing laws relating to water (conservation, utilization, prevention of misuse and pollution) are limited in scope and vary from country to country. They are therefore an impracticable basis for international agreements concerning the use of water.

The present arrangements between the States are unquestionably inadequate[17]. A basis of understanding between the interested countries for the beneficial utilization of the water resources is therefore essential on matters relating to principles, methods of co-ordinating engineering and economic investigations and planning, and action for the execution of works as well as thereafter. Agreements should be multilateral for the Euphrates and, bilateral for the Tigris between the two independent groups of interested States. Pending such agreement, each interested party might undertake in its territory—provided that the rights of a riparian State are not prejudiced—works which by their nature will require no more water than will be contained within the eventual share to be apportioned to the said party; and provided also that the execution of permanent works by the riparian State to compensate for water thus diverted from wasted water flowing through its territory, is not unduly delayed.

Four National Committees acting within their respective countries will be necessary to plan, execute and operate the multiple-purpose development programmes, when construction is over. An International Advisory and Liaison Board should advise and co-ordinate the activities of the National Committees within the terms of reference arrived at by international agreement. Each State should have full latitude to finance and execute the works within its territory in accordance with the broad lines of the programmes. Litigation, if any, between the interested parties should be settled by the said Board.

Expenses for investigation, planning, execution and operation would be financed by each National Committee or State for works within its frontiers, from sources specifically allotted for the purpose. But for works of an international character to be undertaken in one country for the benefit of another or for mutual benefit,[18] expenses, as well as repayment from profits of the invested capital, should be apportioned in relation to the realizable benefits.

The invested capital and accrued interest should be liquidated within a definite number of years from direct taxation levied on (1) land products, (2) state lands sold to agriculturists on deferred payment, (3) water furnished, (4) power furnished, and (5) navigation, flood control etc., when specific projects are undertaken. The indirect taxation deriving from many other sources should be assigned to social welfare and other purposes.

[16]Among the projects which might prejudice Iraq's interests is the proposal to obtain electric power at Bitlis (Turkey) from the salty water of Lake Van which would be conveyed to the Tigris basin. Unless some of the power is used to purify the water, the scheme should not be adopted.

[17]Agreements and arrangements between the four States are as follows:

(*a*) Turco-Persian Boundary Protocol of 1914 allotting to Turkey, half of the Gangir water, a stream now flowing into Iraq, at Mandali.

(*b*) Anglo-French Convention of 23 December 1920 on certain points connected with the mandates for Syria and the Lebanon, Palestine and Mesopotamia:

Art. 3: "The British and French Governments shall come to an arrangement regarding the nomination of a commission whose duty it will be to make a preliminary examination of any plan of irrigation formed by the Government of the French Mandatory territory, the execution of which would be of a nature to diminish in any considerable degree the waters of the Tigris and Euphrates at the point where they enter the area of the British Mandate in Mesopotamia."

(*c*) Convention relating to the Development of Hydraulic Power affecting more than one State of 9 December 1923, acceded to by Iraq on 27 January 1936.

(*d*) Resolutions taken at Cairo by the Regional Conference for the Near East of the Food and Agriculture Organization, 14 February 1948.

Iraq: "It is important in preparing a long-range programme involving the valley of the Euphrates that the international character of this stream be taken into account and that the plans include an agreement between Iraq and Syria relating to the use of water."

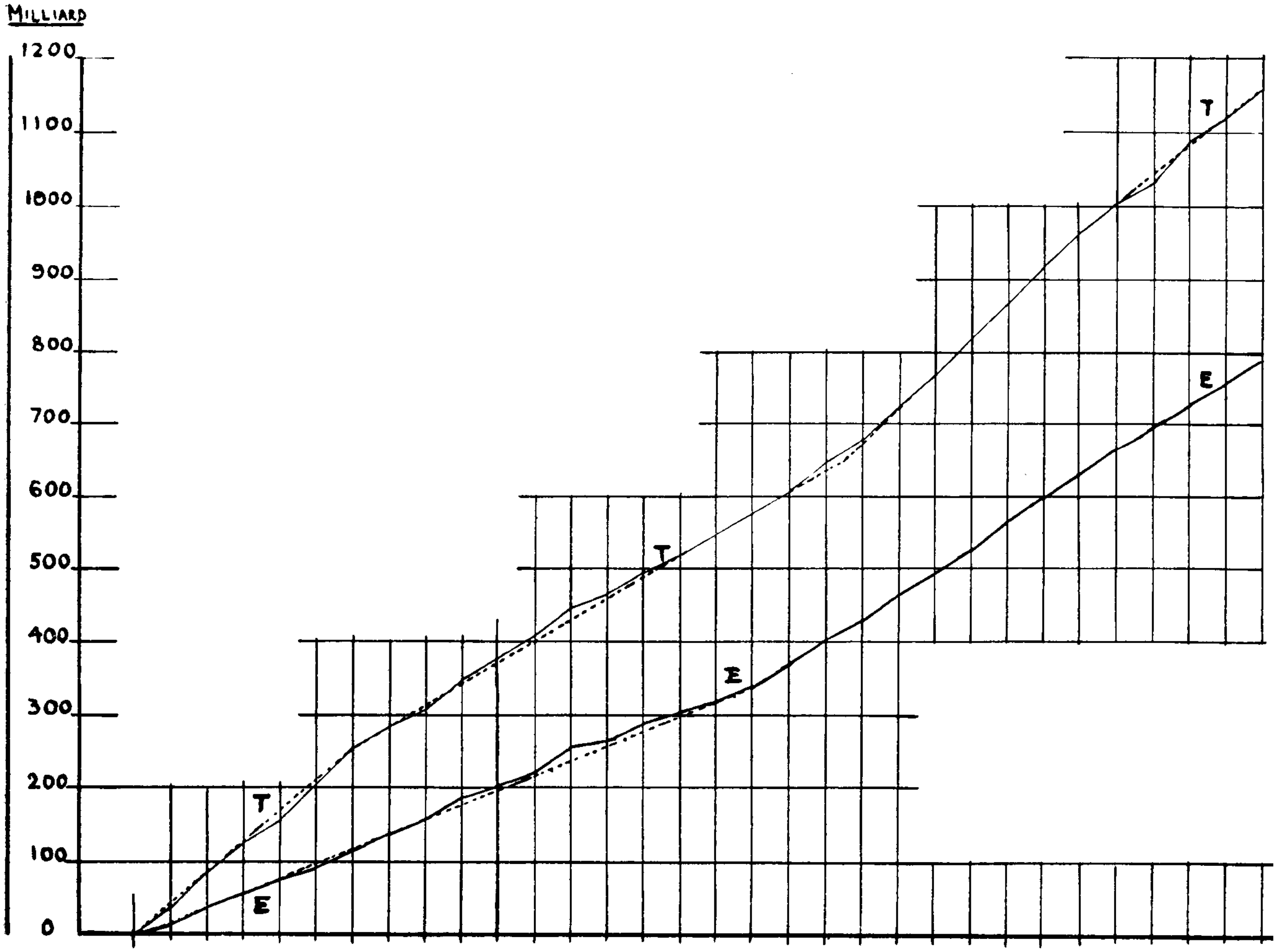
Syria: "This development (in the valley of Euphrates in Syria) would, if carried out to its ultimate possibilities, interfere with the use of water in Iraq and, therefore should be undertaken only after an agreement is reached between the two countries."

(*e*) Treaty of Friendship and Good Neighbourhood between Iraq and Turkey, protocol A, annex I, relating to the control of the waters of the Tigris and the Euphrates and their affluents. This treaty was ratified on 10 May 1948.

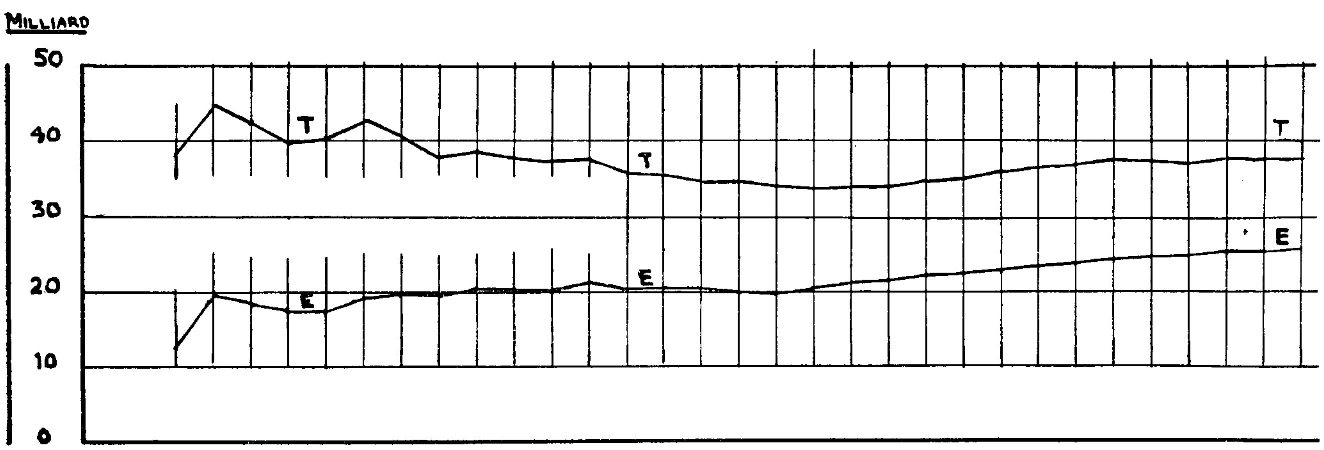
[18]As, for instance, works for supplementing supplies from sources beyond the hydrographic crest of the catchment basin.

APPENDIX

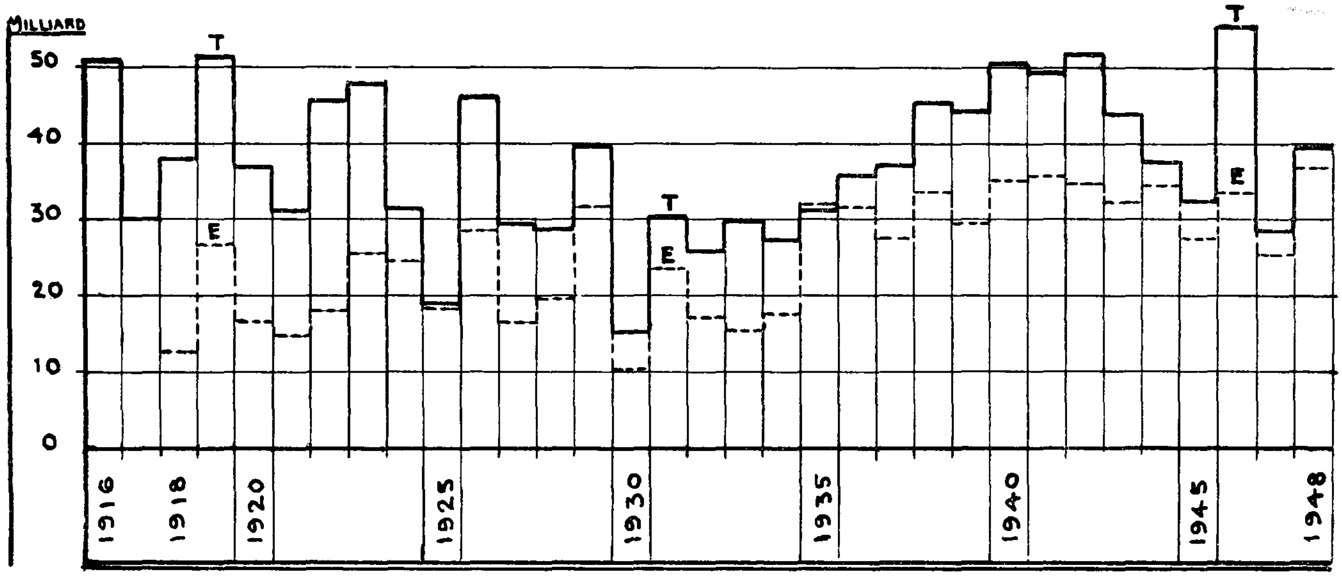
APPEN. II.



MASS CURVES TIGRIS (T) & EUPHRATES (E) 1918-1948 IN MILLIARDS M³ (1000 MILLIONS).



ANNUAL MEAN FLOWS FOR PRECEDING YEARS TO 1918 FOR THE TIGRIS (T) & EUPHRATES (E).



ANNUAL FLOW TIGRIS (T) AT BAGHDAD & EUPHRATES (E) AT HIT IN MILLIARDS M³

1 MILLIARD = 810,700 ACRE-FEET.

Water-Supply in the Agricultural Areas of Western Australia[1]

T. LANGFORD—SMITH

ABSTRACT

A proposal to provide a water-supply for a large part of the agricultural areas of Western Australia required investigation. For the scheme to be approved, it was necessary to show that it could be justified on economic and social grounds. An account is given of the technique employed for an investigation of these aspects. Each phase of the investigation is described, from a study of the history of development within the region concerned and a brief assessment of its resources, to a field survey of existing amenities. In conclusion there is a note on the recommendations which were made.

INTRODUCTION

This paper is not a treatise on water-supply, nor is it intended as a resources survey of the agricultural areas of Western Australia. It is an attempt on the part of the writer to give a brief account of the technique employed to investigate the economic and social aspects of a large-scale water-supply scheme proposed for the area.

Desirable as it may be to develop agricultural resources at this time of world food shortages, it should be recognized that there must be an economic limit to every developmental scheme. It is therefore imperative to analyse each proposal thoroughly, not only on the basis of increased production, but also with regard to its repercussions on the economy of the region concerned, and, in the broader sense, on the whole economic structure of the country.

The use of scientific methods for this type of investigation is of vital importance if the facts are to be examined in their true perspective, without undue emphasis on any one point. This paper is submitted as an example of methods that were adopted for a specific investigation, with the hope that they may prove of interest to others concerned with the development of resources.

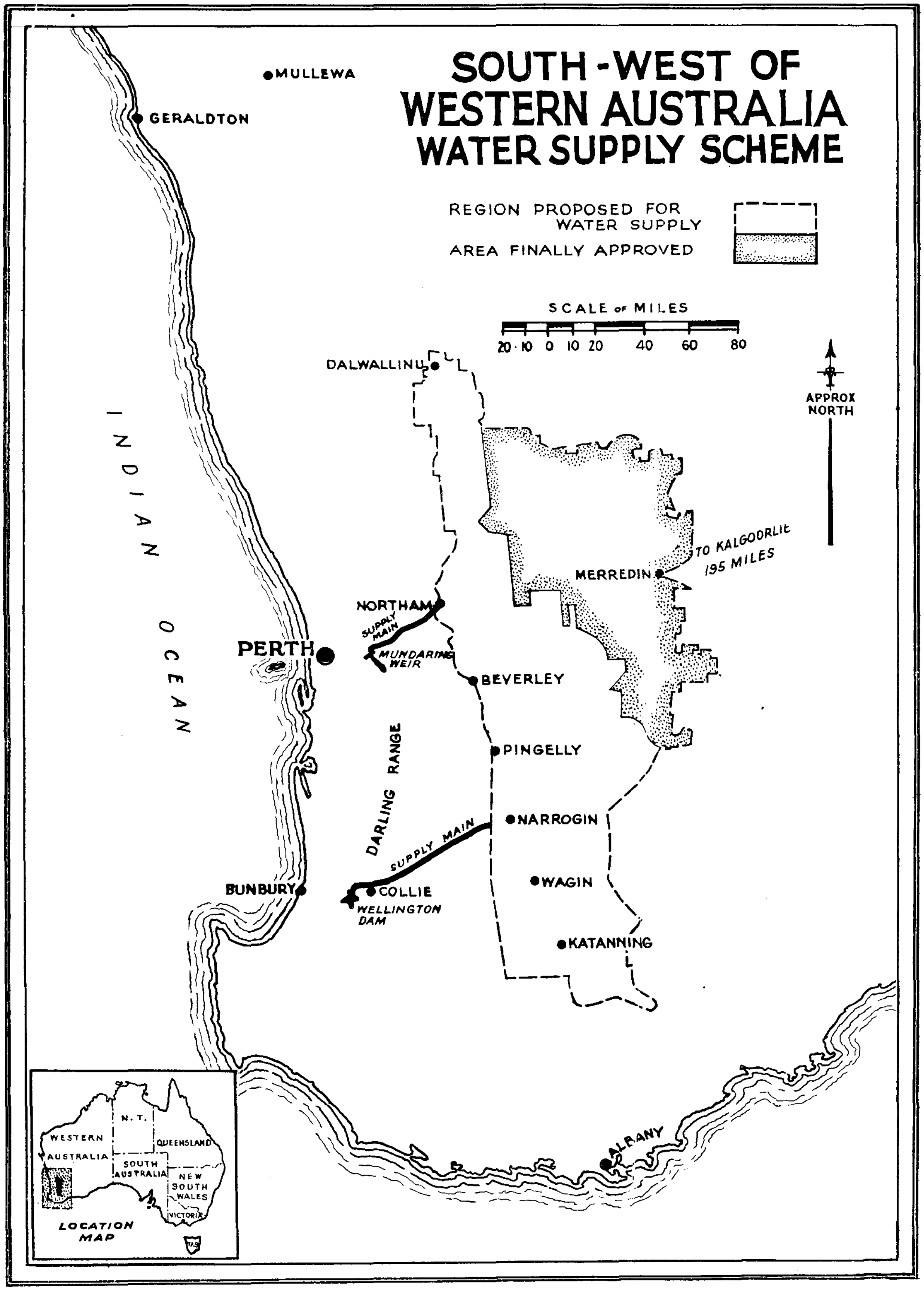
PROPOSAL

It was proposed to provide a water-supply for a region comprising some 12 million acres of agricultural and pastoral land in Western Australia (see accompanying map). Adequate supplies of water could not be obtained within the region, and it was claimed that if a supply could be provided from external sources there would be a marked increase in the stock-carrying capacity, with a resultant increase in production. It was also claimed that a water-supply would raise the standard of amenities on farms and in towns, and would encourage the development of secondary industries.

The scheme envisaged drawing water from two dams near the coast (Wellington and Mundaring), pumping it over a coastal range of hills (the Darling Range), carrying it inland by large diameter mains, and finally reticulating it within the region concerned.

Provided the scheme was practicable in its engineering aspects, the problem was to determine whether it could be justified on economic or social grounds.

[1]The author provided a number of copies, for distribution at the meeting, of a factual account also written by himself, much longer than the present paper but bearing the same title, of a survey of the water-supply. This account was in the form of a pamphlet reprinted from *The Australian Geographer*, vol. 5, no. 6 (Dec. 1947).


SOUTH-WEST OF
WESTERN AUSTRALIA
WATER SUPPLY SCHEME
REGION PROPOSED FOR WATER SUPPLY
AREA FINALLY APPROVED
SCALE OF MILES
20 10 0 10 20 40 60 80
APPROX NORTH
INDIAN OCEAN
MULLEWA
GERALDTON
DALWALLINU
MERREDIN
TO KALGOORLIE 195 MILES
NORTHAM
SUPPLY MAIN
PERTH
MUNDARING WEIR
BEVERLEY
PINGELLY
DARLING RANGE
NARROGIN
SUPPLY MAIN
BUNBURY
COLLIE
WELLINGTON DAM
WAGIN
KATANNING
ALBANY
WESTERN AUSTRALIA
N. T.
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TAS
LOCATION MAP

THE INVESTIGATION

The methods of investigation may be grouped under three major headings, (*a*) History of development, (*b*) Resources, (*c*) Amenities and social aspects.

History of development

The first step was to gain some appreciation of the history of the region. A considerable time was spent consulting all available references on the subject, including government commissions of enquiry and research by private individuals. It was found that publications dealing with the whole of Australia, or even the whole of Western Australia, were of very little practical use, as they were far too general in their application. However, it was found necessary to examine records dealing with all the agricultural areas of Western Australia, and not merely the water-scheme region, as the economy of the region was intimately related to that of the neighbouring districts.

An attempt was made to follow the settlement of the various sections of the region, and then to trace progress during subsequent years. Particular attention was paid to the reasons for successes and failures, and to ascertain whether, and in what way, these were due to factors such as methods of finance, market prices, soil, climate, farming methods or the type of settler. To obtain a clear-cut picture of some of these factors, various graphs were drawn to illustrate trends from the earliest available records to the present day. It was found useful to plot one relationship against another as follows:

(*a*) Wheat acreage in region—wheat acreage in State.

(*b*) Total regional wheat yield as a percentage of total State yield.

(*c*) Wheat yield per acre for region in relation to wheat yield per acre for State.

(*d*) Wheat yield per acre for region in relation to wheat yield per acre for Commonwealth.

(*e*) Wheat acreage—population.

(*f*) Wheat acreage—wheat export price.

(*g*) Wheat acreage—number of sheep.

(*h*) Number of sheep—price of wool.

The wheat industry in Western Australia passed through several major crises. By means of the graphs it was possible to contrast the intensity of each of these crises in the region and in the State as a whole. Since the economic value of the region as a unit of production was of vital significance to the inquiry, an attempt was made to determine the money spent by the State, not only in establishing settlement, but also in re-establishment after each crisis.

Resources

The resources of the region were studied under five headings: Natural resources, industries and power, transport, social resources, and miscellaneous factors.

Natural resources

(i) *Climate.* A brief study of rainfall, temperature and winds. Rainfall map drawn.

(ii) *Physiography.* A general description of the topography, with emphasis on the drainage system. Map drawn.

(iii) *Water.* Remarks on streams, bores and dams.

(iv) *Soils.* Main soil groups discussed. Map drawn.

(v) *Minerals.* Deposits of economic minerals found to be negligible.

(vi) *Forests and natural vegetation.* The region was found to be almost devoid of useful timber.

(vii) *Fisheries.* A proposal to establish a whaling industry at Albany was discussed, for although outside the region, it would have some bearing on its future economic framework.

(viii) *Land use.* A map was compiled, partly from existing data and partly from field observation, showing the distribution of wheat, sheep, dairying, cattle (other than dairy cattle) and orchards and vineyards.

Industries and power

(i) *Primary industry.* The relative yields from the various primary industries were recorded in tables. An estimate was made of the financial return from each industry, and from this was obtained an approximate assessment of the total value of primary production within the region. These returns were compared with similar figures for the state and the Commonwealth.

(ii) *Gold.* This is by far Western Australia's most lucrative industry. Most of the gold-mining activity is at Kalgoorlie, which is separated from the region by an area of marginal land and semi-desert. Kalgoorlie has played an important part in the development of both the State and the region, and some attention was therefore paid to gold production in its relation to the economic structure.

(iii) *Secondary Industry.* The region was found to be very poorly placed in regard to secondary industries, resulting in a state of economic and social instability. Notes were made on existing industries, and instances were recorded where it appeared that industrial expansion was dependent on water-supply.

(iv) *Power.* It was found that there were no primary sources of electric power within the region, and that the local power facilities that did exist were inadequate and expensive. Some attention was paid to the possible effect on the region of a proposed power scheme, based on further development of the Collie Coal-fields which are situated west of the region.

Transport. Only a very brief study was made of this aspect, and it is felt that more attention might have been paid to the economics of road and rail transport facilities.

Social resources.

(i) *Population.* Tables and graphs were compiled showing regional and state trends in population.

(ii) *Employment.* The latest employment statistics were analysed, and some assessment was made of the potential labour force that would be available for work on the proposed scheme.

(iii) *Amenities.* A field survey was made of amenities. Methods employed are described in a following section.

Miscellaneous Factors. There were several items of significance that were not listed under the previous headings. For example, soil salinity was a problem in the region, and this aspect was discussed with authorities on the subject. Likewise, some note was made of other developmental works proposed for the region, and of proposals under the War Service Land Settlement scheme.

Amenities and Social Aspects.

As previously noted, apart from engineering considerations, a decision as to whether the scheme should be implemented in whole or in part depended on the economic and social advantages that would be gained. The major economic advantages lay in an increased stock-carrying capacity that would result from the provision of a water-supply. The investigation of this particular aspect was the responsibility of another Government department, and therefore the writer confined his activities to the collection of the background information already listed, and to a study of other possible advantages. These were dependent largely on the increased possibilities for developing secondary industries, and on general social benefits. To facilitate these investigations, the survey was divided into two main sections, "Towns" and "Farms".

Towns. Every town in the region was visited, and information was obtained on the following topics:

(i) Population;
(ii) Type of town (e.g., "Municipality");
(iii) Communications;
(iv) Utilities (light and power, water, sewerage);
(v) Education;
(vi) Health services (hospitals, infant welfare, general practitioners);
(vii) Meeting halls;
(viii) Hotels;
(ix) Churches;
(x) Recreational facilities;
(xi) Community organizations;
(xii) Parks and gardens;
(xiii) Streets and footpaths;
(xiv) Offices and shops;
(xv) Tertiary industries;
(xvi) Secondary industries;
(xvii) General remarks. (Of special note was the effect of water-supply on any of the above facilities).

From this information, it was possible to obtain a reasonably accurate impression of the living standards in each town, and the degree to which it would be likely to benefit by the provision of water under the scheme.

Farms. Since it would obviously be impossible to obtain information on all the farms in the region, a sampling technique was employed. Information was obtained from approximately 100 farms, including some from every district in the region. In most cases, data was obtained by interrogation only, although, when time permitted, individual farms were examined. Farmers interviewed were chosen at random, and it is believed that they formed a reasonably representative sample, not dominated by minor classes or groups.

A set questionnaire was employed and the results were eventually recorded on one table, a separate column being allotted for each "District". The following items were included:—

A. *General housing standards and amenities*

(1) Number of houses (in each "District").
(2) Age of houses (*a*) median, (*b*) range.
(3) Newly built houses (1937—1947).
(4) Duration of present occupance (*a*) median, (*b*) range.
(5) Average number of occupants.
(6) Walls of house (*a*) brick or stone, (*b*) mud brick, (*c*) timber, (*d*) asbestos, (*e*) iron.
(7) Roof of house (*a*) iron, (*b*) tiles.
(8) Average number of rooms.
(9) Veranda.
(10) Food storage (*a*) refrigerator, (*b*) water cooler or ventilator cupboard.
(11) Lighting (*a*) electric, (*b*) petrol plant, (*c*) kerosene or petrol lamps.
(12) Telephone.
(13) Radio.

B. *Amenities related to water-supply*

(14) Kitchen (*a*) water laid on, (*b*) built-in sink, (*c*) hotwater system.
(15) Bathroom (*a*) complete bathroom, (*b*) bathroom and laundry combined, (*c*) no bathroom, (*d*) water laid on, (*e*) bath heater, (*f*) hot water system, (*g*) shower, (*h*) built-in wash basin.
(16) Laundry (*a*) complete laundry, (*b*) bathroom and laundry combined, (*c*) no laundry, (*d*) water laid on, (*e*) built-in copper, (*f*) built-in wash troughs, (*g*) washing machine.
(17) Sewerage (*a*) septic tank, (*b*) chemical system, (*c*) pan system.
(18) Garden (*a*) flower, (*b*) vegetable, (*c*) no garden.

C. *Nature of water-supply*

(19) From Goldfields or District supply.
(20) From rainwater tanks only.
(21) From rain tanks plus dam, well etc.
(22) Adequate water for house and garden.
(23) Sufficient water for domestic use only.
(24) Insufficient water even for domestic use.

The position of each farm in the survey was plotted on a map and, largely on this basis, it was possible to subdivide the region into three zones:

(*a*) Adequate water for house and garden.
(*b*) Sufficient water for domestic use only.
(*c*) Insufficient water even for domestic use.

CONCLUSIONS

It was found that the zone (*c*) above, "insufficient water even for domestic use," corresponded approximately to a zone in which water was the main factor limiting the stock-carrying capacity. Therefore, after consultation with the investigators responsible for the pastoral aspects of the scheme, and after due consideration of other aspects, it was possible to delineate an area for which the provision of a rural water-supply could be recommended. This included the whole of zone (*c*), and approximately half of zone (*b*). It was decided that a supply for the remainder of the rural areas could not be justified.

This decision was based on supply to farms only. In the case of towns, there existed a different set of circumstances. Several large towns within zone (*a*) presented very strong evidence on both economic and social grounds, for inclusion in the scheme. It was therefore recommended that these towns be supplied by a special pipe-line, but that the surrounding rural areas should not be included.

Experience in the Integrated Development of a River Basin

Excerpt from an Economic Report on the Conservation and Utilization of the Natural Resources of Iran

(With Reference to the Iranian Seven-Year Plan for Reconstruction and Development)

H. PIRNIA

PART 1: DESCRIPTION OF PRESENT CONDITIONS

Rainfall and watershed areas: Among Iran's natural resources water is the most scarce and therefore most valuable. Besides a relatively small area situated on the shore of the Caspian Sea, other parts of the country are very dry. As Iran is essentially an agricultural country, this scarcity is the greatest misfortune for the population and at the same time the most important problem of its national economy. Though there are only a few stations for the measurement of precipitation and these stations are only newly established, nevertheless from the meagre information available, a map showing the approximate amount of precipitation is drawn on which the limit of watershed areas corresponding to the topographic structure of the country are also shown. The table opposite shows the amount of rainfall in each of the watershed areas.

As it is shown on the accompanying map, almost one-third of the country's area has a rainfall of 400 mm. and about one-half between 200 mm. and 400 mm. These figures in themselves are sufficient indications to show the degree of the scarcity of water and the great problems that this condition creates.

Moreover, in areas where the amount of precipitation is not so scarce, unfortunately normal flood does not fit in with the agricultural calendar; the peak arrives too late for winter crops and the period of lowest discharge coincides with the growing season of summer crops.

Rivers: Because of the scarcity of precipitations there are few rivers of any importance in Iran. The table on page 164 gives the most important rivers in the country and their approximate flow of water.

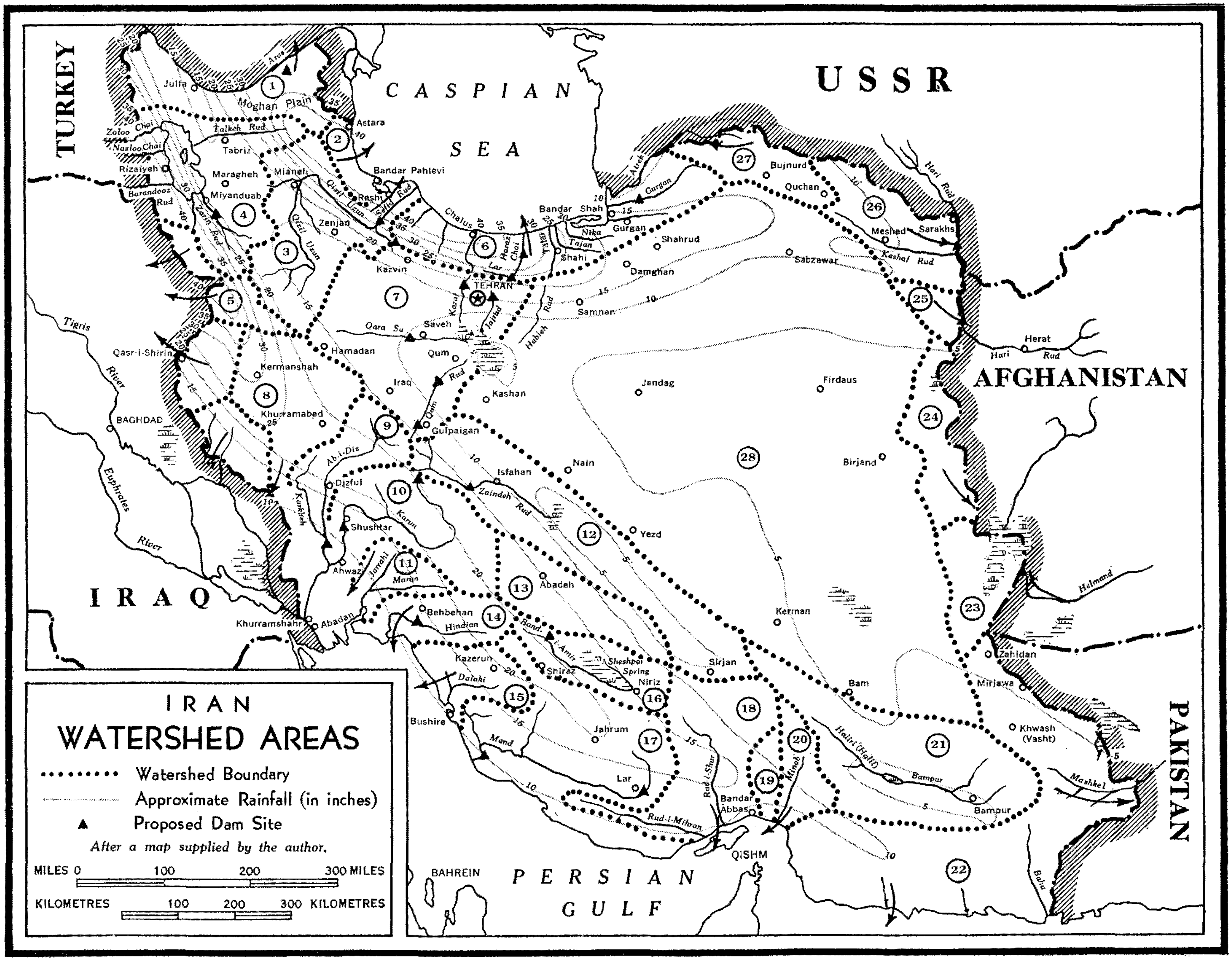
As is seen from the above table, the flow of water in these few rivers is less than 300 cm. per second and therefore less than what is usually known as a medium flow for a river. Many rivers are really only streams of water.

During the months of March and April, that is, the beginning of spring, as the result of precipitation and melting of the snow on the high mountains, many small streams are formed. The waters of these streams are not used for agriculture; they flow into interior salt lakes or into the Caspian Sea and Persian Gulf. During this period the amount of water in the rivers also increases very much, diminishing rapidly afterwards during summer months.

Though the country needs water very badly no attempt has yet been made to store spring water by building dams or artificial lakes etc. These streams and rivers flow in mountainous country and descend from high altitudes and therefore offer an important opportunity for water-power.

Catchment Areas

Area No.	*Sq. km.*	*Average rainfall in inches*
1	40,000	25
2	6,300	40
3	54,100	20
4	57,000	15
4′	5,000	35
5	11,300	27
5′	11,600	25
6	56,500	35
7	87,600	12
8	43,800	20
8′	16,200	15
9	20,200	15
10	34,300	20
AHZ	18,100	10
11	20,800	12
12	102,200	7
13	27,700	17
14	15,500	12
15	20,300	12
16	5,700	17
17	60,000	12
18	51,100	10
19	4,700	7
20	11,000	7
21	69,600	5
22	114,100	5
23	31,800	3
24	25,200	3
25	11,200	5
26	33,400	10
27	25,200	12
28	539,100	3



MAP NO. 309 JANUARY 1951 UNITED NATIONS

Name of the river	Measuring place	Flow cubic metre per second		Remarks
		Maximum	Minimum	
RIVERS FLOWING INTO THE CASPIAN SEA				
Sefid Rood .		4000	15—	
Aras	Near Amol before tributary		14	
Babol	Town of Babol		5.80	
Talar	Kiakola		0.570	
Tajan				
Chaloos . . .				
Neka	In front of the bridge		0.630	
Qarasn . . .				
Gorgan . . .				
Atrek				
Sehezar . . .				
Talar	Shirgah		5.	
Siahrood . .	Shahi		1.62	
RIVERS FLOWING INTO THE PERSIAN GULF				
Karkhah . .	Hamidieh	1500	80	
Karoon . . .	Ahwaz	2100	200	
Jarahi		450	60	
Mund		2000	10	
Maroon . . .	Near Behbehan	600	451	
Tab				
Daleki . . .				
Naiband . .				
Mehran . . .				
Shoor				
Minab . . .				
Karoon . . .	Koohrang	40	4—	
RIVERS FLOWING INTO THE INTERNAL LAKES OR INTO THE MARSHES				
Aji (Talkhrood) . .				
Zarinehrood Joqotoo	Kazkorpi	500	10	
Qoomieh				
Dehkhargan				
Safi Rood				
Marvi Rood				
Tatoo (Simin Rood)	Before tributary	200	1.50	
Taver Rood				
Barandooz Rood .				
Nazloo Rood . . .				
Zoolou Rood . . .				
Zarrin Rood (Garasoo)		300	4.—	
Karaj	Deh Bilgan	123.5	4.2	
Jajrood	Dowlatian	60.50	1.5	
Hablehrood	Bonkooh	40	5.7	
Kordan	Deh Soromeh	20	0.270	
Zayendoh Rood .				
Kor				
Helil Rood				
Bampoor				
Hirmand		1630	1.50	
Harir Rood (Tajeh)				
Dialeh				
Zab				
Simin Rood	Before tributary	200	1.50	

So far no attempt has been made to harness and utilize this source of power.

Underground water: Ghanats, deep wells: A great amount of water used in the country is obtained through the so-called *ghanats*. A *ghanat* is a tunnel which as the result of difference of level brings underground water stored at a higher level to a surface at a lower level. During many centuries Iranians have worked hard to obtain water through this system. Almost all towns and villages obtain their water-supply from *ghanats*. Even today great effort is made by landowners in this direction, and new *ghanats* are being built. Another method of using this underground water is by drilling wells and pumping water. This method has been adopted lately. Many deep wells are being drilled and satisfactory results have been obtained.

Utilization: In a vast agricultural country such as Iran where precipitations are so scanty, the economic and rational utilization of water is of prime importance. At the present time, unfortunately, a great deal of the water of rivers and streams is wasted. The method of irrigation does not make the best use of water available.

To bring about this improvement as well as to increase the amount of water available is the object of an important section of the Seven-Year Plan called Irrigation Projects, which we are going to discuss hereunder:

PART 2: IRANIAN SEVEN-YEAR PLAN PROJECTS

In the Iranian Seven-Year Plan irrigation projects occupy a place of the first importance. This reflects the great necessity and urgency for the conservation and utilization of water in the national economy of Iran. The provisions of the plan for utilization of water fall into three categories:

(1) Measurement and inventory of water-supplies.

(2) Irrigation projects.

(3) Potable water-supply projects.

Measurement of precipitations and water-supplies: The Plan provides for the establishment of 197 meteorological stations throughout the country during seven years. The cost of this scheme is estimated at $1.5 million. During this period an organization for the measurement of stream-flow will also be established. This organization will consist of a central supervising administration with at least four field parties travelling throughout the country and establishing stream-gauging stations and measuring stream-flow. The expenditure for this organization is estimated at $880,000.

Irrigation projects: In previous chapters the importance of the conservation and utilization of water in the national economy of Iran has been made quite clear. It is therefore quite natural to find that in Iran's Seven-Year Plan this problem occupies first position and irrigation projects are the most numerous and most important projects of the whole plan.

We have summarized these projects in the following table:

As shown in the above table, there are on the whole 22 irrigation projects which should be completed during the period of the Plan. Of these projects 19 are irrigation from streams by means of construction of dams, reservoirs, canals and distribution systems; two projects consist of tidal irrigation and one project of irrigation by wells and *ghanats*. The total cost of these projects is about $92 million. These irrigation projects when completed will irrigate at least 432,240 acres of land. This is a great

Water: A summary of the Seven-Year Plan Irrigation projects.

Serial no.	*Designation*	*Designation on the map*	*Details of project*	*Area of land which will be irrigated acres*	*Cost in thousands of dollars*	*Period Years*	*Remarks*
1.	Jahrom-area	Watershed area no. 17 A	70 wells in the area with generating plant pumps and irrigation distribution system	490	1,015	2	
2.	Shahpoor-River (Kazeroon area)	15	Diversion weir bridge, canal and distribution system	2,750	375	1	
3.	Golpayghan area	7-A	Dam, canal and distribution system	2,500	1,800	2	
4.	Jajrood River	7-B	Dam, canal and distribution system	25,000	8,000	3	
5.	Shushtar Island	10	Diversion weir and tunnel, distribution system	65,000	7,200	6	
6.	Zayandeh-Rud	12	Dam, canal, wells; drainage	15,000	4,275	4	
7.	Shadeghan	14	Diversion weir and headwork canals and distribution system	4,000	500	1	
8.	Karkhe-River	8	Dam canal, distribution system	28,000	5,550	3	
9.	Hirmand River	23	Topographic survey, land purchase, diversion dam, irrigation ditches, drainage roads	30,000	2,530	6	
10.	Ghom River	7-C	Dam and reservoir	12,000	3,250	2	
11.	Kor River	13	Dam, canal diversion, weir and distribution system	125,000	18,000	6	
12.	Kerman	28	Deep wells and distribution	4,000	4,120	3	
13.	Miandoab	4	Dam, storage, drainage, distribution system, canal	16,000	12,200	6	
14.	Moghan Plain	1	Canal distribution	60,000	4,880	3	
15.	Saveh	7-D	Dam and distribution system	10,000	1,850	1	
16.	Bampoor-ova	21	Dam and diversion weir		1,500		
17.	Sheshper-Spring	17-B	Dam and distribution	10,000	1,500	1	
18.	Gorgan-Rud	6	Storage dam, diversion dam canal and distribution system	15,000	3,500	3	
19.	Hendyan River	14	Project is under consideration and date not yet available				
20.	Taleghan River	3					
21.	Abadan Island	AHZ	Tidal irrigation, purchase of land, canal and ditches	12,500	9,000		
22.	Bahmanshir Island	AHZ					

improvement not only for the conservation and utilization of water, but it also means a great increase of agricultural production. This increase will be appreciated if we remember that the whole area of land in farms is 19 million hectares. These projects therefore mean an increase of 0.92 per cent of the total area of the land in farms of the country.

Potable water-supply projects: The above projects aim at increasing the amount of arable land, but in addition to them the provision of potable water-supplies for important towns of the country requires important irrigation projects, namely construction of dams and reservoirs, drilling wells, and *ghanats*. The table below gives a summarized account of these projects which are very important not only from the point of view of the utilization of water, but mainly from the public-health standpoint: these projects will provide potable water for the most important towns of the country and for a population of more than 2 million people.

Potable Water-Supply Projects

Serial no.	*Name of towns*	*Population (Thousands)*	*Period for completion of project*	*Cost (Millions of dollars)*	*Details of work*
1.	Tehran	1,000	3	38	Dam, reservoir, filtration
2.	Meshed	250	2	4	Treatment, distribution system
3.	Tabriz	214	2	5	Dam, reservoir, filtration distribution system
4.	Isfahan	205	2	4	Pumping from the river filtration
5.	Shiraz	129	2	2	Well, *ghanats*, filtration, distribution system
6.	Rasht	122	2	2	Pumping from river, filtration, distribution
7.	Hamadan	104	2	1.75	Supply from stream, filtration distribution system

Summary of Discussion

The CHAIRMAN informed the Section members that in view of the number of problems raised in connexion with comprehensive river-basin development covering all aspects of the use and control of water as well as many related resources, it had seemed desirable to draw up a list of subjects which might be discussed during the meeting.

The Chairman and the authors of the papers had agreed on a plan which was to serve as a guide for the discussion without however restricting the points which could be raised. According to that plan, all the questions to be discussed at this session were grouped under the two following headings:

(1) To what extent should river-basin development projects take into account the comprehensive use of all the water and land resources of the given basin?

(2) How should the benefits resulting from those projects be estimated and the expenditure they entailed be divided on the one hand between government and private industry, and, on the other hand, between the various branches of activity which would benefit?

The Chairman suggested that the current meeting should not consider certain technical details which had already been dealt with or were to be discussed at other meetings, such as the fight against water pollution and floods.

Finally, legal and administrative questions relating to river-basin development would be dealt with at the plenary meeting of 5 September.

The discussion might well emphasize the similarities and differences in river-basin development in the various countries where it was projected.

Mr. AUBERT introduced the paper he had prepared jointly with Mr. Varlet entitled "Comprehensive Planning for River-Basin Development."

Mr. MENHINICK remarked that reference was made in the paper to the "dictatorial powers" supposedly given to the Tennessee Valley Authority for carrying out its plan of development. In reality, the powers of the TVA could not be characterized as dictatorial because the only power which it exercised with respect to the people of the Tennessee Valley was the power to purchase their land by condemnation if they were unwilling to sell it and if that land was considered essential for carrying out the plan.

Mr. AUBERT explained that it had not been his intention to imply any constraint whatsoever imposed upon the public. From his thorough knowledge of the work of the TVA, he had, on the contrary, had occasion to observe the very humane manner in which it had treated the farmers of the area: their interests had been protected as far as possible and persuasion had been the principal method used in obtaining their consent to give up lands which had been requested of them.

The point that Mr. Aubert had wished to stress was the independence enjoyed by the TVA in so far as administrative regulations were concerned. Clearly it was not dependent on the authorities which were generally responsible for land development, navigation and electric power. It could therefore be said that it enjoyed very extensive administrative powers.

Mr. EL SAMNY presented a plan for extending cultivation and developing industry in the valley of the Nile which had been set forth in a paper by Mr. Abdel Aziz Ahmed[1] at the International Technical Congress in Cairo.

The plan, which included a scheme for controlling the Nile waters hydro-electrically, would result in a substantial increase in the cultivable area and in agricultural production to the point where there would be an agricultural surplus.

Mr. BOKE introduced the following three papers: a paper by himself on "River Development in the Central Valley of California"; a paper by Mr. Brown on "The Snowy River Scheme in Relation to Utilization of Australia's Water Resources"; and a paper by Mr. Sevian on the "Economic Utilization and Development of the Water Resources of the Euphrates and Tigris".

In introducing the three papers, Mr. Boke wished to emphasize that comprehensive river-basin development was not merely a theory, as one might tend to believe. Even the social and human problems arising from it were of a directly practical nature which the technicians and engineers preparing the plans and carrying out the work had to take into account. So many varied and sometimes opposed interests were involved in those projects that no useful results could be achieved unless they were studied in each of their aspects and, as far as possible, welded into a harmonious whole which would best benefit the greatest number.

Projects of an international character were just as complex because they affected the interests of different countries.

Therefore it soon became necessary, in planning such projects, first to lay down a comprehensive policy for the development of the river-basins in a given area so that those entrusted with their execution might be guided by general directives setting down the national, economic and social objectives which might serve as a background to their plans.

The problem was thus clearly practical and not purely theoretical.

Mr. AUBERT subscribed to the view that practical efforts must be directed towards improving human welfare, which was the ultimate objective of the solutions sought. He felt that the idea of the comprehensive development of a basin was much less simple than appeared at first glance. The question was how to make maximum use of the water resources of a basin both as water-power for irrigation and as navigable waterways. Frequently a choice had to be made between those various possibilities and preference had to be given to a particular method of utilization, the other method being more or less discarded.

[1]This paper, having been prepared for the World Engineering Conference, Second International Technical Congress, Cairo, 20-26 March 1949, was printed in Egypt, by R. Schindler, and is not reproduced herein.

Thus in the TVA project, from the point of view of the utilization of water for navigation, several solutions might have been considered. It had been decided to draw nine feet of water which was, moreover, the system already in use on the Mississippi and the Ohio, but six or twelve feet of water might just as well have been chosen.

Similarly, in the California Central Valley project, it had been decided that part of the available kilowatt hours would be used for pumping the water in order to irrigate high lands. The amount of power thus set aside for irrigation might have been greater or less. There again there had been great freedom of choice.

In another way, facts proved more complex than theory. It would appear that the basin formed the geographic and economic unit which could serve as a framework within the limits of which the water resources could be developed. The Snowy River scheme in Australia showed that not to be the case since it was intended to divert the waters of the river to another basin either to the east or to the west of the original basin. The choice to be made was therefore not guided solely by nature, but was strongly influenced by the personal conceptions of the authors of the scheme.

The Euphrates and Tigris could be taken as an example of a case where the basin of a river was neither a geographic nor a political unit. The borders of four different countries, Turkey, Syria, Iran and Iraq, crossed within the confines of the basins of the two rivers, and their interests must be protected fairly. It was therefore necessary to reconcile national needs and, at the same time, those of agriculture which needed water for irrigation and of industry which required electric power.

While the Nile basin did form a hydrological unit, it did not form a political unit. Its development scheme would have to take into consideration the interests of the Anglo-Egyptian Sudan and of Egypt, the latter being the country which had been principally concerned for thousands of years.

A choice would therefore have to be made between the various possible uses of water resources. That raised the question of the criteria to be applied.

It would appear that the choice depended mainly upon external local circumstances. The engineer would naturally have to take into consideration the economic and human needs of the area concerned. A river-development scheme was thus in course of preparation in Java where the density of population was among the highest in the world. In such a case the food problem was obviously of primary importance and water had to be used entirely for irrigation; not a single drop could be allowed to flow into the sea and be lost.

It was therefore clear that in starting out on any development scheme the main problem was the choice of objectives. Engineers could submit a number of varied solutions and it would be up to economists to direct their work along lines determined after giving due consideration to economic and social factors.

Once the general plan had been clearly drawn up, technicians should start work with a view to achieving the desired objectives. In carrying out that work it was morally incumbent upon them to prevent waste in the use of resources and labour, and consequently, it would be their duty to observe the basic rule of economizing both material and manpower.

Mr. Boke pointed out that the problem of the simultaneous development of several basins existed not only in Australia, where four basins were closely linked, but also in the Central Valley of California where the development scheme combined the river systems of the Sacramento and San Joaquin valleys, both of which would benefit from the scheme, particularly with regard to irrigation and electric power. The linking of the two areas would considerably increase production resulting from the use of the water.

Mr. Boke expressed complete agreement with Mr. Aubert's remarks regarding the need for making a choice before undertaking development schemes. For such a choice to be rational, it was essential that a programme based on social considerations should be prepared prior to the drawing up of general plans.

Mr. Le Van drew attention to the fact that in some areas suffering from a prevalence of malaria, sanitation needs might govern such a choice, whereas it would be a secondary factor in most of the schemes just discussed.

Mr. García Quintero observed that climate governed all human activities, whether economic or social. It therefore also played an essential part in the problems arising from the use of water resources.

In dry climates irrigation was a major requirement since it determined the area of arable land. Power production, water use for domestic purposes, navigation and recreational needs were secondary considerations.

In wet climates, where irrigation was less essential, water resources could, on the contrary, be used for electric power, domestic requirements, navigation and, as an accessory, to regulate the flow of water during the relatively dry months.

Over 90 per cent of Mexico had a dry climate and consequently most of that country's river-basin development schemes were aimed primarily at supplying water for irrigation requirements.

The climate was very wet, however, in some areas such as the southern part of the Gulf of Mexico. The Papaloapan River basin, the development of which had been started during the current year, was situated in such an area. Its water resources would be mainly devoted to the production of electric power, irrigation being a very secondary factor. Only one-thirtieth of the available volume of water would be used for irrigation and the supply of drinking-water. The volume of water made available upon completion of the scheme would be twice that of the Colorado. A small proportion of the water resources of the Papaloapan River basin would be used to ensure a normal supply of water during particularly dry seasons or years.

Mr. Irmay described the water problem as it existed in Israel where, owing to lack of water, only one-third of the land was arable. The country was situated in the semi-arid zone of the eastern Mediterranean where the rainy season extended from November to April, with an average precipitation of some 20 inches per year.

The current high rate of immigration called for an extensive development of farming by means of irrigation. Yet even with the full development of the country's total water resources, not more than 30 to 40 per cent of the arable land could be irrigated.

Those resources were generally situated in the coastal regions and the Upper Jordan, and irrigation plans would therefore have to be prepared on a national scale.

The schemes currently under consideration covered the following projects:

(1) The development of the Jordan basin where the water was exposed to a high rate of evaporation in the Dead Sea. A Jordan Valley Authority, the subject of a recent summarized study published by Mr. Heiss, had been set up to carry out that development scheme.

(2) The development of various Mediterranean water-courses; the water would be diverted through a canal to irrigate the arid Negeb area.

(3) The use of subterranean water in the coastal areas so as to ensure conservation of the water resources.

(4) The draining of marshes, which would lead to the recovery of waters exposed to a high rate of evaporation. Similar work had been carried out in Utah.

(5) The production of electric power due to the difference of nearly 400 metres in the level of the Dead Sea and that of the Mediterranean. The energy thus produced could amount to 700 million kwh. annually. That scheme would make it necessary to bring sea water from the Mediterranean into the Dead Sea in order to compensate for the water-supplies used for irrigation.

(6) Using sewage water to hold drifting sands.

(7) Reducing the salt content of springs which at present could not be used.

(8) Increasing the efficiency of the use of water in farming by means of sprinkling and subsurface irrigation.

(9) The construction of underground reservoirs to lessen the evaporation of stored water.

(10) The use of dew and the application of artificial rainfall methods.

It was obvious that such a large-scale plan could be carried out only through a special and autonomous organ such as the TVA.

Mr. Hamid described the broad outlines of the water situation as it existed in Pakistan, where the winters were very dry and rainfall was limited to two months in the year. The problem of supplying water to such regions was extremely acute.

Its solution would necessitate the use of the five tributaries of the River Indus, the mountain sources of which were in India. Any development scheme would therefore require an agreement with India.

Pakistan was especially concerned with the problem, since large areas in the country remained uncultivated owing to drought and over two million refugees had immigrated into Pakistan as a result of recent developments. The problem of irrigation was therefore a primary one for Pakistan. Its solution would require an over-all plan affecting several basins not forming a political unit.

The irrigation of the Western Punjab would present a special problem on account of the excessive salt content of part of the land and its consequent progressive deterioration.

The development of river-basins would also ensure the production of the necessary electric power. As far as navigation was concerned, Pakistan's system was very limited.

Mr. El Samny said that in Egypt rivers were navigable only in part. Canals were not navigable in winter, so their water could be stored for the summer. Silting was a problem.

The utilization of the river-basins in Egypt assured three good crops a year. The aftermath of the war and the considerable increase in population, however, presented very real difficulties. The Egyptian Government had set aside ten million Egyptian pounds for the development of canals.

In reply to a remark by Mr. Aubert, he explained that the Egyptian Government bore all the expenses of maintaining catchments.

Mr. F. C. Rodríguez examined the problem as it existed in the Philippines, a country with a small area distributed over a large number of islands. With the exception of seven comparatively large rivers, the water resources of the Philippines were very small and had to be utilized to the maximum.

Hydrographical studies had only recently been undertaken in his country: the earliest dated back to 1904 and others had been carried out in 1920. They showed that only very little use could be made of the rivers. Furthermore, the Philippines had very limited funds with which to develop its river system.

In the circumstances, the country had been obliged to restrict itself to putting into effect with as little delay as possible certain plans which could be carried out at once. The comprehensive development of river-beds was, therefore, regarded as an aim for the distant future.

There was a fundamental difference between that method and the one adopted by other countries, where comprehensive plans were first studied, to be divided later into fragmentary plans. The Philippines was obliged to give priority to plans which offering the best immediate returns.

The chief aim of the research on comprehensive development was to prevent current work from compromising future possibilities. Each river was regarded as a part of the country's resources as a whole.

Mr. Papanicolaou said that only a quarter of the land in Greece was cultivable; there was, therefore, an acute shortage of arable land. Among the factors which are to be taken into consideration generally in deciding the construction of comprehensive river-basin development, there are also others which enter the problem, such as the shortage of land, demographic questions, etc. Thus Greece prepared her programme of works of this nature, i.e., reclamation, irrigation and hydro-electric works, all on the basis of the above criteria.

Mr. Ringers thought that Mr. Aubert had omitted certain factors from his summary of comprehensive river development. He wished to draw the meeting's attention to that problem as it arose in the under-developed countries, which should be the concern of the United Nations if the standard of living of their populations was to be raised. He had been asked recently, for example, as a hydraulic engineer, how a million and a half persons could settle in a marshy area of New Guinea. In replying, he had left out the question of navigation, which was a difficult problem owing to the very rapid falls, and had recommended introducing river and flood control measures followed by draining and purifying, which must be carried out before progressive colonization could begin.

Mr. Eysvoogel recognized the advantage of studying all the uses to which water could be put. It was not always easy, however, to choose between them. In some cases it was easy to use a river for irrigation and power at one and the same time, as the same water could be used for both. But a choice had to be made, particularly in densely populated countries where it was a question of generating power and at the same time feeding the population. Furthermore, the problem was likely to become complicated if one of the uses, power, for example, was more profitable than the other.

Mr. Menhinick agreed with Mr. Aubert that it was necessary to weigh the various factors and to decide which were the most important. He noted that the meeting was in general agreement on the question of comprehensive river-basin development.

In his opinion it was usually possible and desirable to combine several principal uses of water, such as navigation, flood control, and hydro-electric power uses. Other multipurpose uses were often possible, also. For example, the Tennessee Valley contained some low-lying land in western Tennessee which would be periodically flooded by the backwaters of Kentucky Dam. Malarial epidemics were a frequent occurrence in that region in summer. To overcome those difficulties, a dyke had been built and the area in question was drained in the summer during the mosquito breeding season. Farmers from the surrounding countryside used the land that had been drained for raising corn and other grain and paid for the rental of the land in a portion of the grain which they left in the fields. In autumn the dewatered area was flooded and attracted tens of thousands of wild ducks and geese, which fed on the grain. Thus a multiple-purpose use of land and water had proved not only necessary but very beneficial to the region.

The Chairman noted that all the members appeared to agree on the idea of comprehensive river-basin development. Almost every one thought, however, that it could not be carried out in his particular country, because of special conditions which favoured, or might appear to favour, more restricted plans.

Mr. Boke spoke of immediate needs as opposed to comprehensive development. He admitted that the Philippines, for example, had an immediate and urgent need of water resources. Assuring Mr. Rodríguez that the Philippines was not alone in that situation, he pointed out that the United States had also to make allowance for the density of the population and the lack of financial resources when drawing up some of its plans. There was therefore no fundamental divergence between the views of the members.

Comprehensive river-basin development was, however, highly desirable. In the Central Valley, for example, which already had two large reservoirs and several canals, the construction of a further thirty odd reservoirs and canals was contemplated. To illustrate the advantages of comprehensive development, he mentioned that the Sacramento Valley possessed two reservoirs, at a distance of 200 miles from each other, one of 7,600,000 acre-ft., and the other of 7,800,000 acre-ft. It was interesting to note that in using the two reservoirs as one, 80,000 more acre-ft. were obtained than if they had been used separately. It would be seen from that example that comprehensive development could offer real advantages.

Mr. Aubert wondered whether the members had really reached agreement on the need for a comprehensive plan of river-basin development. Feeling that a historic outline would be useful at that stage of the discussion, he recalled that comprehensive development was a recent concept which in France dated back to 1919 immediately after the First World War. It was at that time that a law had been enacted concerning the comprehensive development of the Rhône basin. In the United States, the TVA was also a recent undertaking. Until then water resources had been used piecemeal, each plan aiming at a single surpose.

He thought that from that time the idea of comprehensive development was established, but he pointed out that the classing of the various schemes according to their importance should logically depend on local characteristics.

He then proceeded to speak of the importance of the time factor. An over-all plan must be established which would take account of the needs of the population, which were likely to change from year to year, and of the time required for carrying out ambitious projects. Although construction was carried out rapidly in the United States, many projects of importance to other parts of the world would not be carried out for several years. On that point he agreed with Mr. Boke, who favoured construction "by successive stages", giving, within the framework of an over-all plan, the first place to one plan, second place to another and so forth: that solution applied particularly to the Philippines, since it allowed for the utilization of a part of the water resources without hindering the execution of the over-all plan. The latter need not necessarily be detailed. Once a general over-all plan had been drawn up, urgent plans could be put into effect immediately.

Another difficulty arose in the choice in a given country of the most urgent plan. France, for example, was considering the construction of two dams in the Rhône basin, one of 1,500 million kwh. at Génissiat and the other of 2,000 million kwh. at Donzère-Mondragon. Funds did not allow both those plans to be carried out at the same time and a decision had had to be made as to which of the two plans should be carried out first. The choice had fallen on the Génissiat dam, which would be able to produce electric power more cheaply.

He agreed with Mr. Boke that it would be very useful to develop all the various plans as one whole plan, joining, for example, the various generating plants by power lines. All electric plants in France were joined in that manner in a single national grid. Certain reports were already suggesting the creation of an international grid for Europe, joining the power production of various countries.

In conclusion, he explained that in speaking of the utilization of the Nile he had wished to stress the importance of the right Egypt had secured over the waters of that river in consideration of the utilization she had been carrying out for milleniums.

Mr. Irmay expressed his agreement with Mr. Aubert on the idea of a comprehensive river-basin development plan. He explained that the JVA operated on the same principles as the TVA, with the difference that the JVA was a national undertaking. The various projects under it had been carried out by stages, in order of urgency and with due regard to the needs of the population. Thus there would be no waste of effort.

Mr. Strome, returning to a matter already mentioned by Mr. Boke, said that just as the development of the Tigris and Euphrates basins concerned several countries, the development of the water resources of Canada was of great importance to the United States. River works in southern Canada concerned both countries. A great part of the four thousand mile frontier between the United States and Canada consisted of water. A treaty had been signed in 1911, outlining the use of the common water resources between the two countries and setting up an International Joint Commission. If, for example, a development plan was proposed for the basin of a river which crossed the frontier, and the work was likely to alter river conditions on the other side of the frontier, the plan had to be approved by the International Commission before it could be carried out. During the thirty-eight years in which it had been in existence, the Commission had solved many problems relating to the utilization of water resources.

Mr. Hannum gave an account of the comprehensive plans for the multiple-purpose development of the Columbia River Basin in the Pacific North-west. The potential hydro-electric power capacity of the Columbia River is 30 million kw. The basin development has been planned with a view to the need for power, of which there is a scarcity in the Pacific North-West, the need for flood control, the need for navigation—river control would make the river navigable up to 800 km. from the mouth—and the need for irrigation.

The flood control and power developments planned for the Columbia River and its tributaries in the United States would result in upstream and downstream benefits to both Canada and the United States. Discussions are under way with Canada regarding these relationships.

Agreements have been concluded with Canada which enable the level of Lake Kootenay to be raised. Compensation is paid to farmers whose land is flooded in the course of the work.

Mr. Hannum emphasized that before establishing a comprehensive plan for a river-basin it was of primary importance to take into consideration every purpose so that no purpose or benefit should be rejected without reasonable examination. The scope of a basin plan should not be limited in advance, nor should any decision be made to exploit any single purpose of a basin without a detailed study. The decision to omit any purpose or benefit should be on a positive basis and not by default.

Mr. Fink replied to the speakers who had implied that comprehensive planning and comprehensive river-basin development were only advantageous in certain cases and not in all cases.

He recommended them to study examples of river-basin development which served several purposes, before they took a definite stand on the question. He referred, in particular, to the Muskingum dams in Ohio (Muskingum Conservancy District), though they did not serve for the production of electric power nor were they used for navigation. Watershed developments were possible without the TVA type of Authority Controls. In the Muskingum project—14 dams—the local voice of the people was in control. This was not true in TVA.

Mr. Bernard emphasized the importance of obtaining the basic data, which had not always been done before the work was initiated. It must be remembered that once constructed, water and flood control projects had to serve for a long time. If the basin was not put to the best possible use the result was an irreparable loss which would be felt for a great many years.

He urged those present to encourage international co-operation, with a view to amassing as much data as possible so that the principles for a judicious exploitation of water, might be evolved.

Mr. Dworsky called attention to the importance of the quality of the water of a basin. Hitherto the discussion had emphasized only the quantitative utilization of water. In planning a project, however, consideration ought to be given to recreation, fish-breeding, agriculture, and urban and industrial water-supply. The cost of waste purification works should be taken into account. The effect of dams and of regulation to control low flow for sanitation purposes is an important consideration.

Mr. Kalinski noted that in the final analysis the cost of projects was borne by the users, whether farmers or others. Their money should not be used without their consent. The various speakers had stressed that the only course was to use persuasion. It seemed to him, however, that there should be legislation providing that no individuals and no minority of individuals could obstruct the establishment of a project and that they should submit to the will of the majority if that majority was in favour of the construction of a certain project.

He asked whether there was any legislation of that kind in the United States.

Mr. Dykes explained that in the United States drainage projects were financed by the issue of bonds.

Mr. Boke pointed out that in regard to reclamation projects the farmer who benefited paid either a fixed annual sum for a certain number of years or paid for the water at a fixed rate.

It was the farmers' organizations themselves which negotiated contracts with the United States Government.

Mr. DE VRIES opened the discussion of benefits and costs by observing how important it was to estimate beforehand what material benefits a scheme could provide for a region. Irrigation alone was not always enough in Java to increase the productivity of the soil; it was essential that the irrigated land should be sufficiently rich in nitrates and phosphate, so that crops could be planted the sale of which could serve to defray the cost of the project. If the land was not sufficiently fertile the cost of the irrigation project could never be paid off. New crops might be thought of to cover the expense. In Java sugar cane had been planted.

It was only after taking all those factors into account that a choice of projects should be made. A study of the economic conditions of the country must be made in order to apportion fairly the expense of construction and to eliminate risks as far as possible. In Java the Government levied taxes on the farmers to cover the cost of construction but it was possible to speculate in land there. Thus it had worked out that the speculators had profited most from the project, for they were now asking a much higher rent from the farmers and had raised the price of land. It was therefore the farmers who paid for the project. Furthermore, it was not always fair to ask the farmers to bear the expense. The income of the farmers varied considerably. It sometimes happened that work was started at a time when the cost of construction was very high, and then the farmers were forced to pay very highly for projects which would have cost much less had they been undertaken a short time later. A desirable project was beneficial not only to the farmer but to the community as a whole, at least in the long run, as the multiplier phenomenon was evident in these projects.

Mr. de Vries thought that it would be fairer to apportion the cost as follows: during a first period after the completion of a project, to place the largest part of the expense on the consumers (farmers or others); and thereafter to decrease it progressively, making the community pay an increasingly larger share. As a practical limit a payment of 50 per cent by the farmers was considered to be sufficient. Thereby the "multiplier" was assessed at the figure 2.

Mr. RINGERS recalled the case of the Haarlem Lake which was encroaching upon the land towards Amsterdam. About 1850 the Government had decided to drain it at its own expense. The reclaimed land was sold to private individuals leaving to them all cost of maintenance and development. This was too heavy for the pioneers, who sold their land with heavy losses.

The necessity to produce more food led in 1927 to the reclamation of the Zuider Zee polders. The complete development was now at the Government's expense. It was realized that it is not a sound policy to ask only those who benefited directly from a project of national importance to bear the expense. The Government did not sell the land but rented it at a rate far lower than would be its rental value based on the cost of the project.

Mr. EYSVOOGEL pointed out that in the island of Java the system used for financing such projects was the same as in Egypt. The Government was responsible for the cost of construction, which it recovered from the taxpayer by levying proportional taxes. There was only one important tax in the island of Java: a land tax based on productivity. It followed that when fertility increased, Government revenue increased also. Experience showed, however, that the expenses which were incurred could never be recovered completely. It had therefore been decided that only 50 per cent of the cost would be financed from capital loans. The remaining expense was paid out of surplus revenues, which was justified by the increase in general prosperity resulting from the work that had been done.

Mr. VAN BLOMMESTEIN explained the work of the development scheme for Java to which Professor Aubert had referred. In Java, where density of population reached 360 inhabitants per square kilometre, the rapidly increasing population suffered periodically from a scarcity of rice.

The development scheme, which had been started after the war, was the first multiple purpose plan for Indonesia. It embodied a group of plans based on the construction of two reservoirs on the Tji Tarum, with a total capacity of 4,000 million cub. metres.

The waters thus stored would be used to irrigate the plain extending to the north-west of the island, where 500,000 hectares of cultivable land received no water except during the rainy season. Even during that season only four-fifths of the land received sufficient water. The project would bring about an increase of 500,000 tons in the rice production.

In the south-western part of the island, other installations which would serve partly to produce power would enable the rice production to be increased by 100,000 tons.

Mr. AUBERT made a few general remarks on the financing and total expense of river-basin development. The two possible solutions were at opposite extremes: complete financial responsibility by the Government, or complete lack of any assistance from the Government.

In the case of the Tennessee Valley Authority, it seemed that the Government had finally assumed a part of the expense, which it recovered in the form of indirect benefits.

The development of the Rhône was the example of an intermediate method. The Government had said it would not give one franc to the company organized to develop the Rhône, and so the company had worked without government subsidy and had issued stocks at the current rates of interest. The company had acted as an individual, except that the Government had guaranteed loans, which was the full extent of government aid.

The company itself had decided that the best way of paying off costs of construction was by selling power to *l'Electricité de France*. It was the sale of power that had enabled the company to meet the expense of nonpaying operations such as navigation control. That case was an example of river development for navigation being entirely financed by profits received as a result of its development for electric power.

The CHAIRMAN summarized the discussion of the financing of river projects for hydraulic power: it ranged from situations in which the consumer paid back the entire sums spent by making payments over a fixed period of time, to those in which the Government financed the entire operation by levying the necessary amount on the national budget.

He drew attention to the paper on water supply in the agricultural areas of Western Australia by Mr. T. Langford-Smith, copies of which had been distributed to those present in the form of reprints from *The Australian Geographer*. The author had prepared a short résumé of this original paper for inclusion in the final proceedings of the Conference.

He also drew attention to a paper prepared by Mr. H. Pirnia on experience in the integrated development of a river-basin in connexion with the Iranian Seven-Year-Plan for reconstruction and development. Mr. Pirnia's manuscript had unfortunately been received too late for reproduction in advance of the meeting.

Drainage Basin Management

24 August 1949

Chairman:

J. C. DYKES, Assistant Chief, Soil Conservation Service, United States Department of Agriculture

Contributed Papers:

Drainage Basin Management; Water Control Through Watershed Management
R. M. GORRIE, Conservator of Forests, Rawalpindi, West Punjab, Pakistan

Water Control Through River Basin Conservancy
Marco VISENTINI, President of the Supreme Council, Ministry of Public Works, Rome, Italy

Water Control Through Watershed Management
Reed W. BAILEY, Director, Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Ogden, Utah, U.S.A.

The Federal Supervision of Water Policy in the Interests of Soil Conservation in Switzerland
Walter SCHURTER, Chief Federal Inspector of Public Works, Berne, Switzerland

Water Control Through Watershed Management
V. FROLOW, *Maître de recherches au Centre national de la recherche scientifique; Vice-Président de l'Association internationale d'hydrologie scientifique*, Paris, France

The Effects of Land Management Upon Run-Off and Groundwater
Howard L. COOK, Office of the Secretary, United States Department of Agriculture

Effects of Watershed Management on Water Yield
V. FROLOW, *Maître de recherches au Centre national de la recherche scientifique; Vice-Président de l'Association internationale d'hydrologie scientifique*, Paris, France

The Effect of Stream Management on Water Yields
F. KUNTSCHEN, Director, and J. BIRCHER, Chief of Section, *Service Federal des eaux, Département des postes et des chemins de fer*, Berne, Switzerland

Summary of Discussion:

Discussants:

Messrs. HAMID, RAUSHENBUSH, BAILEY, FORNEROD, DE HAAN, RENNER, MAITLAND, COMPTON, DELGADO, DULEY, DAHLBECK, HOCKENSMITH, MUNNS, FLON, H. L. COOK, M. L. COOKE, LEGGETTE, IRMAY, S. BUCHAN, C. G. LOPEZ

Programme Officer:

S. RAUSHENBUSH

Drainage Basin Management; Water Control Through Watershed Management

R. M. GORRIE

ABSTRACT

Three essential aims:

1. Preserve plant cover wherever in reasonable condition and ecologically stable; where cover already deteriorated or naturally inefficient, run-off control needs engineering devices (contouring to aid afforestation, check dams in gullies, complete terracing of ploughland). The worse the climate for vegetation the more essential are such devices; low costs justify use of machines instead of hand or animal labour.

2. Deal with whole of each small catchment as a unit. Sounds obvious but often prevented by administrative difficulties, e.g., smallness of individual holdings interferes with contouring; consolidation of holdings is lengthy legal routine; government averse to coerce unwilling owners; common land is nobody's business: common grazing rights hinder herd reduction; allotment of funds often cut in emergency; co-operative organization for improving waste land produces "pepper-pot" scattering of effort; land revenue (tax) department averse to changes in field boundaries.

3. Control the water and the soil will look after itself. Highest standard of indigenous control is in low rainfall areas, e.g., 8 in. rainfall can ripen wheat on terraces which preserve every drop, but higher rainfall areas show lower efficiency and greater need for field drainage to dispose of excess. Crop specialists are not interested in flood control as such nor are the makers of new political boundaries.

As the four "experience reports" presented at this meeting on watershed management are all from temperate climates (Switzerland, Italy, France and USA) I shall try to show in this general introductory paper how local experience in extreme climates and amongst primitive people may possibly be applied to the more equable climates and more advanced types of farming represented by our "experience" reporters, particularly by comparing the relative efficiency of soil-moving machinery as compared with the indigenous methods of digging and moving soil.

PRESERVING AND IMPROVING PLANT COVER FOR WATER CONTROL

Under this heading the main activities must obviously fall into two groups (*a*) afforestation and grazing control on the one hand and (*b*) the water use in plough land on the other. In some topographies it may be feasible to separate these completely so that the forester and the cultivator can each be left to do his own work without interfering with the other but Punjab experience tends to show that in our badly gullied uplands the fringe of down-at-heel lands which has passed, or is passing, out of cultivation makes a most intricate pattern around the head of each small catchment and that once land has reached a badly gullied condition with steep flanks sloping into the local main water channel, economical reclamation is essentially a job for a team. The forester and the farmer alone are equally helpless.

AREAS FOR RECLAMATION

Taking the seven upland districts of Rawalpindi, Campbellpur, Gujrat, Sialkot, Mianwali, Shahpur and Jhelum, whose combined total area is 14,693,972 acres, just about half of this is cultivated and the rest is grouped under (1) forest, (2) cultivable but uncultivated (including fallow) and (3) unculturable (this includes roads, railways, towns, river-beds, etc.).

A recent detailed investigation showed the total badly gullied area in these districts to be 1,750,000 acres, most of which is included under the headings of forest and uncultivable waste in the above primary classification. Much of this deeply gullied land consists of excellent soil which has been exposed to considerable depths below the present upland plateau level. Gullies are eating into this plateau land at a terrific rate but much of this erosion can be prevented if machines can be made available.

METHOD OF RECLAMATION

Experience has shown that the most profitable way to use caterpillar bulldozers is to combine them with hand labour. If each cultivator who owns land in a narrow gully or *nala* bed builds a stout masonry dam, the machines can be used subsequently to build up wing walls and raise the height of the structure, thus giving a bigger field behind and quicker silting and levelling. This type of work will give land a higher crop value than the terracing of the more level plateau land. The forest department is already making subsidies to individual owners towards approved masonry bund projects. Some 15,000 acres of *nala*-bottom cultivation has been reclaimed by means of masonry bunds, and this reclamation has cost Rs. 80 to 150 per acre. Such *nala*-bottom dams can only be made safe and permanent if the whole of the catchment above the dam has been brought under a flood control regime, the ploughland being fully terraced and the uncultivated land either afforested or under strict grazing control so that grasslands are kept fully absorptive.

COST OF MACHINE WORKING PER HOUR

All costing figures are based upon: (*a*) actuals—consisting of all running expenses plus operator's pay; (*b*) overhead expenses which include writing-off the costs of the machine over 10,000 hours, plus one-half of that figure for major repairs, plus interest on capital investment at 4 per cent. For machines at present available, all-in costs of D-7 are Rs. 17/- per hour and for a D-4, Rs. 9/- per hour, and the working charges account for roughly half of each. These figures correspond closely with the Caterpillar Company's own published data, which for Punjab conditions are: cost per hour, in rupees (Rs. 13 to the pound, or roughly 3 rupees per dollar):

	D8	D7	D6	D4	D2
Actual running costs .	9.22	6.90	6.11	4.74	4.40
Overheads	11.11	8.29	6.25	4.15	3.24
Total	20.33	15.19	12.36	8.89	7.64

CASH RECOVERIES

D-7s have only recently become available and the recovery in their case at present is a flat rate of 14/- per hour in cash from the owner of the land. This is very nearly the full cost including interest and depreciation for the D-7 when working alone, though the introduction of a scraper attachment costing 23,000/- pushes up the total to somewhere around 17/- by increasing depreciation and interest charges. Although this 14/- charge puts this machine beyond the reach of the poorer classes of owner, this type of work is exceedingly popular and a very large waiting list of applicants for the use of these machines exists in all districts where the machines have worked.

MACHINE COSTINGS ON AN ACREAGE BASIS

There are so many factors affecting the cost per acre that it is dangerous to give a firm estimate for a given area until some work has been done for these or identical conditions. The main factors affecting cost per acre are:

1. Slope. See below.

2. Hardness or toughness of ground surface.

3. Proximity of rock strata, pebble beds or red marl beds.

4. Experience of operators, the cost coming down steadily with practice.

5. Size of individual fields; the small fields typical of Rawalpindi and Jhelum being difficult for any machine but more so for the larger machines which have not room to manoeuvre, or if they can do so, they waste fuel in frequent stops and gear changes.

6. For *nala*-bottom reclamation the cost of the bund has to be offset against the acreage of the silted bed behind the bund.

EFFECT OF SLOPE ON COSTS

Over a period of 6 months' work in the deeply gullied plateau lands of the Ojhri Catchment near Rawalpindi the following data were produced with a D-4 pulling a 5-tine scraper.

Slope class Per cent	*Cost per acre*		
	2nd 3 months	*3rd 3 months*	*Round figure average*
0-2	102	88	90
2-4	108	102	105
4-6	174	121	150
6-8	192	205	200
Over 8	264	251	250

This shows clearly that costs rise steeply as a function of the slope and above 8 per cent the cost mounts so quickly that it soon becomes uneconomic to terrace for fields. Somewhere around 8 per cent therefore is the margin between reclaiming for fields and for afforestation. Steeper slopes can however be profitably worked by machines to produce a contour ditch and ridge or *gradoni* (Italian for shelf or platform) on which tree sowing or planting or grass cultivation will still pay a good profit through the quicker and better growth which will result as compared with planting on an unimproved slope.

RECLAMATION AS AN INVESTMENT

To define the position for agricultural land, the paragraph above gives a clear indication of the cost for plateau land completely levelled between field boundaries. Unimproved land of this type near Rawalpindi can be purchased for Rs. 600 to Rs. 800 an acre, so allowing a further Rs. 150 per acre for terracing, and with wheat at its present price, the whole cost can be recovered in the first four wheat harvests.

For deeply gullied land the purchase price is less, roughly 100 to 150 rupees an acre; the cost of reclamation may go as high as 300 rupees an acre, but even so, it still seems a good investment.

In the case of more ambitious *nala*-bottom bunds, which are now becoming so popular with the larger Attock and Mianwali landlords, it pays to build big soil-saving bunds with donkeys and head-loads, so it must obviously pay even better with bulldozers which can do this work cheaper and quicker and can extend the crop area by filling up the torrent bed and breaking down hillocks in the reclaimed area. The cost of such reclamation works out at from Rs. 80 to Rs. 150 per reclaimed acre.

THE PRINCIPLE OF THE CATCHMENT AS A UNIT

In our anxiety to recover as much as possible of the costs for government it is very easy to be sidetracked away from the principle of the catchment. No matter how successful or popular our land reclamation is proving, it will fail if we do not insist upon each unit catchment being dealt with as completely and as comprehensively as possible for water conservation and flood control. This is the only justification for our intrusion into the reclamation of agricultural land. The endless and ragged fringe of bad cultivation retreating before each advancing gully-head must be mastered and it can only be made safe and profitable by adopting every possible type of land use and adapting our machine attack towards easy afforestation, fodder production, village tanks and ponds as well as plough land.

FURTHER DEVELOPMENT

The disadvantage of applying any hard and fast rule for recovery of costs is that it precludes us from attempting further experimental work. The building of dams in broad shallow *nalas* and the terracing of fields on the easier slopes are safely past the experimental stage and we have a long waiting list of applicants clamouring for the use of our machines on such land. But a great deal of pioneering and experiment still remains to be done on the partial terracing of steeper land for afforestation and on the type of earth dams and masonry escape needed to store floods in the deeper and narrower *nalas*. To insist upon a fixed return of the government's investment would, therefore, be a serious mistake. We must be allowed freedom to experiment as and when required in order to make as complete a job as possible of each catchment.

VALUE OF WORK PURELY AS FLOOD CONTROL

A scheme for the 55,000-acre catchment of the Leh River whose periodic flooding causes great damage and inconvenience in Rawalpindi city has been prepared, based upon the building of numerous earth dams with masonry escapes distributed throughout a semi-circular perimeter of gully heads. Numerous other areas are now covered by working plans drawn up in the same manner as the stereotyped forest working plan, but providing for all feasible forms of flood prevention. The most recent is the Murree Suburban Conservation Plan which lays down a five-year programme in the badly denuded mountain forests and village lands around the hill station of Murree. Here and in other Himalayan areas the prescription for the steep and rocky hills is checkdams in the torrent beds; afforestation of both government and village lands where tree-lopping has caused denudation; and stone terraces for the cultivation, much of which is far steeper than can be controlled by ordinary contour ridges.

EXAMPLE OF UNCOORDINATED FLOOD CONTROL

An example of how not to control floods is seen in the Malakmala Bund. In a remote corner of Attock district adjoining the Indus River an outlying spur of the Himalayan foothills forms the Gangarh range.(8)[1] In the Emperor Babar's time this was well wooded and a series of hill streams ran down from it through a flat tract which became well known for its tobacco growing. Gradually however, disforestation of Gangarh hill brought trouble, the middle slopes became wide sandy torrent beds and the outlying flats became a swamp. In 1925 an enterprising civil official got engineers to produce a scheme for a five-mile-long earth dam with a masonry escape for each of the five major torrents. The dam was planned as a delay reservoir with the idea of ponding back the silt and flood-water on the sandy slopes in order to reduce the water-logging which was already becoming serious in the lower lying tract nearer the Indus bank. The dam was built at a cost of Rs. 100,000 ($33,000) and with a capacity for storage of about 93 million cub. ft. The rainfall is about 10 inches and the run-off from such hill torrents is exceedingly high, as is shown by the peak flood figures published for the Rabbi torrents which have to be passed through or under the Upper Jhelum Canal. (1) The dam was breached by all of the main torrents within a year or two of being built. Very large sums of compensation were paid out to the villagers on a legal decision that the Government being responsible for the dam was therefore responsible for all subsequent flood damage. The flood damage recurred in several years and in 1931 an attempt was made to get the villagers to devote their flood compensation sums to repairing and improving the dam but they refused and since then the dam has remained as it is now. No question of afforestation or catchment control was raised until 1945, when a soil conservation plan was produced by the Forest Department which had previously not functioned in this part of the district at all. Since then parts of the hill catchments of these torrents have been brought under protection by means of voluntary closures to grazing, and some afforestation and torrent training work has been attempted, but it will take some years more of energetic afforestation before any appreciable effect can be seen in reduced flood peaks. Meanwhile the meandering paths of these torrents through the fertile tobacco growing belt are being canalized by planting. The local demand for manure for this tobacco belt is such that farm-yard manure is brought 60 miles by camel load. In the absence of firewood, local fuel is mostly grass roots and costs Rs. 3/8/- a maund (or a dollar and a half a cwt.). It would surely be hard to find a better example of unbalanced economy due to lack of watershed management in the past.

[1]Numbers within parentheses refer to items in the bibliography.

CATCHMENTS AND POLITICAL BOUNDARIES

The Punjab Forest Department established a Soil Conservation Circle in 1939 and this was made permanent in 1945. As a result of the Partition of the Muslim and Hindu halves of the province, this work in the new West Punjab province was incorporated in the Rawalpindi Forest Circle in August 1947 and this still remains the only official unit dealing with local flood problems on the basis of prevention being better than cure. Unfortunately none of the larger rivers which provide the irrigation supply for the southern half of this new province is amenable to local control, because the Indus, the Jhelum, the Chenab and the Ravi all rise in Tibet or in the Kashmir Himalayas. Even many of the smaller torrents such as the Bhimber and the Tawi have their catchments in the Jammu and Poonch provinces of Kashmir State, though the damage they do is all in the Punjab. Kashmir and West Punjab form the upper and lower catchments of a number of rivers which provide the only economic route for working the valuable coniferous forests of Kashmir and whose water is the source of the Punjab's irrigation canals as well as of its flood problems. From this it will be seen that the drawing of a new political boundary may greatly complicate the administration of water resources.

OTHER ADMINISTRATIVE DIFFICULTIES IN APPLYING SOIL CONSERVATION PRINCIPLES

Many other difficulties have arisen in the course of our Punjab work and some of them should be of general significance even in more fully developed countries so short notes are given on the following points:

(*a*) The smallness of individual holdings and the continued fractionizing due to laws of succession to property interfere with any attempt at scientific contouring through rendering the shape and size of each field awkward for terracing and even in extreme cases too small for the use of a plough.

(*b*) One answer is in the consolidation of holdings but this is a lengthy legal routine which takes some years to make operative through a separate branch of the civil administration which deals with it. The consolidation of scattered shares into one holding and the stopping of further fractionization are essential if field boundaries are ever to be brought under modern concepts of run-off control, but in the meanwhile much work is being done on the contour ridging of fields on the existing and often unsatisfactory boundaries as defined in the land revenue registers.

(*c*) The land revenue authorities are responsible for the records of individual field boundaries and in India and Pakistan the main work of the revenue *patwari* is to record all changes in ownership. His record of field boundaries is an elaborate affair and he holds the whole village economy in his hand and is a power in the land. He does not welcome any proposals which are likely to upset his precious record and so the whole moral force of the revenue subordinates is against any idea of contouring or revision of boundaries.

(*d*) Most Governments are averse to using any force or coercion in order to persuade unwilling owners, even when the number of objectors is small; and when it is large the fear of losing votes is an effective deterrent. In some cases one may even find that sound legislative measures have been passed and could be applied but local action is withheld because it will be too unpopular. The answer is of course in basic education because an informed public opinion will do more than anything else to coerce the objectors, once the *bona fides* of government and the soundness of the local proposals have been accepted. With primitive populations some form of regimentation is desirable because if the average voter is illiterate and ignorant he cannot be expected to know what is really best for his own interests and those of his community. In the case of the contouring of fields the average peasant proprietor knows what water conservation is needed to grow his crops in his peculiar climate, but few indeed have any realization of the harm done by overgrazing and overfelling. The gradualness of deterioration which brings desiccation and gullying as its ultimate end cannot be understood by the countryman whose memory is seldom accurate. Any sort of co-ordination of effort therefore comes easier for ploughland than for waste or grazing land, and so we often find our downstream reclamation for cultivation out-distancing the control of the uncultivated uplands, which ought of course to come first in priority.

(*e*) Common-land is nobody's business. The commons in almost every country are in poorer condition than they ought to be in terms of their natural ecological climax type of vegetation. In India early revenue settlements insisted upon 25 per cent of the village land being left unploughed in order to guarantee the poor men's grazing rights on the common land, but generally speaking the more grazing provided the worse are the live-stock raised on it, for the less attention is paid to the quality of the stock and breeding control. The districts that have practically no common grazing produce the best plough cattle and milk buffaloes, because every animal is stall-fed and no surplus animals are tolerated. The answer is obviously to organize the remaining common land so that it becomes some individual's responsibility. This can best be done by forming a co-operative society which can act as if it were a single owner for the common land and put it to the best use, either for plough land, rotational grazing, the growing of fuel trees, timber, fruit or fodder-grass, or for water-catching, or all of these combined.

(*f*) The allocation of funds by government to their subordinate departments recalls the Biblical story of the servants' talents, for in times of shortage the revenue producing activities obviously must be kept going whereas the beneficent activities are the first to be closed down. The best guarantee against this is a periodic plan, for which five years is as good a period as any. Once a government has committed itself to supporting such a plan for the development of beneficent activities it is always a little harder for it to jettison the work. Such a plan also is an essential in the calculation of recruitments and the various grades of technical staff, and the higher the standard of training, as in the officers, and rangers' grades the longer it takes to produce the trained bodies.

(*g*) The voluntary principle for the organization of co-operative societies is an excellent one and should have the Government's full support in terms of loans on a low interest and an inspection staff to ensure proper organization of each society and the conduct of its business and records. The tendency, however, is for the departmental cadre of inspectors to feel that they can tackle any technical problems themselves rather than call in the appropriate technical department to deal with afforestation, animal husbandry, flood control, public health, and so forth. Another snag is the wide scattering of effort. When a society can be formed on an application of a majority of owners in one village, the tendency is for societies to spring up as if scattered from a pepper pot. This may suit the co-operative inspectors who like to travel but is the antithesis of what we need in flood control in organizing the whole of one catchment.

(*h*) The natural ability of the cultivator in building his terraced fields is inversely proportional to the average rainfall. Where the rainfall is 8 to 15 in., the standard of terracing is exceedingly high because it is only by trapping all the rain that a wheat crop can be ripened. Where nature is more bountiful the standard is definitely poorer, and it is only in the 20 to 25 in. belt and over, that draining off excess moisture becomes a serious problem and elaborate field drainage systems have to be worked out.

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Water Control Through River Basin Conservancy[1]

MARCO VISENTINI

ABSTRACT

The two purposes of river-basin conservancy are the slowing down of the stream-flow in order that flood-waters should rise at a slower rate and to a lower level, and the elimination, or at least the diminution, of soil erosion by surface-water.

The measures adopted in Italy to achieve these purposes are then described.

Information is given on the management and regeneration of forests and pastures and on the technical authorities responsible for this service.

There is a more detailed description of the measures taken in the case of surfaces where landslips may occur and which slope very steeply and of the good results obtained by the application of such measures.

Finally, an account is given of the water-control measures adopted in the case of land not very steeply sloped which is used for agricultural purposes. These consist mainly of removing channels which follow the slope of the terrain and replacing them by channels which more or less follow the horizontal contours.

Stream-flow control of river-basins has a twofold purpose. The first objective is to prevent the water from flowing too quickly from the higher to the lower levels and so making major floods briefer in duration. The higher flood levels reached in the absence of such control make it more difficult to protect the valley from flood disasters. The second objective is to prevent the water from flowing over the ground so fast that it carries away small particles of soil, thus causing erosion, making mountain land less productive and at the same time damaging valley land by the silting up of river-beds and the depositing of layers of soil carried down from above.

If water is to be used to the best advantage, the flow must be kept as even as possible, with only small deviations above or under the average rate.

We shall now survey the measures adopted in Italy to achieve a satisfactory system of water control by means of river-basin conservancy.

FORESTS

The Law does not confine itself, in some of its articles, to prohibiting the destruction of existing forests. It also makes it obligatory to improve those which are no longer capable of affording sufficient protection to the land and, where necessary, even enforces the afforestation of land which would otherwise inevitably be liable to damage from erosion by water.

To ensure observance of the various ordinances and prohibitions, and also for the direct operation of reafforestation, a forestry corps has been set up under the Ministry of Agriculture and Forestry. This corps works in collaboration with the Civil Engineering Corps, which comes under the Ministry of Public Works. Any general problem concerning water comes within the latter's province.

Since the function of forests is to slow down the flow of surface water and facilitate its infiltration, and to protect the soil against erosion, afforestation is one of the most important operations in river conservancy. Unfortunately, it can only have a limited application in Italy because the arable acreage is too small compared with the size of the population.

PASTURE LAND

Land sown to grass, especially if it is not ploughed up every year, but merely re-sown and manured, is absolutely immune from erosion. Therein lies the importance of maintaining existing mountain pastures and of creating new pastures on land which because of its nature, and particularly its slope, is most liable to erosion.

Not every kind of grass is equally suitable for this purpose; the best varieties are those with not too long but very close-set roots so that both the roots and the surface growth offer stout resistance to erosion.

The Forestry Corps is also responsible for the maintenance and conservation of pasture land.

ARABLE LAND

The greatest difficulties in achieving satisfactory water control are met with in the case of land which is naturally or economically unsuitable for the formation of forests or pastures. This is often the case in Italy, especially in the Apennines, and several major schemes have been, or are still being, executed with a view to controlling the water and, at the same time, stabilizing the soil.

The cases most frequently met with include those of the *calanchi*, an untranslatable Italian word meaning a kind of ravine. Soil erosion and flood damage are, unfortunately, still features of these *calanchi*. Their characteristics are as follows:

(*a*) Lengthwise, the bottom of the ravine slopes very steeply, so that the rapid flow of water washes out the soil;

(*b*) The transverse section is shaped like a narrow V owing to the large quantities of soil which are being constantly washed away from the bottom;

(*c*) Dangerous fissures and gullies appear in the sides of the valley so that the soil is constantly tending to cave in.

In such cases as these the following action will be required:

(i) The water above the part of the basin that is subject to erosion should be drained off by small, gently sloping channels, care being taken to lead them away from the ravine to an area where the soil is firmer;

(ii) Barriers, preferably made of earth, should be erected on the floor of the valley, to retain the matter swept away

[1]Original text: French.

and to make the fall less steep, thus slowing down the water-flow;

(iii) The shape of the sides of the basin should be corrected by constructing another series of small barriers in the secondary channels, and the formation of less sloping surfaces should be facilitated by demolishing, artificially or frequently by the use of explosives, the parts most likely to cave in.

Such measures will gradually transform the river-basin into a succession of terraces which can later be tilled or put under grass without any risk of serious harm being done by water, which flows off more slowly and more regularly when the slopes are made less steep.

The *calanchi* or ravines which have just been mentioned occur most frequently in clayey soil. In giving effect to any scheme for their improvement it is essential, while making the slopes less steep, to secure a regular and continuous flow of water; otherwise, when the clayey soil becomes saturated with water that has been held on it too long, it is liable to slip, which is very much the same as a landslide.

Improvements such as those described above have been carried out over large areas of Emilia and the Romagna and on the slopes of the Apennines, and the results have been fully up to expectations, both in controlling the water-flow and in stabilizing the soil.

There can be no general solution of these conservation problems. Each individual case must be studied by itself after very careful investigation has first been made of the nature and morphology of the soil and the climate of the river-basin concerned.

In those sections of river-basins nearest the plain, where the slope of the ground makes it possible to dispense with barriers and other kinds of artificial water control methods, without, however, eliminating all danger of erosion, or in sections where the rate of flow is still too rapid for proper water control, the chief objective should be to make the water flow along a network of channels sited more or less horizontally, and to block up those which slope too steeply because they are sited too much athwart the contours. These channels would thus be fairly long, but would have almost no fall.

With these improvements and especially if cultivation is carried out on similar lines and not in haphazard fashion, more water will tend to penetrate into the soil, and a more appropriate degree of humidity will be secured; the inflow of water into the river-beds will thus be retarded, and the outflow will become much more regular.

Even in these cases, of course, the nature of the soil should always be kept in mind, so that no water is allowed to lie on clayey soils where landslips might occur.

Conservation by means of tilling the soil or digging trenches parallel to the contours is sometimes complicated by altimetric or planimetric irregularities. It will then be necessary to begin by a thorough regrading of the soil surface, if this can be done without too much cost.

When this cannot be done by following the horizontal contours, the compromise may be adopted of laying channels which follow the natural slope of the ground; but in order to lessen the drawbacks of this arrangement, the channels should be broken up by a fairly large number of ledges in close succession to one another.

Finally, the water-flow can also be controlled on the level ground by suitable methods of tilling and preparing the soil, so that a certain amount of rainwater infiltrates into the subsoil. The surface-flow will thus be diminished, and it is usually desirable to increase the humidity of the soil for the benefit of plant life.

All these systems of conservation for the control of water-flow have been practised in many parts of Italy for a long time past and, as they have given consistently favourable results, they are becoming more and more common.

It is noticeable, however, that in regions where river-basin improvements have for some years past had to be suspended because of difficulties created by war conditions or for other reasons, river floods have become more frequent and have often given rise to disasters of a magnitude seldom experienced in recent times.

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Water Control Through Watershed Management

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ABSTRACT

The United States is making slow but significant progress toward control of run-off through watershed management. This approach to run-off control is based on the fact that plant cover and the soil mantle influence the disposition of precipitation and that these characteristics of watersheds can be altered. Because some degree and frequency of flooding is normal in all basins, watershed management is effective largely in preventing the occurrence of abnormal run-off and in restoring normal hydrologic functions on areas which have become deteriorated. The report describes the application of these principles and concepts and the effectiveness of the measures employed in controlling certain floods in Utah.

Investigations into serious mud-rock floods from deteriorated watersheds in northern Utah brought about a programme of watershed improvement designed to restore higher, more nearly normal, infiltration rates and thus reduce the incidence of such floods. The programme to date has proved successful and serves to demonstrate that control of run-off can be re-established on watersheds where run-off restraining functions have been impaired by destruction of the plant cover and disturbance of the soil.

INTRODUCTION

The United States Government has become firmly committed to a policy of handling land for run-off control. The first step in this direction was taken some fifty years ago when the present system of national forests was created. The dominant purpose of that movement was to place extensive areas of headwater lands under a form of managed use that would insure desirable conditions of stream-flow as well as continuously abundant supplies of wood, forage, and other wild land resources. Since then, and particularly in the past thirty years, additional legislation has recognized the need for extending some form of watershed management to virtually all lands.

In spite of these measures, accomplishments have been less than the promise. Large areas of important watershed lands were seriously impaired before the need for management was recognized. Effective action has been limited on agricultural lands and on many privately owned forest and range lands because the individual's interest did not in many cases coincide with the public interest. Even on public lands adequate programmes of watershed management have been slow in getting under way because of apathy on the part of the public and the lack of knowledge in some of the important phases of management.

Notwithstanding these obstacles, significant progress has been made toward the goal of achieving run-off control by watershed management. For one thing, our concepts of certain basic principles of watershed management both for wild lands and cultivated lands have been clarified by research. We have also learned much about the practical application of these principles through action programmes of watershed improvement measures in various parts of the country. The purpose of this paper is to outline some of the major concepts that have been found to be important in the management of forest and range lands for water control and to describe how these were used in solving a serious flood problem in Utah.

HYDROLOGIC FUNCTIONS OF WATERSHEDS

The concept that watershed management can be a means of controlling run-off stems from the fact that plant cover and the soil mantle influence the disposition of precipitation as run-off. This is important since the plant cover can be modified—either increased or decreased by man—and the soil mantle can also be altered in such a way as either to be favourable or unfavourable to the infiltration and retention of water.

Run-off may come from any watershed site as delayed and generally clear, seepage flow or as rapid and generally silt-laden overland flow, or both. Whether run-off occurs as seepage flow or overland flow depends primarily on the infiltration capacity of the soil surface and secondarily on the percolation capacity of the underlying mantle material on each watershed site.

There is, of course, much variation in the capacity of sites to infiltrate and percolate water due in part to the structure and porosity of soils, but more particularly to the kind and amount of plant and litter cover. Infiltrometre measurements have shown that some sites are capable of infiltrating water at rates in excess of six to ten inches per hour for several hours without producing any appreciable amount of overland flow. It is also known that other sites having less pervious soil mantles are capable of infiltrating water at rates of less than 0.5 inch per hour. It is entirely normal, in other words, for some areas to yield water largely as overland flow and for others to produce only seepage flow. Both types of run-off may develop into floods.

THE CONCEPT OF NORMAL FLOODS

In the United States so-called "normal" floods may develop under a variety of climatic and physiographic conditions. For convenience these may be grouped into three broad categories.

Watersheds in the humid South and East, as well as in the Pacific North-west and the Pacific South-west, are frequently subjected to copious rains or to heavy snowfall and rains. Well-vegetated soil mantles in most parts of these regions are capable of infiltrating virtually all of the rain as it falls. There is, therefore, little overland flow. Frequently, however, these areas receive more precipitation than the mantle can hold. Under these conditions large volumes of water drain from the soil into channels to create great flood discharges. These may be entirely normal.

Floods can be called normal events also in regions where low temperatures cause the freezing of the surface soil and thus prevent the infiltration of water from rain or melted snow into the mantle. This type of hazard is especially serious in parts of the North-eastern and Central States. There, periods of very cold weather and tightly frozen ground conditions may be followed by rapid snow melt or heavy rainfall, which result in the delivery of large volumes of water by overland flow to stream channels.

Also, floods are normal occurrences under certain conditions in the so-called arid regions. Much of the western United States is subject to torrential summer storms. Though these are generally of short duration and sometimes involve less than two inches of rain over areas of but a few square miles, the rain falls in large drops with great impact, and at very high rates. This type of rainfall is a powerful eroding agent, particularly on areas where the soil surface is exposed. It can also produce large amounts of overland flow which can develop into remarkably destructive stream-flow discharges. Typical of such areas where the geologic norms of erosion, of flood frequency, and of sediment loads are high, are portions of the Colorado River drainage in southern Utah and the Badlands of the Dakotas.

THE CONCEPT OF ABNORMAL FLOODS

It is possible to increase the frequency and severity of all such floods through mismanagement of the land. The potential for inducing abnormal floods is especially high in humid regions. The normal storage capacity of the mantle on these lands can be reduced by destroying or diminishing the litter and other organic matter in the soil. Water storage capacity can also be decreased through the removal of the soil by erosion. Each increment of water storage loss increases the amount of run-off in essentially the same manner as the capacity of a reservoir behind a dam can be reduced by lowering the height of the spillway. The same processes lead to reduced infiltration rates and to increased amounts of overland flow. Thus, as mantle storage capacity is lost and as infiltration capacity is reduced, smaller storms are capable of producing flood discharges, and large storms will produce increasingly bigger floods.

The normal incidence and magnitude of the so-called frozen mantle floods can also be stepped up by poor land management. It is known, for example, that removal of the plant cover, depletion of the organic matter in the soil and compacting the soil cause harder and deeper freezing of the soil. This increases the opportunity for flood run-off.

There are extensive areas in the West, particularly the high mountains and plateaus, on which a plant cover and soil mantle have developed, and which are capable of absorbing even torrential rainfalls. The normal incidence of flooding on these areas is low. The geologic normal rate of erosion on such areas also is very slow—so slow in many places as to be imperceptible. However, the ecological balance is tenuous, and the consequences of disturbing the plant cover and soil mantle on these watersheds may be exceedingly drastic.

INDUCED MUD-ROCK FLOODS

Some of the most spectacular manifestations of this sequence of land abuse and impaired watershed functions are certain mud-rock flows which have occurred in recent years along the west front of the Wasatch Mountains in northern Utah. Six of seven adjacent watersheds ranging in size from about 1,200 to 6,000 acres in the Farmington-Centerville portion of Davis County, Utah, have produced such floods. Here, in 1923, and again in 1930, mud-rock flows issued from the short, steep canyons and deposited boulders weighing as much as 200 tons and other debris on valuable community property at the base of the mountain.

This area offered unusual opportunities for the study of the normality of these floods. It also provided a test area for measuring the effects of watershed management on run-off.

These watersheds drain into the Great Salt Lake, which is the shrunken relic of the much larger and deeper Lake Bonneville of Pleistocene time. Because the ancient lake left deltas, terraces, and other deposits at the mouths of the canyons, it was possible to differentiate between pre-Bonneville, and post-Bonneville deposition. Geological observations at the mouths of the canyons revealed that the recent floods cut to extraordinary new depths into sands and gravels of the deltas and terraces of the ancient lake. The floods also deposited quantities of debris and sediment on the former bottom of the old lake far in excess of the post-Bonneville normal rate of deposition.

Evidence on the watershed slopes corroborated the downstream geologic evidence regarding the newness of the flood events. The floods were traced to their source by following the freshly scoured channels. These led to areas of from a few acres to less than one acre in extent in the headwaters at elevations of from 7,500 to 9,000 ft. on which the plant and litter mantle had been drastically reduced by very heavy overgrazing and to some extent by fire. That these areas were the source of the flood run-off was evidenced by an efficient system of gullies freshly cut in the soil mantle. In the aggregate these deteriorated and gullied flood-source areas covered less than 10 per cent of the mountainous catchment areas.

Further observation on the headwater lands clearly suggested that run-off from the flood-source areas was unnaturally great. Surrounding and intermingled with these flood-sources were well-vegetated areas on which there was no evidence of surface run-off or of soil loss. Here the litter was undisturbed and there were no rill marks and freshly incised gullies. That these areas received as much rainfall as the gullied, flood-producing areas but were able to absorb and hold it is supported by examinations of the soil mantle immediately following flood-producing storms. These showed penetration of moisture to depths of 6 to 10 in. on the non-flood sources, whereas on the deteriorated areas, penetration of moisture was generally less than two inches.

Significantly different conditions were found on the seventh watershed in this area. The people living at the mouth of this canyon years ago had arranged for keeping razing guse of the headwater lands on a conservative basis. This action resulted in the maintenance of plant cover and soil mantle conditions that were capable of absorbing virtually all summer rainfall. No mud-rock floods have issued from this managed watershed in historic time.

RESTORATION BY WATERSHED MANAGEMENT

Because all evidence indicated the recent mud-rock floods from six of the basins were due to a drastic reduction in the amount of plant cover and to compaction of the soil, chiefly by overgrazing of live-stock, a watershed programme was designed to re-establish the plant cover and to stabilize the soil on the deteriorated headwater areas. Fire control was intensified and live-stock grazing was discontinued in order to prevent further depletion and to permit recovery of the vegetation. Additional measures, including contour trenching and artificial reseeding of grasses, were applied on about 1,300 acres of flood-source areas in five of the flood-producing basins.

The contour trenches were made by throwing up continuous, level, earth dikes with power bulldozers, horse-drawn plows, and hand shovels to a height of about two feet at horizontal intervals of about twenty-five feet. These dikes formed a trench on the uphill side with capacity for impounding the equivalent of 1.50 in. of run-off between trenches. The contour trenches were installed to break up the gully system, to store and force infiltration of precipitation in the trench and thus prevent overland flow and erosion, and create favourable conditions for revegetation. Artificial reseeding was done to hasten recovery of the most depleted areas by vegetation and litter.

The intensively treated watersheds have responded remarkably to the improvement measures. Depleted and eroded slopes are now being reclothed with vegetation and gullies are rapidly disappearing.

WATERSHED MEASURES PREVENT FLOODS

This programme of rehabilitation has been tested by numerous summer storms since work was initiated in 1933 and to the present time no floods have developed from the adequately treated areas. The non-flooding behaviour of these watersheds is particularly significant when it is considered that they have been subjected to very high intensity summer rains, some of which produced greater rainfall rates than have ever been recorded in the State of Utah. These major storms on several occasions have attained rates in excess of the previous state record of 4.80 in. per hour for five-minute periods, and on 10 August 1947, a rate of 8.40 in. per hour was registered at one of a dozen recording rain gauges in the area.

The behaviour of the fully-treated watersheds during the period 1936 to date marks a radical departure from their behaviour when in deteriorated condition in 1923 and 1930. This change from one of violent flooding and very high debris-content to one of virtually regulated flow and low sediment load demonstrates that a high degree of control of run-off can be re-established on areas where destruction of the plant cover and disturbance of the soil has impaired the run-off restraining functions of the watershed. These watershed slopes are now exercising as effective control on summer rainfall as the adjacent well-managed watershed.

By contrast, two additional mud-rock floods have occurred during the period 1936-1947 in the one deteriorated watershed where intensive measures were not applied.

There is another important lesson to be learned from this experience in this Utah area. Misuse of the land, though it brought profit for a time to those whose flocks grazed the area, resulted in damage to their neighbours equivalent to an investment of $810 in each of the 1,300 acres of flood-source land. Furthermore, it cost the public another $230 per acre to install the improvement measures that were necessary to rehabilitate the watershed areas. The controlled behaviour of run-off on the deteriorated areas since they were treated, as well as on the well managed watershed, clearly indicates that both of these costs to society could have been prevented by a more conservative use of the land resources.

Fortunately, not all watershed areas in the West are in such deteriorated condition as to require so intensive treatment as the flood-producing areas in Davis County, Utah. The great bulk of the forest and range lands in need of rehabilitation in the West must and can be restored by less intensive and costly measures.

Watershed management alone will not provide effective control of run-off in all areas. Considerable storm-flow must always be expected from basins on which aridity precludes the development or maintenance of a fully effective plant cover. Floods within normal limits must also be expected from watersheds that from time to time receive more precipitation than can be stored in the soil and rock mantle. Run-off control under such circumstances must be achieved by engineering works. However, watershed management can make a big contribution to the solution of the run-off control problem on the great bulk of the forest and range lands by keeping storm-flow discharges within normal limits and by restoring the normal hydrologic function of the land where those functions have been impaired by misuse or abuse of the land resources.

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The Federal Supervision of Water Policy in the Interests of Soil Conversation in Switzerland[1]

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ABSTRACT

The superintendence by the Swiss Confederation, as the supreme authority, over water conservancy is exercised in pursuance of article 24 of the Federal Constitution and of the Federal Law of 1877. The Cantons, the owners of the waterways, receive financial assistance from the Confederation in carrying out their duties. From 1862 to this day, the cost of constructing embankments for torrents and rivers subsidized by the Confederation has amounted to 660 million francs (155 francs per inhabitant).

The technical measures adopted may be subdivided into three categories :

(*a*) Works for the prevention of vertical or lateral erosion and for ensuring the flow of the waters and debris without overflowing the banks ;

(*b*) Drainage works to prevent landslides ; and

(*c*) Afforestation of unproductive slopes.

If, taking into account the topographical, geological and hydrological factors, the rational combination of these protective measures is to be obtained, each separate case must be subjected to a detailed study. In addition, careful consideration must be given to the extent required in each case to the law governing the pressure of deposits (research carried out by the Hydraulic Laboratory of the Zurich Polytechnic School between 1932 and 1949). The durability of the works should be ensured by their execution in conformity with technical rules and climatic conditions.

The correction of the Nolla (Canton of Grisons) and of the Rhône (Canton of Valais), are cited as practical examples which have resulted in the reclamation of nearly 170 sq. km. which have been transformed from swamps into fertile land.

Since the productive soil in Switzerland only ensures the subsistence of *half* of the country's population, the conservation of this soil has been and will always be considered as a vitally important measure.

THE LAW

In view of the special economic importance of soil conservation, the Federal Assembly of the Swiss Confederation passed, on 22 June 1877, the "Federal Law concerning water-conservancy in the mountain regions". In so doing the legislative authority based its action on article 24 of the Federal Constitution, which gives the Confederation "the right of superintendence as the supreme authority over the embankments and forests in the mountain regions". This law, which is still in force, now applies to the whole territory of the Confederation, since the Swiss people decided, by vote in 1897, that the words "in the mountain regions" should be deleted.

Constitutionally speaking, the Cantons own the waterways and the Confederation gives them financial support to carry out their tasks.

In addition to conferring jurisdiction on the Confederation as the supreme control authority, the abovementioned law and the Order of 1879 issuing administrative regulations lay down the general conditions under which the Confederation is authorized to grant subsidies to the Cantons for soil conservation by regulating torrents and rivers. To these general provisions are usually added further conditions for the granting of subsidies so that technical and financial consideration may be given as far as possible to individual cases.

By the end of 1948, the competent service of the Federal Administration, i.e., the Inspectorate of Public Works, which is a branch of the Federal Department of the Interior, had allocated subsidies amounting to some 255 million francs under the water-conservancy law and subsequent legislative enactments and international treaties. Since the average total of the Federal subsidies since 1862 has been 38.9 per cent, this sum corresponds to a total expenditure of 660 million francs, or 155 francs per inhabitant of Switzerland. The work of correction is continued every year. The afore-mentioned total does not include grants made during the same period for land improvement properly so-called.

EMBANKMENT OF TORRENTS: CORRECTION AND REGULATION OF RIVERS

General

In the mountains, work for the consolidation and conservation of the soil usually begins with the torrents, that is to say, the waterways having the steepest incline and, consequently, the greatest power of erosion. Damage due to erosion is most serious in places where the subsoil offers little or no resistance and where erosion in depth gives rise to landslides and promotes the formation of alluvial deposits. In times of flood large masses of detritus are sometimes carried into the valleys, where they cause considerable havoc. In the plains, erosion in torrents and rivers is usually not in depth, but from the banks (lateral erosion), the effect of which is to eat away the cultivable land and sometimes cause serious floods, since the riverbed cannot evacuate the flood-water and detritus swept down by the river.

There are in principle three types of protective measures, namely:

(1) The construction in torrents of transverse banks and longitudinal dykes or, if necessary, the construction of completely paved channels to prevent vertical or lateral erosion. The best method for correcting rivers is the construction of works to protect the banks, taking into account the requirements of discharge and the movement of detritus;

(2) Drainage works to prevent landslides;

[1]Original text: French.

(3) Afforestation of unproductive slopes.

The judicious combination of these three measures for protection against the destructive elements necessitates a detailed study of the situation in each case (bases of the plan). The success of protective works against the ravages of floods depends upon the procedure used in the corrective work, in which the co-operation of nature herself should be sought (work programme). Owing to the variety of cases, the regulation of torrents and rivers raises highly interesting problems, the solution of which often requires the co-operation of civil engineers, agronomists, forestry engineers and even geologists.

Transversal works to prevent erosion are constructed, according to the nature of the subsoil, either of wood and stone combined, or in the form of masonry dams, of stone or concrete. When the ground is unstable, the combination of wood and stone is to be recommended, since, in addition to being relatively less costly, it is adaptable to a certain extent to the movements of the soil without jeopardizing the solidity of the work as a whole. In order that the wood in these dams may keep in good condition, they should be sheltered from the sun and the torrent should have a certain constant flow. In the case of the costly construction of masonry dams, it should not be forgotten that the works are constantly exposed to the humidity of the soil upstream and on the lateral slopes, and also to frequent and sudden changes in temperature, and especially to the effects of frost in the mountain regions.

Thus, the durability of masonry dams depends on the quality of the masonry, natural stone and concrete used, the absence of violent waters and, finally, the supervision of the construction of the works.

The precise determination of the hydraulic base of the plan is not so important in correcting torrents as in regulating the flow of waterways in the plains. In the case of torrents, flooding properly so-called along their course is not usually to be expected. It is sufficient to give the waste weirs of the dam the requisite dimensions to prevent the flood-water from submerging the wings of the dams and to ensure that the flood-water flowing over the dam will be concentrated in the central channel of the torrent. Thus, the banks immediately below the dam, which are usually unprotected, will not be exposed to the impetuous action of the water.

It is most important to make a precise calculation of the flood-water, including the detritus carried down, which a dam is intended to contain in a river in the plains, and this sometimes gives rise to serious difficulties. Another difficulty consists in giving the transverse contour of the corrective channel a shape compatible with the regime of the stream, the slope and the detritus. A bed which is too narrow and which is not consolidated tends to become deeper, whereas the bottom of a channel which is too wide, especially if the stream carries down detritus, tends to rise and to reduce the contour for the run-off of the water and thus to cause floods. The Laboratory of Hydraulic Research of the Federal Polytechnic School at Zürich has established the ratio between specific discharge and the curve of the potential energy on the one hand, and the volume of the detritus and the diameter of the shingle characteristics of the gravel on the other hand (detritus formula). This ratio represents scientific progress of great value in establishing the bases necessary for planning hydraulic constructions.

The formula is as follows:

$$q^{\frac{2}{3}} J = ad + bg^{\frac{2}{3}},$$

in which

q = the volume of water per metre of the width of the stream, in litres per second;

g = the weight of the detritus per metre of the width of the stream, in kg. per second;

J = the gradient of the line of energy;

d = the diameter of the characteristic shingle, measured in a screen with square meshes, in metres;

a = a constant of 17 for natural alluvium ($\gamma = 2.68$);

b = a constant of 0.4 for natural alluvium.

(See also the recent publication in the *Revue polytechnique suisse* (Swiss Polytechnic Review) (*Schweizerische Bauzeitung*, Zürich, Dianastrasse 5) of 15 January 1949: "*Eine Formel zur Berechnung des Geschiebetriebes*" (A formula for calculating detritus) by Messrs. Meyer-Peter and Muller, Professors at the Federal Polytechnic School at Zürich.)

In applying the formula, very careful attention must be paid to the criteria resulting from the nature of each case. In view of the fact that the research methods are still in the process of development, it is essential, especially in cases where it is intended to give a river a uniform channel by means of dykes and works for the protection of the banks against flood-water, that the engineer should continue to base his plans on experiments so far carried out. It may even be impossible definitively to reconcile the flow, taking the detritus into reckoning, and striking a balance for an indeterminate period for a given stream. It should not be forgotten that the longitudinal section of a river-bed will be permanently influenced by the corrective works carried out in the torrents of its receiving basin and by the special meteorological conditions of each year. It will be increasingly necessary to make allowances for the changing effects of natural forces, bearing in mind the different circumstances in each case.

Technical measures intended to end the destruction caused by torrents and rivers should be undertaken parallel with drainage works for the purpose of preventing or stabilizing landslides, and with the afforestation of unproductive areas, in order to improve the regime of the water and to diminish denudation. When the drainage work is of a specifically agricultural nature, it is carried out by the Federal Land Improvement Office. Reafforestation is carried out by the Federal Inspectorate of Forests, Game Reserves and Fisheries. The Federal Inspectorate of Public Works collaborates closely with these two services in achieving their common aims.

PRACTICAL EXAMPLES

The following are two examples in which new methods were applied to eliminate special difficulties at a minimum cost.

The correction of the Nolla at Thusis, Canton of Grisons

The Nolla is one of the most formidable torrents in Switzerland. It is a tributary of the left bank of the Hinter-Rhein, which it joins at Thusis.

The reception basin of the Nolla has an area of 30 sq. km., 27 per cent of which consists of forests. Its source is at an altitude of 3,002 metres (the summit of Piz Beverin), and its mouth is at an altitude of 700 metres).

From the geological point of view, this torrent is an essential part of the hard limestone schist area. This formation disintegrates easily and often gives rise to extensive and deep landslides. Thus, the terrain on the left bank of the Nolla, as far as the watershed, has been unstable for centuries; on the right bank the rock, however, is stable.

The slope of the Nolla varies between 8.5 per cent in its lower course and 40 per cent in its headwaters.

Since the Nolla has, with time, cut out very steep banks for itself, the foot of the slope forming its left bank has been much eroded. By obstructing the Hinter-Rhein with its voluminous deposits for centuries, the Nolla has caused many serious floods in the Rhine Valley between Thusis and Reichenau.

The correction of this torrent, which was begun in 1870, is not yet finished, because it has to be carried out in stages in accordance with the development of natural phenomena. It should be noted that a landslide took place in the Piz Beverin in 1938, the volume of which was estimated at 600,000 cub. metres of material. This event greatly increased the transport of material of the Nolla and its systematic correction had to be pursued in order to retain the mass of material.

At the beginning, in order to reduce erosion and gradually raise the bed of the torrent and thus consolidate the soil on the left bank, more or less rigid dams were built of wood, stone or masonry. In time these works were destroyed by the pressure exercised by the subsidence of the soil on the left bank and an elastic type of dam was then developed which adapted itself better to the movement of the soil. The central part of the waste-weir of this dam is of masonry and is connected with banks by earthen dykes protected, above and below the central dam, against the effects of the current. Lateral buffers were thus created, capable of considerably lessening the pressure of the soil on the left bank, without threatening the destruction of the work as a whole. These dams have been found most useful in retaining materials, especially the enormous mass of stones carried down by the above-mentioned landslide.

To complete the effects of the correctional work, important drainage and reafforestation work was carried out on the slopes of the left bank of the torrent.

Expenses in connexion with the correction of the Nolla have hitherto amounted to 4,140,000 Swiss francs.

The correction of this torrent has made it possible to dam the Nieder Rhein, which is quite turbulent, below Thusis and to warp the bottom of the valley over an area of 5.6 sq.km. with the silt from the Nolla. This area is at present being cultivated and is very fertile. The silt from the Nolla which is not used for warping is carried by the Rhine to Lake Constance, where it is deposited.

The correction of the Rhône in the Valais and Vaud Cantons

During the last century, the Rhône was corrected for the first time, until 1895, from Brigue to the Lake of Geneva, by the construction of parallel dykes against flood-water, and an attempt was made by means of jetties to restrain the river in a central bed of reduced width. The materials carried down were to be evacuated along this central channel.

Since the system of jetties did not concentrate the current sufficiently, the river-bed rose to a great extent in the next thirty years, owing to deposits, which resulted in the dykes being broken and in flooding at times of high-water. Since 1928, therefore, attempts have been made to improve the hydraulic characteristics of the channel by diminishing its resistance to the flow. For this purpose, a continuous central channel was built, and the ends of the jetties were joined by longitudinal dykes; the spaces between these dykes and the external, unsubmerged dykes were filled with gravel from the Rhône, so as to set up ramps between the central channel and the dykes against flood-water. The longitudinal central channel was graded so as to enable it to evacuate all ordinary high-water. Only extraordinarily high floods overflow into the overflow section formed by the external, unsubmerged dykes. The increase in the dragging power of the current in the central channel has already resulted in deepening the bed of the Rhône in certain corrected sections and, with the exception of some damage caused by the extremely bad meteorological conditions in September 1948, has effectively eliminated the danger of floods.

Thanks to these corrective works, the Rhône valley, which formerly consisted of extensive unproductive marshes, has been changed, with the help of various drainage systems, into a very fertile region, the area of which is approximately 160 sq. km.

The expenses incurred in the management of the Rhône (maximum flow at Sion of 900 to 1,000 cub. metres per second) have hitherto amounted to 27,400,000 Swiss francs, and the cost of drainage channels in the plain bordering on the river has amounted to 30,600,000 Swiss francs.

Water Control Through Watershed Management[1]

V. FROLOW

ABSTRACT

The author emphasizes the following points :

(1) Water control through watershed management should provide for measures for the supply of water to towns, in addition to the uses set forth in the Conference programme.

(2) The increase of accelerated erosion on whole slopes, or only in the form of patchwork erosion, makes it essential that educative work be undertaken so that the inhabitants may take an active part in erosion control.

(3) In view of the inadequate results of conferences, it is proposed that an *international advisory body be set up* with the following programme :

(*a*) The collection of technical documentary material—which should be kept up to date—based on publications and information provided voluntarily by States and

(*b*) Measures to facilitate the training, in areas similar to their own, of technicians for soil conservation and restoration.

MANAGEMENT PLANNING

As regards measures for watershed management, it should be noted at the outset that French practice shows that they should be extended not only to pastureland, forests and cultivated land but also to industry and human water-supplies. This last use of water may sometimes be of very great importance, as is shown by the case of the Seine Basin, where regularization of the low water level was effected in about 1870 and where the requirements of the towns were of minor importance. These measures could be applied to subsoil water; thus the city of Paris used several lines of conduits (La Vanne, La Voulzie etc.). Present day costs of catchments or deep borings compel municipalities to consider the use of surface-water and to encourage measures calculated to increase the low water yields. These measures consist, briefly, in the construction of reservoir dams in the volcanic areas of the Morvan and on the impervious clays of the liassic aureole. The accompanying map shows all the dam sites surveyed and it can be seen that approximately one-third of the works has now been completed. It should be pointed out that the dams were originally to be used for storing the high-water in order to control floods in the valleys which resulted in enormous losses in Paris and its suburbs, particularly in 1910. The need for an increase in the low water yield will undoubtedly lead to a somewhat different system for the reservoirs which will have to be filled without waiting for the maximum volume of water the date of arrival of which is uncertain.

HYDROBIOLOGICAL PROBLEMS

Water supply requirements also raise hydrobiological questions, as does the use of water in the thermic works, which, in some summers, discharge a number of calories into the Seine in Paris sufficient to cause mass destruction of fish. This led the National Centre of Scientific Research to include such studies in the syllabus of its Centre of Hydrobiological Studies (Director: Mr. A. Pacaud). Similarly the Scientific Hydrobiological Section of the French National Committee of Geodesy and Geophysics organized a survey of the question by its Seine and Seine Basin Commission and under the direction of Mr. M. Prenant. The results of these studies were given in the Commission's publications (1).

I have thought it well to stress this aspect of the question as the useful purpose served by hydrobiological studies and measures has not yet been generally recognized by river and agricultural hydraulic technicians. However, the relationship between the human problems involved is so close that the purely hydro-technical aspects of watershed management cannot alone be considered.

DEVELOPMENT OF THE SOLOGNE

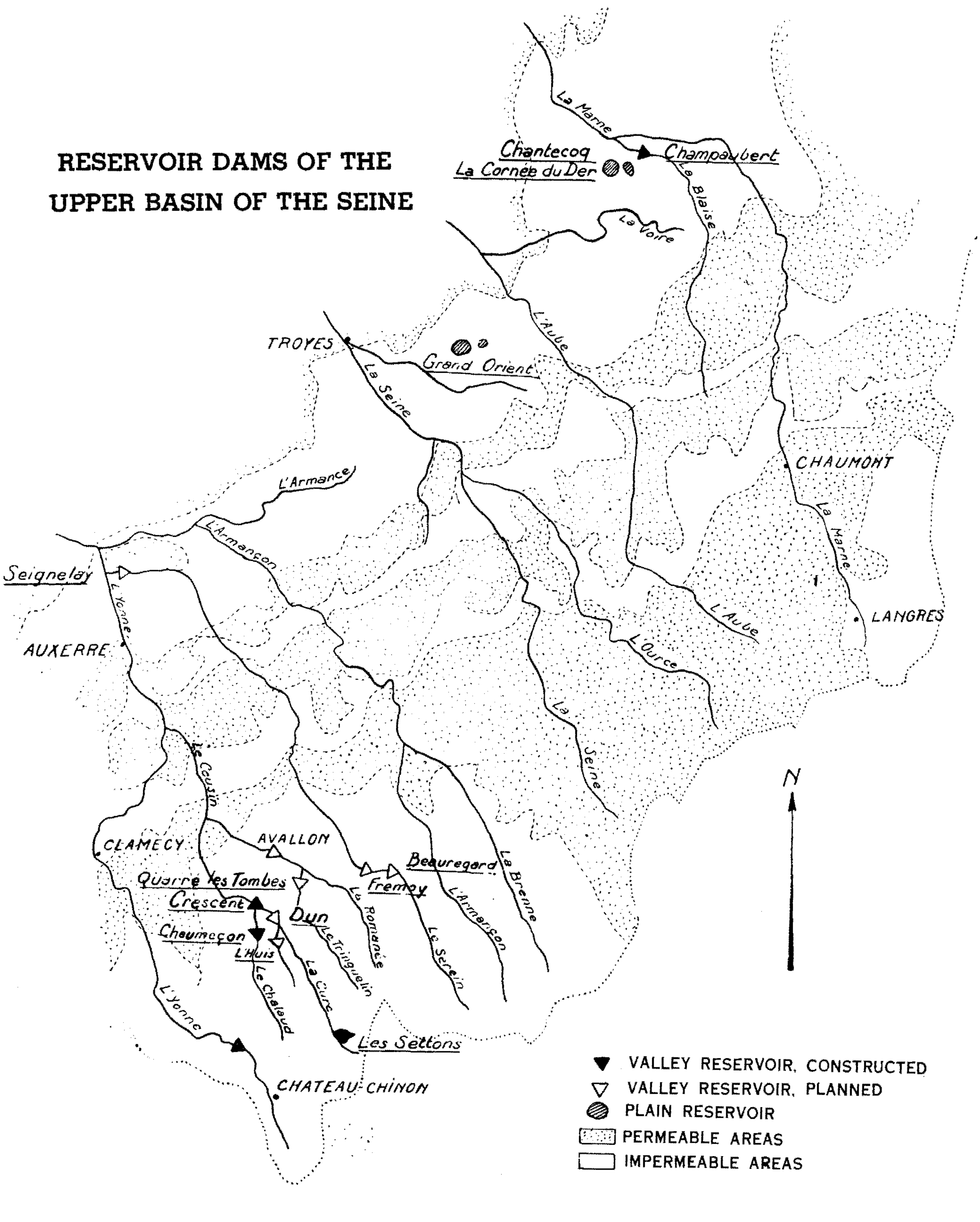
The Sologne is a recent example of watershed management. This area is part of the Loire basin immediately south of the river at Orleans. Its special features are very large sand and clay deposits forming a large enclave of 504,000 km. surrounded by calcareous formations. The area was unhealthy owing to the absence of slopes. Agriculture was almost non-existent, except for pisciculture in the ponds arranged for that purpose and timber felling. The large landowners found it more profitable to let these barren grounds for game shooting; the rabbits have, therefore, become a real pest there and all these factors led to the depopulation of the area (26 inhabitants per sq. km. as against 75 for the rest of France).

Faced by this situation the Ministry of Agriculture introduced a plan for the development of the Sologne. That plan was based, in the first instance, on the regulation of the stream-flow by the use and straightening of the existing beds (some 500 km. of main river, 800 km. of streams and collective channels). It was recognized that the work should at the same time include transposing the land into truly arable soil by the use of fertilizers and the introduction of soil-improving plants. Since the soils were not of the same type, they were classified so as to delimit the areas under forest, grass and cultivation.

These measures clearly had to be directed towards the improvement of the living and working conditions of the direct farmer-producers, which would result in bringing the abandoned farms under cultivation again.

In order to determine the possibilities, a network was organized to include 37 test fields in the Sologne and a 100-hectare pilot farm at Souvigny. The farm was open for visits by Sologne farmers who were free to make a detailed study of the farm accounts. Lastly, experimental

[1]Original text: French.


RESERVOIR DAMS OF THE
UPPER BASIN OF THE SEINE
La Marne
Chantecoq
La Cornée du Der
Champaubert
Le Blaise
La Voire
L'Aube
TROYES
Grand Orient
La Seine
CHAUMONT
La Marne
L'Armance
L'Armançon
Seignelay
L'Yonne
AUXERRE
LANGRES
L'Aube
L'Ource
La Seine
Le Cousin
N
CLAMECY
AVALLON
Beauregard
Quarre les Tombes
Fremoy
Crescent
Dun
La Romanée
L'Armançon
La Brenne
Chaumeçon
Le Trinquelin
Le Serein
L'Huis
La Cure
Le Chaloud
L'Yonne
Les Settons
CHATEAU-CHINON
VALLEY RESERVOIR, CONSTRUCTED
VALLEY RESERVOIR, PLANNED
PLAIN RESERVOIR
PERMEABLE AREAS
IMPERMEABLE AREAS

fields were laid out and it was proposed to expand the pisciculture by opening or arranging ponds giving a total area of 200 hectares of new waters. Thus, from the very outset human resettlement was the determining factor in the technical works, which thus form part of a harmonious whole.

The authors of this work, and particularly Mr. Rolley, Inspector General of Rural Engineering, who was in charge, thus gave practical application to the conviction that the protection of natural resources and the advantages to be derived from them should be so organized as to enable the immediate producer to profit thereby in the controlled areas.

The development of the Sologne has had to be discontinued owing to existing economic conditions. I have referred to it in order to show the views held in France on agricultural conservation and cultivation, arrived at after numerous experiments.

CONTROL OF UNDERGROUND WATER

In a country such as France, where water management has been in effect for so long, the problems of underground water control arise only in connexion with the use of artesian water in the Paris basin and the modification of the canalized river reaches.

Considerable decreases in the water-level were observed in the artesian wells of the city of Paris and geologists such as P. Lemoine, warned public opinion of the likelihood of excessive exploitation of the greensand table. Restrictive regulations were adopted but, after an examination of flow conditions, Mr. Vibert (2) was able to show that these decreases in pressure could be explained by the interference of the individual decreases in pressure of the wells. The matter has not yet been finally decided, but the fact that the pressure is constant in distant wells, such as the well at Chissay (Loir et Cher), supports Mr. Vibert's theories. The detailed studies should be continued.

The water-table in the proximity of watercourses is easily affected by changes in the regime of watercourse levels. Thus, when the Mariot Dam (the dam furthest downstream on the Seine) was removed, the Navigation Services deepened the navigable channel. The removal of the dam and the sediment caused a drop of several metres in the water-level of the nearby wells over a distance of 15 km. along the Seine. There was dislocation in the work of the farms but only over a somewhat limited area. There is no doubt that hydrological research before the works would have enabled the deepening of the wells and installation of new pumps to be carried out in good time and the legal proceedings and difficulties on the farms would thus have been avoided.

These two instances, which bear out what we know of works carried out abroad, show the need for the introduction of scientific research in water-supply works.

The Hydrogeological Service of Morocco provides an instance of the usefulness of such research. That department, which is directed by Mr. Robaux and is still in its infancy, has already carried out a certain amount of research. Hydrogeological research, consisting of the preparation of a piezometric chart of the waters of the phreatic layer and the study of its physico-chemical characteristics, led to the siting of two productive wells which will increase the Marrakesh water-supplies by approximately 60 per cent. Yet, the circumstances were especially difficult as there is very considerable use of the underground water in the plain where the town is situated and it was necessary to find a solution which did not encroach on acquired rights. The Service has also decided that the underflow of the Wadi Massa (south of the town of Agadir) can be harnessed by the construction of underground dams, one of which has been put out to tender. This first irrigation scheme covers only 1,480 hectares in all but is based upon almost complete objective observations. If scientific observation is continued, the project should permit the study of several matters having practical effects, including the problem of the limitation of the underground water level by evaporation. These studies of underground water levels in French West Africa have led to the conclusion that there is a minimum thickness of the sedimentary layer without which the whole of the water evaporates. For instance, under the conditions prevailing in the upper Volta there can be no underground water unless it is covered by a minimum of 15 metres of sediment. In the Agadir area and in the valley of the Sous there is a drop of 12 to 14 cm. in the level of the head wells of the underground water catchments when the chergui (hot wind) blows. It is true that at such periods a very large volume of water is pumped off by the settlers but it is possible that the increased evaporation plays its part, in view of the position of the head wells in the area where the drop in level is observed. This phenomenon, knowledge of which might result in improved use of underground reserves by means of water-level control, is to be observed by the underground rain gauges devised by F. Dienert (3) which have been tested in France. The object is, in short, to ascertain the feasibility of underground works similar to those constructed at Lake Sevan in the Caucasus where large additional quantities ot water were made available by the elimination of evaporation losses. It should be noted that the phreatic water in the valley of the Sous produces local incrustation and the catchment galleries should therefore be of sufficient size to permit of inspection and easy cleaning. It is evident that prior knowledge of the chemical composition of the water is essential and is one of the reasons justifying the existence of the Hydrogeological Department. It can only be hoped that its officials will be provided with portable measuring apparatus (such as the electrolytic bridge of the Bureau of Soils) so that they may easily observe the zonal extension of the global water characteristics (temperature, resistivity) etc. and follow the seasonal evolution of these characteristics.

WATER SPREADING

A special method of underground water control consists in the spreading of the flood-water of the north African wadis for the purpose of creating a temporary reserve in the soil. This water-spreading technique, which has become fairly widespread in Tunisia and above all in Morocco, consists of a diversion dam which spreads flood-water through a network of channels on the surface of the soil where it percolates.

One of these dams in southern Morocco is 7 metres high and 92 metres long. It spreads water over 5,000 hectares. The water is used for the cultivation of cereals and part of it flows back into the underground water.

It is proposed to spread flood-water in the valley of the Sous by means of a dam to be built at the Aoullouz. In this case it is a question of spreading flood-water on the surface of former dejection cones, some of which are more or less consolidated. But this is not an absolute contra-indication, as, provided that a surface condition permitting of absorption is observed, it can be taken as certain that the underlying consolidated layers of sand form an excellent reservoir rock ensuring underground flow slow enough for use by plantations of trees. Percolation studies by means, for instance, of Muntz apparatus will determine the actual feasibility of water-spreading on these alluvial cones.

The construction of such systems would be too costly for the local budget unless the inhabitants agree to provide free of charge the labour for the works which will enable them to make use of the soil. It is extremely important that the native inhabitants should be aware of the value of basin management works.

Another instance is provided by the increasing use of a system called "fraction barrages" in Morocco. These are nothing but small walls of dry stone, one or two metres high, built in the beds of the *thalwegs* where there is no permanent flow. Small alluvial terraces rapidly form upstream from these dams and the retained humidity is sufficient for the cultivation of a barley crop. There are now some tens of thousands of these small works in the valleys of the slopes south of the Anti-Atlas. They are obviously vulnerable to very heavy volumes of flow but, as these seldom occur, the "fraction barrages" are undoubtedly profitable. The native population has fully appreciated their value and their use is becoming increasingly widespread. I have seen dams of this type at Souk el Arba (Ait Baha) (northern slopes of the Anti-Atlas).

WATER AND EROSION CONTROL

These structures, which are used also for water and erosion control, form the subject of this last paragraph. Certain general ideas must first be borne in mind. The following four zones of erosion should be distinguished:

(*a*) High altitude zone, without human settlements, where the bare rock has disintegrated and from which the coarse and fine elements, which have not been transformed into soil, descend.

(*b*) Zone of existing soil, where soil formation may be more rapid than soil destruction and where forests and pastureland may establish themselves. This zone is therefore occupied by man but this sometimes leads to the destruction of the soil, if the forest vegetation is destroyed and if the slopes are overgrazed. It then becomes a zone of mass soil destruction and large-scale measures are necessary for the restoration of the soil.

(*c*) Zone where soil destruction never becomes widespread, owing to the lithological and slope conditions, but occurs in rills. Localized slides displace the soil but do not carry it away finally. In this zone the work of the local population should suffice, provided that educative work and demonstrations are conducted in order to show the danger and the methods of overcoming it.

(*d*) Flat zone, where rills and gullies form following renewed erosion due to the drop in the local base-level. In this zone too, erosion control may be organized by the inhabitants but, in addition to water-supply measures, an important part is played by agricultural organization itself and particularly by the introduction of pasture grass in crop rotation.

The above classification shows that there are very large areas where the local population must be induced to play an active part by means of a positive educational campaign. Everywhere the inhabitants can be seen making terraces for their crops, and willingly undertaking the very heavy work of retransporting the soil torn away by rain: they can and must be taught better methods of erosion control.

But it is clear that this involves a soil-conservation organization consisting not only of water-supply, forest and agricultural technicians but also of instructors, a fact which is not always understood.

SOIL CONSERVATION AND RESTORATION

A few examples will now be given to support a general view on the rational organization of soil conservation and restoration. The torrent control and reafforestation works carried out in France are too well known to warrant description in this paper. However, one special point, which enters into the conclusions, should be mentioned. This is the spontaneous reafforestation of the upper slopes of Mount Pelvoux where two strips of forest have spread well beyond the plantations, owing to upward winds. This unexpected success shows the value of including air-circulation studies in mountain soil restoration plans. Knowledge of air currents may, at least in certain cases, influence planning by reducing expenditure.

MOUNTAIN SOIL RESTORATION

Before giving examples of such work in Morocco, I would recall that the aims of mountain soil restoration are as follows:

(*a*) To eliminate the harmful effects of run-off on the soil on the slopes.

(*b*) To increase percolation and thereby to augment underground water-supplies.

(*c*) To make the ground productive by the growth of trees and by animal production.

(*d*) To preserve the valley floors and plains at the foot of mountains from the encroachment of unproductive gravel.

These aims are of very great importance in Morocco where the population is increasing and where, as a result of that increase, cultivation has spread to the slopes and forest regression has become still more widespread with consequent overgrazing. Moreover, the construction of an essential road network has disturbed the equilibrium of the terrain. There is also the disquieting problem of the duration of the reservoir dams now being constructed or planned for the seasonal regularization, at the least, of water-flow for agricultural use and the production of power.

A new Soil Conservation Department under the Directorate of Rivers and Forests has recently been set up; the Directorate nevertheless had previously conducted tests in several areas.

I had occasion to visit some of these areas in June 1949 and this was of particular interest, as in the spring of 1949 the rainfall was well above normal (about 50 per cent in the Marrakesh area) and so intense that in two consecutive days the rainfall in a large number of places amounted to some 90 mm. (for instance 22 mm. fell in a few hours at Amizmiz). This rainfall in excess of the normal cannot be regarded as really exceptional; it is therefore possible that the destructive effects may be exceeded but they display certain features which should be borne in mind.

My observations relate to the works in the areas of Taddert (Grand Atlas, on the Marrakesh—Ouarzazate road), and Amizmiz (upper valley of the N'Fis Wadi), the valleys of the upper tributaries of the Chichaoua Wadi and particularly at Im N'Tanaout and Tizi Machou, the Djebilets (schistous massif north of Marrakesh), the valley of the Ourika (Grand Atlas) and the Agadir—Tizi N'Test —Marrakesh road.

The formations of these areas are composed of schists and permo triassic rocks covered in places by mantles of detritus. Technical measures consist of benches built on the slopes, drains at the foot of cliffs and roads. A few dams in the *thalwegs* help to correct small temporary torrents and some of them will be able to direct streams to the water-spreading areas.

DESTRUCTION CAUSED BY ROADS

The first thing that arrests the attention is the destruction caused by roads. This is caused in two ways. Gullies are produced by inadequate road drainage: the waters which flowed separately before the construction of roads come together and are released on the slope, generally in secondary *thalwegs* which they rapidly erode. In such cases drainage or *thalweg* corrective works can be undertaken with comparative ease.

The second effect of roads is the disequilibrium caused when they are cut in the slopes. Deformations in the banks, and even slides of large volumes of detrital formations, schists and small permo-triassic rocks may be observed, and the difficulty consists in the fact that no equilibrium slope is produced, but the steep part of the slope is carried above the road and further slides will occur when heavy rain again falls.

The remedy clearly consists in the elimination of diffused and concentrated flow on slopes rising above the roads and in drainage of the banks.

Drainage is particularly essential in the zones where detritus is in contact with the rocks over whose wet surface it slides.

This also applies to areas where benches have been constructed. The greatest damage observed by me occurred in these zones of contact. In the case of benches it is all the more understandable as they cause a very large part of the diffused run-off, which they retain, to percolate into the ground.

Other damage to the benches is due to the fact that they are not absolutely horizontal. In some places excessive quantities of water were accumulating and destroying the ridges by overflowing them. Small transverse levees spaced at intervals of approximately 5 metres have proved completely effective. The ratio of the bench width and its distance from the neighbouring benches may sometimes be inadequate if percolation is too small to prevent an undue rise in the water on the bench. Here again, tests should be made with Muntz apparatus. I refer only to this simple apparatus, as, in areas where benches already exist, sufficient data can be found to measure the results obtained with this apparatus by comparing them with areas which have successfully withstood heavy rainfall.

For experimental purposes the vertical interval between the benches has been varied from 3 to 5 metres on steep slopes, and 1.5 to 3 metres on gentle slopes.

Once the soil stability has been ensured by benches, there remains for consideration the behaviour of the former rills in which the water was concentrated. Two methods have been tested in Morocco: continuing the benches across the rills which were then closed off by dry walls or cutting them off at right angles to the rills. The second method is based on the somewhat theoretical idea of the complete elimination of the run-off. In actual fact, the traces of the action of rills, after the construction of the benches, are visible in the areas visited. Then again the possible inadequacy of subsequent conservation should be foreseen and the aim should be not only the stabilization but also the reconstruction of the soil. There are also soil slopes which are sufficiently stable—and where no action is necessary—which produce moderate flow in the rills that are little developed in those areas and are not intercommunicating. The water on such slopes should be retained or, at the least, its flow into the rills should be slowed down. It therefore appears preferable to block the rills with coarse and fine materials, a mixture which will ensure slow percolation and thus prevent concentrated flow likely to carry away the dams.

Let us now consider the extent to which the experiments in Morocco have answered their purposes.

RESULTS OF MOROCCAN EXPERIMENTS

It is clear that the benches are adequate to reduce run-off and prevent deterioration of the soil even when it is almost devoid of herbaceous vegetation. But it is essential that run-off be eliminated as soon as possible, as even slight and diffused run-off between the benches will provide them with fine materials to the detriment of the slope. Knowledge of soil evolution is an important factor in success, and reafforestation should therefore include the study of dynamic pedology.

Percolation has certainly been increased but, in the absence of continued observations, the exact extent of the increase cannot be given. Qualitatively it can be stated that in certain cases the level of the wells appears to have been higher in the proximity of the experimental areas and that the flow in the *thalwegs* has perhaps been smaller in those areas, but it is clear that serious control measures should provide detailed figures. Hence, it is essential that action should be taken by the administrative and university organizations engaged in hydrological studies. The experimental planting of forest species (Aleppo pines, carob-trees, Argan trees, eucalyptus trees, fruit trees, etc.) shows that productivity can be restored fairly easily. In this connexion it should be pointed out that Aleppo pine seedlings (after one year's nursery growth) and pine seeds mixed with barley and sown in drills on the bench ridges, or broadcast, have been equally successful. This latter method was used by a forester in the Forestry Department, a native of the Sologne, where it is the usual practice. This example of the entirely separate use of knowledge acquired in a far-off and quite distinct region is of significance, as it shows the value of the organization of exhaustive technical information proposed later in this paper.

Another of the plants tested, namely the cactus, should be mentioned. It has proved very successful and provides considerable additional nourishment in dry years but the protection afforded by it in wet years is indifferent, as its roots are too shallow.

Reafforestation will affect the quantity of underground water. Evaporation and transpiration will have to be taken into consideration and this shows the need for studies of this matter in the experimental stations.

These reafforestation experiments also expose the existence of two very dangerous enemies—rabbits and acrididae—and the consequent need for protective measures and co-ordination of reafforestation planning with the anti-acridian services.

Lastly, as regards the protection of valley floors, the experience gained in Morocco is insufficient to warrant any conclusions.

OTHER CONSIDERATIONS

The experiments described above have been considered only in so far as they relate to rainfall and plants. We must also consider whether the methods employed are justified by events on the grazing lands and land cultivated by the inhabitants.

It should be stated that the zones of mass soil destruction are mainly confined to mountain countries and only cover small areas elsewhere. The rill erosion zones are far more extensive and, as in this case the soil is transported only a short distance, limited protective measures should be applied. An instance of this is provided by the area of Izher-N'Ait Daoud (Djebilets), where benches have been constructed on a slope on which the erosion grooves are still clearly visible. On an adjacent cultivated slope, where a barley field existed in June 1949, rills can also be seen starting above the field and penetrating into it. But they disappear in the field and it is clear that there has been a sort of natural water-spreading caused by the heavy rainfall during 1949. It is evident that in this area accelerated erosion occurs in the form of rill erosion and that it can be controlled by organizing ploughing and cutting off rills by more rudimentary and less expensive methods than benches.

Thorough knowledge of the ground to be covered by the works is required when deciding upon the areas where more or less intensive action is to be taken. It would seem that detailed pedological maps are necessary and that this type of information is likely to result in large savings.

It should be also noted that the native practice of constructing terraces several metres wide, often by conveying soil or at least by placing them on contours, appears well justified. It is only in very exceptional cases that vertical rills can be seen on such terraces, which remain intact even in the case of mass slides some dozens of metres wide and up to one metre high.

The fact that they hold firm is probably due to the large volume of loose materials of which they are composed and whose absorptive capacity has not been reached for many years. Moreover, in these rill erosion zones the processes are more often slow enough to enable simple methods to be effective. Thus, in the Tamaroute valley, near Tizi Machou, the forest was destroyed by clear-felling. Overgrazing is to be observed and, as a consequence of the displacements of the loose layer covering the rock, there are slides of approximately half a metre of masses extending about the road. But the *thalweg*, where the wood cutters have constructed small terraces behind stone walls in order to make charcoal, has remained perfectly corrected. This again shows the desirability of enabling the inhabitants to take an active part in soil conservation and reconstitution.

Lastly, I would draw attention to another aspect of soil conservation, namely, that presented by the flat zones in countries with well defined seasons and very heavy rainfall. In such zones any excavation causes gullying which tends to divide the fields into sections. For instance, small gullies can be seen on the Marrakesh-Ait Auric road penetrating 50 metres into the fields and running to the opening of the road ditches, which also deepen. This is controlled by the construction of sills. There is no doubt that in that area, too, the population can be taught to overcome the evil.

The inhabitants can also remedy another phenomenon: soil sterilization by downpours of rain. These destroy the soil structure, a smooth-surface crust, which does not easily absorb water, is formed and encourages unproductive flow-off of rainwater. Crop rotation in these plains (for instance in the Haouz of Marrakesh) should include perennial herbaceous plants. As the natives have not discovered such plants, it is for the Agriculture Department to deal with this matter. It can be said that, even if it were necessary to reduce the area of land sown with corn, productivity would be increased and would reward the farmers' efforts which are too often wasted.

STUDIES REQUIRED

I have shown the successes achieved, and the difficulties to be overcome, by means of specific examples. The examples have been given in order to provide illustrations, but the conviction that soil conservation and restoration problems are not merely technical is based on French practice as a whole. Their proper solution depends on the co-operation of specialists in various branches of knowledge and should be based on the following studies:

Demographic: Determination of number of inhabitants and rate of population increase.

Economic: Classification of products in relation to local consumption and in relation to trade.

Pedological: Determination and mapping of soil categories. Observation of their evolution during the works.

Topographical: Determination of the zones of characteristic slopes. Preparation of plans on a scale of at least 1: 20,000 in the areas where action is to be taken.

Climatic: Pluviometry (rainfall and its instantaneous intensity). Temperature. General and local air currents. Hygrometric situation.

Agronomic: Classification of native and foreign plants in relation to the soil and to water requirements.

Hydrological: Inventory of water resources. Determination of its mode of occurrence, its physical and chemical properties, movements and volume. Forecasting of modifications in the surface and underground water regimes as a result of the works.

A harmonious programme of studies of this kind had not been achieved when the works were undertaken, and it was precisely during their execution that the need for it was realized. At the present time there are so many regions where almost everything remains to be done that mention of the scope of the studies required is not an idle criticism of the past but a contribution which should facilitate the vast works of the future and render them less costly.

The administrative services undertaking the works of soil conservation and restoration were frequently confronted by difficulties caused by local conditions and, as they realized that they could not start afresh in each case, they asked specialists for advice.

All too often these leading technicians or scientists paid too short a visit to the country, did not gain thorough knowledge of local characteristics and their advice, although judicious in broad outline, was influenced by the somewhat mechanical application of experience in other places and under different conditions and by reports of too limited a nature on local conditions. As a result, their recommendations were not easily accepted by the administrative officials and the authorities' efforts and the specialists' work were rendered less fruitful.

CONCLUSION

This state of confusion should give way to rational organization on the international plane: accordingly, I propose the *establishment of an international advisory body for soil protection and restoration,* which would be available to all countries and would place the acquired knowledge of theoretical and engineering science at the disposal of the authorities concerned (by means of analytical bibliographies and papers offering reliable guidance). It would also assist them to send local technicians, with experience of the true nature of conditions in their own areas, for adequate periods of training in countries similar to their own.

These technicians would then be well equipped to organize and carry on the studies in accordance with a programme such as the one set out above. They would obtain authoritative information from the data gathered and would be able to supervise the works admitted to be necessary. Visits by leading specialists would then attain their full value by improving the local direction of the works and by acquiring information for themselves, and thus adding to the general body of the world's scientific knowledge.

This international advisory body would collect published documentary material or material voluntarily provided by the authorities and would not intervene in any way in the various countries, but would serve to provide objective technical and personal information that would be available to all. It would acquire great moral value and assist man to husband his efforts to conserve and restore the soil.

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The Effects of Land Management Upon Run-off and Ground-water

HOWARD L. COOK

ABSTRACT

This paper deals with the effects of man's use of the land upon floods, total run-off, and ground-water.

When an area of high subsurface storage capacity is subjected to a given storm the amount of flood run-off is governed by the infiltration capacity of the land. The flood from such an area can, therefore, be reduced by measures that increase infiltration. The same storm occurring upon a thin-soiled area may result in infiltration in excess of the capacity of the soil to retain water. In this event the volume of the flood is not controlled by the amount of water infiltrated, but by the available subsurface storage capacity. Such floods cannot be reduced as much by treatment of the land as can those governed by infiltration capacity. Nevertheless, to the extent that land treatment measures increase evapo-transpiration during inter-storm periods, they do augment the available subsurface storage capacity and diminish the volume of subsurface flood run-off.

Land management that increases evapo-transpiration reduces total run-off. Conversely, a reduction in evapo-transpiration augments total run-off.

Where the elevation of the ground-water depends upon the amounts of infiltration into the overlying land surface, the use of the land affects the height of the water table and hence the low water flow of streams. Practices that decrease the value of the quantity (infiltration minus evapo-transpiration) lower the water table. It follows that the conversion of a forested area to cropland normally results in a lower water table and a reduction in dry-weather stream-flow.

INTRODUCTION

The water precipitated upon a drainage area flows out of it in various ways. Part is discharged in liquid form as stream-flow and ground-water. Another part returns to the atmosphere as vapour. The division of the precipitation among these several kinds of outflow depends upon the characteristics of the precipitation itself and upon certain properties of the land on which it falls; in particular, upon the nature of the soil and the material underlying it, the kind and quality of the vegetal cover, the topography and the condition of the land. The activities of man change soil, cover and condition. It follows that they also change, in some degree, the rates and amounts of run-off, the storage of water in the earth and the amounts of water passing off as vapour. But how large are these changes, and in what direction? This is a question of both scientific and practical importance. And for many years earnest attempts have been made to answer it. Yet until comparatively recent times they resulted in little more than conjecture and controversy; primarily, because the underlying physical processes were not fully understood. The past fifteen to twenty years have, however, been a period of rapid progress in the formulation of sound concepts. It is now possible to make approximate quantitative evaluations of most of the effects in question. This paper reviews recent progress in the development of ideas and procedures and summarizes briefly what has so far been learned about the magnitude of these effects.

Attention will be confined to:

(1) The effect upon floods;

(2) The effect upon total run-off;

(3) The effect upon ground-water.

DEFINITIONS

Land management. In the interest of brevity this term is used in the present paper as a name for all activities of man that affect the land.

Surface run-off (R_s). Run-off that has not passed below the surface of the land during its journey to the surface outlet of the drainage area considered.

Subsurface run-off (R_u). Run-off derived from precipitation that passed into the earth but returned to the surface before reaching the surface outlet. Subsurface run-off is the outflow from zones of saturation within the earth. The term "ground-water run-off" is usually applied to outflow from the "permanent" zone of saturation below the ground-water table. In some drainage areas "ephemeral" zones of saturation formed during storms contribute to the run-off. When these ephemeral zones are near the surface the infiltrated water may return to the channel system relatively quickly. The resulting subsurface run-off is sometimes called "quick return flow" and sometimes "subsurface storm-flow". In this paper, run-off derived from the water below the permanent ground-water table will be called "ground-water run-off". Subsurface run-off that enters the channel system while a flood is in progress will be called "subsurface flood run-off", whether it comes from ephemeral or permanent zones of saturation.

Total run-off (R). The total amount of water passing out of the drainage area as stream-flow during a selected period of time. By definition $R = R_s + R_u$.

Evapo-transpiration or vapour outflow (E). The water that flows out of a drainage area as vapour. This vapour outflow is made up of surface evaporation and plant transpiration.

Underground outflow (U). Water that passes out of a drainage area below the surface of the earth.

Soil storage (S). The amount of water stored in the soil of a drainage area at any instant excluding water in zones of saturation (measured above some selected datum).

Infiltration. The passage of water through the surface of the soil into the soil mass. The total infiltration during a selected period of time will be designated by F.

In this paper R, E, U, S and F are expressed in terms of depth of water upon the area considered. Numerical values of these quantities are given in inches.

BASIC RELATIONSHIPS AND CONCEPTS

Disposition of precipitation

The disposition of the water precipitated upon a drainage area during a given period is indicated by the following equation:

$$P = R + E + U + \triangle S \tag{1}$$

in which $\triangle S$ represents the increase in soil storage within the area during the period considered. It follows that:

$$R = P - E - U - \triangle S \tag{2}$$

To give greater meaning to the above relationships Figure 1 has been prepared.[1] It shows the disposition of the daily rainfall falling upon an elementary area through a period of a year beginning on 15 May when, it is assumed, the outflow of liquid water from the soil layer considered has just ceased; that is, that the moisture content of the soil is at that level commonly designated "field capacity". Diagram A shows the daily rainfall. Diagram B depicts the division of this rainfall into surface run-off and infiltration for a certain condition of the land that is labelled on the figure "unimproved". If it is assumed that the vegetal cover on the land is "improved" the surface run-off would be decreased, and the infiltration increased, as shown by Diagram C. Diagram D shows the manner in which soil moisture might vary through the year for a layer of rather permeable loam about 20 in. deep overlying an impervious material. Diagram F shows a similar progression for the top six feet of a deep soil.[2] Diagram E shows the amount of water that would pass through the thin soil and collect in an ephemeral zone of saturation above the impervious material—since even minor water-courses provide outlets for zones of saturation situated close to the surface of the land, water entering such zones travels but a relatively short distance underground. Diagram G shows amounts of water that would percolate out of the top six feet of soil B. Whether or not this percolate would pass on to the ground-water, and eventually become run-off, would depend upon the dryness of the underlying materials.

The maximum effective storage capacity of the soil is shown on Figure 1 as the difference between the moisture content at field capacity and that at the wilting point. No significant proportion of the space occupied by water remaining in the soil when the moisture content reaches the wilting point is available to store infiltrated water because plants do not reduce the moisture below that level.

Drainage area size

Run-off characteristics are powerfully influenced by drainage area size. Of particular importance, for the purposes of this paper, is the relation between size and subsurface run-off. A great deal of experimental work is conducted on plots and small upland watersheds. The measured run-off from such areas is usually surface run-off. For large areas, however, subsurface run-off may constitute a large proportion of the total run-off.

Soil, cover, and condition

Two drainage areas identical except for soil may dispose of an identical series of rains in widely different ways. If the soil is impervious, a great deal of the precipitation may be converted to surface run-off. On the other hand, if the soil is pervious, nearly all the precipitation may infiltrate. But this does not mean that the infiltrated water will not appear as run-off. In thin-soiled areas it may enter the streams very quickly; quickly enough to augment flood flows. But on deep-soiled areas, the return of infiltrated water to the streams may be greatly delayed. Thus, it is clear that the characteristics of the soil exercise a profound influence upon run-off.

Another factor that greatly influences the disposition of the precipitation is the vegetal cover. Lands covered with a dense stand of vegetation have a much higher capacity to infiltrate water than similar lands with no vegetal cover or with a poor cover.

The condition of the soil also affects run-off. Tillage or cultivation of the land may increase the rate at which a small amount of subsequent rainfall infiltrates. But this effect is short-lived. During the first rain after cultivation the infiltration capacity decreases very rapidly and quickly falls below that of similar land protected by vegetation. In general, therefore, surface run-off from land used for tilled crops greatly exceeds that from pastures and woodlands.

The moisture condition of the soil is also a powerful factor. When the soil is wet, both the infiltration and storage capacities are greatly reduced.

The condition of the cover is another factor influencing run-off. For example, the burning of the humus layer built up by a forest strikingly reduces the rate at which water infiltrates. The deterioration of a grass cover under excessive or poorly managed grazing has a similar effect.

Cover and condition also influence the evapo-transpiration E. This will be discussed in a later section.

The activities of man can also affect the disposition of precipitation by changing the surface storage capacity of the land or, to a limited extent, by modifying the capacity of thin soils to store water.

EFFECT UPON FLOODS

Introduction

The effect upon floods of changes in the land was for many years a subject of controversy. The confusion engendered in the popular mind has not yet disappeared. Many still have the impression that were the land to be returned to its pristine condition, floods would cease to occur. Others continue to believe that no matter what is done to the land the magnitude of floods remains unchanged. Both of these ideas are incorrect. They arose when little was known about the underlying physical processes. At the present stage of development of the science of hydrology there is no excuse for their persistence.

Perhaps the greatest single step forward in achieving an understanding of floods was the development of the

[1] The purpose of this figure is to illustrate the processes and principles discussed in this paper. Obviously the amounts and dates of rainfall identify the examples used with a humid region in the northern hemisphere. This has no particular significance. Other examples for other sets of conditions can readily be devised. To avoid introducing unnecessary complications all precipitation was assumed to occur in the form of rain.

[2] For the purposes of this example it is assumed that no lateral flow takes place in this profile above the ground-water table.

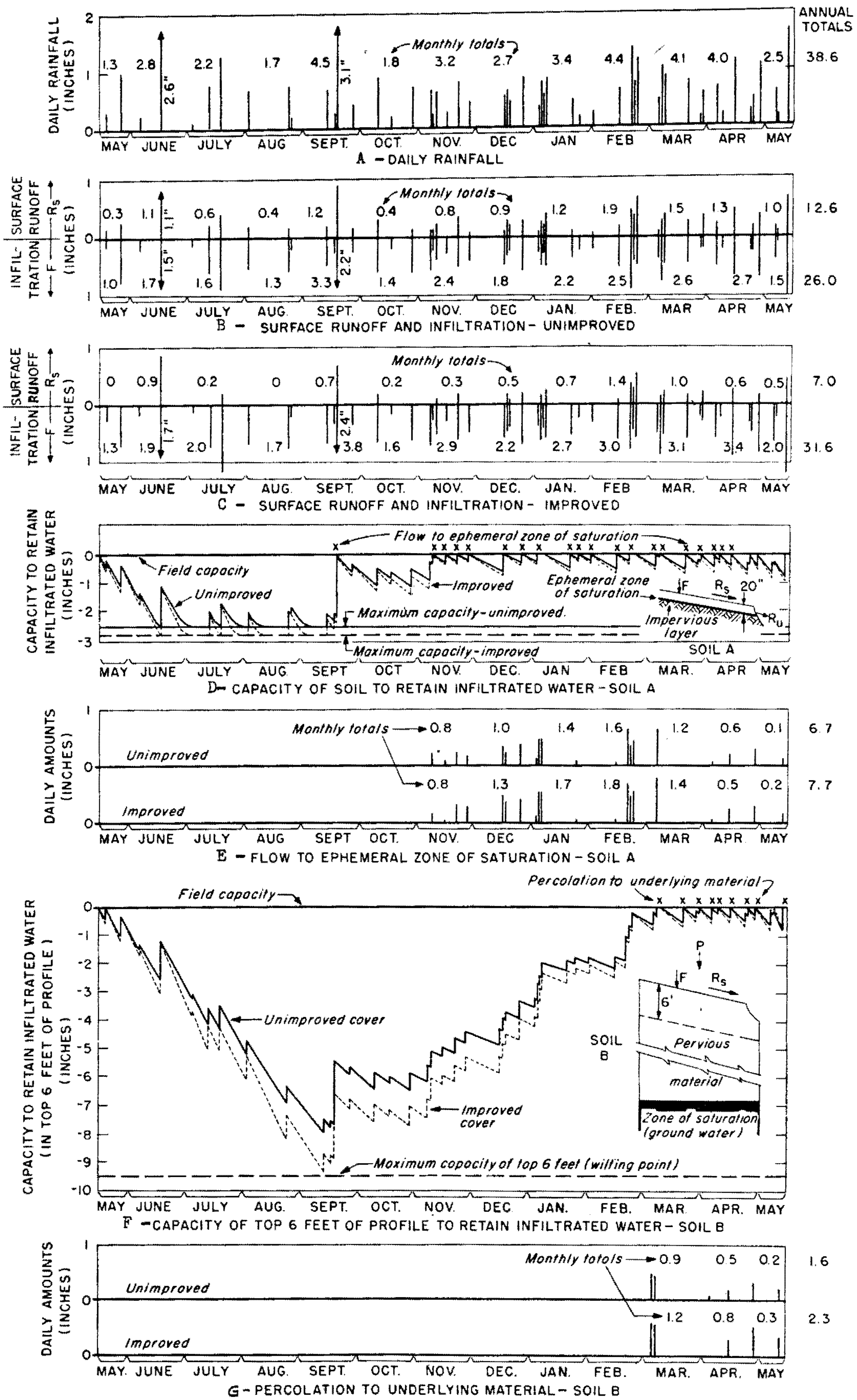

Figure 1. Illustrating effects of land treatment and depth of soil upon the disposition of precipitation.

so-called "infiltration theory" of surface run-off during the 1930's. Yet this did not provide the complete answer and, for a while, even added to the confusion as a result of efforts to use it as an explanation of all flood phenomena. Within a few years, however, it became evident that a combination of both new and old ideas was needed. This led to the following concept of floods:

(1) That floods are, in general, made up of both surface and subsurface run-off;

(2) That the surface run-off produced by a given storm is dependent upon the infiltration characteristics of the land and these in turn are profoundly influenced by the vegetal cover and by the way the land is used;

(3) But that unless the soils of the area can retain or detain the infiltrated water it may return to the streams in time to become part of the flood in the lower reaches of the stream thus largely nullifying the effectiveness of high infiltration capacity.

The surface and subsurface components of flood run-off may now be separately considered.

Surface run-off

Surface run-off is, as previously indicated, water that did not pass into the soil in the course of its journey to the outlet of the area considered. It was not until the rather hazy earlier concepts of run-off as precipitation minus infiltration began to crystallize into a "theory" of run-off, particularly through the work of Horton, (1)[3] that a rational understanding of surface run-off was possible.

When rain falls at intensities greater than the rate at which it can enter the soil, or infiltrate, water is stored upon the surface of the soil. This water flows down-hill toward the streams. That part of it not retained as "surface storage" reaches watercourses and becomes stream-flow. To calculate the surface run-off that would result from a given rain, therefore, it is necessary to estimate the rates at which infiltration will occur and the amount of water that will be retained by surface storage. Figure 2 illustrates the role of infiltration in the generation of surface run-off. Of the area under the intensity-time graph those portions that lie above the infiltration curves represent the water available for surface storage and run-off. By deducting the estimated surface storage, estimates of surface run-off are obtained. The areas under the infiltration curves represent, of course, water infiltrated.

As will be clear from the foregoing the "infiltration theory" of run-off is inherently simple. However, its application to the calculation of surface run-off becomes quite complex and will not be dealt with here. The references listed at the end of this paper may be consulted by those interested. Of these, references (2) and (3) are particularly concerned with problems of methodology.

For the purposes of this paper the principal value of the infiltration concept of run-off is that it provides a rational basis for visualizing the effects of changes in the land upon flood run-off.

The effects of soil, cover and condition upon surface run-off have been thoroughly investigated, both by the measurement of run-off from experimental plots and by

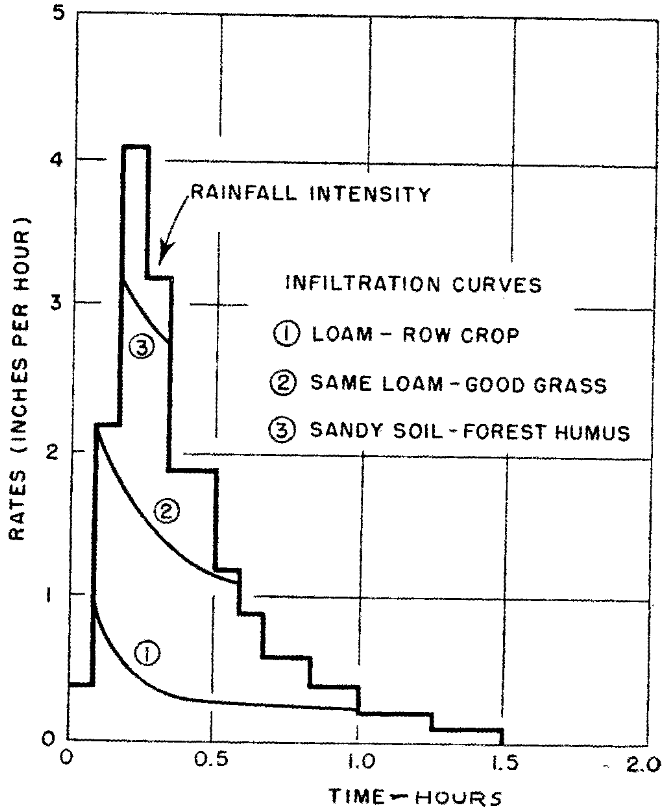

Figure 2. Illustrating the use of infiltration curves in the estimation of surface run-off.

the study of infiltration *per se*. It has been demonstrated that surface run-off is profoundly affected by these factors[4]. Figure 3 shows some average curves that illustrate the wide range in surface run-off under various covers on the same soil. An examination of the diagram will show that, on the average, a 3-in. storm produced 1.5 in. of run-off on bare land, 1 in. on land in row crops, ½ in. on land in close growing crops and negligible run-off on land in undisturbed permanent grass. The surface run-off from a plot in the same series on which a good cover of forest humus was maintained was also practically nil. These curves are quite typical of results obtained at other experimental areas. It was results like this that led many early investigators to conclude that floods might be greatly reduced by reafforestation or other changes in use or management.

In some soils a certain combination of circumstances may result in the saturation of the topsoil. When this happens the infiltration rate no longer depends upon the factors, such as cover, that normally govern, but is controlled solely by the rate of subsurface flow out of the saturated topsoil. The topsoil may become saturated either: (*a*) Because the ground-water table has risen to the surface of the land, or, (*b*) through the formation of an ephemeral saturated zone above a relatively impermeable layer in the soil profile. The permanent ground-water table normally reaches the surface only in marshy or other low-lying lands. In upland areas, therefore, this is not an important factor. But, as will be more fully brought out

[3]Numbers within parentheses refer to items in the bibliography.

[4]References (4) and (5) present typical results.

in the discussion of subsurface run-off, it is not uncommon for ephemeral zones of saturation to be established in upland topsoils underlain by tight subsoils or their equivalents in the form of layers of soil frozen while wet. When the lateral velocity in such a saturated zone is low, and the inflow rate high, the zone of saturation may occupy the entire depth of the topsoil. As indicated above, the rate of infiltration is then reduced to the rate of outflow from the saturated zone, and this may be extremely low. Under these circumstances, rates of surface run-off can become very high, even on areas that ordinarily produce very little surface run-off. This is most likely to occur on level or gently sloping lands where relatively shallow topsoils of low transmission capacity overlie less permeable material such as "claypan". The following discussion of subsurface run-off will throw additional light upon this phenomenon.

Subsurface run-off

When, during the course of a storm, the moisture content of the soil exceeds field capacity, existing zones of saturation are augmented, or new ones are formed. The principal zone of saturation is, of course, the "groundwater", the upper surface of which (the "water table") lies, in most regions, at a considerable distance below the land surface. But, as indicated previously, in some soils ephemeral zones of saturation may be established during storms. Of particular importance in flood production are the ephemeral zones formed above the relatively impermeable layers underlying some of the so called "thin soils". Such zones may, of course, also form in deep soils when the subsoils cannot pass on infiltrated water as rapidly as it can enter and pass through the topsoil. These ephemeral zones are of special importance because, since they are usually near the surface, the infiltrated water will return to the channel system at locations much closer to the points at which it passed into the soil, and much more quickly than will water reaching the permanent groundwater. In some areas the ephemeral saturated zones formed in thin soils are the main sources of subsurface flood-flow.

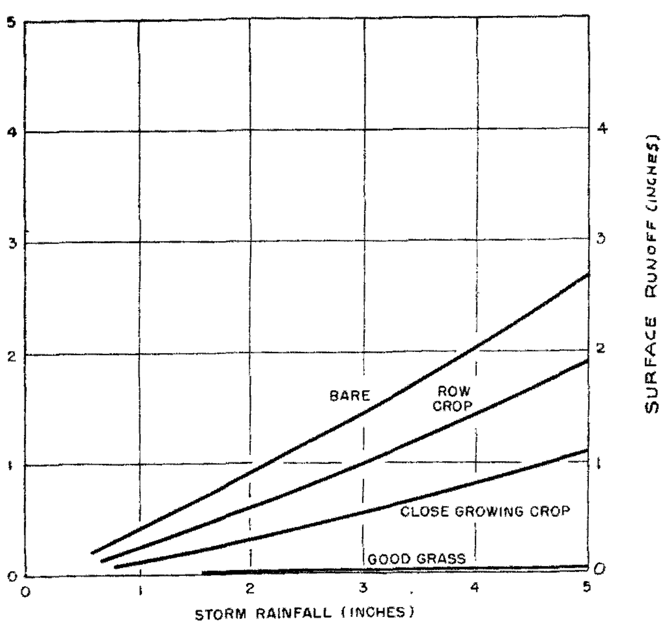

Figure 3. Illustrating the effect of vegetal cover upon the surface run-off caused by individual storms: average relationships at one site.

The larger a drainage area the longer it takes its flood-waters to assemble in the lower reaches of the main stem. For this reason, detention of infiltrated water in the earth for any given length of time has a lesser effect upon flood run-off as the size of the basin increases. Except in the smallest tributaries, therefore, flood volumes must be decreased to reduce peak flows by land treatment.

Flood run-off from areas of low subsurface storage capacity

On thin-soiled areas a flood may be composed largely of subsurface run-off. The reason for this is made clear by Diagram D of Figure 1. In making this diagram it was assumed that about 20 in. of loam rested upon an impervious layer. It will be noted that in the fall soil moisture reached field capacity and remained very close thereto throughout the winter and spring. As a result, the available storage capacity at the time flood-producing storms occurred ordinarily amounted to but a small fraction of an inch. The water infiltrated in excess of this storage capacity passed to the bottom of the soil and built up an ephemeral zone of saturation. The water in a saturated zone this close to the surface would soon escape into the many minor watercourses that dissect all upland areas. As a result, the flow to the saturated zone would, in this assumed situation, become subsurface flood flow, even in headwater tributaries. Under such circumstances little would be gained in the way of flood abatement on large streams by increasing the infiltration capacity of the uplands. This is demonstrated in Figure 1 by assuming that the vegetal cover on the areas is improved and that this would: (*a*) decrease surface run-off as indicated by Diagram C; (*b*) increase the maximum storage capacity by 0.3 in.; and (*c*) increase the evapo-transpiration rate by 20 per cent. The resulting effect on soil moisture and storage capacity is shown by the dotted lines on Diagram D. The effect on subsurface flood flow is shown by Diagram E. It is easy to see that under such a set of circumstances an increase in infiltration capacity may not significantly reduce total flood run-off. An example will bring this out. Consider the three days in February during which 3.4 in. of rain fell. For this storm the effect of the improved cover is indicated below:

	Run-off-inches		*Change*	
	Unimproved	*Improved*	*Inches*	*Per cent*
R_s	1.60	1.30	—0.30	—18.7
R_u	1.60	1.86	+ .26	+16.2
R	3.20	3.16	— .04	— 1.2

The *surface* run-off was reduced by almost 19 per cent, but the *total* run-off was decreased by little more than 1 per cent. And this decrease was brought about, not by increasing the amount of water infiltrated, but by increasing the evapo-transpiration during the short inter-storm period immediately preceding the flood-producing storm.

It must be understood, however, that for a storm occurring at a time when the soil moisture is low, the effect of improving the cover may be considerable. For of the results of such studies has been rendered difficult and uncertain because grass, weeds and shrubs very quickly spring up on such areas.

Perhaps the most careful experiment to date is that carried out at the Coweeta Experimental Forest of the U.S. Forest Service and reported by Hoover (11). In this experiment one of a pair of small drainage areas in the mountains of western North Carolina, a region of very high rainfall, was denuded of forest cover and an attempt made to prevent growth of vegetation. But the humus cover existing under the forest was retained. Measurements and comparisons indicate that the total run-off from the denuded area was increased by the following amounts:

Water year[a]	*Increase in total run-off Inches*
1941-1942	16.74
1942-1943	10.68

[a]November through October.

These results are somewhat affected by inability to suppress all vegetation. Hoover concluded from a study of all information available to him, that if all vegetal growth could be prevented the total run-off might be increased by 17 to 22 in. annually.

Another approach to the evaluation of the possible effects of land treatment measures, or of changes in use or management, upon total run-off is by estimating the effect of the proposed measures upon evapo-transpiration by use of lysimeter and other experimental results. This was found necessary in the previously mentioned flood control surveys of the U.S. Department of Agriculture in estimating the effect of proposed programmes upon the floods generated on areas of low storage capacity. It was found that in typical farming areas such programmes might increase basin-wide evapo-transpiration by from 5 to 10 per cent.

Increasing total run-off

The total run-off from a basin can, as shown in the foregoing, be increased by reducing E. But this method of increasing R has little practical application. It is true that in some dry areas the land is fallowed to decrease evaporative losses. But this is done merely to store up soil moisture so that it may subsequently be used by a crop. The long-term value of E is, therefore, not decreased at all. It would be possible to continue the fallowing and eventually this might increase total run-off, although often far from the locality where the water entered the soil.

Another way to reduce E would be to remove, and prevent the regrowth of, the vegetation on a drainage area. This is what was done in the Coweeta experiment previously described. Without protective cover, however, the soils of the area would soon be eroded into the streams. Moreover, the expense of preventing plant growth would probably exceed the value of the water gained. This latter statement does not generally apply, however, to riparian and aquatic vegetation.

There is, of course, the possibility of paving a drainage area. But this is ruled out by economic considerations except under the most unusual conditions.

EFFECT UPON THE GROUND-WATER

The effect of land use and management upon the ground-water has long been a subject of wide-spread interest and controversy. It is often declared that the ground-water table is being lowered by cultivation of the land. But it is also held that available ground-water records substantiate no such effect. It is probably true that examinations of actual records yield inconclusive evidence. One reason for this is that the records are too short; the land was in essentially its present use before they began. Another reason is that, as for floods, the exact combination of influencing variables is not repeated in nature. However, where the ground-water is derived from water infiltrated into the overlying soil, the simple basic relationships previously set out enable some very useful conclusions to be drawn.

In applying these relationships to the ground-water problem it is helpful to recast them somewhat. Attention need be focused only upon the amount of water that reaches the water table. This makes it possible to confine consideration to an elementary column of soil extending to the ground-water table. Infiltration is an inflow to this column. Evapo-transpiration is an outflow subsurface movement of water into, or out of, the column above the water table (lateral subsurface flow above a relatively impermeable layer, for example, may be considered either a net inflow or a net outflow).

From this, the following equation may be written:

$$G = P - R_s - E \pm U_a - \triangle S \tag{5}$$

G = amount of water reaching the ground-water during some selected period

P = the precipitation[8]

R_s = the surface run-off

E = the evapo-transpiration, including here evaporation from surface storage

U_a = net lateral subsurface inflow or outflow above the water table.

$\triangle S$ = the increase in the moisture stored in the soil during the period, excluding water in zones of saturation.

As in dealing with total run-off the period may be selected so that $\triangle S$ is zero and

$$G = P - R_s - E \pm U_a \tag{6}$$

For sites at which lateral flow can be neglected the expression can be still further simplified to:

$$G = P - R_s - E \tag{7}$$

Expressed in other terms:

$$G = F - E \tag{8}$$

An examination of the above expressions quickly demonstrates that any treatment of the land that increases either the surface run-off or the evapo-transpiration diminishes the amount of water that reaches the ground-water. Certain agricultural practices do both. These practices will, therefore, lower the ground-water table and diminish stream-flow during dry periods.

Equation (8) shows that, where U_a can be neglected, the flow to the ground-water table is the difference between

[8]Strictly, that part of the precipitation reaching the land surface.

the infiltration and the evapo-transpiration. If a change in conditions decreases the value of (F-E) the water table will, other factors remaining the same, decline. Conversely, an increase in the quantity (F-E) will result in higher water tables.

Figure 1 again provides an example. For Soil A the values of (F-E) before and after improvement of the cover are as follows:

	F *Inch*	*E* *Inch*	*(F-E)* *Inches*
Unimproved	26.0	24.4	1.6
Improved	31.6	29.3	2.3

NOTE: Assuming, as in the previous tabulations, that all percolate becomes run-off.

It is clear from the above that under the improvement programme assumed in constructing Figure 1 the ground-water table would rise.[9]

The long term effect of any change in land management upon ground-water can be approximated by use of the equations set out in the foregoing. For making quantitative estimates, records of the surface run-off from experimental plots can be used directly. It is more difficult to obtain dependable information on evapo-transpiration. For grass and field crops considerable data have been obtained by the use of lysimeters. Data on evapo-transpiration from forests are relatively scarce. However, studies such as those being made at Coweeta (11) provide valuable guides. And these field data may be supplemented by the results of laboratory studies of transpiration.

Enough is known about the magnitude of the variables of equations (7) and (8) to permit the following generalizations:

(1) Removal of forests and use of the land for crop production will *lower* the water table.

(2) Conversion of croplands to grasslands or forest will *raise* the water table.

Should the necessity arise, a "dead cover", or mulch, could be used to raise the water table. Such a cover (a layer of straw, for example) greatly decreases both surface run-off and evapo-transpiration. As a result it maximizes the value of (F-E) and thus the accretion to ground-water.

Another possible method of raising the water table would be to keep the surface free of vegetation and open by frequent tillage. This is sometimes done to increase the soil moisture available for crop production, in which event it is called "fallowing". But as pointed out in discussing total run-off, when fallowing is done for crop production the stored moisture is extracted by the crop and the value of E is not decreased. Were it possible to pursue such a practice over a sufficiently long period of time without cropping, the value of (F-E) would be greatly increased and the flow to the water table augmented. This approach is put to practical use in "water spreading" areas in arid and semi-arid regions. But to be successful over a long period the material on which the water is spread must be quite coarse. The structure of aggregated soils soon break down under such treatment and infiltration is minimized. This can be avoided by maintaining a vegetal cover on the spreading-grounds. The vegetation, however, uses water and results in a lower value of (F-E).

[9]In constructing this figure it was assumed that evapo-transpiration would be increased by 20 per cent. The increase usually attainable is between 5 and 10 per cent. Ordinarily, therefore, the increase in (F-E) would be greater than indicated by this example.

It is self-evident that the discussion of the effect of land use and management upon ground-water is closely related to the previous discussion of total run-off. As the ground-water table is raised the amount of subsurface run-off from this source is increased. In fact, for areas to which equations (7) and (8) apply, the value of G over a sufficient period of time equals the value of R_u. In symbols:

$$G = R_u = (F\text{-}E)$$

It is apparent from the foregoing that practices which increase the quantity (F-E) increase the proportion of the total run-off derived from subsurface sources. Where the infiltrated water requires a considerable time to reach a stream outlet (as on lands where it must pass to a permanent ground-water zone at considerable depth) run-off rates are more uniform. Of great practical importance is the augmentation of low water, or dry weather, flows.

It should be understood that under some outlet conditions a small increase in the elevation of the water table is accompanied by a large increase in the rate of ground-water discharge into the stream system. It is easy to see that in areas where this is true a substantial increase in (F-E), and hence in the low water flow of the streams, can occur with but a relatively small rise in the ground-water table.

It will be apparent upon reflection that the principles outlined will also serve in the study of the effect of various practices upon soil moisture. This is a matter of importance but one that cannot be treated in this brief paper.

ECONOMIC ASPECTS

To deal adequately with the economics of the broad subject of this paper would require a great deal more space than is available. However, brief mention will be made of a number of the more important economic problems and effects.

It was previously noted that in the United States substantial progress has been made in evaluating the effect of land treatment upon flood run-off through the flood control surveys of the U.S. Department of Agriculture. Reductions in flood flows result in amelioration of flood water damages. It is apparent that flood flow reductions of the magnitude indicated by Figure 4 do not greatly reduce the damage done by great floods on large rivers. Nevertheless, they may considerably diminish the total average annual flood damage experienced in a river basin. There are two reasons for this:

(*a*) A large proportion of the total damage is caused by small floods that occur frequently; and it is precisely these floods that are most affected by land treatment programmes.

(*b*) A land treatment programme reduces flood flows throughout a river basin. In agricultural areas the aggregate flood damage along the many miles of small headwater streams may greatly exceed damage in the comparatively short main valleys. Consequently, in such regions, even a small reduction in flood flow may result in surprisingly large aggregate benefits.

For the reasons outlined, it has been found that in the rolling and deep-soiled farmlands of the central United States a complete land treatment program may reduce the total flood-water damages in a river basin of intermediate size by 20 to 50 per cent. In thin-soiled areas where flood reductions are limited by the storage capacity of the soil, flood damages are reduced by smaller percentages, in some areas the reduction falling below 10 per cent.[10]

Land treatment programmes do a great deal more than reduce flood-water damages. They are even more effective in keeping sediment out of streams and reservoirs. Moreover, they nearly always increase agricultural production on the lands treated. Both of these kinds of benefits can be expressed in monetary terms. In the better farming areas of the United States it has been found that the benefit resulting from increased agricultural production exceeds the reduction in flood water damages by from five to twenty times. The benefits attributed to reduction of sediment damages are more on the order of magnitude of the flood reduction benefits but usually exceed them. In addition, many benefits accrue to such programmes that cannot be expressed in terms of money. The most important of these is undoubtedly the preservation of the soil.

The economic effects of changes in total run-off may be even more important than those resulting from modification in flood flows. Yet this is an almost untouched field of investigation. Economic studies are especially needed in arid and semi-arid regions. In the major valleys of these regions are irrigated lands, or lands that might be irrigated. The mountains are usually forested. And there are large areas of range land at intermediate altitudes. The greater the amount of water used by trees and grasses on the mountains and ranges, the smaller the amount that passes down the rivers. But vegetal cover is essential to prevent excessive erosion and to keep reservoirs and stream channels from filling with sediment. Moreover, in some instances the net economic return from the water used to grow more and better upland grasses or trees considerably exceeds the net returns it would yield if used by an irrigation enterprise. But it is not safe to generalize about this. Comparisons must be worked out for specific areas and specific development schemes. There is an urgent need for investigations in this field. If they are to be conclusive, they must embrace not only economic, but hydrologic and legal studies as well.

The economics of the effect of land management upon ground-water has also been but superficially explored. Here again some of the most urgent problems are those of the arid and semi-arid regions. In many localities ground-water supplies are being drawn upon too heavily to provide water for irrigation. In some instances, it is possible to increase the amount of water reaching the underground reservoir. The "water spreading" already referred to is an example. But in many areas the water pumped from wells today entered the soil many years before on lands many miles away. The farm economy founded upon such a supply will be destroyed by the continued extraction of water at rates exceeding the rate of replenishment. As in the case of total run-off, studies of specific areas are needed to determine the problem and the cure. And here again, these should be co-ordinated studies of the economics, the hydrology and the legal aspects of the problem.

[10]Reference (12) deals somewhat more fully with this matter.

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Effects of Watershed Management on Water Yields[1]

V. FROLOW

ABSTRACT

The writer stresses the following points:

1. The necessity of taking the run-off of water yields into account when it is desired to obtain a correct estimate of the effects of basin management works; this may be done by using the analysis method of M. and Mme. H. Labrouste.

2. The writer is of the opinion that it would be inadmissible to call upon private enterprise in soil erosion control, for it is on the soil that human life is founded and it must not be made the subject of *jus in re aliena*.

3. The high cost entailed in the reinforcement of the slopes makes mechanization desirable.

EFFECTS OF PROTECTIVE MEASURES

The existing data on the increase in underground water-supplies as a result of reafforestation and soil conservation work are still very incomplete and are often criticized.

I think it desirable to draw attention to the fact that there is a slow run-off of these water reserves and that this run-off may vary considerably in adjacent valleys.

This may serve as an explanation of the discrepancies in estimates when they are based on the comparison of averages for several years.

An example drawn from work in progress on the basin of the Tech (Eastern Pyrenees) may facilitate the explanation. The curves of Figure 1 relate to measuring stations set up on the Tech and some of its tributaries.

The curves of the graph were obtained by first estimating by E. Maillet's (1)[2] method the volume of underground water corresponding to the lowest level of each year concerned. Short-term variations were then deleted from the series of values thus obtained, by drawing an estimated curve s_2 s_3 on the basis of these variations, in accordance with M. and Mme. H. Labrouste's method of analysing graphs by linear combinations of ordinates. (2) The curves of the graph therefore represent the run-off of underground storage. The horizontal weather column of this graph is common to all the stations, but the graph of the volumes varies according to the stations, so that all the curves are drawn up in equal detail.

A perusal of the graph will show that this gentle curve is not identical in any of the stations and that the difference is such that some of the phases are opposite (Prats de Mollo on the upper Tech and Mondony on the Mondony), but reference to the diagram of the Tech basin at the bottom of the chart clearly shows that the simple comparison of neighbouring basins may lead to error when estimating the effects of reafforestation or other work tending thus to establish a new division of rainwater between infiltration, stream-flow and evaporation.

In order to be able to reach valid conclusions from comparisons between one valley and another, it must be proved that the run-off has been modified as a result of works, and that is obviously not always possible.

Another more reliable process may be pointed out, namely, that of observing the phase of one or more elementary components of the series of volumes which led to the drawing-up of curves s_2 s_3. The elementary components are also calculated by M. and Mme. H. Labrouste's method. It is true that their phase varies slightly in natural conditions, but it is highly sensitive to human intervention, as is shown, for instance, by the studies on stream-flow disturbed by reservoir dams. (3)

It is to be hoped that in all cases where there is a series of observations on daily yields, extending over at least twenty years, the above process may give valid criteria for appraising the real effect of works.

The above case is concerned with a series of water yields considered separately, but reference is sometimes made to pluviometric observations, from which the variations of the flow may be deduced. Figure 2 is included to show the errors which may result from this. This figure is drawn on the basis of three series which represent the maximum annual level of the Seine in Paris, the total annual rainfall in Paris and the average annual temperature in that city. It must be pointed out that the last two series are sufficiently characteristic of the meteorological conditions in the Seine basin above Paris to be comparable with the level of the highest flood observed in Paris, but formed above that city.

The three curves of the graph were drawn up on the basis of series by using the multiple formula s_5 s_6 of the method of M. and Mme. H. Labrouste.

It will be seen at once that there is no constant relation between the curves of the Seine and of the rainfall. The direction of their undulations is by no means invariably concordant, whereas the temperature curve is intimately connected with that of the Seine; this may be explained by the natural fact of the dependence of the stream-flow in this river-basin upon evapo-transpiration.

An examination of this figure also explains the variability of the coefficient of correlation, which is often used, according to the length of the series. This coefficient only serves to describe the body of data which have been used in its calculation and does not take into account the natural evolutions which are essential for the comparisons in view.

QUANTITATIVE APPRAISAL OF ADVANTAGES

Paragraph 4 of the "Notes for authors of papers for the UNSCCUR (E/CONF.7/Inf.1) says:

"However, the point of emphasis is clear. The economic costs and benefits of the application of a given technique, rather than its scientific or technical originality, is the touchstone which determines whether or not the public or private effort will put it to use."

[1]Original text: French.

[2]Numbers within parentheses refer to items in the bibliography.

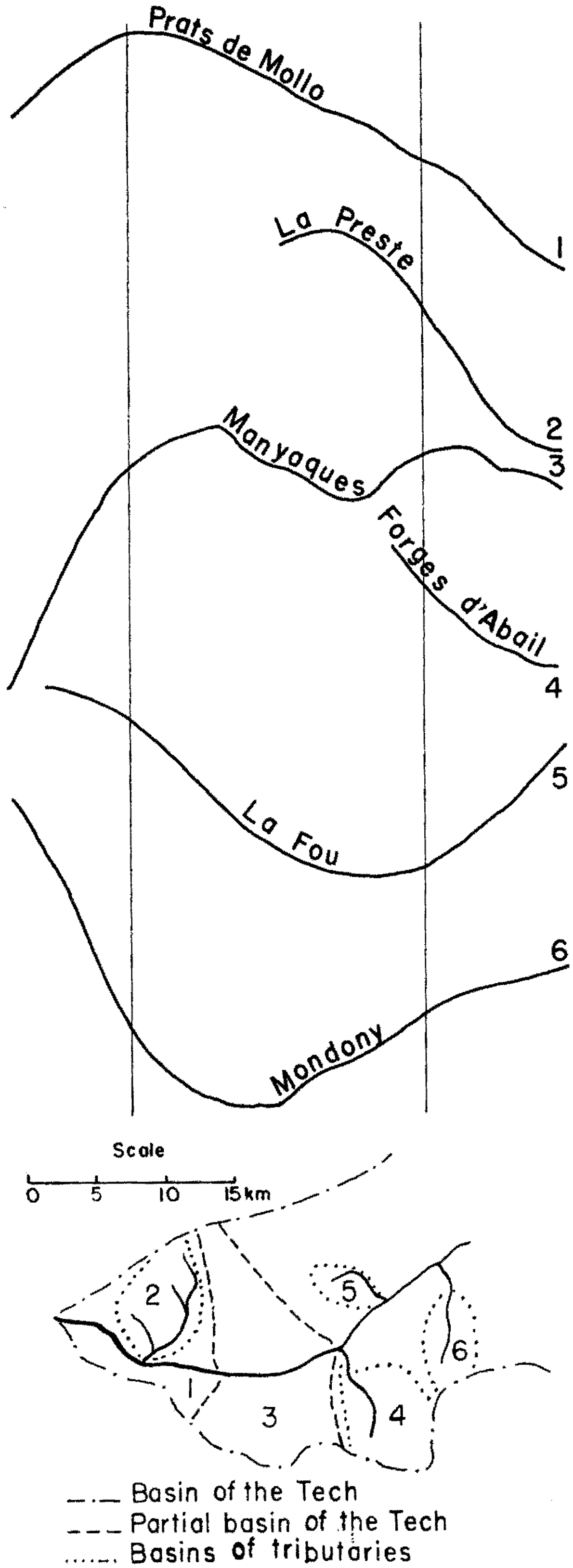

Figure 1

I cannot in any way subscribe to these views.

Soil erosion is a very general calamity, which menaces that part of man's heritage from which he derives the very essence of his subsistence. To contemplate allowing what is called private enterprise to concern itself with protection against erosion would really mean accepting the mortgaging by private interests of a factor most vital to humanity.

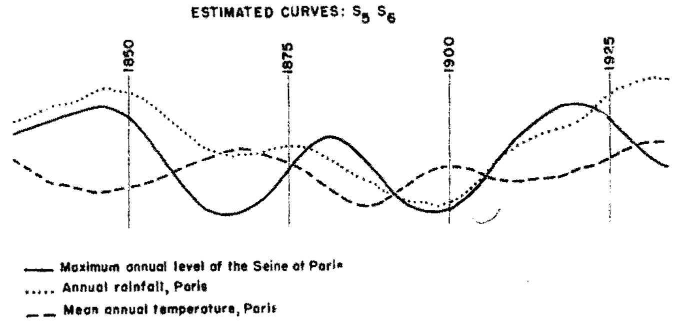

Figure 2

In protesting vigorously against the views expressed in the document I have quoted, I am in agreement with the resolution of the first General Assembly of the World Federation of Scientific Workers, which adopted the following motion (4, p. 71):

"This Congress advises the associations affiliated to it to propagate unceasingly the understanding of the social functions of Science and the necessity for scientists to participate in the social life of the community, having in mind that technical perfection alone does not constitute the highest value of civilization and culture."

In view of the fact that, in the case of the French Union, soil conservation mainly concerns former colonies, I would refer to another resolution of the same congress (4, page 75), which binds scientists to seek "an immediate and substantial elevation of the standards of living, particularly of health and nutrition as a primary necessity" for these populations.

With the exception of the limited zone of accelerated general erosion (zone b of the report on chapter 4, paragraph *a*), soil conservation work lies within the reach of local budgets (departments, districts, communes), which is clearly shown by the extension of "fractionized dams" in southern Morocco.

The cost of larger-scale work amounts to a maximum of approximately 400 working days per hectare in Morocco, taking into account the necessity of making wide benches and subdividing them with transversal ridges. This work is so extensive that it is not reasonable to continue it by hand. It is to be hoped that the Scientific Conference will demonstrate the possibilities of mechanizing work on slopes which vary considerably not only in their resistance to progress, but also in stability.

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The Effect of Stream Management on Water Yields[1]

F. KUNTSCHEN and J. BIRCHER

ABSTRACT

The natural rate of flow of streams in Switzerland varies greatly by reason of geographical and meteorological conditions, differences in elevation, the geological character of the ground and differences in plant life. This subject is covered in the first part of the paper.

The second part of the paper deals with changes in the regime of watercourses by artificial means. The primary purpose of these measures is to prevent water damage and to manage streams and rivers in order to use them for water-power and navigation. If the regime of watercourses is changed the conditions of transport of alluvium are also changed.

The correction and regulation of rivers and the effects of these measures are first described, and attention is then given to several cases concerning regulation of lakes. One chapter deals with systematic experiments to determine the effects of deforestation and reafforestation.

The utilization of water-power is dominated by the fact that all Alpine watercourses have high yields in summer but low yields in winter when power needs are greatest. Consequently, it is necessary to build high-head stations with large storage-basins.

NATURAL RATES OF FLOW

The area of Switzerland is 41,324 sq. km.; this is one-two-hundred-and-thirty-fifth of the total area of Europe. The meteorological, climatic, geological and hydrological conditions in this small country are very varied. The ground structure is characterized by the Alps in the south and by the Jura range in the north with a relatively uneven plateau between them. The country's average height above sea-level is about 1,300 metres. The highest point is Pointe Dufour in the Mont Rose massif with a peak that reaches 4,634 metres above sea-level, and the lowest point is on Lake Maggiore, which is 193 metres above sea-level. In round numbers this represents a difference in altitude of 4,400 metres between these two points. The Rhine leaves Swiss territory at Basle at an elevation of 244 metres, and the Rhône leaves the country below Geneva at an elevation of 332 metres.

Because of the extremely varied surface-formation and the imposing mountain ranges that cut up the country, precipitation conditions vary greatly from region to region, both in the mountains and in the plains. The great differences in altitude also affect the climate and make its extremes more marked. Throughout the entire country, however, rainfall is more plentiful in summer and less abundant in winter. Although this condition is of great benefit to agriculture, it is less favourable for the utilization of water-power.

The Alps are covered by perpetual snow which, on the north face for example, extends down to between 3,000 and 2,500 metres above sea-level. This snow feeds glaciers that have snouts which descend to varying distances below the snow-line. Glaciers and *nevés* cover about 2,000 sq. km. of the area of Switzerland. This represents 5 per cent of the total area of the country and is a rather high percentage.

Owing to the geographical and meteorological conditions we have ascribed to the differences in altitude, to the geological character of the ground and to the differences in plant-life, the rate of stream-flow is very variable in Switzerland. Rainy periods may occur in any part of the country and at any time of the year and may cause high-water and even flood-waters in any of the watercourses. In addition, the melting of the snow in the spring also increases rates of flow. In general, however, the great Alpine watercourses, such as the Rhine, the Rhône, the Ticino and the Inn, the catchment areas of which extend into the regions of the glaciers and perpetual snow, have low levels in winter and high levels in summer, a condition that is governed by the melting of snow and ice.

Swiss streams flow into the basins of the following five rivers: (1) the Rhine, which leaves Switzerland at Basle; (2) the Rhône, which leaves the country below Geneva; (3) the Danube; the Inn River leaving Switzerland at Martinsbruck in Lower Engadine; (4) the Po, into which various watercourses in the south of Switzerland flow; (5) the Adige, into which flows the small Rombach River in the Münster valley (see Figure 1).

The volume of water that leaves Switzerland each year is estimated at an average (covering a long series of years) of about 53,000 million cub. metres, of which 33,500 million cub. metres, or 63.4 per cent, are accounted for by the Rhine; the Rhine basin covers two-thirds of the entire area of Switzerland.

The total discharge of Swiss watercourses is distributed as follows: 63 per cent during the summer months from April to September and 37 per cent during the winter months (see Figure 2).

Switzerland is fortunate in possessing over a thousand lakes, scattered over the entire country. These lakes cover altogether about one-twentieth of the country's area. They form a very useful compensatory function. As an example of this, the Rhine has a ratio between maximum and minimum rates of flow of 53: 1 when it enters Lake Constance, which has not been regulated, but a ratio of only 10: 1 when it leaves the lake. If we consider not only the Rhine but also all the other watercourses that discharge into Lake Constance, this ratio between maximum and minimum rates of flow then rises as high as 150: 1.

Furthermore, watercourses leaving lakes are free from solid matter, for the streams flowing into such lakes deposit the alluvium and matter in suspension that they transport.

CHANGES IN THE REGIME OF WATERCOURSES BY ARTIFICIAL MEANS

The primary purpose of changes in river regimes is to prevent damage or to manage watercourses in order to

[1]Original text: French.

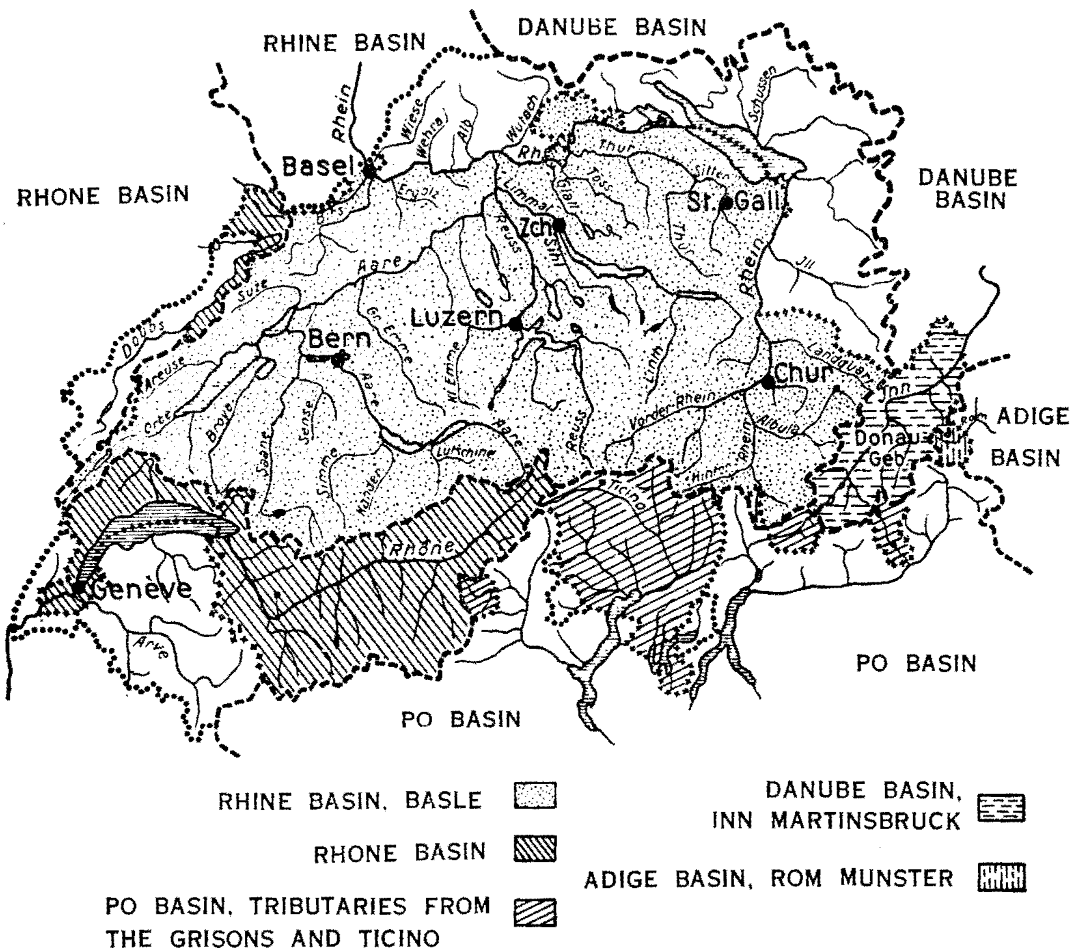


Figure 1

use them for water-power and navigation. These measures often make it possible at the same time to reclaim new arable land by improving previously non-fertile areas.

Artificial control measures not only affect the rates of flow in a stream but may also change the conditions under which alluvium is transported and consequently the volume of such alluvium. For this reason the Federal Water Service has not merely been concerned with determining rates of flow but has at the same time studied the transport of alluvium. Information on the total volume of matter transported has been obtained from numerous delta surveys.

Just as in natural lakes, deposits of alluvium and matter in suspension are also found in lakes created artificially by damming. It has been estimated that the volume of material deposited in storage basins in Switzerland will amount over a period of one hundred years to between 3 and 16 per cent of their capacity. At this rate the basins will have a useful life of 600 to 4,000 years, and it is for this reason that no steps are being taken to prevent these deposits.

When, however, the storage basins are situated not high in the mountains but in cultivated or wooded areas of the fore-Alps, it becomes necessary to control this deposit of alluvium, though for another reason, which is that these deposits may raise the bed of tributary rivers at their mouth and thus cause floods or infiltration of water in the arable land.

To overcome these difficulties torrent control work can be done throughout the whole drainage basin, but this is often a very difficult and costly undertaking. Other remedies are correction of the beds of the tributaries, retention of the alluvium in places of deposit, and dredging.

We pointed out earlier that during the summer months the rates of flow in the catchment areas of the Alpine regions are almost twice as great as during the winter months. The principal purpose of storage basins is to act as an equalizing factor between the two seasons. The regulation of lakes helps to a certain extent in improving winter flow, while at the same time lessening the effects of flood-waters.

Correction and regulation of rivers

The principal purpose here is to prevent damage caused by high water and to protect cultivated land from floods. A large number of Swiss watercourses have been regulated. In most cases the regulation has not affected the water regime because it has been limited to embanking works that do not change the rate of flow. The history of efforts to control the destructive effect of water goes back very many years. As examples we may mention the regulation of the Rhine above Lake Constance and the embankment of the Rhône above the Lake of Geneva.

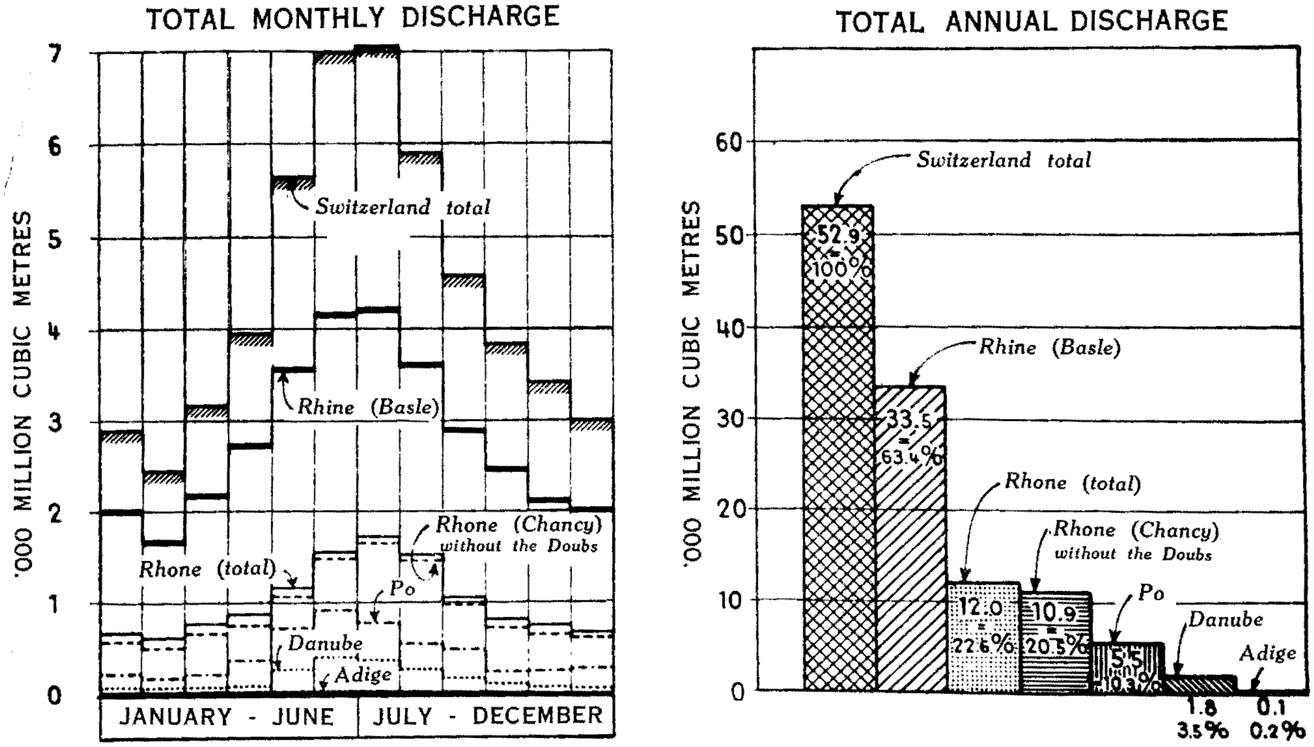


Figure 2

As cases in which there was correction accompanied by a change in regime, we shall refer to the Linth and the waters of the Jura.

(*a*) *The correction of the Linth.* More than one hundred and fifty years ago two plains that today are fertile, namely, the plain situated between the Lake of Walen and Grynau and the plain in the valley of the Linth below Netstal, were marshy areas and centres of malaria in which the water in times of heavy floods rose as high as the first floors of the houses. The Linth, which when in spate transported large quantities of alluvium, was constantly building up its bed and thus made any kind of embankment works impossible.

Between 1807 and 1827 the course of the Linth was corrected. This immense work included diversion of the river into the Lake of Walen and improvement of the discharge conditions of that lake. Since that time the Linth has been depositing its alluvium in the lake, which serves at the same time as a retention basin for flood-waters. The level of the lake was lowered by about 2.30 metres. Despite these corrective efforts, the regime of the Linth has not undergone any essential change. Even to this day the lake has not been regulated (see Figure 3).

(*b*) *Correction of the waters of the Jura.* This project was carried out between 1869 and 1891. The cost was approximately 19 million francs. Its purpose was to prevent the periodic flooding which used to occur in the region of the Jura lakes and the Aare. This was accomplished by lowering the level of the lakes and by re-routing the Aare into the lake of Bienne. The project consisted essentially of the following correction works: canalization of the rivers connecting the three lakes of Bienne, Neuchâtel and Morat (see Figure 4, a and b), diversion of the Aare into the lake of Bienne (Figure 4, c) and construction of the Nidau-Büren canal (Figure 4, d) for the discharge of waters from the lake of Bienne. It was also possible on the same occasion to eliminate the harmful effects of sediment transported in the Aare inasmuch as its alluvium is now deposited in the lake of Bienne. As a result of the canals connecting them the three lakes now form a communicating vessel; the discharge from these lakes is now regulated by a control dam situated at the lower end of the lake of Bienne.

These measures had the following effects:

(i) *The lakes.* The levels of the three lakes were lowered, their levels now being from 2 to 2.8 metres lower than before correction. Because the rate of flow in the Aare is almost three times higher than the total rate of flow in all the other affluents of the lakes, the levels vary more rapidly and more frequently, particularly in the lake of Bienne. The extent of annual variations in levels has also increased. The regime of the lakes, which before correction depended principally on weather conditions in the Jura and the Plateau, has been modified and become Alpine since the Aare was made to flow into the lake of Bienne. The highest levels, which formerly occurred in spring and late autumn, now appear in summer, whereas the minimum levels no longer occur as formerly in August and September but in winter.

(ii) *The Aare below the lakes.* As was to be expected, the rates of flow in the Aare have been to a great extent equalized. Whereas formerly the rate of flow in flood-time would reach 1,500 to 1,700 cub. metres per second at Büren, the maximum rate of flow observed since correction is only 700 cub. metres per second (1944).

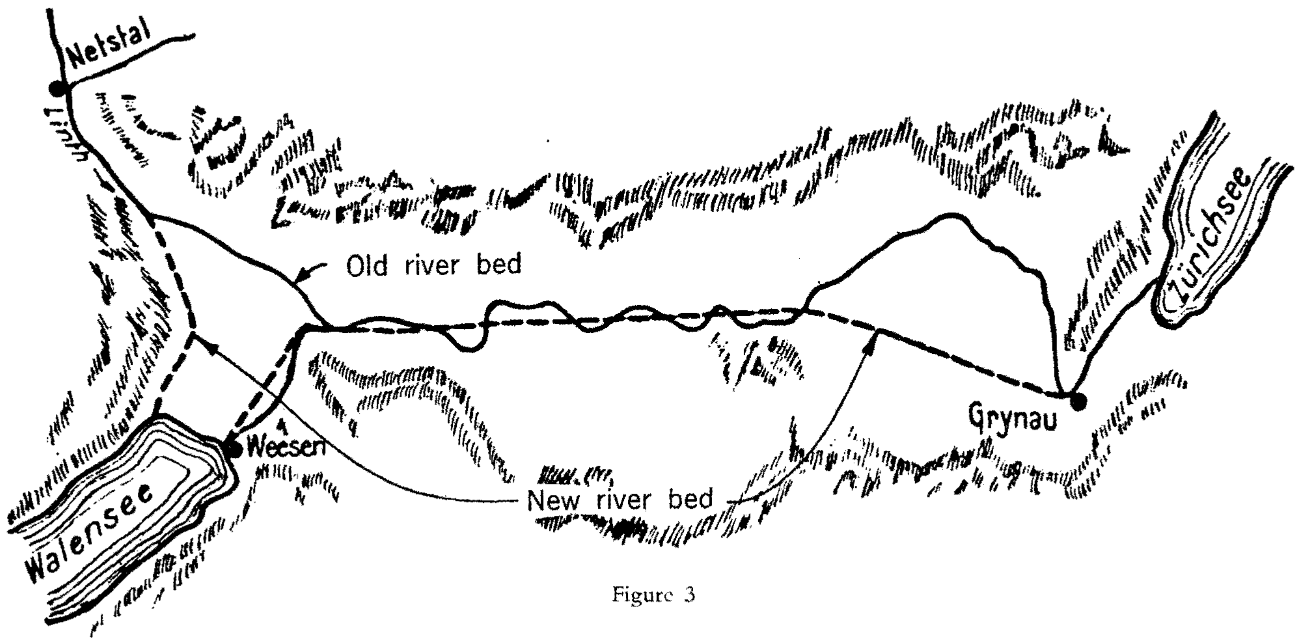


Figure 3

Owing to the storage ability of the lakes, the duration of low-water periods has been noticeably reduced.

In conjunction with the works described above, drainage of the formerly flooded plains was undertaken. A region of about 100 sq. km. was drained and its value considerably increased. In the course of time the surface of the Grand-Marais (the largest of the areas drained) has dropped about 70 cm. Where there was an enormous swamp seventy-five years ago, there now extends fertile land as far as the eye can see.

Regulation of lakes

In the first part of this paper we discussed the equalizing effect of non-regulated lakes. This effect can be increased by regulating the rates of flow of the outlets. Another purpose of regulation is to control the level of lakes within limits acceptable to riparian landowners. Certain lakes have been regulated for a long time, and the measures taken have in varying degree affected the rate of flow of the outlets. The intensity of flood-waters is reduced, and a certain reserve of water may be established for the winter. No detailed surveys have been made on changes in regime resulting from regulation.

Deforestation and reafforestation

The disastrous effects that the clear cutting of forests has on the regime of watercourses and especially on the transport of alluvium are well known. Reafforestation, however, is possible only below the tree line, for the regions situated above this line are not amenable to the work of man.

Systematic studies on the influence of forests on the regime of watercourses have been undertaken in Switzerland. In the vicinity of Montreux, on the Lake of Geneva, an area is being reforested in order to prevent recurrence of disastrous floods. Thorough and extensive research has been done since 1934 on the effect of reafforestation on water regimes and the transport of alluvium. This work is still going on and its results are not yet known. Similar research has also been conducted since 1934 in a valley of the Canton of Ticino, but the results there have not yet become known either.

In addition to this activity, systematic experiments have been carried on since 1900 in two adjacent regions situated in the Emmental (Canton of Berne). These two regions have the same meteorological characteristics. The first of these, Rappengraben (R), is only partially covered with forests (one-third of the area), whereas the other, Sperbelgraben (Sp), is completely wooded. The extent of the drainage basins is as follows: R: 0.59 sq. km., Sp: 0.56 sq. km. The following are the most important results obtained:

(*a*) The amount of run-off water, expressed as a percentage of precipitation (discharge coefficient), is 12 per cent greater (evaporation thus being less) in the thinly wooded region (R) than in the heavily wooded region (Sp).

(*b*) Taking the average for fifteen years, this same discharge coefficient in March—April is 77 per cent in the Sp region, whereas it reaches 101 per cent in R; for August and September it is 35 per cent in Sp and 43 per cent in R.

(*c*) When precipitation follows a dry period, generally causing no more than an insignificant flow, such flow may be exceptionally higher in the Sp region than in the R region.

(*d*) In the case of precipitation which follows a rainy period at the time when snow is melting and which often causes very dangerous flood conditions, the flow in the R region is almost always 30 to 50 per cent higher than that in the wooded Sp region.

(*e*) The flow at low water is less in R than in the wooded Sp region.

(*f*) From 1906 to 1942 the Sp region produced an average of 85 cub. metres of alluvium per year per square kilometre, whereas the thinly wooded R region produced 145 cub. metres, or 70 per cent more. This difference is

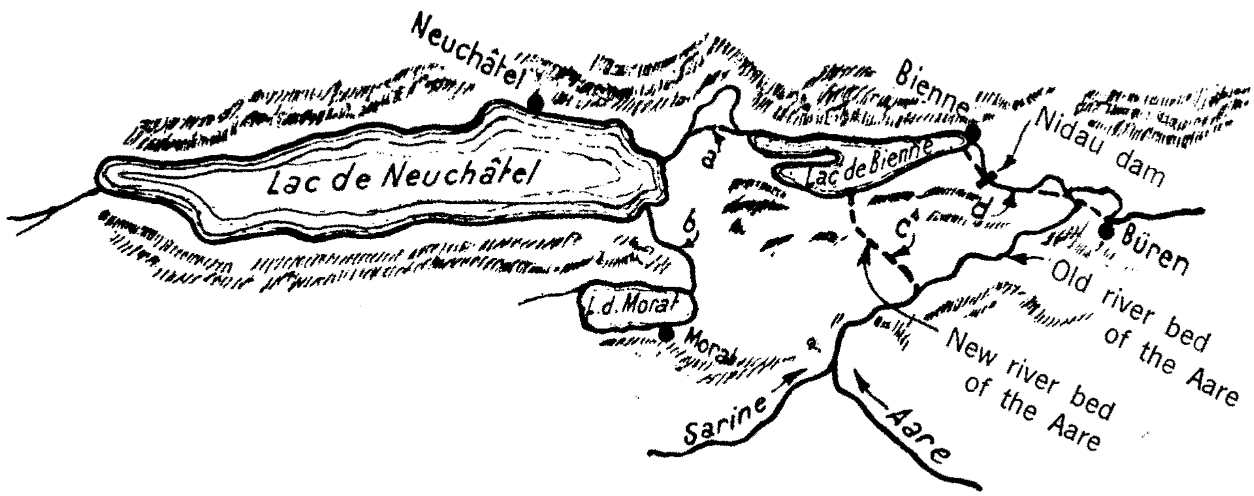


Figure 4

relatively small since almost the entire surface of R is covered with weeds, plants and brush.

Surveys, the results of which are known to us, have proved not only that forests diminish the intensity of flood-waters but also that they reduce the transport of alluvium.

Utilization of water-power, storage lakes

As has already been pointed out, all the Alpine watercourses have high rates of flow in summer but low rates of flow in winter when power needs are greatest. The construction of high-head power stations fed by storage-basins in the Alps is therefore indispensable. By storing the summer flow in these basins and using it to produce energy in the winter, the rates of flow are better distributed throughout the year, and this benefits both the downstream stations and navigation on the downstream sections of the watercourses. A few examples follow:

(1) Storage-basins have been established in the drainage basin of the Limmat, which includes several natural lakes. In the course of the past forty years the low-water flow of the Limmat below Zürich has been increased by an average of about 30 per cent, while by contrast the summer flow has decreased about 10 per cent on an average.

(2) In December 1948, which was a very dry month, the average rate of flow in the Rhine was 412 cub. metres per second. The portion originating in the Swiss storage lakes amounted to 60 cub. metres per second, which was 15 per cent of the total flow. A percentage as high as this, however, does not occur except in periods of very low water.

(3) In the case of the Rhine at Basle, the effect of all the work done throughout the basin is most clearly shown by comparing the duration curve of the period from 1875 to 1890 with that of the period from 1932 to 1947 (we chose these two periods because the average rate of flow is almost the same in each case). During the second period the winter rates of flow, which were equalled or exceeded on 220 to 365 days a year, are 4 per cent higher than the corresponding rates of flow during the first period.

(4) Flood-waters of the Rhine at Basle have become less intense as is seen in the following table:

	Period	
	1875—1890 *cub. metres per sec.*	1932—1947 *cub. metres per sec.*
Highest flow in flood period (point)	5,700	3,500
Flow exceeded during 12 hours a year	3,500	2,720
Flow exceeded during 24 hours a year	3,100	2,470
Flow exceeded during 48 hours a year	2,670	2,360

Summary of Discussion

The CHAIRMAN noted that many papers had been prepared on water control through watershed management and on the effect of such control on water yields and soil conservation. He regretted that the authors of some of the papers were absent. He proposed that the papers should first be presented, after which an exchange of views would take place.

Mr. HAMID, presenting the paper on "Water Control Through Watershed Management", prepared by Mr. Gorrie, who was absent, pointed out that a large part of the seven plateau districts of the western Punjab was deeply gullied by torrents, the yield of which varied greatly according to the seasons. The region consisted mostly of excellent soil, which had been exposed to considerable depths. Large areas had thus been devastated and had become uncultivable.

The Forest Department had for some years been studying management schemes involving the construction of dykes, dams, and terraces. Unfortunately, the execution of part of those plans had had to be postponed. The Forest

Department was, however, already granting subsidies to private owners so that some of the dam construction projects could be carried out. Reclamation by bulldozer was not subsidized but was paid for in full by the owner of the land reclaimed.

Mr. Gorrie's paper showed that the price of land varied between Rs. 60 and Rs. 1,000 per acre, according to whether it was land which could be improved by simple methods of husbandry, whether it was deeply gullied, or situated in torrent beds. To that price must be added anything between Rs. 100 and Rs. 250 per acre for soil reclamation. In the case of easily improved land, the cost was usually recovered in the first harvests.

In Mr. Gorrie's opinion, the existing land reclamation programme would fail unless it was realized that each basin and each river and its tributaries must be regarded as a single unit, to be dealt with as completely as possible for the purpose of water conservation and run-off control.

With regard to flood control, Mr. Gorrie recommended the construction of checkdams in torrent beds, afforestation of denuded land, the construction of stone terraces and the improved management of pasture lands.

The Punjab Forest Department had established a Soil Conservation Circle in 1939. As a result of the partition of the province into Moslem and Hindu regions, the work in the new West Punjab Province had come under the jurisdiction of the Rawalpindi Forest Circle. It could not control the large rivers which provided the irrigation water for the southern part of the new province, since all those rivers, as well as most of the torrents, rose in the State of Kashmir. A treaty, such as the one which existed between the United States and Canada, should be concluded between Pakistan and Kashmir. That would make it possible to control the exploitation of Kashmir's valuable forests, to protect existing irrigation canals in the West Punjab and to solve mutual flood problems.

Mr. Gorrie's paper went on to deal with other administrative difficulties which arose in connexion with the enforcement of the principles of soil conservation. The entire village economy was in the hands of the *patwaris*, who were responsible for land registration. They did not welcome any proposals likely to upset their records and they often used their moral influence to oppose the idea of contouring or revising boundaries. The Government, moreover, was averse to any form of coercion. Certain existing laws were not enforced because the Government did not apply them for fear of becoming unpopular. To remedy that state of affairs, Mr. Gorrie advocated education of the public to prove to it the need for applying restrictions.

In the absence of Mr. Visentini, Mr. Raushenbush presented his paper on "Water Control through River Basin Conservancy", which stressed the need for water control through watershed management. In Italy forests were protected by the law, which also enforced the afforestation of certain areas in order to overcome the effects of erosion. Pasture land was also protected. The arable acreage in the country being comparatively small, it was difficult to develop both forests and cultivable land at the same time. The paper stressed the fact that there were numerous gullies, and recommended the system of draining off the water by means of channels and correcting the shape of certain catchments by the construction of barriers. He pointed to the need of water control on clay soils where saturation might cause land slides. Describing the conservation measures carried out in the Appenines, Mr. Visentini expressed the view that they had shown satisfactory results. The suspension of work during the war, however, had led sometimes to serious damage from flooding. Arable land was protected by simple drainage.

Mr. Bailey, presenting his paper on "Water Control through Watershed Management", spoke of the influence of plant cover and soil mantle on the run-off of precipitation. Man could increase or decrease plant cover in such a way as to be favourable or unfavourable to the infiltration of water. The disposal of precipitation, whether it infiltrated into the soil mantle or ran over the surface of the ground, was determined by the nature of the soil and the amount and kind of vegetation growing on it. These factors varied from place to place, giving rise to different norms of flooding.

So-called "normal" floods could be divided into three principal categories:

(1) Those caused by heavy rainfall or snowfall in the river-basins of the humid southern and eastern regions, as also in the Pacific north-west and south-west. They were the result of a large volume of precipitation falling on already saturated soil.

(2) Those caused by precipitation falling on frozen soil: such floods were serious in certain parts of the north-eastern and central regions.

(3) Those caused in arid regions by torrential summer storms falling on naturally barren or nearly barren ground. Such rains were a powerful eroding agent, especially in areas where the soil surface was exposed. They could lead to particularly destructive mud-rock flows. Examples of areas of this character where floods may normally be frequent and severe are to be found in certain parts of the Colorado Basin in southern Utah and in the Badlands of the two Dakotas.

So-called "abnormal" floods could be caused even by light rainfall in areas where the normal storage capacity of the soil had been reduced by the destruction or reduction of the plant and soil mantle.

There were extensive areas in the West, particularly in the high mountains and plateaus, which were protected from floods and erosion by a plant cover and soil mantle which were capable of absorbing even torrential rainfalls. From a geological point of view, however, the balance was precarious and necessitated constant protection of the plant cover and soil mantle.

He then described certain mud-rock flows which had occurred recently in the Wasatch Mountains in northern Utah. That area offered unusual opportunities for study and provided a test area for measuring the effects of watershed management on run-off. The watersheds drained into the Great Salt Lake. Geological observations had revealed that recent floods had cut to extraordinary new depths into sands and gravels of the deltas and terraces of the ancient lake. The floods had also deposited a considerable amount of debris and sediment on the margins of the old lake—now agricultural land. The floods had been traced to their source by following the channels. Comparisons were also made with a nearby area which was well-vegetated and on which there was no evidence of surface run-off or loss of soil, though it had received as much rainfall as the gullied area.

These facts proved that recent mud-rock floods were due to drastic reduction in the amount of plant cover and to compaction and erosion of the soil. A watershed management programme was therefore designed to restore plant cover and to stabilize the soil in deteriorated areas. Live-stock grazing was curtailed in those areas and measures such as contour trenching and artificial reseeding of 520 hectares was carried out in flood-source areas. Dykes about 2 ft. in height, at horizontal intervals of about 25 ft., formed trenches with capacity for impounding the equivalent of 1.50 in. of run-off.

These improvements had had remarkably good results in the basins in which they had been carried out.

No flooding had occurred in adequately treated areas, even in summer, in spite of intense rains. On several occasions such storms had attained precipitation rates of over 4.80 in. per hour for five-minute periods.

Watersheds which had been fully treated from 1936 to date had shown a radical change in comparison with their previous behaviour. Their flow was almost regular and they carried very little sediment.

The lesson to be learned from the experiment in the Utah area was that it was essential to be careful with the plant and soil resources. Although watershed management alone was not deemed enough to provide effective control of run-off in all areas, it could nevertheless make a big contribution in areas where the plant cover and soil had been deteriorated below their normal capability for control of run-off.

In the absence of Mr. Schurter, Mr. FORNEROD presented his paper on "The Federal Supervision of Water Policy in the Interests of Soil Conservation in Switzerland". The paper spoke of the "Federal Law concerning water conservancy in the mountain regions" of June 1877, which was later extended to apply to all Swiss territory, and which gave the Confederation the right of superintendence "as the supreme authority over the embankments". This law was still in effect. By the end of 1948 the Swiss Confederation had allocated subsidies amounting to 660 million Swiss francs.

Damage due to erosion was most serious in places where the subsoil offered little or no resistance and where erosion in depth gave rise to landslides. Floods, which caused serious damage ; were brought whenever the river-bed could not evacuate the flood-water and detritus swept down by the river.

Three types of protective measures had been taken: (*a*) the construction of transverse works and longitudinal dykes to protect the banks; (*b*) drainage works to prevent landslides; (*c*) afforestation of unproductive slopes.

The Laboratory of Hydraulic Research of the Federal Polytechnic Institute at Zürich had established a detritus formula which was of great value in the planning of works.

The author then gave two examples in which new methods were applied to eliminate special difficulties at a minimum cost. The first concerned the correction of the Nolla, the second the correction of the Rhône above Lake Leman. By the construction of longitudinal dykes in that region extensive areas of unproductive marshes had been transformed into fertile land covering an area of 160 sq. km.

In the absence of Mr. Frolow, Mr. RAUSHENBUSH presented his report on "Water Control Through Watershed Management". After considering certain aspects of the problem as it appeared in France and Morocco, the author concluded that many factors have to be considered and that many studies should be undertaken: demographic, economic, pedological, topographical, climatic, agronomic and hydrological. Those studies had hitherto been neglected by scientists, as a result of which the value of the efforts of the authorities and of specialists had been reduced.

For that reason the author recommended the establishment of an international advisory body for soil protection. All countries might receive information from that organization, which would place at their disposal the scientific and practical knowledge it would acquire through voluntary contributions from different countries.

The report discussed at length the development of the Sologne in the Loire basin. When the Ministry of Agriculture had decided to develop that region, it had been an unhealthy area of sand and clay deposits with no agriculture and no industry other than fishing and hunting. Unfortunately the development project had had to be discontinued owing to economic conditions.

There followed an account of underground water control in the Paris basin and the creation of underground reserves in Morocco. It appeared that the systems to be used were too costly but if the inhabitants were assured of having the free use of the land, their voluntary participation might permit the realization of the work.

With regard to erosion, the report enumerated different zones of erosion and recommended control methods for each one. There also the inhabitants must be induced to play an active part in the establishment of control.

Finally the author explained the danger of flood and erosion caused by roads. He pointed out that that problem had already been studied in North Africa.

Mr. DE HAAN had read Mr. Gorrie's paper with special interest in that it was the only one which dealt with drainage basin management in a tropical country. He would like some information, however, on the density of the population in the region discussed by the paper, the average size of the holdings of individual landowners, the different crops, the climate and the quality of the soil. The paper appeared to indicate that the region in question was a plateau without much agriculture in spite of the excellent quality of the soil. Rainfall was relatively low for a tropical country in that it varied from 8 to 25 in.

Mr. de Haan then described the situation in Java, where there were 45 million inhabitants and the density of the population was approximately 370 per sq. km. The farmers owned on the average 0.8 hectares per family. In Java there were no large holdings, for a law had been passed in 1875 forbidding Indonesians to sell land to foreigners. For that reason commercial crops were practically speaking non-existent. The rainfall varied from

80 in. in the plains to 160 in. in the mountains. Those conditions made possible the cultivation of rice, which played a large part in the life of the country. The humid climate and abundant rainfall served to maintain forests, which covered 22 per cent of the total area and were adequately protected areas. The rubber plantations, covering 8 per cent of the area, also contributed to the protection of the soil.

Forty per cent of the area, however, consisted of arable but dry land, which was seriously affected by erosion. In that area rain was dangerous on account of the bare slopes.

The Netherlands Government had taken steps to protect the soil wherever that was essential. A law of 1874 made the building of terraces obligatory in certain regions. The landowners agreed to the necessity for those measures and accepted the cost which they entailed, realizing the benefits which would be derived from them.

Mr. de Haan admitted that the development of arid land had never been really successful on account of the impossibility of putting into effect the necessary measures in areas which were difficult of access. To remedy that situation a programme of community education had been launched, the benefits of which had not taken long to appear. The work accomplished by the farmers themselves in a fertile volcanic area in west Java had made it possible to develop 20,000 hectares of land. Tens of thousands of families had participated in the control of erosion, building walls and terraces over a metre high on slopes of 60 degrees or more. It had been estimated that that type of work had taken between four and five hundred working days per hectare. Within five years, 20,000 hectares of slopes had been replanted with fruit trees and bamboo plantations.

Such facts showed what admirable results could be obtained by the use of simple and effective methods suitable to the needs and potentialities of the areas in question. In Java mechanization was not the solution of the problem, as it appeared to be in the Punjab.

Replying to Mr. de Haan, Mr. Hamid explained that in the Punjab temperatures were extreme and the rainfall was approximately 25 in. a year. There was great density of population; most of the arable land was under cultivation. Irrigation performed by means of open wells was confined to only 3 per cent of the northern upland areas; irrigation from major canals was practised only in the southern half of the province.

Mr. Renner stressed the importance of the question discussed in Mr. Gorrie's paper, especially that of the necessity of considering each catchment as a unit.

The basic principles of soil conservation and water control were well known and had been expounded at length in the works which dealt with the question. Unfortunately those principles were not always applied, hence the numerous failures, which retarded progress in that field. In the United States much remained to be done before satisfactory conditions could be achieved.

Mr. Maitland[1] had listened with great interest to the summary of Mr. Gorrie's paper. He himself had studied the question from very close quarters in India when he had been in charge of the Forest Conservation Service in the Central Provinces of that country.

The Central Provinces formed a region of uplands, of an area of about 100,000 square miles. Government-owned forests covered one-fourth of the land, while privately-owned forests covered 8,000 square miles. The upper basins of five great rivers, including the Ganges, were situated in those uplands; hence the importance of efficient water control in that zone to counteract floods in the Madras and Bombay areas.

It had been seen to be essential that Governments should realize the need to enact legislative measures to reduce grazing in State-owned lands, which presented grave danger to the plant cover, and to prevent haphazard exploitation and misuse of private forests. The fact had to be faced that the population of those upper basins could not be removed; the only possible solution, consequently, lay in educating the population and inducing it to exploit the region in a way which would be consistent with the requirements of water control.

The Chairman opened discussion on Mr. Bailey's paper on water control through watershed management.

Mr. Compton had read Mr. Bailey's paper with great interest. It showed that watershed management made it possible to control and equalize the stream-flow, thus decreasing the need for flood control works in the lower reaches. With particular reference to the distinction drawn by Mr. Bailey between overland flow and seepage flow, Mr. Compton inquired whether it was possible by means of proper drainage basins, to convert precipitation into seepage rather than overland flow.

Mr. Bailey remarked that the possibility of seepage depended on local conditions, climate, the nature of the soil and the subsoil etc. Experiments in some parts of Utah had shown that it was possible to effect complete infiltration of the precipitation falling on soil instead of letting it flow off. In regions where the climate was unfavourable to the growth of plant cover, on the other hand, most of the run-off was overland flow. He himself had taken part in experiments in which the plant cover of an area where most of the water had seeped into the soil had been artificially destroyed; as a result, 60 to 90 per cent of the rainfall had become overland flow.

Mr. Delgado asked whether reafforestation seemed to be the decisive factor in the control of run-off in the parts of Utah described in Mr. Bailey's paper.

Mr. Bailey explained that in the parts of Utah described in his paper it had been noted that on slopes with a maximum amount of vegetation the total precipitation seeped into the soil; experts had then attempted to determine the density of that vegetation and its dispersion index. It was hoped to determine the density of vegetation and the index of dispersion required for different slopes and different types of soil. Experts were trying to discover first what had occurred in the region before the coming of man; if it was found that there had originally been complete seepage, it should be possible to re-establish it by proper treatment.

Mr. Renner remarked that one of the effects of watershed management was to clear the water, which was

[1]Deceased, 25 April 1950.

extremely important. He cited in particular the case of a small river used by the textile industry, which required very clear water. It was necessary at present to treat the water in the factory itself, but it was thought that the muddiness of the water could be reduced by one-third or one-half through the proper management of the drainage basin.

Mr. DULEY, in reply to Mr. Delgado's question concerning the importance of reafforestation, said that experiments had shown that infiltration increased greatly when the territory was used as grassland. The results of those experiments had been published in a bulletin which he would be glad to show to Mr. Delgado if the latter so desired.

Mr. DELGADO thanked Mr. Duley.

Mr. BAILEY, in reply to requests for explanation, confirmed the figures given in his paper concerning the great financial losses caused by misuse of the land.

Mr. RAUSHENBUSH, Programme Officer, referring to the passage of Mr. Bailey's paper which dealt with the disastrous effects on lower level regions of the mismanagement of certain lands in the upper reaches of the river, wondered whether any countries had laws penalizing those responsible for such mismanagement. Laws of that kind existed for industry; if, for example, a factory produced noxious fumes which caused the death of animals in neighbouring fields, its proprietor was held financially responsible.

Mr. MAITLAND and Mr. FORNEROD replied that laws modelled upon French legislation contained implicit provisions to that effect.

Mr. DAHLBECK said that there were laws in Sweden forbidding deforestation of the mountains and the construction of dams which might impair structures on the lower levels.

The CHAIRMAN opened discussion on Mr. Schurter's paper on the superintendence by the Swiss Confederation of water conservancy for the purpose of soil conservation.

Mr. HOCKENSMITH was of the opinion that the measures described in that paper would be applicable in a great many cases. It was, for example, both possible and advisable to guide debris in a given direction in order to improve the land at that point.

He stressed the necessity of soil conservation in the upper reaches of river-basins for the protection of hydro-electric or other plants in the lower reaches.

The CHAIRMAN opened discussion on Mr. Frolow's paper on "Water Control Through Watershed Management".

Mr. MUNNS wondered whether in plans for river-basin development sufficient heed was paid to the need for management of the upper reaches of the rivers. Engineers in charge of hydro-electric, irrigation and flood control works did not seem sufficiently concerned with conditions in drainage basins, the deterioration of which often interfered gravely with the proper operation of waterworks and involved costly repairs.

The Rio Grande and the Colorado presented striking examples of that situation in the United States. A reservoir on the Rio Grande used for the production of hydro-electric power as well as for irrigation was filling with sediment at such a rate that its effective life would be reduced to one hundred years. In a reservoir on the Colorado, sediment was being deposited so rapidly that the mere upkeep of the reservoir would cost about one hundred dollars for each dollar already spent. Such extreme sedimentation might have been avoided if care had been taken to prevent soil erosion in the upper basins of those rivers.

As Mr. Bailey had shown, the deterioration of drainage basins could be counteracted by afforestation, reclamation of pasture land and proper cultivation, but such conservation work was frequently either neglected or included in other programmes instead of being part of river exploitation plans.

Mr. FLON supported Mr. Munns' remarks. He pointed out that difficulties similar to those cited in the case of the Rio Grande and the Colorado had arisen in connexion with the dams and reservoirs of North Africa. It would be advisable for experts to draw the attention of their Governments to those difficulties.

The CHAIRMAN drew attention to Mr. H. L. Cook's paper on "The Effects of Land Management Upon Run-Off and Ground-water".

Mr. H. L. COOK introduced his paper and read the abstract to be found at the beginning.

He remarked that in the field of hydrology great advances were now being made and previously intractable problems were being solved. One of those problems, that of subsurface run-off, was attracting great attention; the question was closely connected with the capacity of the soil to store water.

He stressed the importance of the effects of land management on run-off but pointed out certain limitations. Drainage basins could not be treated from the sole point of view of run-off control; economic needs and agricultural requirements had also to be taken into account.

He then drew attention to Figure 4 of his paper, which gave typical curves showing average reductions in flood-flow attainable through treatment of the land. The first curve showed the results that might be obtained on watersheds with deep soils: They were considerable, involving a reduction of 30 to 40 per cent in the case of minor floods and 12 per cent in the case of major floods. The second curve showed that the results would be far less favourable in watersheds with thin soils which could not retain the infiltrated water, the reduction in major floods under some circumstances being less than 3 per cent. It should be noted, however, that minor floods were of considerable importance, because they occurred frequently and resulted in large aggregate damage to agriculture. Any reduction of such floods was therefore most desirable.

He then referred to the question whether the underground water-level was lowered when the land was cultivated and whether the contrary process involved a rise in that level; that question had been widely discussed.

The CHAIRMAN called on Mr. Raushenbush to present a brief outline of a second paper submitted by Mr. Frolow. This paper was entitled "Effects of Watershed Management on Water Yield".

Mr. Raushenbush pointed out that according to Mr. Frolow's paper it had been noted from observations carried out in the Paris area that variations in the level of the Seine River were related more to temperature than to rainfall.

Mr. Frolow stated that in his view we must look mainly to public action, rather than to private initiative, for the prevention of soil erosion and the solution of other soil conservation problems, especially in colonial or lately colonial areas.

In conclusion, Mr. Frolow expressed the hope that the Conference would bring to light further information on the possibilities for mechanizing soil conservation work on difficult and sloping ground.

The Chairman called on Mr. Fornerod to give a summary of the paper submitted by Mr. Kuntschen and Mr. Bircher, on "The Effect of Stream Management on Water Yields".

Mr. Fornerod explained that the first part of the paper described the natural rates of flow in Switzerland; these rates varied greatly according to geographical and meteorological conditions, differences in altitude, the geological character of the ground and differences in plant life.

The authors pointed out that precipitation varied according to climatic regions, rainfall being more abundant in summer than in winter. While that condition was of benefit to agriculture, it was less favourable for the utilization of water-power. Rainfall varied also according to the river-basin; when it coincided with the melting of glaciers it could cause considerable damage. The annual flow amounted to 53,000 million cub. metres, two-thirds of which were accounted for by the Rhine. In conclusion, the paper pointed out that Switzerland possessed more than a thousand lakes which performed a compensatory function.

The second part of the paper dealt with changes in the regime of watercourses by artificial means. The Federal Water Service in Switzerland had been closely studying the movement of deposits; a number of artificial lakes had been created and they served the same purpose as natural lakes; they provided an outlet for flood discharges and at the same time accumulated alluvium deposits which might otherwise cause considerable damage to grassland.

Work undertaken in Switzerland to control the course of tributaries and torrents had greatly improved existing conditions. Moreover, reafforestation work had contributed to a decrease in floods and in the volume of deposits.

The Chairman invited members to present their observations on the paper presented by Mr. H. L. Cook.

Mr. M. L. Cooke inquired concerning the status of ground-water tables in the United States. He asked if there had been a general decline such as had occurred in an Ohio industrial area with which he was familiar.

Mr. H. L. Cook replied that he could not give an authoritative answer to this question and pointed out that the U.S. Geological Survey would be the logical agency to answer it, since that agency had charge of ground-water measurements in the United States.

Mr. Leggette explained that the alarming drop in the water-level in some industrial areas was due to excessive pumping. He had previously been connected with the U.S. Geological Survey in the study of ground-water and he could say that it was the view of the agency that no general decline in the water-table was taking place in the United States.

Mr. Irmay referred to the equation given in Mr. Cook's paper: $Rs = P - F$ (surface run-off equals precipitation minus infiltration). He stressed that the F factor failed to take into account losses arising from causes other than infiltration, namely, the evaporation of water which could not infiltrate, such as dew and surface moisture or raindrops falling on plants. A considerable loss of water was thus involved, particularly in dry and semi-dry areas.

Mr. H. L. Cook replied that the equation was but an approximation and that in some instances evaporation should be taken into account. The equation was one frequently given and was useful for some purposes. However, it was not essential in the present paper.

Mr. S. Buchan described an experiment carried out during the war, in England, where, owing to the fact that marginal land was used for agriculture, it had been found necessary to make use of upland peat for bogs-grazing ground. They were at first found to be unsuitable and a large number of sheep died from disease. After ditches had been dug, the soil had dehydrated rapidly and grass had started to grow, but the population of the lowlands had then complained of the great increase in the volume of water flowing downhill.

He wondered whether it was possible to solve that problem.

Mr. H. L. Cook replied that he was not in a position to give any specific information on the subject. As far as he was aware, the only studies in the United States that might yield applicable results were those under way in the Everglades.

Mr. Flon observed that similar phenomena had been noted in Belgium, where peat-bogs soaked up the water and regulated its flow. As in England, they had been drained, but those responsible for the operation had soon regretted it, since the peat-bogs had then been seen to be a necessary element in regulating water in the uplands.

Mr. Munns pointed out that the volume of ground-water depended to a great extent upon the soil cover. Water escaped rapidly wherever ditches were formed or where insufficient plant life existed. Infiltration would therefore have to be increased by means of suitable cultivation. In forest zones, for instance, ground-water was apt to increase. In other words, plants were like human beings in that their consumption of water varied. To protect and increase ground-water, it was necessary to eliminate those plants known for their high rate of water consumption. That process could lead to an increase in the volume of water available for human use.

Mr. C. G. Lopez stated that he had followed with considerable interest the development schemes carried out in various countries. He proceeded to give a brief description of the work done on soil conservation and water control in a Latin-American country, namely in Ecuador.

Ecuador's topographical structure consisted of uplands, lowlands and steep mountain slopes. In early days, farming on the high and middle plateaux had been very much restricted by the fact that water flowing down the high mountains did not settle on the slopes. It was a matter of controlling the flow of water and causing it to remain on the slopes. Several methods had been tried, including reafforestation by means of the planting of eucalyptus trees, which at times grew to a height of 100 metres. It was found that the tree not only held back the water and maintained ground moisture on the slopes, but it also prevented landslides.

Mr. Lopez pointed out that ditches had been built to channel the water towards gullies and forests, where it would be useful for crop-growing and pasture land.

Ecuador had thus been able to control the flow of water, keep the soil from shifting and prevent damage caused by run-off towards the lowlands. Moreover, increased infiltration had resulted in a higher rate of flow from river sources.

The CHAIRMAN thanked the speakers who had taken part in the discussion and added that the statements made and the views exchanged had been most fruitful.

Water Control Structures

26 August 1949

Chairman:

Andres García Quintero, *Director de Hidrología en la Secretaría de Recursos Hidráulicos*, Mexico, D.F.

Contributed Papers:

Latest Developments in Design, Construction and Operation of Major Water Control Structures, including Dams, Canals, Locks and Desilting Works

J. Aubert, *Professeur à l'Ecole National des Ponts et Chaussées; Président de la Cie Française de Navigation Rhénane*, Paris, France

Water Control Structures: Dams

André Coyne, Chairman of the International Commission on Large Dams, Paris, France

The Preliminary Comparison and Selection of Dam Sites

Milton G. Speedie, Senior Designing Engineer for Dams, State Rivers, and Water Supply Commission, Melbourne, Victoria, Australia

Deterioration of Large Dam Structures

L. N. McClellan, Chief Engineer, United States Bureau of Reclamation Denver-Federal Center, Denver, Colorado

Preservation of the Aswan Reservoir

Y. M. Simaika, Deputy Inspector General, Nile Control Department, in Charge of Hydraulic Researches, Ministry of Public Works, Cairo, Egypt

Modern Principles for the Construction of Hydro-Electric Stations and River Development Projects

Anton Grzywienski, Professor, Technical University, Vienna, Austria

Construction of Jablanitza and Mavrovo Dams in Yugoslavia

Ministry of Water Economics, Federal People's Republic of Yugoslavia

The Use of Models in Planning Structures for Measuring and Dividing Water

F. J. Domínguez, *Corporación de Fomento de la Producción*, Santiago, Chile

The Use of Scale Models in the Planning of River Engineering Works

E. Meyer-Peter, *Professeur à l'Ecole Polytechnique Fédérale*, Zurich, Switzerland

The Use of Models in Planning Water-Control Works

Inayat Hussain and K. J. Kabraji, Government of Pakistan, Karachi, Pakistan

The Use of Small Scale Models in River Research

M. Danel, *Ingénieur en Chef des Services d'Essais et Recherches, Etablissements Neyret Beylier Piccard Pictet à Grenoble, France*

The Use of Models in Planning Water Control Works

L. G. Straub, Director, St. Anthony Falls Hydraulic Laboratory University of Minnesota, Minneapolis, Minnesota, U.S.A.

The Measurement and Control of Silting

A. N. Khosla, Chairman, Central Water Power, Irrigation and Navigation Commission, Government of India, New Delhi, India

Recent Experience in Lift Irrigation and Drainage in Egypt

Abdel A. Ahmed Bey, Under-Secretary of State, Chairman, Hydro-Electric Power Development, Ministry of Public Works, Cairo, Egypt

The Importance of Sediment Control in the Conservation and Utilization of Water Resources

E. W. Lane, Consulting Hydraulic Engineer, United States Bureau of Reclamation, Denver, Colorado, U.S.A., and

Owen G. Stanley, Chief, Engineering Division, South Pacific Division, United States Corps of Engineers, Oakland Army Base, California, U.S.A.

The Silt Problem in the Basin Development of the North China Plain

C. T. Fong, China

Costs and Benefits of Canal Linings

T. V. Woodford, United States Bureau of Reclamation, Denver, Colorado, U.S.A.

Summary of Discussion:

Discussants:

Messrs. Aubert, Raushenbush, McClellan, El Samny, Karpov, Kalinski, Sain, Papanicolaou, Blee, Fornerod, Hamid, Straub, Lane, Stanley, Woodford

Programme Officer:

Mr. S. Raushenbush

Latest Developments in Design, Construction and Operation of Major Water Control Structures, including Dams, Canals, Locks and Desilting Works[1]

J. AUBERT

ABSTRACT

Only navigable waterways, or those likely to become navigable, are dealt with in this paper.

It is based on the needs of navigation and deals with:

Dams built across large watercourses,

Locks and boat lifts,

Still-water canals,

Running-water canals and desilting works.

1. *Dams:* **The choice of the impounded water-level determines the spacing of dams, whose number should be restricted. This selection is partially conditioned by the accepted effects of the existence of the structures on the previous conditions of high-water flow.**

The nature and size of the dam openings depend on whether vessels are to be obliged or not to use the locks whatever the water-level.

The new types of dams with small parts used for the last twenty years in Europe but still unknown in the United States of America, enable vessels to cross the dams at high-water without using the locks.

2. *Locks:* **The various questions examined deal with the increase in the fall of certain modern locks. The use of boat lifts is also considered.**

3. *Still-water canals:* **A study is made of the methods used to permit the passage of large vessels navigating faster than formerly.**

4. *Running-water canals and desilting works:* **Power-station canals and ship-canals are considered in turn.**

SCOPE OF REPORT

The very fact that locks are mentioned in item 5 of the programme leads us to restrict our study to navigable waterways or, at least, to those of similar importance.

There are very few rivers which, in their natural state, provide satisfactory navigable waterways. The lower course of the Mississippi and the Congo downstream from Stanley Pool are amongst the exceptions.

It is almost always desired to increase the size and tonnage of vessels able to use a particular watercourse. It is then necessary to adapt it for that purpose, the essential aim being to increase the depth of water for navigation.

It should be noted, however, that even when navigation is the sole specific aim in view, it is essential not to increase the high-water flow unduly.

Water control structures for navigation fall into two distinct categories: those in which the flow is unrestricted and those in which the flow is restricted by dams.

In the first case the water control structures serve to collect and, to a certain extent, to concentrate the river water. They consist essentially of works for the protection of banks or sections of dykes almost perpendicular to the banks and known as groins. The construction of these works may involve the use of large resources but the technique employed has not made appreciable progress during the last few years and this matter will, therefore, not be dealt with.

Item 5 of the programme refers, in particular, to "dams, canals, locks and desilting works" and this encourages us to pay particular attention to canal works.

Even if limited as above, the subject has various distinct aspects, for it is possible: to navigate in the watercourse itself after construction of dams with double locks; to navigate in still-water canals; to navigate in running-water canals which are simultaneously used for conveying a certain quantity of water from which solids have sometimes to be separated.

Accordingly, the following will be considered in turn: dams constructed across large watercourses; locks; still-water canals; running-water canals and desilting works.

DAMS CONSTRUCTED ACROSS LARGE WATERCOURSES

DESIGN OF DAMS

Determination of the impounded water-level of dams

The first characteristic to be determined is the impounded water-level of the dam. The normal practice is to be satisfied with the minimum level ensuring the necessary depth of water for navigation at all volumes of discharge (and even in the extreme case of a nil volume corresponding to horizontal reaches).

However, it must be recognized that, even when navigation is the sole aim, it might be well to provide for a depth of water appreciably above the minimum. This would reduce the speed of flow and thus facilitate the movement of vessels. On the other hand, an additional area would be flooded and part of the impounded water might be silted up.

Hence, it is above all in cases where there are other

[1]Original text: French.

aims, besides navigation, that an impounded water-level above the minimum is sometimes adopted. However, a detailed study of this question would involve a lengthy digression.

Suffice it to say that, when the height of dams is determined, there is the further consideration that high-water-levels should not be increased (or should not be increased beyond a fixed amount). The spacing of dams is dependent upon their height and, from the standpoint of navigation alone, it is obviously advisable to space the dams as apart as possible so as to reduce their number.

Determination of the area of fixed and movable parts of dams

When the impounded water-level of a dam has been fixed, the most important question to be decided is the area of the fixed part of the structure. The other part must be made movable and this necessitates a suitable sluice for closing it. This question is governed by navigation conditions on the waterway in question.

In some cases vessels are always permitted to pass through the dam by using the adjoining lock, in other cases it is desired to give them additional facilities by permitting passage through the movable parts of the dam during the period of the year when they are open. In the latter case the dam is said to have one or more navigable channels.

It is necessary to consider this question of navigable channels before examining the effects on dam construction of the above alternatives.

(1) *Advantages of navigable channels.* Their usefulness clearly depends upon the length of time during which the dam is open.

Thus, the dams on the Seine are open, on an average, for one month in each year and during that period vessels avoid using the locks.

On the lower course of the Ohio the period is appreciably longer, whilst on the downstream section of the canalized part of the Mississippi between St. Paul and St. Louis the period exceeds six months a year.

Similarly, the German engineers arranged that the dam which it was proposed to construct near Magdeburg in 1938 should be open for approximately half the year, during which period navigation on the river was to be completely free.

It is obvious that the navigable channel alternative is preferable as it relieves vessels of the onerous task of passing through the locks (a procedure involving considerable loss of time) during a period which varies on each river.

We believe that this point is not disputed by any engineer, it being, of course, understood that navigable channels are particularly useful when the dams must remain open for lengthy periods.

It has, however, been noted that in certain recent canal works (for instance, the reconstruction of certain old dams on the Ohio and the canalization of the Mississippi) navigable channels have not been provided for. This decision is all the more surprising in that on those rivers there are frequently large trains of barges, coupled together and propelled by tows, the effective tonnage of one such train amounting to 20,000 tons. This system of towing has not yet been employed in Europe but is shortly to be tried out on the Thames.

The American engineers' decision to dispense with navigable channels is not due to lack of knowledge or to disregard. It is due to the fact that, in their opinion, it was impossible to provide navigable channels several hundred feet or even one thousand feet wide with satisfactory sluices.

Indeed, it is known that Chanoine-Pasqueau shutters (known in the U.S.A. as Chanoine shutters) used on the old dams of the Ohio are the only system of sluices with small contiguous parts known and used in the U.S.A.

This system unquestionably has the following disadvantages:

Once the shutters have been lowered, it is impossible to raise them to the prescribed level when the water-level is dropping after high water. Consequently, the shutters cannot be raised until the water-level has dropped well below that level.

Control is effected from a boat which requires a fairly large crew of skilled dam workers; their work is difficult and dangerous and fatal accidents occur from time to time.

We recognize that these disadvantages should lead to the abandonment of Chanoine-Pasqueau shutters, but it does not follow that one should forego the advantages of navigable channels.

A new system of electrically controlled shutters, without the need for a boat, was perfected in France between the two World Wars. After twenty years experience it can be said that this system is extremely strong—it even resists the impact of vessels of several hundred tons—and gives rise to no difficulties. It is controlled by one man and, whatever the water-level, it is not more difficult to control than a tram. Control is not hampered by the presence of a large volume of solids.

Apart from the Seine, this system has been used on the Marne, on the Loire and in Italy in the regulating dam on Lake Maggiore.

In 1938 the German engineers intended to use it for the proposed dam on the Elbe in the Magdeburg area.

It has also been used for the large Sansanding Dam on the Niger which has 14 channels 55 metres wide.

Openings of 100 metres between piles can very easily be achieved and, if a suspension foot-bridge is used, a width of 1,000 ft. is not impossible.

In the case of the Seyssel Dam now being constructed on the Rhône, the carriage and sluices are controlled from the ground and the effective height of the various parts is 7.08 metres. The first part of the dam will be put into service towards the end of 1949.

(2) *Dams with navigable channels.* In order that vessels may pass through the dam when it is open, it is not sufficient that the masonry piers be widely spaced. It is also essential that vessels moving upstream should not have to contend with too strong a current. Experience shows that when the gradient does not exceed 20 cm. per km. a local contraction of 15 to 20 per cent is barely perceptible. Part of the total area of the dam roughly

corresponding to this percentage may, therefore, be fixed, the remainder being closed by a movable sluice.

(3) *Dams without navigable channels.* The size of the fixed parts is sometimes not appreciably larger than in the above case, although the river is obstructed by a very large number of piers. This was the method adopted by the Mississippi engineers who decided not to increase the flood-water-level by more than one foot in certain sections and by six inches in others.

If, on the contrary, it is possible appreciably to raise the water-level, and in particular the high-water-level at any time, the number of dams may be considerably reduced by increasing the height of each dam and decreasing the size of the movable parts. This is the solution adopted in the canalization of the Tennessee.

The area of the fixed parts is then large and the visitor has the impression of a fixed structure containing at the most several openings closed by sluices.

When the sluices are open, the outflow is torrential, so that the water-level above the dam is dependent only on the discharge of the river and the area or on the nature of the openings in the dam. It in no way depends on the water-level below the dam.

The determination of the area and nature of the openings in the dam consists in the solution of a particularly simple hydraulic problem: a pre-determined volume of water must be allowed to discharge without decreasing the water-level above the dam below a given level in the same conditions.

Given an equal area, the flow capacity is larger if the openings are deep than if they are wide. That is why the lifting sluices of the type standard in the Tennessee dams are forty feet in height.

The fact that every builder has to consider the conservation of the dam might, however, lead to the adoption of another solution. If the rock-bed of the watercourse above the dam is not of very good quality, it is preferable to spread the discharge over the greatest possible width rather than to concentrate it at a few points.

Other characteristics of movable dams

It is clear that the choice of the impounded water-level and the determination of the area of the fixed parts of the dam are not the only problems to be solved when the plan is drawn up.

The choice of the type of sluice is also of great importance. We have seen that the adoption of wide navigable channels leads of necessity to the adoption of types of dams with small contiguous parts.

It is not proposed to deal with the question of the types of masonry to be used because that matter is dealt with in Mr. Coyne's report.

CONSTRUCTION OF DAMS

The draining of foundations is normally considered essential in the construction of a masonry dam across a large watercourse. It should, however, be pointed out that as an exception to this rule, the construction of a dam with undrained foundations (which will include sluices and groups of turbo-alternators for a tidal energy plant) is now being studied in France. The width of the dam will be approximately one kilometre and the height from the bed to high-water-level will be about 25 metres (both above and below the dam).

Two methods are normally employed for draining foundations.

The usual method consists in isolating the various parts of the bed by means of metal sheet-piling. If the depth is less than five or six metres, ordinary sheet-pile curtains are used, whereas heights of approximately twenty-five metres can be attained if gabionade curtains are used. This latter method was used in the construction of the Grand Coulee Dam on the Columbia River.

It is difficult to use the above method when the watercourse is smaller and if it runs along the bottom of a rocky gorge.

In such cases one or two diversion channels (which are usually subterranean) are dug and the river-bed is cut so as to force the water through the diversion channel. This method was used in the Boulder Dam on the Colorado and at Génissiat on the Rhône.

It is usually considered that a large quantity of materials must be very rapidly dumped into the current in order to cut off a large flow of water. This was the method selected at the Fort Peck project (across the Missouri) and for the closing of the large dyke on the Zuyder Zee in Holland.

Another method was used to cut off the Rhône at Génissiat. By dumping a specific volume of rock-filling over the whole width of the river it is possible to bring about a rise in the water-level sufficient to force almost the whole of the water through the diversion channel.

At Génissiat the necessary volume of rock-filling was reduced by approximately three-quarters by incorporating metal tetrahedrons secured by cables, the other end of which was made fast to a buoy.

We cannot, without digressing, give further details on this method. Similarly, we will not deal with the question of dam construction after the ground has been drained for the foundations.

OPERATION OF DAMS

The operation of dams for navigation is relatively simple. In principle, it is sufficient to ensure a constant level of water at the shallowest point in the reach, which is generally the upstream end, and for instance, at the downstream sill of the lock.

In order to avoid too swift a current and troublesome overflowing, a constant water-level may be maintained immediately above the dam.

Generally speaking, it may be said that the problem of control consists in maintaining immediately above the dam a water-level in accordance with the flow of the watercourse.

Hence, it is only when problems of accumulation arise with a view to the decreasing of high-water levels that it may be decided to operate in accordance with the flow of water not at the dam itself, but at varying distances upstream or downstream. When this is the case, the water-levels recorded upstream are reported by telephone, telegraph or even by using the more expensive method of long distance fluviograph transmission.

In any event, when control is effected by means of a constant upper pond water-level immediately above the dam, the use of automatic control apparatus is not advisable. This method, far from enabling natural flow variations to be reduced, would have the effect of increasing them by a kind of pumping action.

When several dams in a related series or a number of dams on watercourses in the same basin are operated, it may be advisable to issue all orders through a single authority.

It is assumed, in the above, that the operation of the sluices in the various dams presents no difficulty, whatever the levels reached, and that it can be carried on without interruption. These two conditions are to all intents and purposes fulfilled by all modern dams.

Although the principal problem is that of water-level control, other problems arising out of the operation of dams must also be considered. One of the most difficult is the problem of discharging solids. This is often effected by openings placed at varying depths below the impounded water-level and closed by flushing sluices.

If the sluices are opened and the upper pond water-level maintained at approximately the normal level, the effect of the flushing is perceptible only a few metres above the dam. The quantity of solids discharged is then so small that it is of little practical importance.

If the deposits formed along the reach as a result of the slowing down of the current, which is an inevitable result of canalization, are to be removed, it is essential to lower the level of the reach.

When considering the design of dams, we pointed out that the problem of discharging solids might lead one to increase the area of the movable part of the dam at the expense of the fixed part.

In extreme cases in which almost the whole of the dam is movable, there is no variation in the outflow of flood-water and any danger of accumulation of deposits is averted.

It should, however, be noted that that is not always the case if the deposits remain movable in certain water-courses (and are therefore discharged when the water velocity exceeds the velocity at the time of their formation). Such deposits may cohere increasingly as time passes and their subsequent removal may therefore be difficult.

The Génissiat Dam on the Rhône has been provided with large flushing openings sited approximately 40 metres below the normal impounded water-level. The large size of these openings will enable the river-flow to be restored, even in the case of large discharges, along a profile in length corresponding to a fall of 40 metres at right angles to the dam. It is thought that this precaution will remove the possibility of any silting up in the upstream part of the upper pond. Deposits will form in the deep parts of the river several kilometres upstream from that point but there will be no disadvantage in that filling up.

LOCKS

Locks are an important cause of delay in navigation. Their number should therefore be reduced as far as possible. The increase in the height of falls resulting from that reduction gives rise to difficult problems.

In the case of still-water canals, the water-supply of which often presents difficulties, the water consumption of high-fall locks is sometimes regarded as inadmissible. In Europe, and in particular in Germany, water-saving reservoirs are frequently used. This may lead to a large saving in water consumption but also to an increase in locking time.

The rapid filling and emptying of locks on canals and rivers produces positive or negative waves upstream and downstream which may involve the vessels in difficulties.

If the reaches are short, the variations in level may be excessive and this makes it advisable to provide reaches of sufficient area between the flights of locks. This may be achieved by widening or lengthening the reaches.

The rapid filling of a lock may also result in eddies which are dangerous for the vessel in the lock. New plans for aqueducts are now being studied in the U.S.A. and in France.

Another problem to be solved in the construction of locks is the selection of their horizontal dimensions.

At one time, locks enabling the passage of single vessels were considered sufficient, subsequently it was desired to lock whole convoys simultaneously. This practice became too burdensome in the case of high-fall locks.

It should also be borne in mind that the replacement of a high-fall lock by several locks of shorter fall increases the total capacity of the navigable waterway; the capacity being dependent on the period of time between the passage into the slowest lock of two vessels navigating in the same direction.

If it is decided to use a flight of locks, it will be seen that the locking through small capacity locks of three or four vessels in convoy is practically as rapid as in locks which enable the whole convoy to be locked simultaneously. Obviously this is true only if modern equipment permitting rapid entry and exit of individual vessels in the various locks is available.

It should be pointed out that the use of locks is not absolutely essential in the case of high falls, as boat-lifts may well be used.

They have been used above all in Germany. Two 1,000-ton vessels navigating in the same direction and locked separately can be handled at an interval of fifteen minutes on the Niederfinow lift. The mobile chamber covers the fall of 37 metres in five minutes.

Floating lifts have been chosen for use on the Elbe (junction of the Mittelandkanal and the Elbe). They appear preferable as there is a saving in installation costs (particularly on bad ground) and operating costs. The vertical movement of the chamber is somewhat slower—approximately nine minutes for a fall varying between 11 and 18 metres.

STILL-WATER CANALS

In such canals the only current is, of course, that produced by the maintenance of the canal water-level and water-supply for the locks. There is therefore a flow of several cubic metres per second at the most and a current of that size does not necessitate any kind of bank protection.

However, bank protection cannot be dispensed with, as the movement of the vessels and, more particularly of the tug, and vessels' screws, sets up an agitation which is more dangerous to bank stability than a fairly swift current.

The present tendency is to allow vessels, and particularly self-propelled vessels, to navigate much more rapidly than formerly. Thus, self-propelled vessels are permitted to navigate at 10 km. an hour on the Albert Canal (which was put into operation in Belgium in 1939 to connect the Liége area with the port of Antwerp).

In order to remove any danger to bank stability, that canal had to be provided with a section permitting easy but slower movement of the large 2,000-ton Rhine barges.

In order to facilitate operation, the present tendency is to reduce the number of local contractions or even to eliminate them. Thus, the slopes of banks at right angles to road and railway bridges across the canal are no longer steepened. In the case of Roves tunnel, which joins the port of Marseilles to the Berre Lake, a width of 22 metres and a total area of some 230 square metres was permitted.

Similarly, the Germans have dispensed with one-way sections on the Mittelandkanal, even in the case of such costly structures as canal aqueducts. The canal aqueduct over the Elbe, which includes a central span of 100 metres, is a two-way aqueduct.

Certain still-water canals are designed for very large vessels. Thus, the Niagara Falls are by-passed by the Welland Canal No. 4 which can be used by cargo boats of 20,000 to 30,000 tons. This canal followed three other canals which had been designed for larger and larger vessels. The number of locks was reduced in the case of each new canal.

The Panama Canal is also a still-water canal and even a summit-level canal. Its transformation into a lockless canal joining the two oceans, by means of a considerable deepening of the great central cut which is several kilometres long, is under consideration.

In the case of the Albert Canal, the Belgian engineers abandoned the idea of a summit-level canal and decided to dig very deep cuts and other cuts whose construction was still more difficult owing to bad ground. Thus, there is a steady drop in the Albert Canal between Liége and Antwerp and it may be regarded as a new Meuse from which Belgium will doubtless profit for centuries.

RUNNING-WATER CANALS AND DESILTING WORKS

These canals are intended, apart from their use for navigation, to convey water from one point to another in order to provide water for irrigation purposes or for hydro-electric plants.

One of the important problems is the velocity to be permitted. This is dependent upon whether the canal is or is not used for navigation and whether it is lined or unlined. When the canal is to be navigable, high velocities may be permitted, if the same vessels are to be capable of meeting even higher velocities in the sections of rivers which they are obliged to use.

In the case of unlined canals, average speeds are approximately 1.20 metres per second.

The slower the velocity, the more difficult the problem of keeping afloat the solid discharge carried along by the water. In this connexion, a distinction should be made between floating discharge and solid discharge rolled on the canal bed, which can sometimes be prevented from penetrating into the canal.

Power-station canals and irrigation canals should be considered separately.

Power-station canals

It is sometimes considered that floating solid discharge may be allowed in a canal supplying a power-station, even if there is a certain amount of wear and tear of the turbine blades as a result; the re-metalling of the blades after wear and tear may, in certain cases, be less expensive than the installation of special desilting devices.

If it is desired to avoid deposits in the supply canal, the velocity of the liquid discharge must be permanently maintained. Hence, sluices must be installed near the power-station and be opened when the turbines are stopped.

If the canal is intended to take a discharge appreciably greater than the normal flow, and if the water above the power-station is to be maintained at a more or less constant level, as is normally the case, there will at times be reduced supply velocities. Deposits are then inevitable.

Consequently, it may be advisable, in the case of discharge canals to admit only water from which the floating solid discharge has been largely removed.

One method of water purification consists in supplying the canal with water from the upper section of a fairly deep lake. The desilting problem then becomes the same as that dealt with in the case of reservoir dams.

If, on the other hand, the water intake is from a shallow part of a watercourse, a special structure may be installed on the canal near the upper gate.

Such a structure is based on the principle of considerably enlarging the discharge section so as to reduce the velocity of flow. The producing of eddies also contributes to the formation of deposits. These are evacuated through openings in the bottom of the settling tank and the openings are joined to a pipe or to a canal into which a certain discharge of water flows by gravity to a low point which may, for instance, be downstream from the intake dam.

Irrigation canals

The same desilting problem arises in the case of irrigation canals, as the formation of deposits is still more dangerous. These are particularly to be feared, not in the main outlets, but in the small section canals which follow them. It is almost inevitable that these will have to be cleaned out from time to time.

The desilting devices which may be placed at the beginning of an irrigation canal are the same as those described above in the case of power-station canals.

Water Control Structures: Dams[1]

ANDRÉ COYNE

ABSTRACT

After discussing the influence of progress in civil engineering equipment on the development of dam construction technique and in particular on the scale of construction, the author surveys the various trends with particular reference to the factors determining the choice of this or that type of construction.

The "mass produced" gravity dam adopted by the Americans for reasons of speed and ease of construction depends on the use of powerful standardized equipment.

In contrast, the trend of the European style is toward the "made to measure" dam where the main consideration is economy of material which rules out the gravity dam in favour of other types such as pure arch, thick arch and buttress dams.

The progress made in pure arch construction is due to the steady increase in the ratio of length to height and in the greater and greater stresses accepted for concrete.

When the width of the valley becomes really great, it is still possible to realize a large saving of material by means of thick arch construction.

In more extreme cases, multiple thick arch dams with spaced buttresses often provide an economical solution.

The author describes the "ski-jump" spillway, which makes it possible to concentrate the dam, spillway and powerhouse in a single work in a narrow valley.

The interesting possibilities of pre-stressing in the form of tension braces are indicated.

In conclusion, the author analyses the increasing importance of earth dams due to the development of standardized mobile equipment particularly well adapted to such work.

More detailed information illustrating several of the structural problems and solutions is presented in an annex.

One may well be astonished that most countries have hesitated for so long to embark on the large-scale utilization of their one source of natural power which, while easy to develop and of proved value has the advantage of perpetually renewing itself, namely, water which falls from the sky.

It has taken two world wars, marked by a serious drain on oil and coal deposits and followed by an ever-increasing demand for power, for consideration to be given more or less everywhere to large-scale investment programmes designed to make up for lost time.

Twenty years ago only the United States of America and the Union of Soviet Socialist Republics were, as far as we know, attaching full importance to programmes of this kind planned from the dual standpoint of the development of desert areas and the creation of new sources of power.

The construction of the greatest dams in the world dates from that time. It is therefore no paradox to say that the causes of the unprecedented development of this branch of engineering are to be sought in the economic depression and the war which followed it.

To what extent can the technical progress achieved in this field repay this debt by stimulating and assisting the general economic effort? That is the subject of the lines that follow.

GENERAL CONSIDERATIONS

Scale

The very scale of the constructions undertaken, although they may be questionable from the financial point of view because of their very, size is in itself a factor making for technical economies.

Repetition and concentration of effort, the accumulation at one point of massive equipment, the increase of the unit power of the equipment, the enormous volume of water placed in storage and therefore available as required have had as a direct result a decrease in the prime cost of the water stored and of the power available, as well as making the latter move dependable.

Moreover, the ever-growing audacity of constructional engineers which has sometimes led to the accusation of megalomania, makes it possible to tackle problems today which only a few years ago seemed insoluble.

The face of the earth is thus in the process of being profoundly changed.

To realize the extent to which this is true, one need only recall that the most massive works of all time have been constructed in the form of dams in the last twenty years of human history. This record seems formerly to have been held by the Pyramids of Egypt. It was wrested from them for the first time by the Boulder Dam and since then by a succession of large American dams.

But in contrast to what happened in the days of the Egyptians, the enormous quantities of material that must be employed in a dam are today handled solely by machines. They are hardly ever touched by the human hand.

Here, as in many other fields, the lead has been given by the United States of America and there can be no doubt that the grandiose visions of the great statesman who gave the initial impulse to these gigantic works would have had only a limited outcome if he had not been backed by the parallel efforts of his compatriots in the field of civil engineering equipment.

Civil engineering equipment

While it is certain that the magnitude of the works undertaken is a stimulus to the development and perfection of increasingly powerful and improved tools, the latter in turn make it possible to build better and faster. Civil engineering equipment therefore is and always will be the source of the most important progress in construction.

[1]Original text: French.

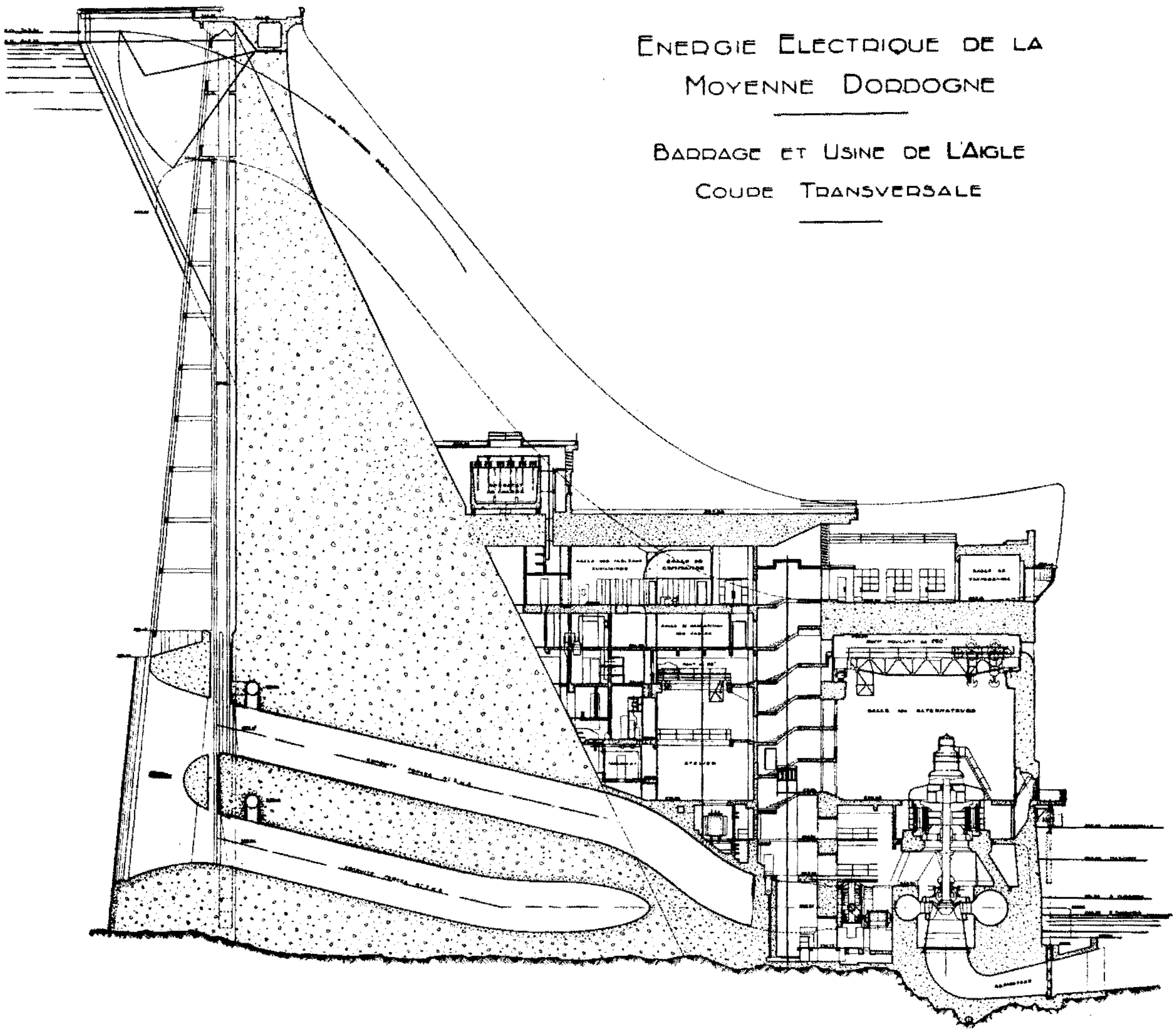


Figure 1. Moyenne Dordogne electric power station: Aigle Dam and plant—cross-section.

It is for this reason that civil engineers are always urging manufacturers not to relax their efforts and to provide construction machinery of high efficiency, great durability and great ease of maintenance.

At the present time delivery delays are so long that they are usually a serious handicap to the starting of construction operations.

In the majority of cases it is therefore imperative to employ standardized equipment.

Man-power

As the tasks which had to be performed by hand in construction work and which were rightly regarded as degrading are gradually being reduced and receding into the past, the need for a sort of upgrading of workers is becoming apparent as an unexpected and frequently challenged consequence of the increasingly large part played by machinery.

As a result there is a shortage almost everywhere, not of manual labour, but of specialists. The specialists are no longer the same as they used to be. The stonecutters and masons have given way to cement-workers, form makers, machine drivers and maintenance mechanics.

Structural engineering workers are often impossible to find.

This development, as will be seen later, has repercussions on the actual conception of work which differs from country to country in accordance with the level of education of the labour force and the relative importance of manual labour and machinery in construction work.

According to circumstances, the search for the greatest economy and the speediest possible results leads in different countries to widely divergent results.

For this reason it seems difficult and dangerous to transplant this or that construction technique without precaution from one country to another, particularly from a highly industrialized country to another which is practically unindustrialized but where man-power is plentiful and cheap.

These commonsense considerations should, I believe, be given some weight in the discussions which are likely to arise in the Congress regarding construction styles of the

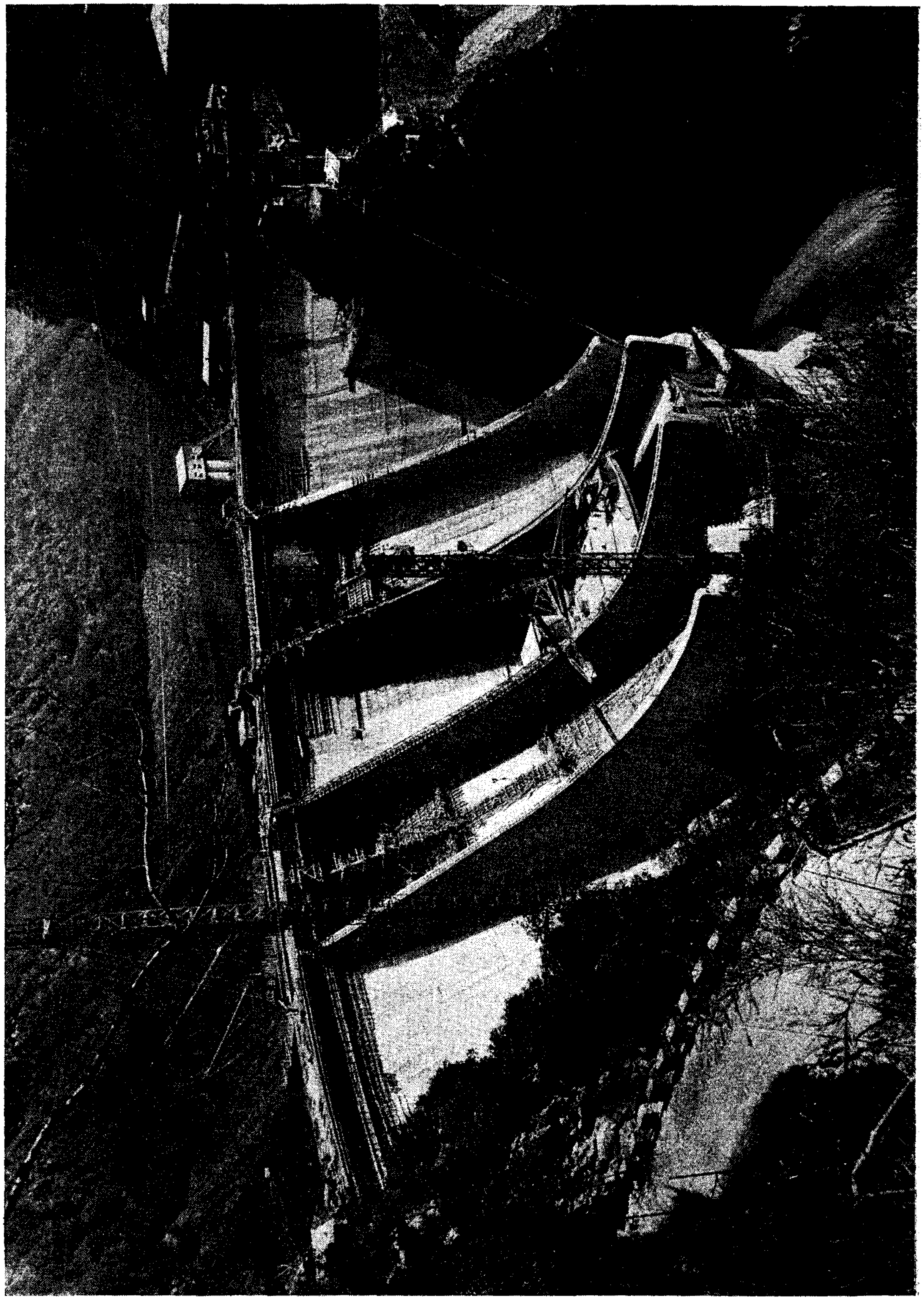


Figure 2. Aigle Dam and powerplant—downstream view.

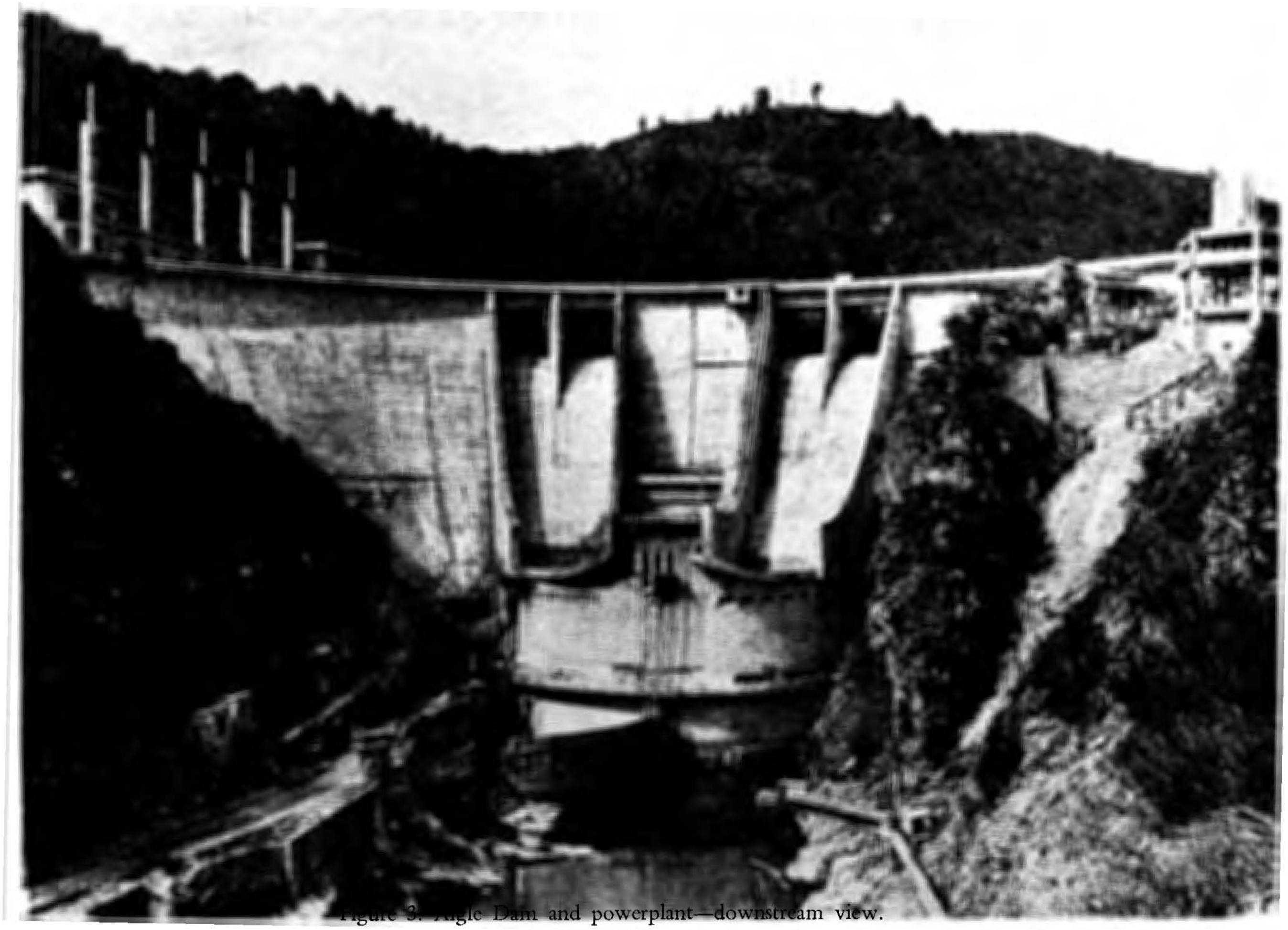


Figure 3. Aigle Dam and powerplant—downstream view.

various countries, as outlined below, and on the possibility of transplanting them from one country to another.

ENGINEERING CONCEPTIONS

Gravity dams

With the exception of Boulder Dam, the largest dams are straight gravity dams.

This style has become almost standard practice in America, both for topographical reasons and because of their greater ease of construction.

The resulting simplification and speeding-up of preliminary work, the repetition of layouts which have already been tested—in spite of still unsettled controversies regarding the effects of uplift, up to a height of approximately 200 metres—the possibility of using and re-using standard equipment, in which derricks, cranes and travelling-gantry cranes occupy an increasingly important place, have, it seems, outweighed all other considerations.

The "mass-production" dam

The adoption of more complex forms involves, in American eyes, a loss of time, perhaps in itself, a loss of money. It would be preferable to sacrifice volume rather than to slow down construction and increase costs by replacing machines by men on any considerable scale and failing to give full scope to the machines.

This conception of the "all-purpose" or "mass-production" dam has found its finest expression in the series of dams in the Tennessee Valley where the mere repetition of the dams gave added weight to the arguments I have already quoted.

Planning of works

To judge by results, the authors of this theory have been right, particularly as regards speed of construction. On closer consideration, we find, however, that this is to a great extent due to the extreme care with which the construction programmes are drawn up and prepared in advance down to the smallest detail, so that everyone knows in good time just what is required of him. American team spirit does the rest.

The European style

In contrast the European style has remained very different. During the recent troubled past, owing to large-scale requisitions by Germany and to the blockade, planners and constructional engineers have been dominated, one might say obsessed, by the need for economy in the use of materials.

But these exigencies are no novelty on the old continent, which is far from possessing the resources in basic material and machinery which are characteristic of American industry. Moreover, they encourage certain tendencies of the Latin people which are given to individualism and sometimes flaunt to excess a taste for technical refinement.

The "made-to-measure" dam

These reasons, combined with the lack of financial resources sufficient for mass-production, explain the prevalence so far of the conception of the "made-to-measure" dam strictly adapted to the site on the one hand and to its function on the other, providing unique and ever-varying examples of an art whose aim is perfection.

In consequence the gravity dam, although originating in Europe, is generally discarded in favour of other types of structure, such as pure arch, thick arch or buttress dams (including the hollow gravity dam).

Arch dams

By adopting an arch form which is appropriate to the size of most European valleys, it is possible to obtain a saving of volume, as compared with the gravity dams, of two-thirds of the total volume, in the case of small works (height 50 metres) and one-third and sometimes one-half in the case of medium structures, although in special topographical conditions it is possible to do even better.

There is nothing radically new in the arch dams so far constructed. There are many examples in America, and what progress has been made lies in the ever-increasing ratio of the length to the height and in the stresses imposed on the concrete, which will be discussed later.

Pure arches

Pure arch dams are now in general use for damming valleys with a width, at pond level, of five to six times the height.

Contrary to the misgivings which may have been felt in this connexion, no difficulties have so far been encountered with regard to the foundations of the central walls which, because of the width of the valley, are subject to very large bending stresses.

Stresses

As regards the stresses allowable in structures of this kind, measurements made on the works themselves, the few performances discussed in the attached documents and experience everywhere show that we are still far from having exhausted the reserves of stability open to us and that there is still a possibility of spectacular lightening and refinement of arch dams which are both the most economical and the safest type in valleys suitable for their use.

Thick arch dams

Substantial savings can still be made in the case of thick arch dams which French engineers in particular have used almost everywhere to replace gravity dams.

In certain cases, a valley may not lend itself to a relatively thin arch or, to use the American expression, pure arch dam, if the valley is too wide or if the rock is not hard enough to bear the stresses involved.

In such cases, there is an obvious solution half-way between the pure arch and the gravity dam where the deficiency of curvature is replaced by gravity and vice versa, namely the thick arch or mixed dam (arch gravity dam) in the style of Owyhee, Sautet or Grimsel.

This formula which may be accused of a lack of technical simplicity and of being neither "fish, flesh nor fowl" has on the practical level the advantage of reconciling several fundamental requirements—safety derived from the curvature, however slight, which is a guarantee against all major risks, an ease of construction hardly less than that of the gravity dam and an economy which may be considerable.

The upstream facing will usually be cylindrical. The batter of the downstream facing will vary and will approach the vertical the nearer it is to the symmetrical axis of the structure. It will be least and the saving will be greatest where the cross sections are larger.

In a dam like the St. Etienne-Cantalès Dam (France) (Figures 25-26) the saving of material is almost 30 per cent as compared with a straight gravity dam. The stresses are very little larger.

Figure 4. Aigle Dam and powerplant—overflow (1.000 cub. metre per sec.)

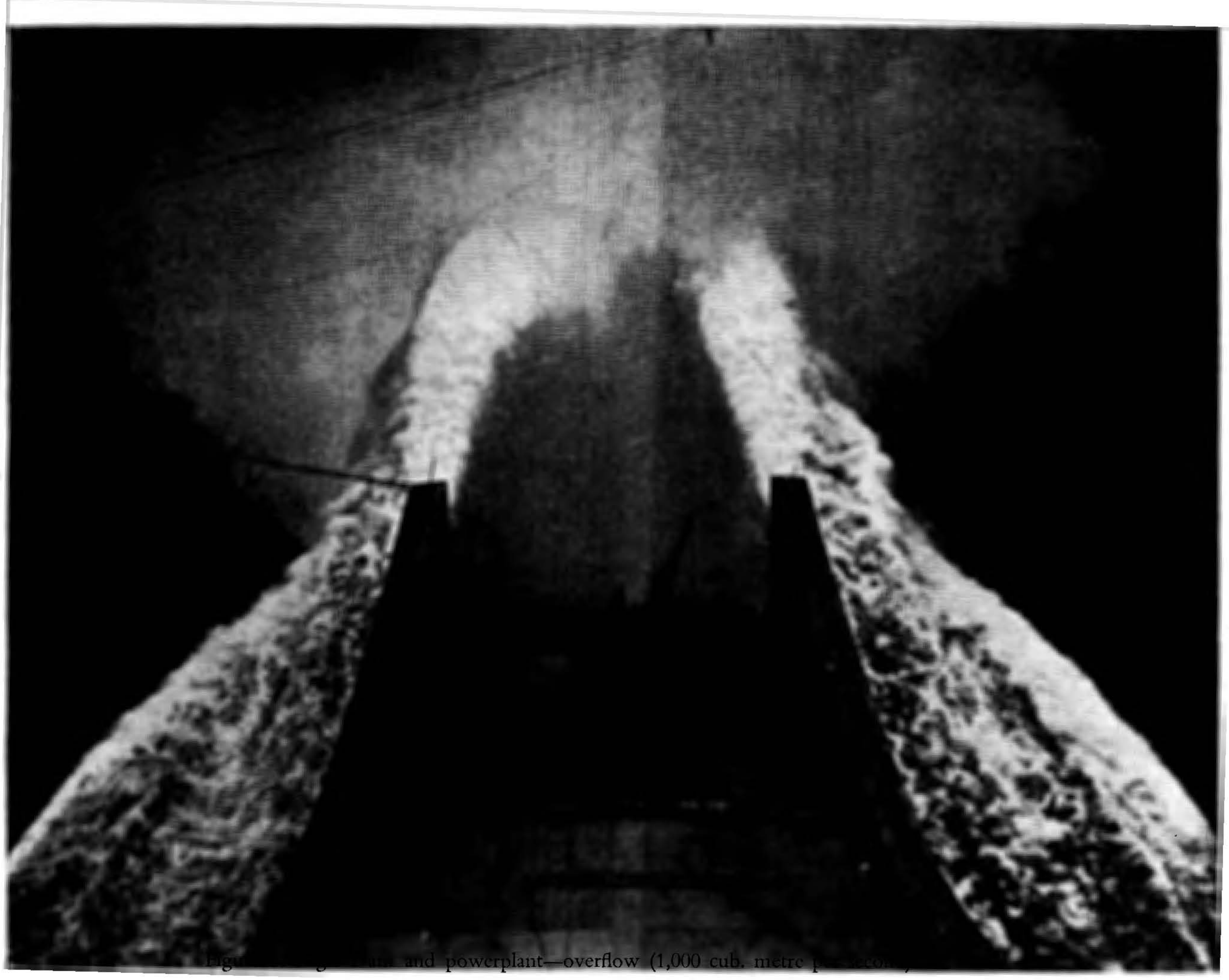
Calculations

Concurrently with the more or less empirical activities of the constructional engineers, there have been great and praiseworthy efforts, particularly in America, to make further progress in the analysis of the stresses at work in structures of this kind by calculation.

However, here as elsewhere, Fresnel's axiom that "Nature snaps her fingers at analytical difficulties" remains true.

The analytical difficulties are great so that it is necessary, for the purposes of calculation, to resort to extreme simplification of basic hypotheses, particularly as regards the elasticity of the foundation soil, which is regarded as mechanically isotropic, whereas engineers and geologists know that it never is.

The calculations made along these lines, although very encouraging, are not yet sufficiently reliable to make it possible, for many years to come, to dispense with the careful checking of their results by direct experience.



Figu... and powerplant—overflow (1,000 cub. metre per secon...)

Hollow-gravity dams

Hollow-gravity dams which are favoured in various countries result in a saving of material which is sometimes not matched by an equivalent reduction of expenditure, owing to the cost of the laying of foundations and of the forms for concrete.

Multiple arch dams

It is therefore desirable to space the buttresses and consequently to form the watertight deck with arches. A worthwhile saving becomes possible once one decides to dispense with reinforcement and not to reduce the thicknesses too much.

Spillways

With the exception of the large dam at Génissiat on the Rhône, the concrete dams constructed in France during the last few years are all designed to carry their own spillways.

Whenever possible, indeed, it is better to place the spillway on the structure itself so as to return the river to its natural bed by the shortest and most direct route. What, however, is to be done if the dam has an overfall spillway and the power station is at the foot? The question becomes all the more acute if the plant fills the whole valley as it does in the case of most European rivers.

What can be done to reconcile the requirement for a direct spillway and the presence of turbines at the bottom of the fall? The simplest method is clearly to direct flood-waters on to the roof of the plant, which is reinforced for the purpose, and to allow them to fall freely into the bed of the river.

In France, where it was first used on a large scale, this type of spillway has been called the "ski-jump" spillway.

The water is first set in rapid motion and then launched into the air in such a way as to fall as far as possible beyond the works and their foundations.

The ski-jump spillway consists essentially of a launching track or race between two leaders ending in a water-shoot projecting beyond the downstream facing of the dam or placed if necessary on the roof of the plant.

Observations over a period of years of the Marèges and Aigle spillways have shown that erosion was concentrated at a good distance from the operative parts of the works and showed no tendency to work back.

Figure 6. Aigle Dam and powerplant—overflow in left-bank spillway.

Observations recently made in France in this connexion will be found in the annex.

Pre-stressing

In quite another order of ideas, French dam-building technique has been tending for many years towards the use of pre-stressing.

The first and most extensive application of this technique was made in Algeria in connexion with the strengthening of the Cheurfas Dam, an old gravity dam the cross-section of which was narrow and dangerous.

By means of high-tension steel braces passing through the whole structure of the dam and penetrating into the earth beneath, an artificial ballast or "live load" was created equivalent to one-third of the dead load or one-half of the water pressure.

Today, nearly twenty years after the placing of these braces, periodical checking of their initial tension (1,000 tons), which is done by introducing jacks under the anchor points, shows that it has varied very little.

Full details are given in the annex as well as examples of the application of this technique to new structures.

They show that we now have an accurate, powerful and economical method of creating artificial elastic states

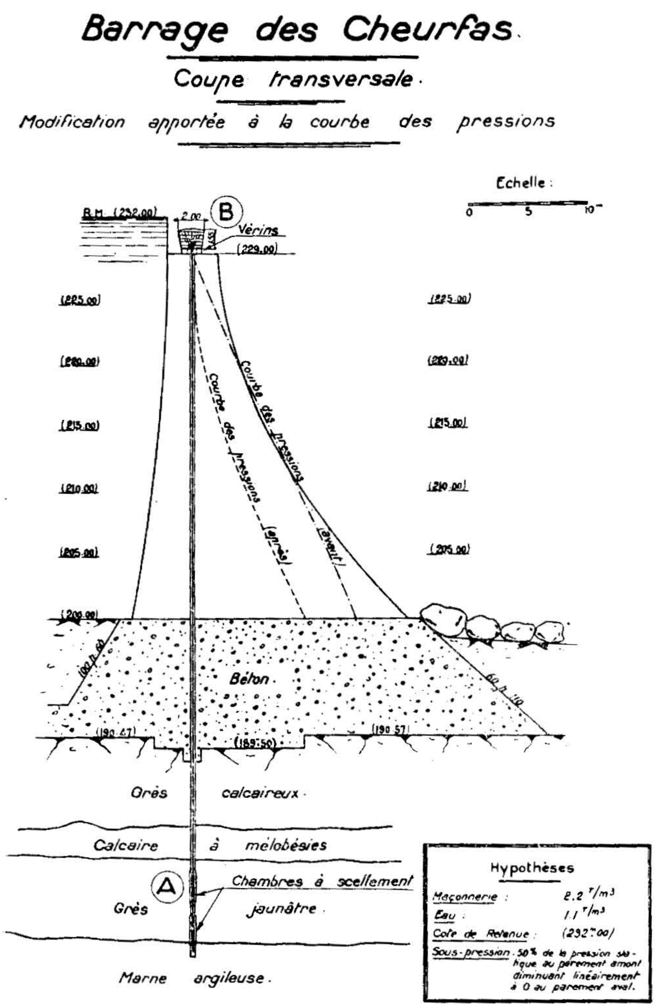


Figure 7

Figure 8. Ch

in masses of masonry or even of profoundly modifying their static equilibrium. If shafts are used instead of bore-holes, there is no reason why braces of several tens of thousands of tons should not be used in medium soils.

Rock fill and earth dams

Turning our back, as it were, on the technical niceties which I have been discussing, we must now mention the not unexpected but certainly unexpectedly rapid development of earth and rock fill dams.

At first considered—at any rate in the case of earth dams—as only suitable for use on difficult or doubtful foundations, they have in a very short time become to be accepted everywhere and now compete with the gravity dam even in its own field, i.e., on hard rock and approach its maximum height.

Their increased use is basically a result of the development of constructional equipment, particularly of equipment for transporting, spreading and rolling the earth; progress in this connexion has relegated to the background the hydraulic filling methods which were rightly regarded as somewhat uncertain.

Generally speaking, in view of the present price of concrete, plus the further cost of cooling and selecting cement in the case of large works, the argument of economy militates in their favour.

But, in the eyes of practical engineers and construction managers, they enjoy another advantage, that of requiring relatively less time for construction.

There is no need to allow, as in the case of a concrete dam, for long periods of time for the ordering, supply

Figure 9. Cheurfa's Dam. Braceheads.

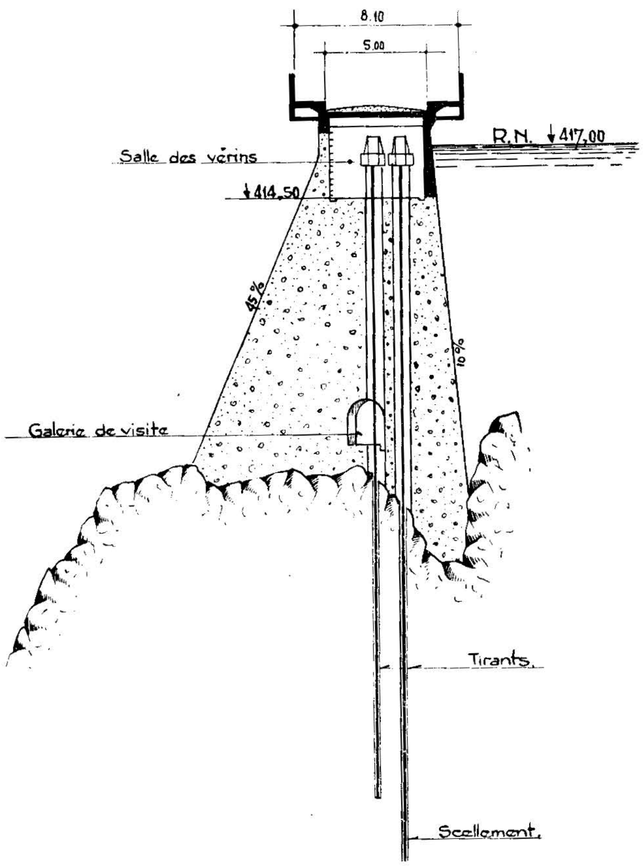


Figure 10

and setting up of machinery, which under the difficult post-war conditions in Europe now account for three-fifths of the total time of construction.

Here the equipment is standardized, has great tactical mobility and is not tied down to the earth. Like cavalry on the field of battle, it can go into action at a moment's notice and disappear when it is no longer required. All the expenditure and delays inherent in the enormous mobilization of equipment required for concrete dams vanish at a single stroke.

It should not, however, be concluded that because they mobilize enormous masses of materials the planning of works of this kind is devoid of all niceties and that quantity can to some extent replace quality in their case.

On the contrary, works of this kind require of the planner the greatest intellectual flexibility, a highly developed clinical sense, so to speak, meaning very acute powers of observation and great discrimination in the study of the natural conditions of a problem which never repeats itself and which evades any kind of *a priori* judgment.

For this reason, moderation in the use of theories of soil mechanics, which are often too simplified to be directly applicable, is to be recommended.

There are no fixed rules defining the best methods of employing the earths available in the vicinity of the undertaking and with which one must contrive to attain the necessary degree of stability and watertightness. This is what makes it so difficult to appraise the present tendencies amongst dam builders which seem indeed to be in process of rapid evolution.

Suffice it to say that the tendency generally is towards a mixed structure, rock on the facings and compacted earth in the centre, thus forming an impervious screen between two filters.

In a neighbouring field, the whole problem of treating soils with a view to consolidating them and making them watertight has been enriched with new remedies, the only defect of which is that they may tempt engineers to misuse them, in the same way as the modern pharmacopoeia tempts some doctors.

Nevertheless, the consolidating *in situ* of alluvial deposits and their transformation into concrete, if found possible, would, in many locations, provide a solution for the problem of exceptionally difficult foundations.

ANNEX

ILLUSTRATIVE MATERIAL

SKI-JUMP SPILLWAY

The best example of a "ski-jump" spillway is provided by the Aigle Dam on the Dordogne (Figures 1-6) which is designed for a maximum flood-water discharge of 4,000 cub. metres per second.

This discharge is divided into two equal parts in discharge troughs or channels sited symmetrically on each side of the axis of symmetry of the power-plant.

Each spillway is in its turn divided into two sluiceways separated by a carefully streamlined intermediate pier. Overhanging entry wing-walls reduce or even eliminate lateral contractions and slightly increase the discharge coefficient.

Each of the sluiceways, discharging 1,000 cub. metres per second under the normal impounded water-level, is closed by a large segment-shaped sluicegate. On leaving the sluiceways, the water gathers in a single sheet contained by leaders converging towards the centre of the dam. The floor of each channel consists first of a local thickening of the downstream face and then of independent rough masonry (on reinforced concrete supports embedded in the concrete mass of the dam) which progressively slopes down to the roof of the power-plant thickened for this purpose under the water passage.

The actual water-shoot is sited at the downstream end of each of the channels. It is designed so that the overflow, which is in rapid motion, shoots into the air, flattens out, spreads vertically and loses part of its force before falling into the river.

For this purpose, the surface of the water-shoot is askew so as to produce an initial torsional effect on the jet of water.

Moreover, the extreme downstream end is raised in the form of a spoon in order to accentuate this torsional and spreading effect in the vertical direction.

It will be noted that the guide channel of the spillways projects well over the front of the plant. This is to protect the plant from volumes of water which might fall on it at low overflow velocities when the discharge and the velocity of the jet are insufficient to throw it well clear.

Such velocities are extremely rare—they occur only at the beginning of the opening and the end of the closing of the sluicegates.

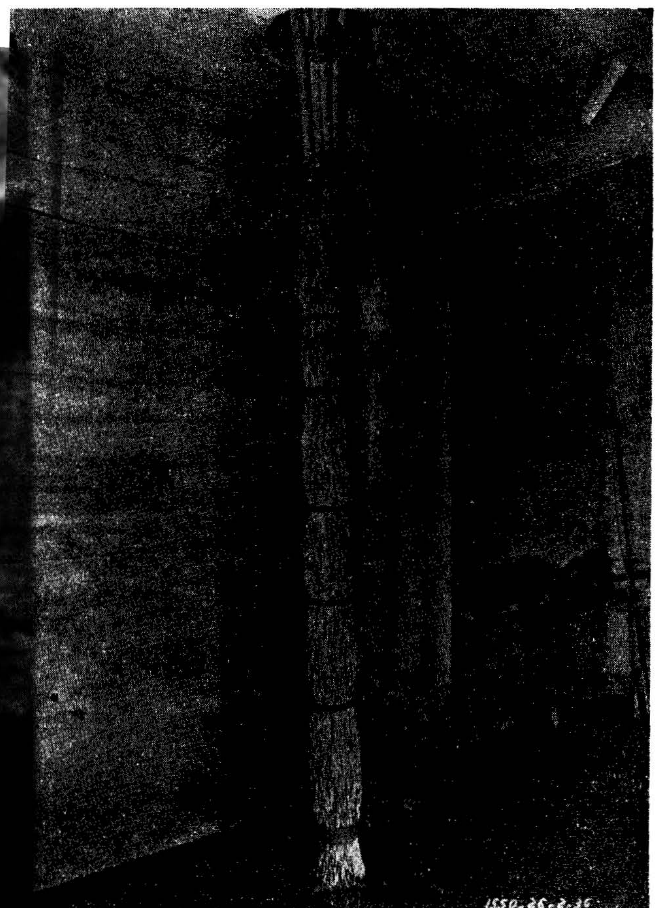
As will be seen later, small high-water discharges do not pass over these spillways but through the drainage outlets.

It will be observed that the power-plant is circular. This is due to lack of space. Although it is equipped with only four main units developing 50,000 kw. each and absorbing a total discharge of 300 cub. metres per second, a figure which would seem absurdly low in comparison with some American works, its dimensions are such that it could not be placed in the very narrow valley without being made compact in order to save space.

These considerations of space are the reason why the works are so concentrated and consist of a single block between the dam, the plant and the spillway.

Since the flow of the water over the roof of the plant entailed a considerable thickening of the roof it was hoped then (1939) that it would be possible to give the machinery at the same time adequate protection against aerial bombardment. But as always happens in these matters, the gun has now far outstripped the armour.

Figu… Right-bank abut… an anchorage-brenolle.



…gure 12. Marèges Dam. Right-bank abutment. Anchorage-brenolle formed.

The spillways have been tested up to 500 and 1,000 cub. metres per second respectively and there were no unexpected developments. The water passes over the roof of the plant without shock and almost noiselessly.

The front of the plant, which is entirely removed from the huge volumes of water which fall some one hundred metres away, is accessible at all rates of discharge. The water is perfectly calm between the plant and the point of impact and there is a drop in the water-level when the spillway starts to operate, owing to the suction produced by the jet when it falls into the river.

The photographs show the characteristic appearance of the overflow checked by the air which thoroughly penetrates it, splits it into foam-flakes and then rolls with it into the chasm whence it at once escapes in light puffs of spray.

As a result of the presence of the air, the bubbles caused in the stilling basin are more rapidly stilled. This basin cuts down to varying depths according to the quality of the rock. A bar forms at a short distance and has to be dredged during the first years of the spillways' operation.

PRE-STRESSING

Cheurfas Dam (*Figures* 7-9)

Vertical holes 0.25 metres in diameter and 50 metres deep (Figure 7) were drilled through the dam masonry and the underlying ground consisting of fairly soft sandstone. These holes widen at the bottom and form two staged anchoring chambers 3 metres long and 0.38 metres in diameter drilled by an under-reamer.

A steel cable, composed of 630 steel galvanized wires 5 mm. in diameter and laid parallel, is introduced into each hole.

These wires are lashed throughout their length except for a few metres at the lower ends. On reaching the anchoring chambers they spread under the weight of the cable. Cement is then injected into the bottom of the hole through a tube lowered at the same time as the metal brace. In order to avoid sealing the cable over its length, it was sheathed above the anchoring chambers with a special "sandwich" of bitumen between two wrappings of sail-cloth. Consequently, it is completely independent of the masonry except at the point of sealing.

On the crest of the dam the wires spread in a reinforced concrete brace-head and jacks, bearing thereon, exercise the required tension. The unit-tension of the steel is about 80 kg. per sq. mm. Each brace therefore exerts a stress of 1,000 tons on the structure.

All the anchoring carried out in this way is successful at the first attempt and in the course of time loses, at the most, only a few hundredth parts of its initial tension. Owing to the precautions taken, the tension, which is easily controllable, can be renewed at any time by replacing the cable on its jacks.

Marèges Dam (*Figures* 10-13)

On the right bank abutment of the Marèges Dam six braces of 900 tons are composed of 15 strands of 0.035 metres, each consisting of 37 wires of 5 mm. which are not twisted for 3 metres at their lower ends (Figure 10).

Contrary to the practice at Cheurfas, however, the holes, 30 cm. in diameter, pierced in the rock are not enlarged at the bottom. Despite this, the anchoring is no less secure, provided that the rock, which in this case is granite, is hard.

St. Michel Dam (*Figures* 14-15)

This is a multiple-arch dam whose buttresses (1 metre thick) support arches, with 25-metre openings, a thickness of 0.70 metres and a batter of 1 in 2.

As the shearing ratios are very high on the underpinning joints, owing to the light weight of the structure and the slight gradient of the waterproof curtain, this was remedied by stressed braces anchored in the ground and exercising on the structure an oblique artificial compression of about 500 tons on the highest buttresses.

Each brace is buckle-shaped and its two ends are sealed in the ground by a power-hammer at a depth of approximately 5 metres on each side of the buttress.

The two arms of the buckle consist of one and the same cable composed of a strand of 61 wires of 4.8 mm. with a breaking strength of 120 kg. per sq. mm.

The working tension is about 80 kg. per sq. mm., that is: approximately 87 tons per strand, or 174 tons for the complete buckle.

Each brace bears on the external edge of the buttress through a semi-cylindrical hooped concrete brace-head under which the single jack is slipped to take the stress.

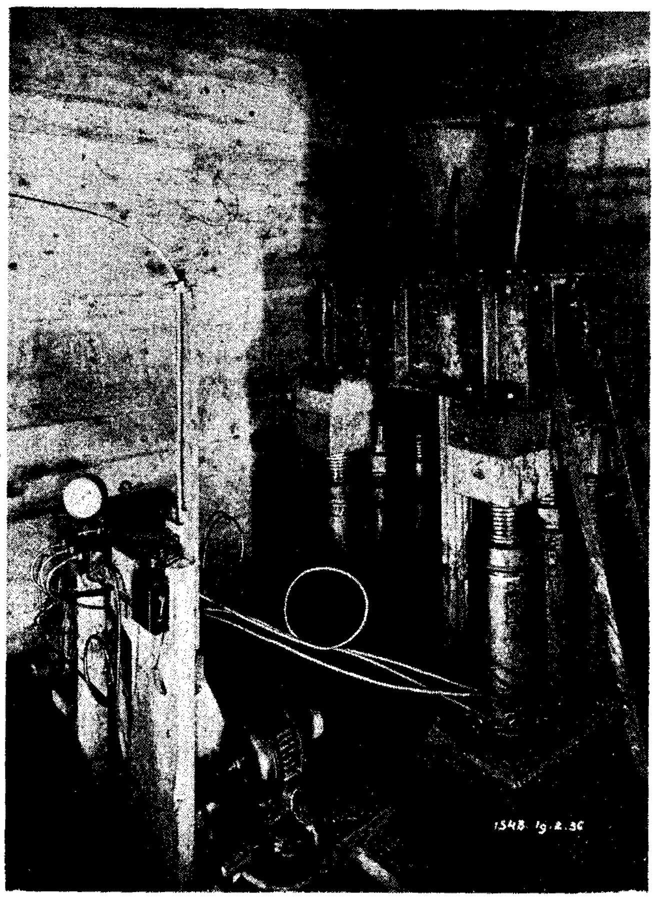


Figure 13. Marèges Dam. Right bank abutment. Arrangement for lightening cables.

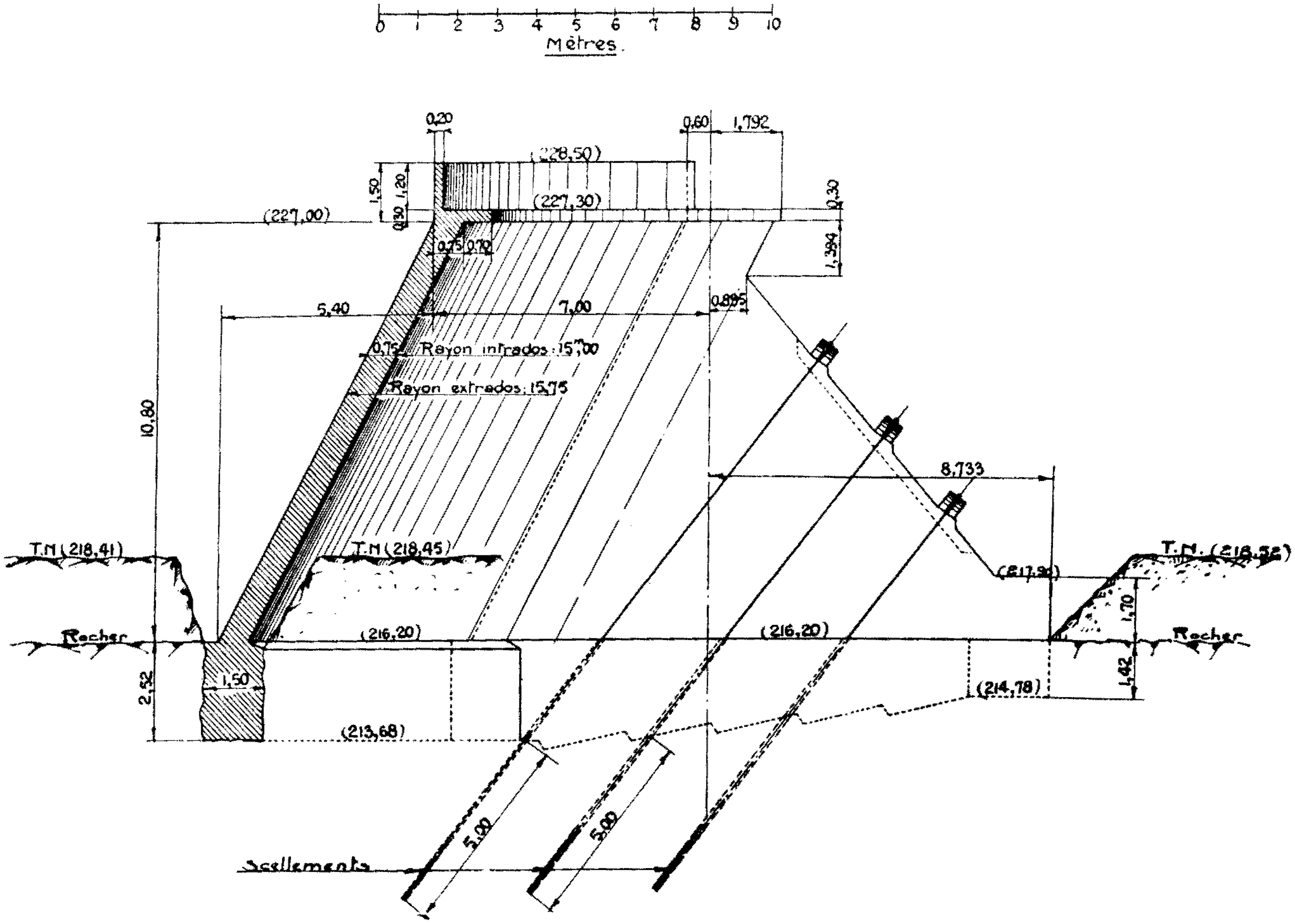


Figure 14

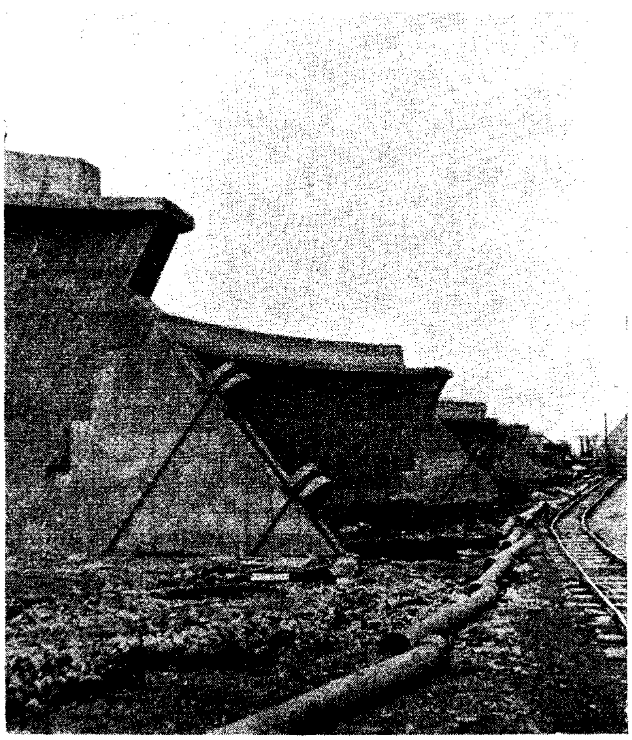


Figure 15. St. Michel Dam. Detail of a buttress.

These braces are visible and are protected only by a coat of paint, except in the ground where cement is injected to protect them from corrosion.

One ton of steel stressed in this manner replaces 1,000 tons of materials, that is, 400 cub. metres of concrete.

Extension of the Process

Recent methods involving the use not of drillings but of shafts sunk in the rock enable the strength of dozens of thousands of tons per shaft to be used.

The braces are still visible and accessible over their whole length, unless it is preferred to fill in the shaft with concrete in order to protect the steel from corrosion or possible sabotage.

UPSTREAM COFFER-DAM AT VENDA-NOVA (*Figures* 16-17)

The upstream coffer-dam of the works at Venda-Nova (Portugal) is a thin concrete arch which, as can be seen from its characteristics, may be classed as one of the boldest structures of this type yet constructed in any part of the world:

Height of crest above rock bed . . . . . 17 metres
Length of crest between abutments . . 33 metres
Cylindrical upstream face . . . . . R = 25 metres
Angle in centre of crest . . . . 75 degrees

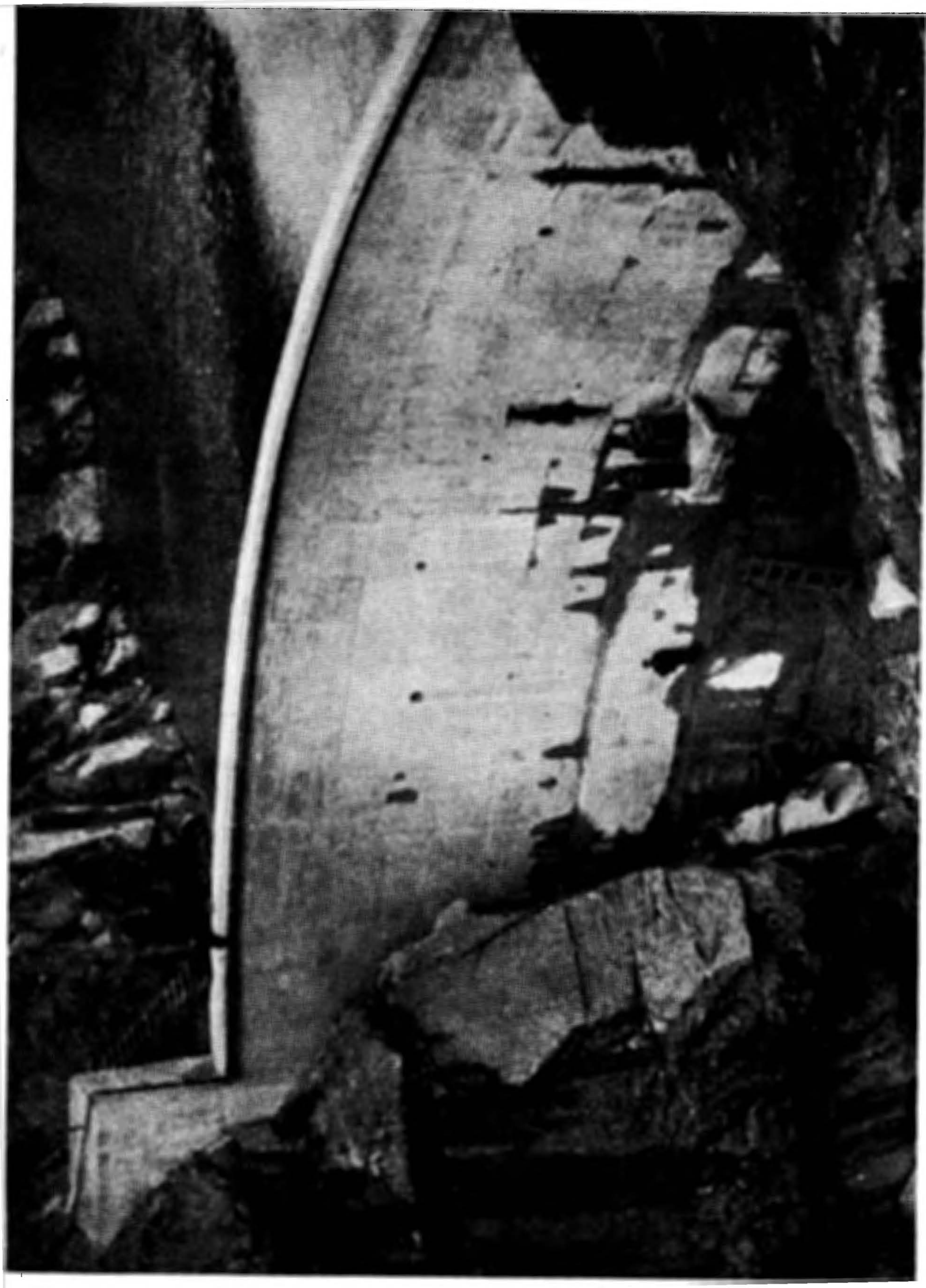


Figure 10. Upstream coffer-dam at Venda-Nova (Portugal).

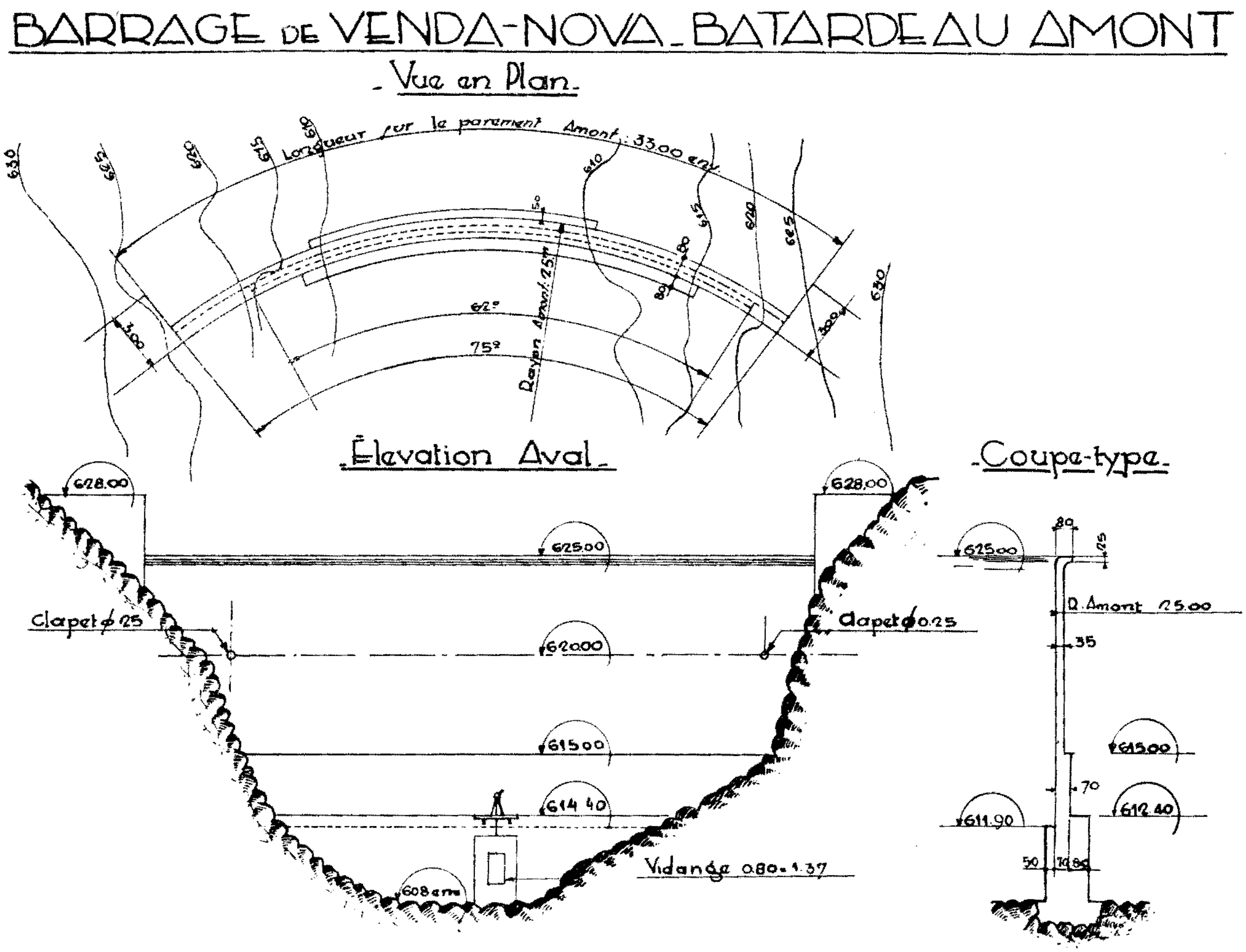


Figure 17

Thickness over upper 10 metres (between points 615 and 625) . . . . 0.35 metres
Thickness below point 615 (down to base) . . . . 0.70 metres
Volume of concrete in elevation approx. 200 cub. metres

The crest is constructed in the form of an overflow sill, as the structure must allow of the passage of large volumes of flood-water by free overflow on its crest; in the case of the maximum discharge provided for—500 cub. metres per second (of which 150 cub. metres per second are discharged through the temporary diversion gallery)—the water-level upstream from the structure will rise 3 metres above the crest.

The stresses of the structure were calculated on the basis of this water-level:

At point 615, that is, at the bottom of the part 0.35 metres thick, the mean stress of the arc $\frac{(pr)}{e}$ under the effect of the hydrostatic pressure, rises to 93 kg. per sq. cm. and the maximum stresses at the intrados of the springs and the central voussoir of the extrados, calculated by breaking the structure down into horizontal rings, are 127 and 110 kg. per sq. cm. respectively.

These stresses naturally will come into play only in exceptional cases and, if the water does not rise above the level of the crest, the mean stresses will generally remain below 75 kg. per sq. cm.

Since it began operating (on 2 December 1948) the structure has already withstood a high flood-water level: on 11 December 1948 the water-level rose 1.70 metres above the crest but no abnormal developments were observed.

In these conditions the mean stress at point 615 was 83.5 kg. per sq. cm.

The concrete stresses are observed by extensometers (sound recorders) placed at the points of greatest interest. Although they have revealed appreciable extensions at certain points, no fissures have yet been found on the faces.

RUPTURE OF AN EXPERIMENTAL ARCH (*Figures* 18-21)

An experimental arch constructed near the Aigle Dam on the Dordogne was loaded to breaking point. This thin and lightly reinforced arch was rectangular, with an

Figure 18. Experimental arch. Downstream view after rupture.

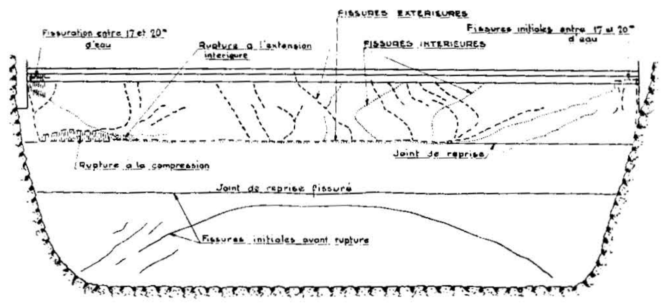


Figure 20

opening of 26 degrees and a radius of 20 metres and was 9 metres long and 3.50 metres high. As the natural water pressure was insufficient to cause the desired rupture, the arch was backed by an almost vertical wall so that it was possible to transform the very limited space between the rock and the arch into a barrel in which Pascal's law would have free play, that is to say, it was possible to introduce a controllable water pressure into this space which was closed above by a cover offering great resistance and mechanically separated from the arch.

The arch was 20 cm. thick and encased on three sides; the casing at the foot had transformed itself during the experiments into a semi-casing by the creation of a horizontal fissure flush with the foundation rock.

The concrete, which was designed for 350 kg. had a strength of approximately 500 kg. per sq. cm. at the time of the experiments.

After a large number of tests of putting under instantaneous pressure and maintaining the load for several hours, the rupture test was made by a progressive increase in the pressure. Rupture occurred when the pressure reached approximately 32 metres of water. It started on the crest, the upper part of which had been arranged to provide for the arch-cover joint. This was too stiff, was unable to follow the deformations of the arch and broke at the flexure (destruction of the concrete by compression downstream). Once it had started, the rupture extended vertically through the concrete and then horizontally along an underpinning joint in the concrete, detaching an arch bay which buckled forming torsion fissures at 45 degrees.

The measuring apparatus showed that the deformations and stresses remained elastic until the rupture, although

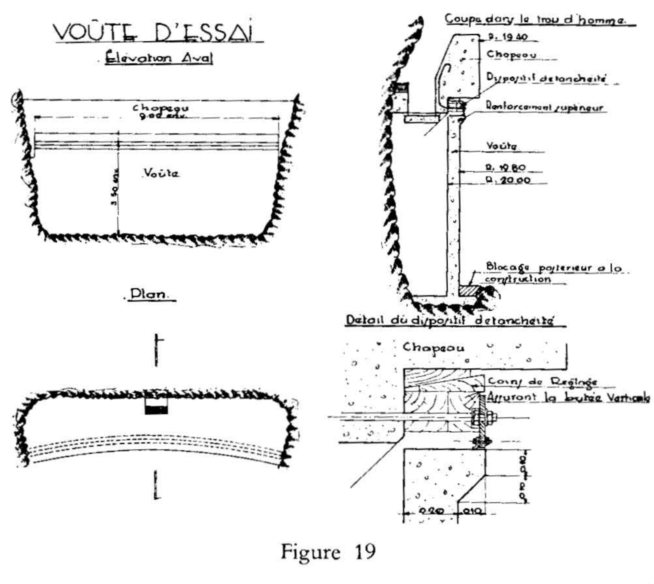


Figure 19

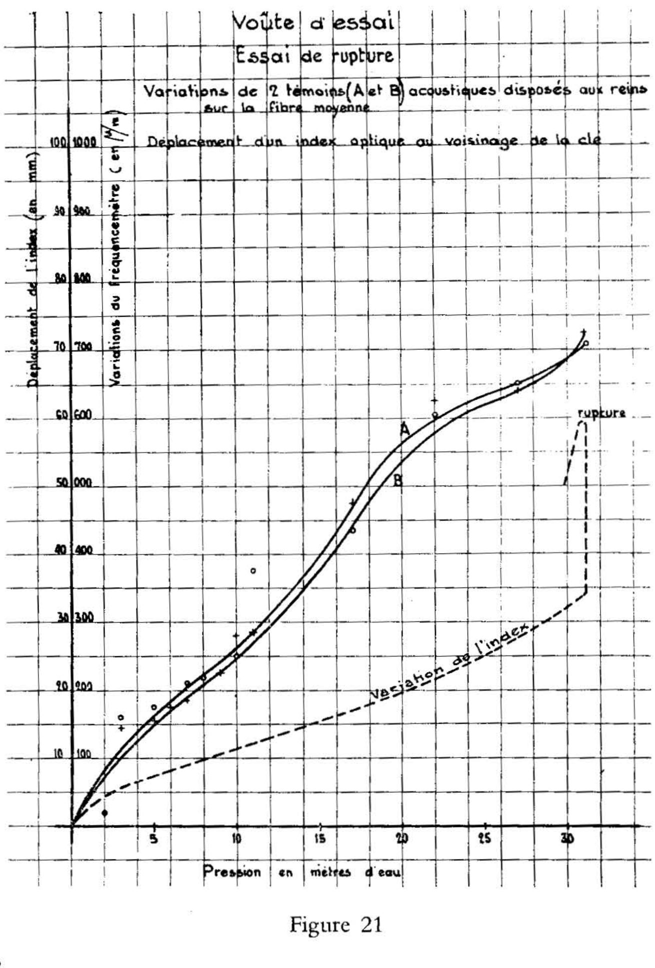


Figure 21

the mean load in the arch $\frac{(pr)}{e}$ reached 300 kg. per sq. cm. as registered by the extensometers placed in the spandrels on the centre line and verified by calculations. The lower two-thirds of the arch returned to the original condition at the end of the experiments. The deformations and stresses remained proportional to the load until the latter reached 20 metres of water.

These results relate to rapid tests in which the coefficient E of the concrete (measured) is 420,000 kg. per sq. cm. It decreases when the load is maintained and it was noted that the deformations increased in this case.

BRIEF DESCRIPTION OF DAMS

L'Aigle Dam (*Figures* 1-6)

Dam

Mixed "gravity arch" dam.

The upstream face is a vertical cylinder and the downstream face a conoid.

	Metres
Maximum height	90
Length of crest	290
Thickness of crest	5.5
Thickness at base (central voussoir)	45.5
Radius of curvature of upstream face	150
Batter of downstream face on axis	0.50
Batter of downstream face 100 metres from axis	0.82

	Cub. metres
Volume of concrete	240,000
Volume of excavation	80,000
Volume of water impounded	160,000,000

Flood-water discharge.

"Ski-jump" spillway

2 spillways each composed of 2 sluiceways closed by segment-shaped sluicegates 12 metres × 11.80 metres. Total discharge . . . . . . 4,000 cub. metres per second.

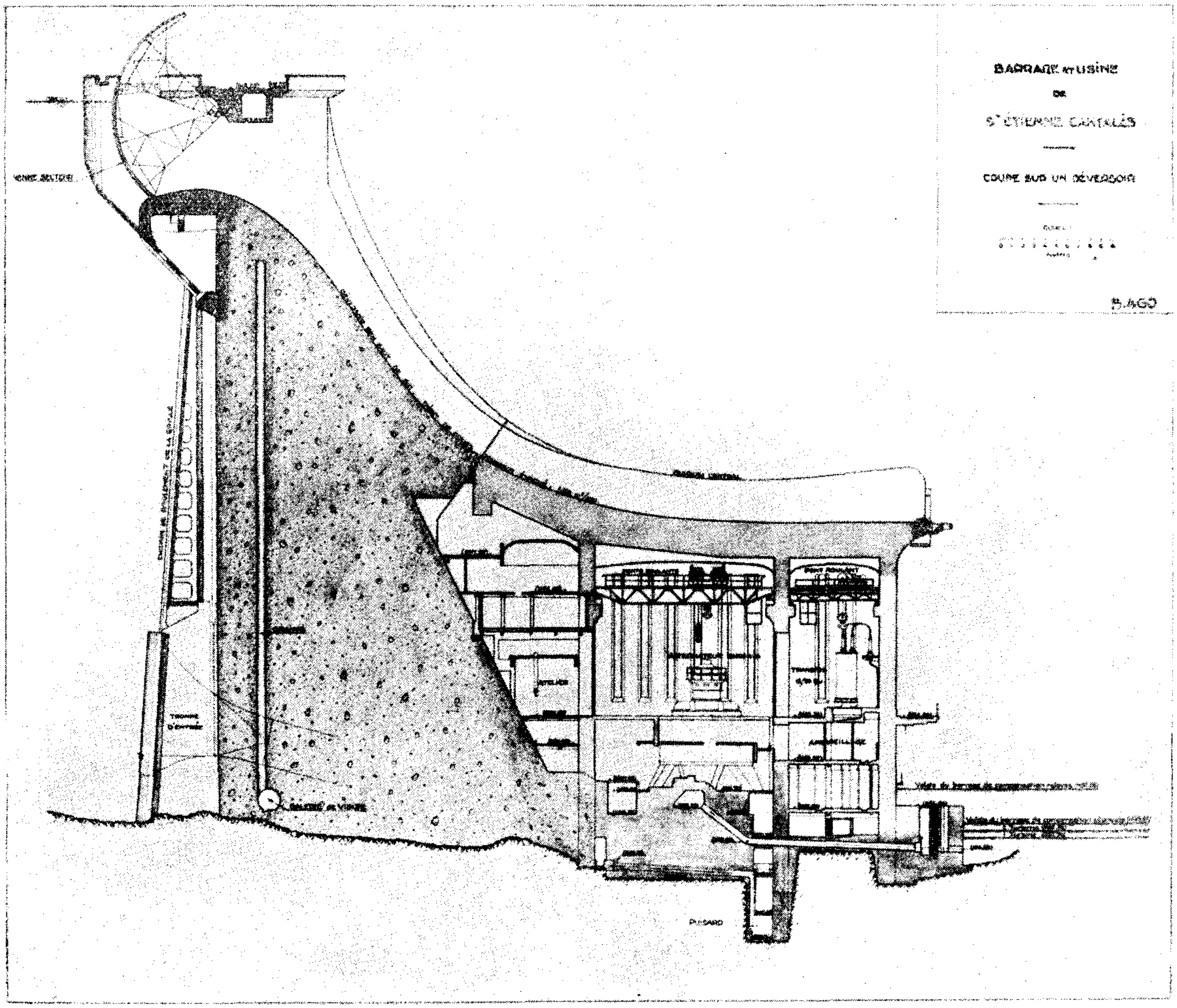


Figure 22

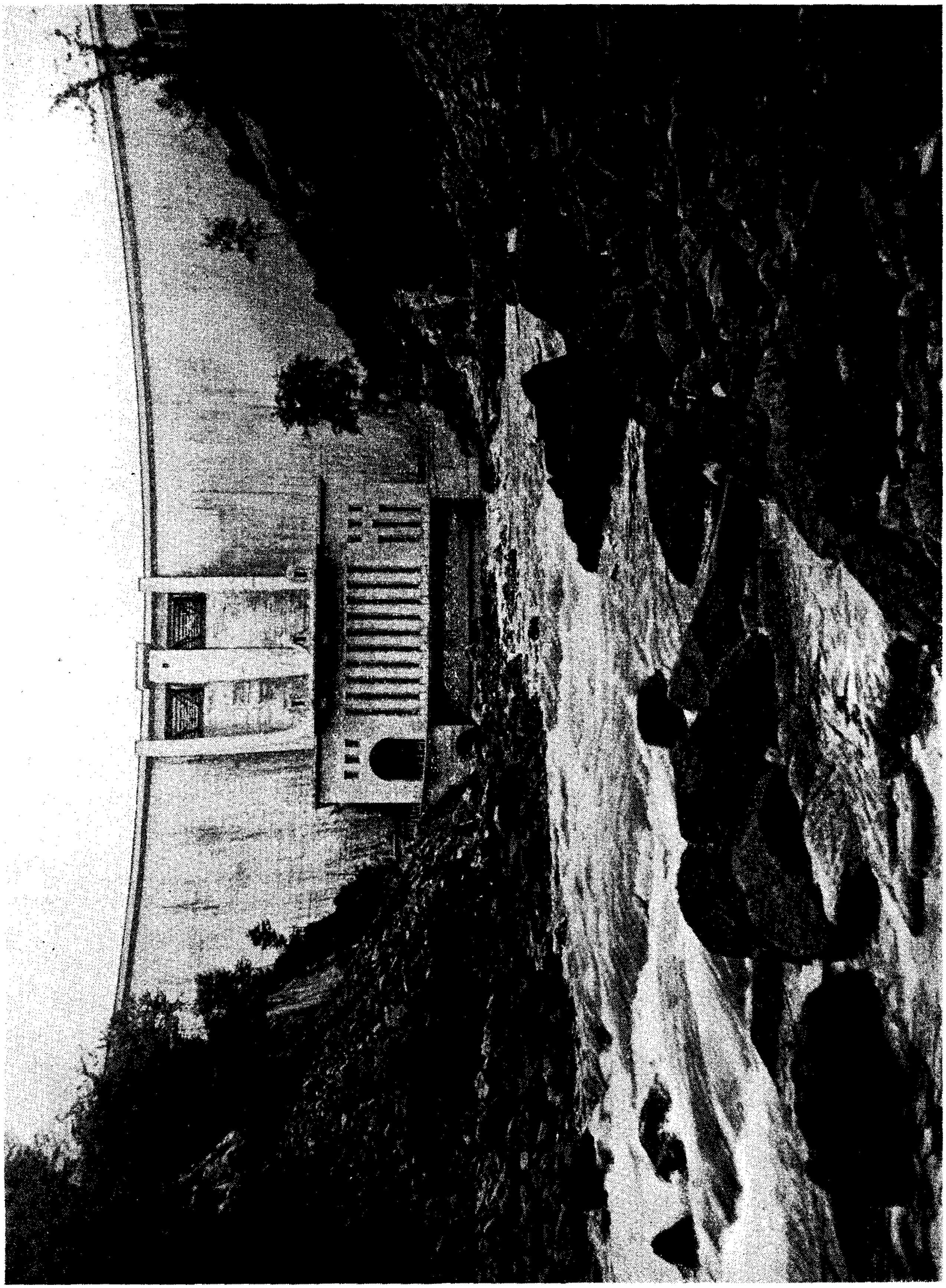


Figure 23. St. Etienne-Cantalès Dam and powerplant. Downstream view.

Outlets

2 outlets, 2.5 metres in diameter with a total discharge of 275 cub. metres per second.

Plant

Maximum net fall	80 metres
4 pressure pipes 4.7 metres in diameter with a maximum discharge of 75 cub. metres per second.	
4 main units of	60,000 kva.
1 auxiliary unit of	7,000 kva.
4 transformers	12/220 kv.
Annual output	500 million kwh.

St. Etienne-Cantalès Dam (*Figures* 22-23)

Dam

Mixed "gravity arch" dam. The upstream face is a vertical cylinder.

	Metres
Maximum height	70
Length of crest	270
Thickness of crest	5
Thickness at base (central voussoir)	35
Radius of curvature of upstream face	150
Batter of downstream face at central voussoir	150
	Cub. metres
Total volume of concrete	150,000

Flood-water discharge

"Ski-jump" spillway.

1 spillway composed of 2 sluiceways closed by segment-shaped sluicegates 11.67 × 8.40 metres.

Total discharge . . . . . 1,200 cub. metres per second.

Outlet

1 outlet 2.10 metres in diameter with a discharge of 80 cub. metres per second.

Plant

3 pressure pipes 4.15 metres in diameter with a maximum discharge of 55 cub. metres per second.

Maximum net fall	62 metres
3 main units of	3,000 kva.
1 auxiliary unit of	375 kva.
3 transformers	15/90 kv.
Annual output	220 million kwh.

Dam at Fumel-sur-Lot (*Figures* 24-25)

A former navigation dam in masonry whose height was doubled without underpinning the foundations (height increased by 5.50 metres).

Stability is ensured by 42 stressed braces each consisting of a strand of 37 steel wires of 5 mm. (quality 150/155 kg. per sq. mm.) subjected to tension of 70 tons, corresponding to a stress of 97 kg. per sq. mm.

These braces are sealed in depth in the rock over a length of 3 metres.

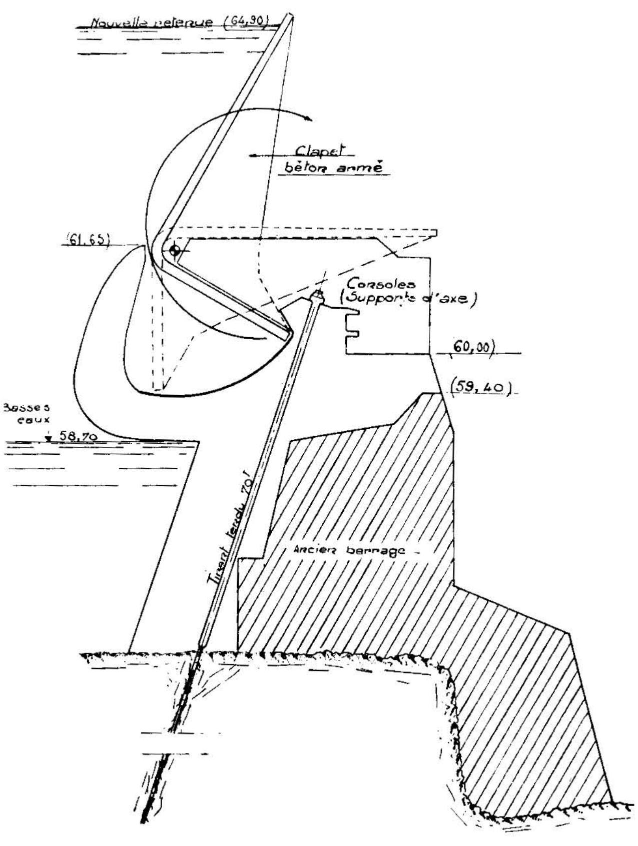


Figure 24

gure 25. T dam. P

The raising was mainly achieved by means of 11 reinforced concrete flap sluicegates 3.9 metres high, 6.5 or 7 metres wide with hydraulic self-drive. These are very sturdy, light and economical.

Two sluiceways with segment-shaped sluicegates 13 metres × 9.5 metres were installed on the left bank on the site of an old shipping lock.

An intermediate pier built on one of the side-walls of the lock is stabilized by three braces each of which is stressed at 450 tons.

Dam at Monceaux-la-Virole (*Figure* 26)

"Pure arch" dam.

The downstream face is a vertical cylinder with a radius of 62.5 metres and an opening of 102 degrees.

This dam is supported on the right bank by a gravity abutment 40 metres long.

	Metres
Maximum height	29
Crest length	105
Thickness at crest	2.5
Thickness at base (central voussoir)	5

Batter of upstream face at central voussoir: 0.256

Flood-water discharge

3 surface sluiceways on the dam crest provide for free overflow.

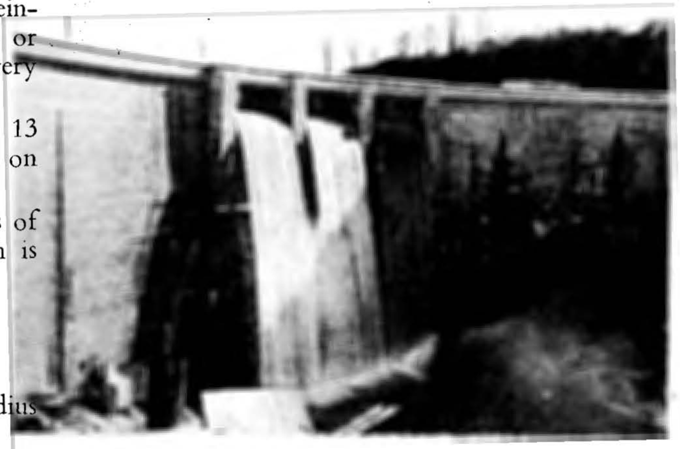


Figure 26. Dam at Monceaux-la-Virole.

These sluiceways are closed by horizontally projected sliding and descending sluicegates 7 metres × 5 metres.

The total discharge is 350 cub. metres per second.

Outlets

2 pipes 1.5 metres in diameter pass through the base of the dam.

Total maximum discharge: 50 cub. metres per second.

Figure 27. Dam at la Girotte. General upstream view.

Dam at la Girotte (Figure 27)

This dam, which is situated at elevation 1750 raises a lake whose capacity is thus increased from 25 million cub. metres to 50 million cub. metres.

There is no road leading to the site and the work-yards were served only by two cable railways.

As the dam was to be built on a rocky and uneven ridge, the multiple-arch solution had to be adopted.

The piers are self-stabilizing and the mass concrete arches are not reinforced. Provision has been made for a possible raising from elevation 1754 to point 1765. But as the rocky ridge is too narrow, the piers cannot be given the foundation corresponding to this increase in height. Stability will therefore be ensured by stressed braces.

For this purpose, shafts were drilled in the piers and these will enable the structure to be anchored to the rock by clusters of cables placed in the shafts and put under tension. The upstream face of the arches has been so constructed as to use the hydrostatic thrust for the stability of the whole structure and allowance has been made for a possible increase in height.

The arches are cylinders of revolution whose axis, parallel to the generators, is inclined at 54 degrees to the horizontal.

They are joined at their lower ends to vertical cylindrical arches anchored in the rock by means of spherical elements and at their upper ends to vertical cylindrical arches by means of toric elements.

The total length of the structure is 500 metres. There are 19 piers 7.6 metres wide, spaced at intervals of 24 metres from axis to axis.

The 18 arches are not reinforced and have a constant thickness of 1.7 metres and an average span of 20 metres.

The maximum height of the structure, including the foundations, is 55 metres. The total volume of concrete used in the work was 120,000 cub. metres and the volume of excavation was 60,000 cub. metres.

The Preliminary Comparison and Selection of Dam Sites

MILTON G. SPEEDIE

Much time and labour can be saved in the preliminary comparison of dam sites by using short-cut methods or techniques which will indicate sites worthy of more detailed consideration, and those which can be eliminated. The notes presented hereunder describe methods which the author has found useful.

The best available topographical and geological maps and aerial photographs are obtained for the purpose of selecting the most promising locations for dam sites, following which the sites are inspected and preliminary surveys made. If aerial photographs or suitable maps are not available, the whole catchment should be inspected for the purpose of locating possible sites.

The sites should be inspected by the engineer accompanied by a geologist. The latter can be of great assistance to the engineer in pointing out the probable nature and depths of foundations and the geological structure likely to be encountered at the site.

Preliminary Surveys

Rapid survey methods are essential in the preliminary stage if a number of sites is to be compared at small cost. For this purpose the author has found a battery of survey aneroid barometers with a continuously recording barograph at a base station, very useful for determining levels. Military type rangefinders of appropriate ranges and a tape can be used for measuring distances, and clinometers for vertical angles. A light level is also useful for locating positions of equal elevation although a clinometer has frequently been used for the purpose.

A preliminary survey of the dam site consists of determining the profile of the valley along the likely centre line using aneroid barometers, clinometer and rangefinder. Short distances are measured by tape or pacing. When making this survey the river-bed and valley walls are inspected to determine likely-rock levels, and attention is given to the general topography for the purpose of ascertaining the suitability of the site from the point of view of low cost river diversion, outlet works and spillway structures. Consideration is also given to the availability of dam building materials.

For the purpose of ascertaining the approximate reservoir capacity available, sufficient elevations can be determined to permit sketching the contour corresponding to full reservoir water-level and possibly also a lower contour. Where stereoscopic pairs of aerial photographs are available relatively few elevation observations are required, the chief necessity being to determine the position of the contour in streams, tributary gullies and on major spurs. In open country much time can be saved by setting up on the contour at a prominent point from which many other points at the same elevation can be located by the clinometer or level, and marked on photographs.

Rangefinder measurements of distance and compass directions are useful in controlling the scale of the subsequent plot and correcting for photograph tilt. Contours can be sketched under the stereoscope or photogrammetric plotting machine after obtaining the above-mentioned elevations.

Reservoir Capacity

The author has found the following formula useful for determining the approximate reservoir capacity available.

Capacity in acre-ft. $= C = KMH$

where K = parameter which varies according to the topography of the reservoir basin.

M = Inundated area in square miles.

H = Maximum depth of water in feet.

Table 1. Relation Between Reservoir Capacity, Submerged Area and Maximum Depth

Values of K in Formula C = K M H
C = Capacity of reservoir — acre-ft.
K = Parameter.
M = Area of water surface — sq. miles.
H = Maximum depth of water — feet.

Reservoir	*River*	*C.*	*M.*	*H.*	*K.*	*Remarks*
Australian:						
Hume	Murray	95,700	12.8	40	188)	A larger proportion than usual of loaded area in the lower portion of the basin.
		1,250,000	51.1	94	260)	
		2,000,000	72.7	114	241)	
Eildon	Goulburn	306,000	12.5	123	199	
		2,350,000	46.9	238	210	
Rocklands	Glenelg	272,000	24.8	54	203	Depth above cease to flow Level quoted. Local hollow at dams makes actual depth greater.
Eppalock	Campaspe	9,900	0.84	60	197)	Low values of K result from tributary valleys and wide flats near top of reservoir.
		60,000	3.9	93	165)	
		165,000	9.05	120	152)	
		325,000	14.4	140	160	
Cairn Curran	Loddon	120.000	7.20	94	178	
Glenmaggie	Macalister	104,500	5.71	100	183	
Upper Coliban	Coliban	25,700	1.32	78	250	
Lauriston	,,	12,000	0.685	74	237	
Malmsbury	,,	14,400	1.19	54	224	
Rodborough	Tullaroop Ck.	40,000	2.26	65	272	Rapids in upper reaches of reservoir.
		60,000	2.81	77	277	
Pykes Crk.	Pykes Crk.	19,400	0.78	101	244	
Melton	Werribee	19,100	0.98	84.5	230	
Upper Yarra	Yarra	110,000	2.35	245	191	
Selvan No. 1.	Stoneyford Ck.	32,518	1.29	120	211	
Maroondah	Watts	23,045	0.76	125	247	
O'Shannassy	O'Shannassy	3,418	0.116	96	308	
Gong Gong	Fellmongers Crk.	1,510	0.097	72	217	
Moorabool	W. Moorabool	5,430	0.61	41	216	
Junction	E. Kiewa	1,300	0.078	72	232	
Upper Stony	Stony Creek	2,770	0.206	75	179	
Mt. Cole	Mt. Cole Ck.	330	0.031	67	159	

Reservoir	*River*	*C.*	*M.*	*H.*	*K.*	*Remarks*
USA:						
Boulder	Colorado	30,500,000	229	589	226	
Grand Coulee	Columbia	9,645,000	128	380*	198*	
Shasta	Sacramento	4,500,000	46.5	500	194	
Denison	Red	3,080,000	148.5	112	185	Part Storage only included.
Norris	Clinch	2,567,000	62.8	215	191	
American Falls	Snake	1,700,000	88	77*	250*	
Davis	Colorado	1,750,000	43.8	130	307	
Roosevelt	Salt	1,420,000	27.3	240	216	
Wheeler	Tennessee	1,150,000	106	58	187	
Parker	Colorado	700,000	39.2	80	224	
Cascade	Payette	700,000	41.5	80	225	
Anderson Ranch	Boise	500,000	5.85	330	259	
Friant	San Joaquin	520,000	7.66	262	260	
Tygart	Tygart	290,000	5.35	207	262	
Arrowrock	Boise	286,000	4.7	263*	232*	
Bartlett	Salt	200,000	5.0	188*	212*	
Tieton	Tieton	197,000	3.9	214*	236*	
Deadwood	Deadwood	164,000	5.0	139*	236*	
Alcova	Platte	160,000	3.44	170	274	
Green Mountain	White	147,000	3.33	250	177	
Deer Creek	Provo	150,000	4.14	137	266	
Tionesta	Tionesta Crk.	128,000	4.22	125	232	
Taylor Park	Taylor	106,200	3.17	154	268	
Echo	Weber	74,000	2.3	115	280	
Agency Valley	Malheur	60,000	3.0	80	250	
Guernsey	North Platte	54,600	3.65	75	200	
Stony Gorge	Stony Creek	50,200	2.0	117*	214*	
Boca	Lt. Truckee	41,000	1.5	99	276	
Easton	Yakima	4,000	0.375	55*	195*	

Average for 21 Reservoirs, 219.
In most cases contour plans of USA reservoir basins are not available to the author so reasons for variations in K are not known.

Average for 29 Reservoirs, 232.
*Depth and hence K are approximate only.

Table 2. State Rivers and Water Supply Commission. Volumes of Dams Compared with ΣH^2dl of the Valley Profile

Dam	*Location*	*Max. height of embank. in Feet*	*Volume in Dam — Cubic yards*			*ΣH^2dl — Cub. yd. Units*		*K2 = $\frac{Volume}{\Sigma H^2dl}$*		*Remarks*
			Earth	*Rockfill*	*Concrete*	*Earth & rockfill portions*	*Concrete portions*	*Earth & rockfill*	*Concrete*	
EARTHEN DAMS										
Silvan No. 1	Australia	142	1,680,000	—	60,000	634,000	—	2.66	0.095	Embankment has concrete core wall.
Hume	,,	125	3,893,000	400,000	533,000	1,260,000	853,000	3.40	.63	Large concrete wing walls and overfall spillway.
O'Shannassy	,,	113	331,000	—	12,500	118,000	—	2.81	0.106	Concrete core wall.
Deer Creek	USA	235	3,000,000	—	19,000	713,000	—	4.21	0.027	
Denison	,,	170	17,500,000	500,000	558,000	4,450,000	—	4.05	—	Concrete mainly in large separate spillway.
Boca	,,	120	1,020,000	—	8,000	261,000	—	3.92	0.03	
EARTH AND ROCK-FILL DAMS										
Upper Yarra	Australia	260	2,650,000	4,000,000	—	2,190,000	—	3.04	—	Proposed structure designs in progress.
Eildon	,,	250	4,500,000	6,240,000	267,000	4,480,000	—	2.4	—	Proposed structure designs in progress.
Anderson Ranch	USA	456	7,500,000	2,100,000	54,000	2,758,000	—	3.48	0.02	
Mud Mountain	,,	425	427,000	1,539,000	—	820,000	—	2.40	—	Narrow impermeable core.
San Gabriel No. 1	,,	376	1,150,000	9,450,000	—	1,760,000	—	6.03	—	
Green Mountain	,,	270	3,535,000	955,000	34,000	1,107,000	—	4.07	0.031	
Alcova	,,	256	1,500,000		—	400,000	—	3.75	—	
Tieton	,,	222	1,570,000	430,000	44,000	465,000	—	4.30	0.95	
Davis	,,	200	1,050,000	2,920,000	—	644,000	—	6.16	—	K_2 high due to flat slopes at toes and deep excavation with back fill.
Taylor Park	,,	200	834,000	156,000	—	244,000	—	4.06	—	
Echo	,,	151	1,377,000	243,000	10,000	438,000	—	3.7	0.023	
Agency Valley	,,	120	483,000	107,000	6,000	152,800	—	3.86	0.04	
Cascade	,,	105	320,000	66,000	5,200	93,400	—	4.13	0.056	
Guernsey	,,	105	365,000	196,000	22,000	152,900	—	3.67	0.144	
GRAVEL FILL DAM										
McKay	,,	165	—	2,290,000	25,000	1,070,000	—	2.14	0.023	
MASS CONCRETE DAMS										
Maroondah	Australia	162	—	—	172,000	—	393,000	—	0.44	
Glenmaggie	,,	120	—	—	100,000	—	244,500	—	0.41	
Rocklands	,,	84	20,000	—	70,000	7,000	105,000	2.9	0.67	
Boulder	USA	727	—	—	3,240,000	—	7,140,000	—	0.45	
Grand Coulee	,,	550	—	—	11,250,000	—	26,100,000	—	0.43	
Shasta	,,	540	—	—	5,640,000	—	12,600,000	—	0.45	
Friant	,,	310	—	—	1,910,000	—	4,400,000	—	0.43	
Norris	,,	265	—	—	1,002,000	—	2,250,000	—	0.44	
Easton	,,	66	—	—	5,800	—	9,600	—	0.60	
MASSIVE BUTTRESS DAM										
Lauriston	Australia	108	—	5,500	32,100	1,560	109,500	3.5	0.29	
MASS CONCRETE ARCH DAMS										
Butler's Gorge	Australia	190	—	—	200,000	—	680,000	—	0.29	Concrete vol. approx. only.
Owyhee	USA	417	—	—	500,000	—	1,405,000	—	0.36	Additional 36,000 cub. yds. concrete in foundation shear zone.
MULTIPLE ARCH REINFORCED CONCRETE DAM										
Bartlett	USA	270	—	—	147,400	—	783,000	—	0.19	
AMBURSON REINFORCED CONCRETE DAM										
Stony Gorge	USA	142	—	—	42,960	—	211,000	—	0.20	

The parameter K is generally in the range of 200 to 250 as shown in Table No. 1. Low values of K occur when river grades flatten near the upper end of reservoirs or the reservoir surface widens in this location due to the confluence of streams in flat wide valleys. K is also low if the valley walls tend to be convex upwards. On the other hand a high value of K is found if the upper parts of the reservoir are unusually narrow or steep, or the valley is flat-bottomed with steep walls.

For Australian conditions the author uses an average value of 220 for K unless the topography warrants some modification.

In cases where more than one contour is plotted the capacity at each elevation can be plotted against maximum depth of water on log paper and the points joined by a straight line, thus indicating the capacity at any other water-level. It is always desirable to select for plotting a contour close to the likely top water-level of the proposed reservoir as estimating capacity—height curves may lead to considerable errors. Capacity generally increases approximately as the cube of the height although the index varies considerably, even from level to level within any given reservoir. Twelve cases investigated by the author showed values varying between 2.15 and 4.4 and averaging 2.97. In such computations it seems better to consider depth of water on river flats rather than river-bed in a wide flat-bottomed valley with a relatively narrow watercourse, but the full depth of water is used in the above-mentioned formula.

Embankment Volumes

The relative embankment volumes involved in dam construction at the various sites can be determined by plotting the valley profile as in Figure 1, and then the H^2 curve in such a way that the ordinate represents the square of the embankment depth. The area between the line representing the embankment crest and the H^2 curve is

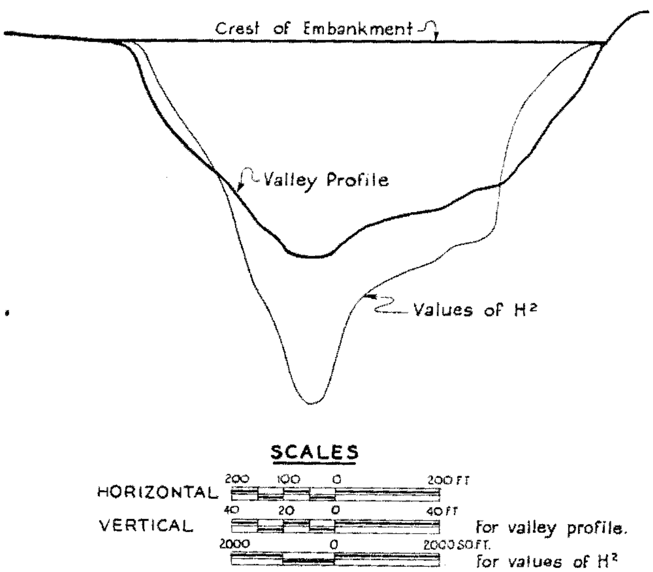


Figure 1. Valley Profile.

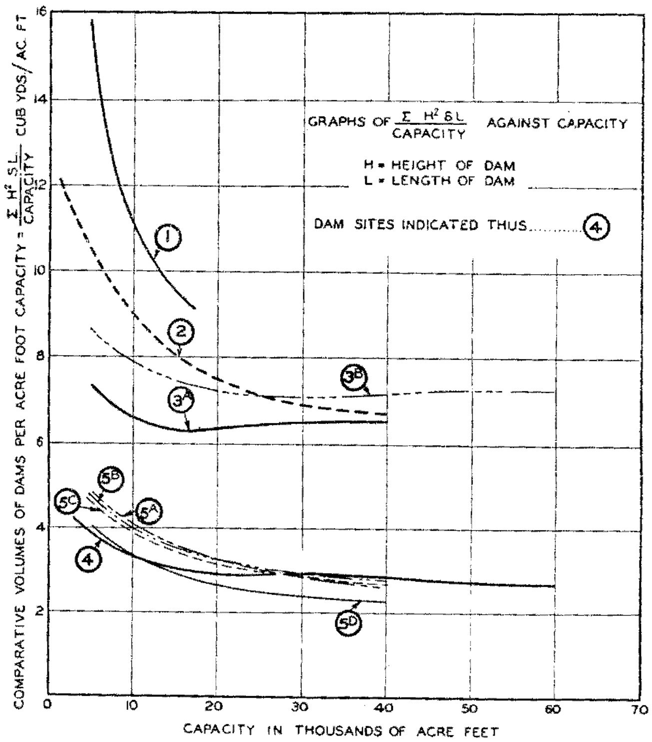


Figure 2. Comparative volumes of dams.

The above comparative volumes are expressed in cubic yard units per acre foot and represent ratios which, if multiplied by reservoir capacity and a parameter that varies according to the dam profile, will give embankment volumes.

measured by planimeter, and expressed in cubic yards. The value is termed ΣH^2dl. and is roughly proportional to the embankment volume and cost of the structure.

In determining the value of H for computing H^2 values, the average foundation level is used, viz. the natural surface for most earthen dams and the estimated average foundation rock level at each cross section for concrete and rock fill structures.

The ratio between ΣH^2dl. values and actual dam volumes is shown in Table No. 2, and is useful when determining the approximate embankment volumes and rough estimates of cost.

It is useful to compare values of $\frac{\Sigma H^2dl}{\text{capacity}}$, when considering alternative dam sites and if capacity height curves are available $\frac{\Sigma H^2dl}{\text{capacity}}$ can be plotted against capacity as shown in Figure 2. Such curves show which sites can be eliminated although due consideration must be given to other factors, such as availability of dam building materials, ease or difficulties in constructing spillways, outlets, flood diversion works, etc., and disturbances to other interests, values of lands flooded, diversion of services, etc. In the case shown in Figure 2, sites 4 and 5A were selected for further examination and No. 4 was ultimately adopted for a reservoir of 60,000 acre-ft. capacity.

Deterioration of Large Dam Structures

L. N. McCLELLAN

ABSTRACT

The deteriorating influences acting on large dams of the Bureau of Reclamation and the measures taken to minimize their effects are summarized. Foundation leakage can cause deterioration through excessive uplift or by loss of support of concrete structures and is treated by drainage and grouting. Cracking is associated with volume change and is controlled by contraction joints and by carefully controlling the rate of cooling the mass. Low-cement concretes have suffered deterioration from weathering, which may be forestalled by using more durable concrete at exposed surfaces. Leakage in horizontal construction joints is prevented by proper joint clean-up and by use of a mortar seal for new concrete. Expansive reaction has been observed in certain dams constructed of concrete made with reactive aggregate and a high alkali cement, resulting in extensive surface cracking. When not used in combination, these materials can produce lasting concrete. Pozzolan gives added assurance against expansive reaction. In an earth dam, slumping of the upstream face was caused by rapid drawdown of the reservoir. By zoning embankments and providing free draining material at the upstream face, this type of deterioration is eliminated. Wave damage is prevented by using riprap backed up by graded material that will not be washed out through the riprap. To preserve freeboard in earth dams, consolidation of the foundation and embankment is essential. Examples are cited of damage to appurtenant structures and facilities from cavitation and erosion. Skilfully designed and constructed water-passages are required to avoid the destructive effects of cavitation.

Since the first dams were built, man has been faced with the problem of conserving the structures he has built in stream channels to store, control and divert water. This challenge faced our predecessors, the ancient dam-builders of Arabia and Egypt, who made prosperous civilizations possible 6,000 years ago by diverting the waters of the Tigris, Euphrates and the Nile from their banks to bring agricultural wealth to large valleys.

The same challenge of preserving structures confronts the modern dam-builders, but in more demanding form. For as our civilizations have progressed, the conservation of our water resources has become more important not only to local self-sufficiency but to national and even international prosperity. We have increasingly come to depend on our dams for food and water to sustain life, for power to drive our industries and for the protection of life and property from the ravages of uncontrolled floods. Thus, as our dams have become such necessary facilities, the magnitude of our structure deterioration problems has become greater and their impact more vital to all of us.

This paper summarizes some of the deteriorating influences that act upon large dams of the Bureau of Reclamation and some of the measures that have been taken to minimize their destructive effects. Our water-control structures gradually have become larger and more complex, and the problem of deterioration has become one of increasing importance. In its forty-seven years of operation, the Bureau of Reclamation has invested over one billion dollars in dams in the western United States, so you can readily appreciate our serious concern with the subject of deterioration. The fact that our records contain no case of deterioration to the point of failure does not lessen this concern.

In discussing deterioration we ignore the catastrophic forces, such as flood and earthquake, and consider the effect upon materials and the structures themselves of such influences as climate and water, which can just as certainly cause ultimate destruction. While these deteriorative influences may be the same, their effects upon concrete and earth dams are so different that a separate discussion will be made of each.

DETERIORATION OF CONCRETE DAMS

Potential deterioration of concrete dams exists in the foundations whether it be in the form of water channels through rock seams or instability of the rock formation. The deterioration of structures from foundation causes may be manifested by excessive under-pressure or uplift, solution, piping, poor support or leakage through the abutments.

If sufficiently intense, the uplift or under-pressure at the base of a dam may cause serious damage or even failure to the structure. The value of continued watchfulness of under-pressure was demonstrated at Hoover Dam, where pressure under the base of the dam rose gradually as the reservoir filled until the pressure exceeded the straight line gradient from reservoir to tailwater assumed in the design. The under-pressure was relieved by drilling supplementary drain holes in the downstream high-pressure area and deepening and grouting the upstream drain holes. Additional drain holes were then drilled downstream from this deep grout curtain and the pressures were reduced to a point where they were well below those assumed in the design. The drawing, Figure 1, shows the order of uplift pressure existing before and after remedial measures were taken.

Abutment leakage is present in nearly all high dams. This may not be serious, but if not controlled it may become progressively worse, leading eventually to piping or undermining. At Owyhee Dam, a 417-ft. high arch-gravity structure in eastern Oregon, leakage developed in the felsite rock of the left abutment that aggregated about 15 cub. ft. per second at maximum flow. Despite the fact that the dam was built in disturbed volcanic formations, this leakage was successfully reduced to a safe value, before damage occurred, by deepening and regrouting the cutoff curtain beneath the dam and extending the curtain several hundred feet into the leaking abutment. To illustrate the nature of the rock, it may be of interest to point out that more than 29,000 sacks of cement, or about thirty-five carloads, were used for grouting one hole.

When discussing the causes and prevention of deterioration of concrete dams, a distinction should be made

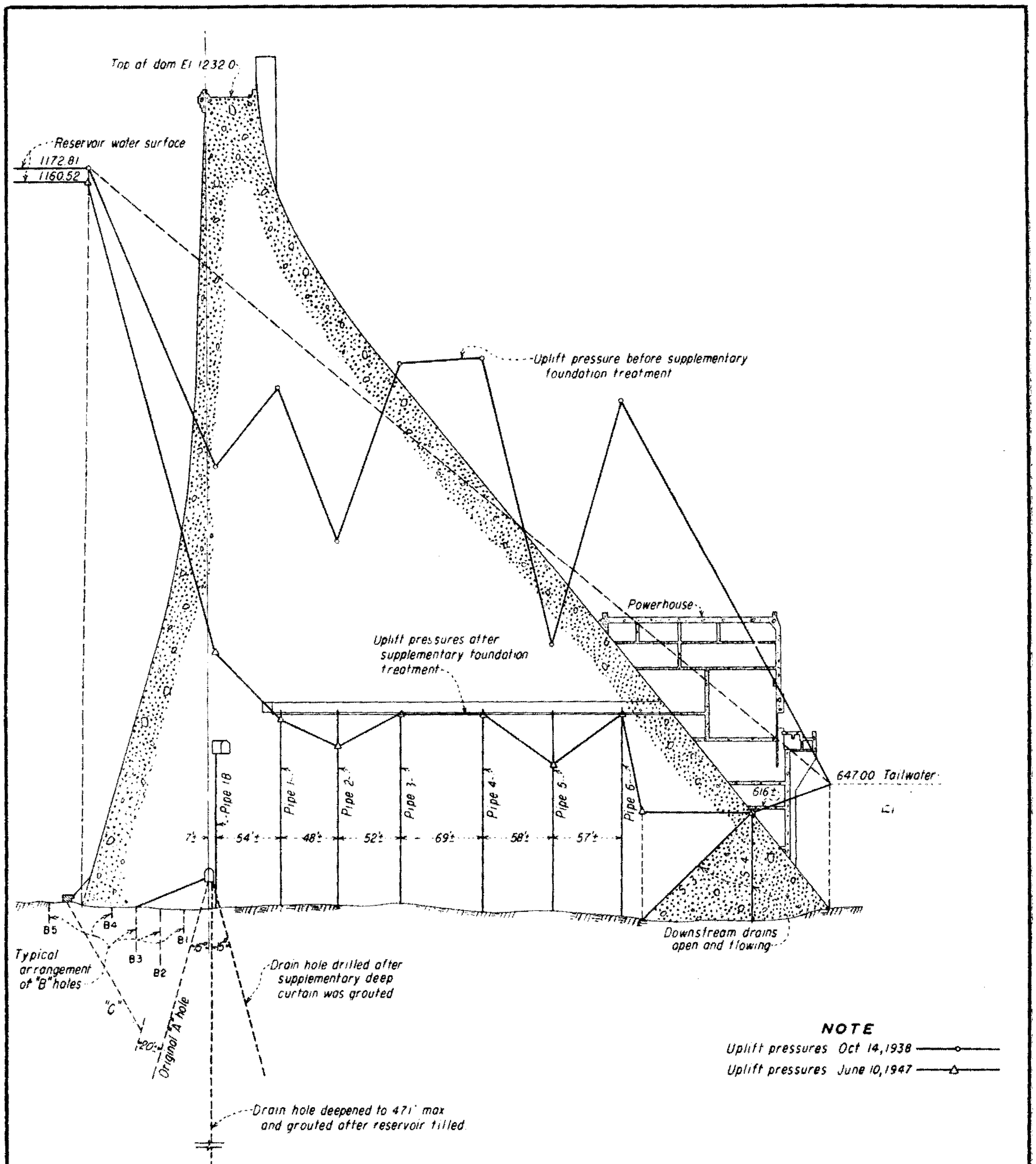


FIGURE 1

MAXIMUM SECTION HOOVER DAM SHOWING FINAL TREATMENT OF FOUNDATION AND RESULTING EFFECT ON UPLIFT PRESSURES

between the problems associated with massive gravity and arch dams, and the more highly stressed thin-section reinforced-concrete buttress dams. Deterioration that may be merely unsightly in a massive dam may be critical in a thin-section dam. However, because our experience is more extensive with the massive-type structures, this discussion will be confined to the massive-type dams.

The principal types of deterioration of massive concrete dams are cracking and weathering. Cracking is an important deteriorative effect because it destroys the continuity of the structure, causes leakage and creates a vulnerable spot which may lead to further deterioration. Cracking is usually associated with volume change resulting from the development and dissipation of the heat of the hydrating cement in the concrete. To minimize this temperature and volume change, the Bureau of Reclamation has reduced the quantity of cement in concrete mixes on a number of large structures, has used special low-heat cements and has installed cooling pipes to remove the heat from the concrete and prevent excessive temperatures in the mass concrete.

If concrete dams were placed as one mass from one abutment to another without joints, transverse cracks would extend completely through the structure. This is demonstrated by Altus Dam, a gravity structure 110 ft. high and 1,112 ft. long, in Oklahoma, which contains only four transverse joints. It had been planned to dissipate the heat in this structure by placing the concrete in shallow layers during the cold part of the year, but the necessity of obtaining early storage of water for irrigation forced the placement of thicker layers during the summer. In the resulting cooling and shrinking, transverse cracks varying from fine openings to 5/8-inch open cracks were formed at an average interval of forty feet throughout the dam. These cracks were later filled with grout to prevent leakage and to insure continuity of this structure.

Figure 3. Arrowrock Dam. View of downstream face showing weathering to an average depth of one foot. Note form ties protruding and pothole eroded under valve.

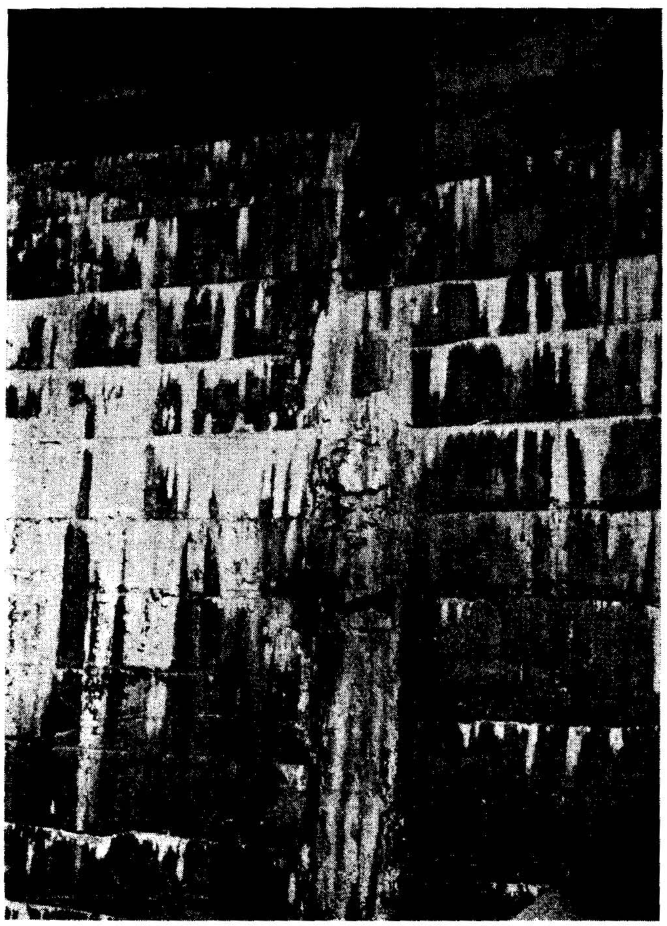


Figure 2. Gerber Dam. View of downstream face showing evidence of leakage and disintegration at construction joints.

It is our usual practice to prevent random cracking in massive concrete dams by placing contraction joints throughout the structure and controlling the temperature of the mass. At each contraction joint, pipe systems are embedded so the artificial crack can be filled with cement grout after the temperature of the concrete has been reduced to final stability.

Most concrete dams are built in successive lifts of about five feet, and one of the construction problems is the prevention of leakage at the horizontal construction joints between lifts. This leakage is the result of improper clean-up at the top of the lift and of inadequate bond with the succeeding lift. Unless the top surface of each lift is thoroughly cleaned, a plane of weakness will be formed which may allow water to pass. An impressive example of deterioration caused by leakage through construction joints is shown by Figure 2, which is a photograph of Gerber Dam, an eighty-eight foot high arch dam 485 feet long. Gerber Dam was constructed in 1925 in five-foot lifts. Leakage became apparent soon after the reservoir was filled and the deterioration of the downstream face of the dam has been progressive since that time. The picture shows the white calcium carbonate deposits which have leached out of the concrete and the weathering of the face induced by this leakage. Such deterioration may be prevented by thorough cleaning of the construction joints and thorough bonding between succeeding lifts of concrete.

Volume change may be reduced by lessening the heat production of the concrete, and low-heat cements have been successfully applied for this purpose. Some methods of reducing heat production may lead to difficulty in other directions, however. With a view to economy, the

Bureau of Reclamation constructed two dams using only about two sacks of cement per cubic yard of concrete. Workability of the concrete was achieved by grinding equal quantities of sand with the cement clinker and using four sacks of this diluted cement per cubic yard of concrete. Arrowrock Dam, a 350-ft. high arch-gravity structure on the Boise River, was constructed using this sand-cement. The concrete surface was of low density and absorbed water spray from the reservoir outlets to such a degree that the concrete progressively spalled from freezing and thawing attack. The entire downstream face, which had weathered and eroded to an average depth of one foot, had to be resurfaced to prevent further disintegration of this structure, which is illustrated by Figure 3. To prevent surface deterioration of dams built with low cement contents, our present practice is to use richer mixes at the faces, air entrainment in the concrete, or absorptive form lining or vacuum treatment to secure more durable concrete at the surface.

Another major form of deterioration is the break-down of the concrete itself. Random pattern cracking on the surface of concrete dams is not unusual and may not be cause for alarm. As distinguished from small-scale crazing or cracking, pronounced map cracking has been attributed to excessive internal expansion which may be aggravated by varying degrees of shrinkage from surface drying.

In some cases deterioration of concrete has been caused by direct chemical reactions between reactive siliceous minerals in the aggregates and the alkalies of the portland cement. This is an expansive reaction forming conspicuous random pattern cracks as shown in Figure 4, which is a photograph of marked pattern cracking on a block at the end of the parapet wall at Parker Dam. Parker Dam was completed in 1938, and two years thereafter the few existing cracks in the structure were discovered to be enlarging and numerous new cracks were observed to appear suddenly and extend themselves rapidly. Fortunately, the cracks so far are largely superficial, as they extend only a few inches into the concrete.

However, in addition to surface cracking such as that at Parker Dam, this expansive reaction between the soda and potassa in cements and certain mineral aggregates has manifested itself in distortion of structures. An example of this is the Stewart Mountain Dam built by a water-users' association on the Salt River in Arizona, where the crest of the dam has actually moved upstream about nine inches and the dam structure has moved away from the power plant located on the downstream toe. Figure 5 shows a joint between the arch and the gravity abutment which opened about one inch as the result of expansion of the arch.

To prevent the occurrence of alkali-aggregate reaction in its dam structures, the Bureau of Reclamation selects non-reactive aggregates or restricts the alkali content of cement to be used with aggregates containing known or suspected reactive minerals to less than 0.6 per cent.

Figure 4. Parker Dam. Random surface cracking due to expansive alkali-aggregate reaction.

Figure 5. [illegible] Mountain Dam. Expansive deteriorating concrete ca[illegible]tion in this structure manifested by a one-inch joint opening.

Aggregates that have been found to react with high-alkali cement include opaline silica, highly siliceous rocks and acid to intermediate volcanic rocks. It has been found that the addition of pozzolanic materials to reactive combinations of cement and aggregate will reduce expansion. We are currently using this precaution at Davis Dam, which is being built on the Colorado River upstream from Parker Dam where the same reactive aggregates that contributed to the deterioration of Parker Dam are prevalent.

DETERIORATION OF EARTH DAMS

The earth-fill dam has come into increasing prominence in recent years, and our efforts to prevent deterioration have been intensified as we have had to adapt our water-control structures to increasingly poorer natural dam-sites. In earth dams, it is more often the structure itself rather than the materials of construction that is normally open to the attack of deteriorative forces. Continuity of an earth structure is maintained by the minute frictional and cohesive forces acting between soil grains, and the deteriorative influences acting on earth dams tend to destroy this continuity.

Although earth dams are constructed to hold back water, no earth dam is ever completely watertight. While some soils are more resistant to the passage of water than others, given sufficient time water will pass through any soil. In doing so, the continuity of the dam can be affected by displacement of the grains of earth in the dam. However, earth dams constructed of uniformly impervious materials are often subject to damage from slides and cracks.

As an illustration, serious deterioration was caused by unbalanced hydrostatic pressure in the embankment of Belle Fourche Dam which was completed in 1911 in South Dakota. This dam was not zoned but was constructed throughout of wetted and rolled clay material faced with 5 by 6.5-ft. precast concrete slabs laid on a 24-in. bed of gravel. In 1931, following rapid drawdown of the reservoir, a slide occurred for about 350 ft. along the upstream face of the 6,000-ft. long structure to a depth of nine feet. Figure 6 is a drawing showing the extent of saturation and a diagram of the slide. Repair required replacing 63,000 cubic yards of material in the fill. It is now a general practice to prevent such deterioration by locating the most impervious materials in the innermost part of the dam flanked by progressively more pervious materials toward the outer slopes. Such zoning provides adequate weight over the saturated impervious material to resist back pressure.

In the same dam, cracks appeared in 1928 parallel to the axis and several hundred feet in length just back of the crest. Because of prolonged low water in the reservoir, the top portion of the dam had become very dry and cracking was caused apparently by drying shrinkage. To prevent such distress, the top parts of embankments are now constructed of free-draining material which reduces the effect of evaporation and frost.

The deteriorating forces which attack the surface of an earth fill are wave erosion, wind and freezing. Wave damage is by far the greatest deteriorating surface effect, and a number of devices have been used to reduce wave damage, of which precast concrete slabs and dumped riprap are among the most economical. Waves caused

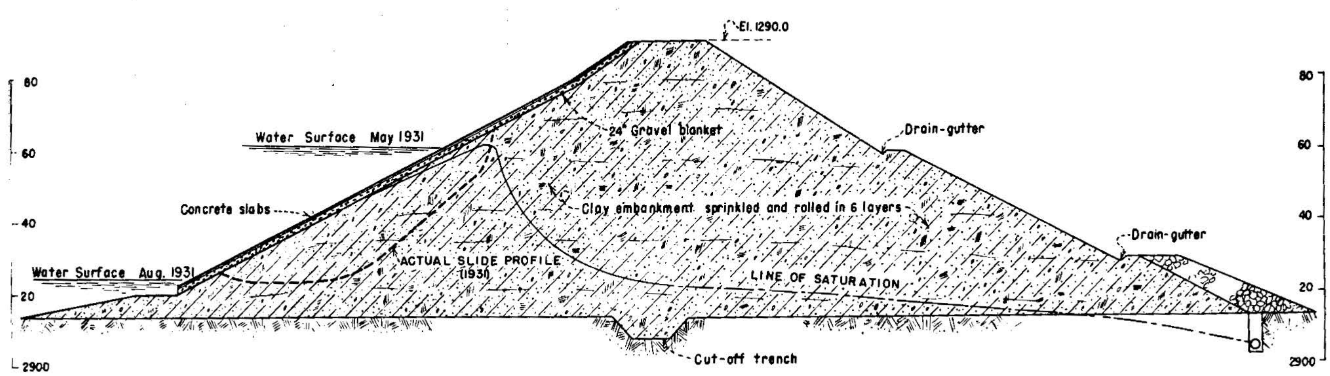


Figure 6. Belle Fourche Dam. Slide caused by unbalanced hydrostatic pressure after rapid reservoir drawdown.

serious slumping of the face slabs at Belle Fourche Dam by washing out fines through joints in the slabs. In more recent structures, transition zones of graded materials, interposed between the coarse surface protection and the fine embankment material, prevent this loss.

Because earth dams are liable to swift destruction through overtopping, precautions are taken to densify the embankment during construction so that its volume undergoes a minimum of settlement. It is equally important that the foundation as well as the embankment attain final consolidation before completion of the dam. However, at Fresno Dam, which was completed in 1939 on the Milk River in Montana, the foundation settled almost eight feet as the clay materials consolidated under the weight of the embankment, the final one-third of this consolidation occurring in the four years following completion of the embankment. A graphical illustration of the rate and amount of foundation consolidation is shown in Figure 7, which indicates the rate of embankment construction. The foundation material at the dam consisted of a clayey silt which contained 20 to 30 per cent water before it was unwatered by well-points. As settlement measurements indicated no rise of the foundation at the toes of the structure, settlement apparently took place in the clay when the superimposed load consolidated the unwatered stratum. In addition to the designed camber of the embankment to allow for expected settlement, an additional two feet of embankment was added following cessation of consolidation, and the dam has been stable since that time.

DETERIORATION OF APPURTENANT STRUCTURES AND FACILITIES

In the appurtenant structures and facilities for dams, which we depend upon to regulate the release of water for beneficial uses and to control excess flows, water passages must be carefully designed and accurately constructed to avoid the destructive effects of cavitation which result whenever pressures are reduced to the vapour pressure of water. Cavitation may be general, as when the average pressure of water in a pipe is reduced to the vapour pressure, or local when low pressures are induced by a sudden change in the direction of flow.

Thus general cavitation may result when the runner of a hydraulic turbine is set too high with respect to tailwater elevation and extensive pitting of the runner blades results. Similarly, when outlet conduits are designed so that the hydraulic grade line lies close to the upper boundary of the conduit, conditions are ideal for destruction by cavitation. Such a condition was disclosed by model studies of the original design for the Grand Coulee Dam outlet conduits, but they were satisfactorily modified by a redesign to increase pressures throughout the conduit.

Local cavitation can be induced by slight boundary irregularities. In the Arizona spillway tunnel at Hoover Dam, a hole 112 ft. long, 35 ft. wide, and 36 ft. deep was eroded through the concrete and into the andesite tuff breccia rock, started by a three-inch misalignment in the tunnel lining. The tunnel had discharged only four months at a low flow that averaged 13,000 cub. ft. per second. The velocity at the vertical curve, at the foot

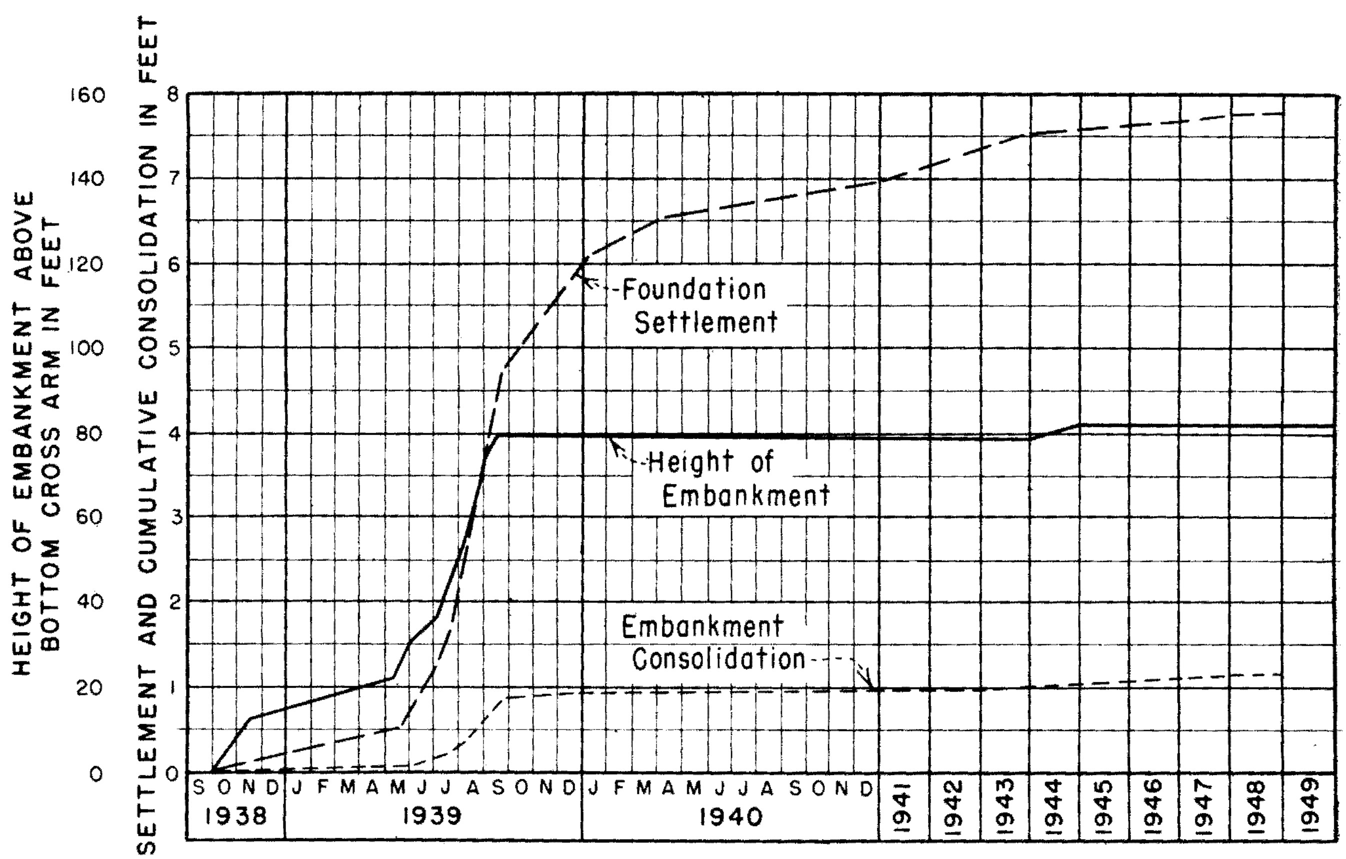


Figure 7. Fresno Dam. Consolidation and settlement.

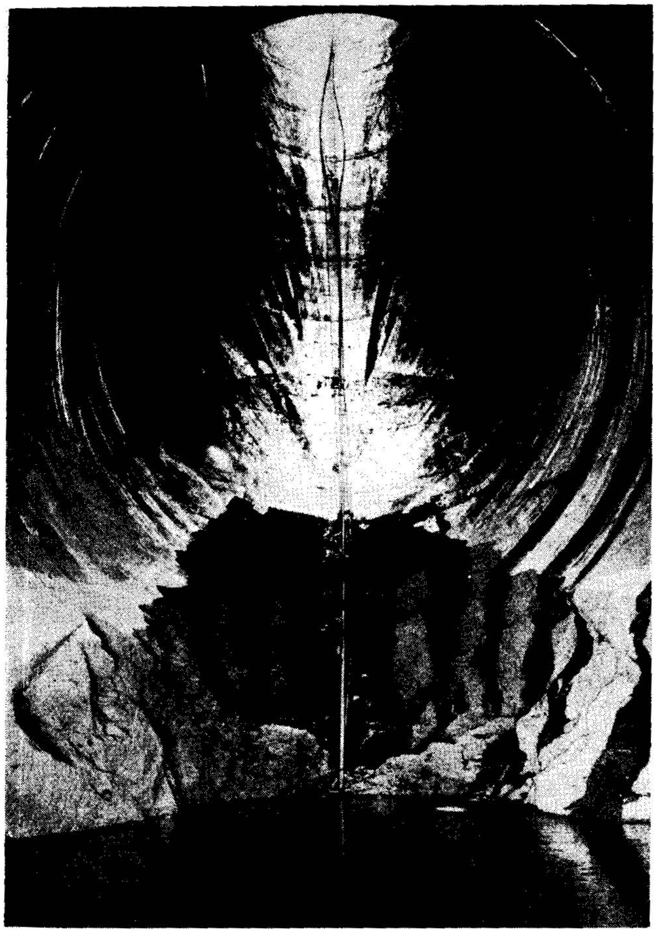


Figure 8. Hoover Dam. Damage to concrete and rock at foot of Arizona spillway tunnel due to cavitation and erosion.

of an inclined drop of approximately 500 ft. where the damage occurred, is about 175 ft. per second. The forces of cavitation and erosion are well demonstrated by Figure 8, which is a photograph of the large hole which was eroded in this tunnel. The cavity was repaired by replacing the lining with prepacked concrete and removing surface irregularities in both the old and the new concrete.

Investigations made to find the causes of pitting of the needles of high pressure valves disclosed that the pressure of the water was progressively reduced as it passed through the valve, due primarily to change in direction of flow, and when the vapour pressure was reached, pitting resulted. This difficulty was surmounted by redesign of the water passage to avoid low pressure areas. The profile of the needle was modified to prevent separation of the jet from the needle. Figure 9 shows the repaired pitting of the needle valve at Stony Gorge Dam.

Distress in outlets has not been confined to needle valves. Guide grooves in the slide-gates have had to be smoothed and streamlined to avoid local regions of low pressure following disclosure of damage caused by cavitation downstream from the early designs. Figure 10 is a photograph of concrete eroded below a gate groove at Parker Dam.

Fast-moving, clear water can erode by cavitation, and given a load of rocks and pebbles for a grinding medium its potentialities for deterioration are tremendously increased. The hydraulic action of the 1,635-ft. long spillway bucket at Grand Coulee Dam, which was designed to dissipate the energy of flows up to one million cubic feet of water per second, caused a ground roll which has carried material from the stream-bed into the bucket where it has eroded the concrete to a depth of three to thirty inches. Extensive repairs are now under way, requiring the use of a specially built caisson for unwatering and concreting successive small portions of the spillway bucket.

Figure 9. Stony Gorge Dam. Needle valve showing welded repairs to pitted needle.

Figure 10. Parker Dam. Erosion induced by local cavitation on side of channel downstream from gate slot.

This paper summarizes a few of the experiences of dam deterioration of the Bureau of Reclamation. Each project, and its local conditions, has its own special problems in deterioration. It is hoped that these experiences may be of interest and assistance to engineers in other countries who may have similar problems.

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Preservation of the Aswan Reservoir

Y. M. SIMAIKA

ABSTRACT

In view of the vital importance of the Aswan Reservoir to Egypt, the effect of using it for flood protection or for maintaining a head on the dam in flood for power generation has been the subject of a great deal of investigation.

When in flood, the Nile annually brings down large quantities of silt, the deposition of which has from time immemorial formed and is still forming the fertile land of Egypt.

The presence of silt in the Nile has, however, the disadvantage of limiting the time during which the reservoir can be filled. It is the rule to start filling after the peak of the flood has passed when the silt concentration has decreased considerably.

Owing to the position and natural features of the Aswan Reservoir, it has been resorted to in 1938 and 1946 as an emergency flood escape. But before it can be definitely looked upon as a protection that can be resorted to, time after time, there is one vital question to be investigated. That question is, how much silt is likely to be deposited and will this deposit ultimately very much reduce the capacity of the reservoir?

Silt experiments based on samples of the suspended matter have been carried on for many years. These have also been combined with hydrographic surveys of the reservoir basin.

A short account of the experiments and results is given.

In view of the vital importance of the Aswan Reservoir to Egypt, the effect of using it for flood protection or for maintaining a head on the dam in flood for power generation, has been the subject of a great deal of investigation.

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Owing to the position and natural features of the Aswan Reservoir, a third heightening of the dam has been considered for the purpose of using the reservoir to protect Egypt against high floods. In fact in 1938 and in 1946 it was used as an emergency flood escape by lowering the crest of the flood. The volume of silty water impounded in 1946 was over 2,000 million cub. metres.

But before the reservoir can be definitely looked upon as a protection hat can be resorted to, time after time, there is one vital question to be investigated.

That question is, how much silt is likely to be deposited, and will this deposit ultimately very much reduce the capacity of the reservoir?

Apart from the loss of content, silt deposits often block the lock and upset navigation at Shellal quays immediately upstream of the dam.

A great deal of information about the silt in the Nile has been collected, mainly by the Physical Department, which is summarized in "The Suspended Matter in the Nile".[1]

The following are the mean concentrations of the suspended matter in the Nile and the percentages of sand, silt and clay.

Date	Mean concentration (parts per million)	Average discharge (millions per day)	Average weight of solids (million tons)		Percentage Sand	Silt	Clay
Aug. 1-10	1760	470	8		15	40	45
11-20	2600	670	17	60	22	45	33
21-31	2860	780	35		25	45	30
Sept. 1-10	2350	800	18		31	41	28
11-20	1830	760	14	42	36	40	24
21-30	1460	700	10		41	38	21
Oct. 1-10	1150	620	7		42	34	24
11-20	840	520	4	14	43	33	24
21-31	710	420	3		45	27	28
Nov. 1-10	540	330	2				
11-20	390	260	1	3			
21-30	170	220	0				

The above figures refer to the suspended matter only and do not include the solid load which is rolled along

[1]Y. M. Simaika, "The Suspended Matter in the Nile", Physical Department Paper No. 40, Cairo, 1940.

the bottom as bed-load. No successful method has yet been devised for measuring the material transported as bed load and in our investigations no attempt was made to measure it. Observations of the vertical distribution of silt in the Nile water tend to show that the bed-load cannot be heavy.

RESULT OF THE SILT EXPERIMENTS

In the years 1929, 1935, 1938, 1943, 1944 and 1946, a head was kept on the dam during flood and silt samples were taken at Halfa, at the tail of the backwater of the Reservoir and at Aswan below the dam.

The experiments of 1929, 1935 and 1938 all show small deposition of silt. In 1929 and 1938 there was very little removal of silt when the reservoir was lowered, while in 1935 the greater part of the deposit was moved. The reason for this has not been investigated but may be connected with the manner in which the sluices were regulated.

In 1946 when there was the biggest hold-up, there was much less trouble at Shellal quays immediately upstream of the dam, the deposit being much smaller. The explanation is thought to be that the level of the reservoir was raised very quickly producing a region of non-flow immediately upstream of the dam, whereas with a small flow there is heavier deposition due to the continuous supply of the silt-laden water.

As silt sampling deals only with suspended matter and does not take any account of the bed-load, and in view of the magnitude of the question of silt deposition in the reservoir, it was decided to combine these experiments with an absolute measurement of the deposition, i.e., to make a careful capacity survey of the reservoir for comparison with previous and future surveys.

SURVEY OF THE RESERVOIR

The Aswan Reservoir was surveyed in 1927 previous to the second heightening and in the course of this, nine areas (or blocks) each of about a square kilometre, were closely covered with soundings.

In 1940 over 200 cross-sections, at accurately marked positions, were taken in the reservoir from the dam to the tail of the backwater at Halfa.

The hydrographic survey of the blocks, taken in 1927, was repeated both in 1940-1942 and in 1946, while the cross-sections were repeated in 1943 and 1946.

In conjunction with the survey, silt experiments were made as usual.

RESULTS OF THE SURVEYS

The results of the 1942-1944 survey agreed with the method of silt sampling. It was not possible to organize silt sampling until the top of the flood of 1946.

The results are:

1942-1944 silt deposited 92 million cub. metres[2]
1944-1947 silt deposited 46 million cub. metres

Comparison of the 1927 and 1942-1944 surveys of the blocks, shows that some blocks were scoured and some were silted, but the total showed an insignificant change of volume of the blocks of about 1 per cent scour.

REMOVAL OF SILT DEPOSITS

Material deposited and allowed to consolidate requires a higher velocity to remove it than at the time it was deposited and the time factor also comes in.

Our knowledge of the factors influencing the suspension and deposition of silt is insufficient for precise estimates to be made of what is likely to occur when silty water is stored under conditions not previously tried. Thus the question of how much of the deposit would be removed is one to which an answer cannot be given.

Although the amount of suspended matter which has been deposited in the Aswan Reservoir when its level has been held up in flood is small, yet its deposition can cause considerable local inconveniences. For example, every year some silt deposits in the channel leading to the lock and later special measures are taken to scour it out. One of these consists in the use of a special scouring gate which is placed at the entrance to the locks. Silt on one occasion was deposited on Philae Island and was afterwards removed by the Antiquities Department. In 1935 the hold-up of the reservoir resulted in difficulties at the quays at Shellal, immediately upstream of the dam, when steamers were unable to approach on account of banks of mud.

Scouring of the silt deposited near the dam is made by keeping all the deep sluices open by a certain amount. In fact the manner in which sluices are regulated has an effect on the amount of silt washed out.

[2]The total content of the Aswan Reservoir is 5,000 million cub. metres.

Modern Principles for the Construction of Hydro-Electric Stations and River Development Projects[1]

ANTON GRZYWIENSKI

ABSTRACT

Progress in the construction of hydro-electric power-stations and river-development projects during recent years has been characterized by greater technical efficiency, efforts towards greater economy and a growing sentiment for good design. These factors will continue to prevail in the future.

Efforts on the technical side have been directed towards simplification of construction and increased safety of plants in normal operation, during periods of floods and ice, and in exceptional circumstances. In the development of entire river areas, standardization will play a definite if limited part. A harmonious adjustment of natural supply to the load diagram will have to be sought through a combination of power-stations with pumping-stations, with supplementary caloric or atomic-energy installations and with intermittent and continuous storage.

At the present time consideration is being given to machine groups with Kaplan turbines and screened generators for such plants, even though a combined turbine and generator similar to the pipe turbine would be desirable. As a comprehensive solution of construction problems, a trend is being noted towards combination and intermingling of the separate constructional components — weir, power-station and locks — into one technical, operational and architectural unit. Inconspicuous plants, such as flood-level and waterfall power-stations, may be preferred in the future.

For the sake of economy, construction must be limited to what is absolutely necessary, and anything that does not further production should be eliminated.

Good design is a part of careful planning, and only thus will technical contributions have a cultural value.

The term "dam hydro-electric power-station", more shortly "hydro-electric power-station", means a hydro-electric installation in which an effective head is created without diversionary channels by impounding or by lowering the river-bed by means of a weir (but not of a dam). Such an installation consists principally of the actual structure (the weir plant and power-station) and the upper pond area as far as to the upper limit of the concession; it may also include a tail-race extending to the lower limit. The principal purpose of these works is to generate electric current, particularly for continuous service. If a considerable portion of the structure (such as a lock, a lift or the like) is intended for water traffic and is immediately adjacent, we then have a multiple-purpose installation that is known as a river-development project.

A characteristic of hydro-electric power-stations and river-development projects is that the power-house and lock are situated in the immediate vicinity of the place of impounding.

In planning and erecting such structures consideration must be given to the technical, economic, architectural, operational and other aspects, for only if these are all considered together can the best solution be found. This paper is confined to a few important modern principles principally concerning the constructional engineer.

TECHNICAL CONSIDERATIONS

EFFECTIVE HEAD H_n

The establishment of an impounding-reservoir power-station at the end of a fixed concession area makes it possible to develop the greatest effective head and consequently to generate the maximum amount of power. The maximum amount of power cannot be produced by a diversion-canal power plant in a comparable concession area; and so preference must always be given to the impounding-reservoir power-station on account of its maximum power yield. If the concession area has not been fixed beforehand, an attempt should be made to maintain as great an effective head as possible, since a greater difference in height is also generally more economical. This has been borne out by experience at various mountain-river plants where installation costs have been divided into a fixed portion and a portion varying with the head. The normal upper pond limit should, where possible, lie above the high-water level.

If Kaplan turbines are installed where the effective head is smallest, and three-part or combined fixed and movable weirs are constructed where the effective head is greatest, then hydro-electric power-stations and river-development projects can be provided for in practically all circumstances. Where the head exceeds 30 metres or so, a closed turbine intake, possibly in the form of a vertical drop shaft, is necessary (the type of construction then being that of a waterfall power-plant).

When deciding upon effective head, machines and structural details, consideration should be given not only to water conditions at the beginning of operations but also to the effects of interference with the detritus system, particularly silt deposition and scouring of the upper and lower river-bed, over long periods of operation. An exact investigation of upper-pond conditions in heavily built-up flat valleys or at river junctions is a task of considerable magnitude (1).[2]

In larger installations it is ordinarily impossible to maintain the upper-pond limit without change at all times. Because of operational and other considerations, the law should allow changes of varying degree in the upper water-line. In this kind of water-level control, attention must be given to the requirements of power generation (intermittent and continuous storage, combination with

[1]Original text: German.

[2]Numbers within parentheses refer to items in the bibliography.

a pump storage station), of navigation (prevention of sharp variations in the water-level and of sudden flooding and sudden lowering of the water-level), and of agriculture (raising of the upstream and depression of the down-stream water table); to protection against high water; to the passage of ice, detritus and materials in suspension; and to settlements, roads, railways and the like. Where the conditions are complicated, the station can be operated by remote control from the upper pond and from the lower end of the tail-race[3]; or the water-level can be brought into a constant relationship with the supply of water to the turbines.

EFFECTIVE QUANTITY OF WATER Q_a

The scope of development will depend upon the greatest quantity of water used by the plant. The total volume of water will be governed by the natural supply (a comparatively small Q_a where the flow has a torrential character, and a large Q_a where it has the character of a river or where there has been an increase by artificial or natural-lake control, as has often been done in Sweden in order to increase the Q_a), and by consumption (a small Q_a in isolated installations and a large Q_a where current is supplied to a network).

The ideal scope of development is principally a question of economy (2), and is determined by comparative calculation from the case in which the quotient of the annual production costs into the potential annual output in kilowatt hours is minimal. At the present time in Central Europe water volumes have been developed for about 75 to 90 days and in very large installations for as much as 100 to 120 days. These figures will probably be considerably improved in the future, particularly if further progress is made in accumulation by hydraulic means through attached pump-storage works or in connexion with thermal storage or some other kind of storage.

OUTPUT N

Output at the place of consumption is expressed by the equation:

$$N = c \, . \, n_B \; n_T \; n_G \; n_T \; n_L \, . \, Q_n \, . \, H_n$$

the small n here represents the various degrees of efficiency with respect to buildings, machines, electricity and output. Although a certain maximum effective power seems to have been reached with respect to machines and electrical installations, a further improvement in n_B might result from improved penstock intakes. The n_L factor depends above all on the distance of the plant from the place of consumption. In particular continuous-service plants should not be situated too far from the centre of consumption. Even in the planning stage, convenient opportunities for measurements and readings should be provided in order to control efficiency.

The number of machine groups depends on the one hand on the most unfavourable conditions of operation (minimum output capacity), and on the other hand on structural, that is economic, factors. At the present time the highest individual output with Kaplan turbine sets is at the Hojum station in Sweden, where $N = 50{,}000$ kw. and $H_n = 33$ metres, and at the McNary Dam in the United States, where $N = 80{,}000$ kw. and $H = 25$ metres. Highest total output is being attained at the Wilson and Wheeler Dam installations on the Tennessee River (TVA); and on the Dnieper and at the works of the Greater Volga Plan. One of the most important river-development projects is the Iron Gate on the lower Danube, but this is still to be completed.

EXPERIMENTS WITH MODELS

Experiments with models are coming into constantly greater use for determining the most suitable form of construction for hydro-electric power-stations and river-development projects. Models are today an indispensable aid in the solution of the most varied kinds of problems. The applicability of experiments with models is, however, limited. For hydraulic purposes the scale should not be too small. A model installation should extend for a sufficient length upstream as well as downstream. In order to obtain results that are true to nature, care must be taken that the model has comparable flow characteristics and bed formation. The conditions under which an experiment is made should be modified until this similarity is attained in respect of at least one controllable phenomenon, such as stream-line or eddying after high flood-waters. It is recommended that sand of about d/90 grain size be used in the model. Experiments should deal with at least the following matters: flood-water discharge, behaviour of the water-surface, rolling-wave formations in various kinds of water-conducting structures, impounding, surface and bottom currents, energy consumed in stilling basins and eddy formation, the effect of scouring on eddy formation and flushing in the presence of silt deposits, the framing of regulations for weir operation, individual pier form, the backs of weirs in structures, the inclusion of emergency sluices, the effect of flushing installations, investigation of hawser stresses when filling and emptying ship locks, currents and variations of water-level in the layby basins of locks and testing of the outlines of excavation enclosures.

SITING

The siting of hydro-electric power-stations and river-development projects depends upon the type of construction and is consequently often made quite difficult by conflict of interests. A straight stretch of river permits a freer choice of situation. If the river bends, consideration must first be given to navigation, high-water and ice passage. The natural river channel is ordinarily the best place for navigation and for the weir, but the power-house may be situated on one side in an inlet protected from flood-waters. Model experiments conducted by the author (3) have shown that impounding is at its lowest where the centre of gravity of the sluiceway openings coincides wilh the position of the river channel in an unobstructed cross-section of the river.

When the weir sluices and the lock gates are wide open as during flood the separate weir piers and lock walls are in no way different from bridge piers. It goes without saying, of course, that these installations should as far as possible be situated in the line of flow. For long piers or guiding walls, a form with a curved ground plan is

[3]Patent applied for by the author.

in some circumstances advantageous from a hydrodynamic point of view.

TYPE OF CONSTRUCTION

The type of construction of the hydro-electric power-station is determined by the arrangement of the machine groups (ground plan, see Figure 1)[4] and by the method of installation (elevation, see Figure 2).

According to the manner in which the units are distributed, there are one-machine power-plants in one section (Figure 1d), two sections (Figure 1c) and three sections (Figure 1b), and island power-stations (Figure 1a), as well as combinations of these. The one-section hydro-electric power-station is the basic form and is ordinarily the most economical. In recent years there has been an increasing tendency in Central Europe to adopt the other special types of construction.

The two-section power-station may possibly come into consideration when a national boundary passes through a river or when factors of design make a more symmetrical effect desirable. A uniform flow to the turbines can be attained on straight stretches of river. The possibility of premature operation of part of a power-station usually calls for increased expenditure on the second excavation enclosure. It is then necessary to install a second separating pier and also, in an open-air power-station, heavier weir bridges.

In multiple-section hydro-electric power-stations with the most economical development and approximately the same volume of concrete, stronger reinforcing is necessary. Each of the power-stations placed in a pier between weir sections requires some arrangement of two separating piers. On the other hand the turbines in straight sections receive a uniform flow, and an installation of this kind is architecturally better (4).

The island power-station, which may be feasible at a river junction, forces the high-water flow against the banks. This type of construction is the least applicable generally.

According to the manner in which the machine groups are installed, a distinction is made between power-plants with superstructures (Figure 2a), open-air power-plants (Figure 2b), flood-level power-plants (Figure 2c) and underground power-plants (Figure 2d). Although power-plants with superstructures were at one time in general use, the open-air (or modified open-air) power-station is now preferred for economic reasons and because of the greater flexibility that it allows in the arrangement of machine groups. Flood-level power-stations, which permit the installation of Kaplan turbines, deserve special consideration where the head of water is greater.[5] In special circumstances where the profile of the weir site is rocky and ravine-like or where there are natural falls or rapids, an "underground" power-station, or one entirely placed in the rock, is also quite suitable for the types of low-head hydro-electric stations being considered here.

The addition of a structure for water traffic to the constructional types of hydro-electric power-stations just described brings us to a consideration of river-development projects. When the order is lock-weir power-station, the asymmetrical river-development project corresponds most closely to the one-section hydro-electric power-plant; the symmetrical river-development project with the weir installation in the middle and locks on either side corresponds to the two-section hydro-electric power-station. The multiple-section hydro-electric power-station with lock installations on one or both banks becomes an asymmetrical or symmetrical river-development project; whereas an island power-station with separate lock installations makes possible a mirror-like type of development.

A river-development project may also be constructed entirely as an open-air type of structure, as is seen in Figures 3 and 4.[6] If the primary consideration is military security, the flood-level and underground types of power-station may similarly be extended to include river-development projects by the use of Rothmund submerged locks, (5) escalators, crane-hoist installations with turntable arrangements, or the like.

In order to make a proper comparison of the various types of construction, I reduced them all to the same basis and found, when all circumstances had been taken into consideration, that the one-section hydro-electric power-station and the asymmetrical open-air river-development project were the most economical and technically the most advantageous. They also offer greater security during construction, in normal operation, in flood and ice passage and in respect of scouring.

STRUCTURAL COMPONENTS

Weir installations

Where movable weir sluices are to be used, preference should be given to two-section and multiple-section construction. Sluices with hinged tops should be used where there are small heads of water, and double gates (wheel gates, interlocking double gates with only one track, capable of being lowered all the way) or double segments (hook segments) should be used where the heads of water are greater. In a very high weir with a fixed middle portion, a gate-lowering construction can be used at the top (rotation-resisting gates, sectoral sluices) and single-section lower gates or lower segments can be used as cut-offs of the bottom outlets. The greatest degree of safety in heavy-duty sluices will be secured by the use of tubular or box-shaped, electrically-welded plate construction. High-grade, rust-resistant steel is often used for these. In addition to local operation, remote control should be provided both from the power-station and by means of a system of reservoir control. Dependable emergency sluices in the upper and lower pond areas are a particularly valuable asset.

In the substructure, attention should be given mainly to good stream flow. In this connexion a solid rock could be used as the floor of the stilling basin. Weir piers and separating piers should be carefully designed on hydrodynamic principles.

The power-station

A good penstock intake is obtained by having as free-moving a flow as possible and by proper design of the

[4] Owing to technical difficulties the illustrations were not reproduced.

[5] Patent applied for by the author.

[6] Patent applied for by the author.

separate items of construction. The inlet should produce as little loss of pressure head as possible; the guide apparatus should be uniformly distributed over the circumference and should permit a through flow; and the energy in the draft tube should be completely recovered if possible. The inlet should also have a well-rounded construction. With large cross-sections the vertical and horizontal partitions in the inlets and discharges should be arranged properly from a hydraulic point of view. Openings of sufficient dimensions in the walls will enable equalizations of pressure and adjustments of speed. In a suitable case, skeleton structures alone can be used for the static part of the construction. Supporting blades of concrete constitute another step forward. Where the internal pressure is high, the turbines should be so installed that as great a portion as possible of the actual weight of the spiral housing is taken by the supporting blades.[7] Where there is a rocky foundation, a floor slab may be used in the draft tube. The stresses will then be conveyed only through the walls in the substructure.

At the present stage of development, machine groups with vertical axles, dual-controlled Kaplan turbines and screened generators are the obvious solution. Some types of construction result in a reduction of the number of inlet points and of the building heights of the machine groups, and this makes the underground part of the construction less expensive.

Greater use is constantly being made of high-grade building materials (e.g., blades of solid, rust-resistant steel to prevent corrosion and cavitation) and welded construction. Detailed research is being made into cavitation-free sites for turbines above the downstream area.

Complete or partial remote control is particularly desirable tor power-stations in out-of-the-way places. (6) Remote control will continue to grow in importance as progress is made in the use of waterways as sources of power. Automatic control keeps down production costs.

In open-air installations use is made of a "universal" crane, which is sufficient for all such work in the power-station as installation and removal of machinery, installation of emergency sluices upstream and downstream, removal of grating panels, unloading of incoming railway trucks etc. This crane may also be used to operate the dam-beam weir (see Figures 3 and 4).

Ship locks

A decisive economic advantage is gained if the locks are so constructed that they can perform the functions of a weir in times of extremely high water, ice passage or emergency, and if their water capacity can be reckoned as part of that of the pound. Such weir-locks must be suitably constructed for the passage of flood-water, rubbish and ice, and they must be similar to a section of the weir, at least at that point where the overflow occurs. (7) The size of locks is determined by the dimensions of the vessels and the fleets in which they travel in mountain and valley traffic. Weir-locks can be filled and emptied either by short diversionary canals connected to the stilling basin installation or, separately from power consumption in times of high water, by distributing the water discharge as uniformly as possible along the length of the chamber or over the entire ground plan by means of a hollowed-out bottom, longitudinal and cross canals, or a combination of both methods. Locking time will be even shorter if water is also taken laterally direct from the stream. Connecting conduits between adjacent chambers save water.

Installation costs can be reduced if rock is present and the bottom of the chambers is not lined. The gate equipment of locks should be so arranged in the design that no fixed superstructure is necessary. The simplest lock gates to operate are those whose supporting members and bearing surfaces are constructed according to the most modern principles.

Personnel costs can be reduced by automatic lock-control.

[7]Patent applied for by the author.

CONSTRUCTION

Construction will usually be possible in open excavations, and diversionary channels will be necessary only when installing a power-station or locks in steep, rocky banks.

The various components of the constructional works must allow the passage of ice and flood-water, and there should be no hindrance to navigation while construction is in progress. For these reasons the various stages of construction and the final structure itself should be carefully studied in models. Systematic research has been undertaken with the aid of models in order to determine the best form of excavation enclosures and the manner in which their various sections can be protected (unpublished work compiled by the author for the Traunweir at Kleinmünchen).

In the construction of a hydro-electric power-station the concrete is usually poured first for the deeper portions, namely the weir installation, and later for the power-station. In the construction of river-development projects the lock installation should be built first so that, once shipping has been diverted, building operations may proceed without further regard to it. An attempt is generally made to reduce the number of excavations and to simplify the enclosures. Work on hydro-electric power-stations can often be done in two stages and work on river-development projects in three or at most four stages. Large enclosures are today built either as concrete coffer-dams with flat or multiple-arch weir walls and intermediate piers or, where the head does not exceed 30 metres, as cylindrical steel coffer-dams.

ECONOMIC CONSIDERATIONS

The economic feasibility of an installation can be expressed as a ratio between the selling price of the power annually generated and the annual production costs (8). If this value is greater than unity, the project is profitable; otherwise it is unprofitable. Over a longer period of time the ratio between total numerators and total denominators is the decisive factor.

Greater profits are made possible by increasing production on the one hand (this is discussed under Technical Considerations) and by reducing production costs on the other hand. Production costs depend in large measure upon installation costs. The pressure of competition on hydro-electric plants makes it necessary to eliminate all components, both static and hydraulic, that are not absolutely essential to the generation of power. Consequently intake structures, sills, submerged sidewalls and the like, and the superstructure (in the open-air type of construction) may be dispensed with, as may all parts above the spiral housing, and the fixed superstructure of weir piers and lock walls. A systematic use of ship-locks to assist in flood-water discharge is of great economic importance, for a very considerable reduction in weir costs can thus be secured in river-development projects.

Other means of reducing costs and simplification are: standardization of installations to be built in rapid succession in the same river area; standardization and manufacturing in series of machine groups and other equipment; the utilization of dam beams, reserve transformers, and the like for several plants at the same time; the development of entire rivers and valleys in order better to use available stocks of equipment and to reduce administrative costs by more comprehensive organization, like that of the State Power Board in Sweden and the TVA in the United States (9).

Good design does not mean additional expenditure for "architecture" but rather consideration of the natural beauties of the area, proper co-ordination of buildings, orderly arrangement of the various components of an installation, proper use of materials and the giving of a convincing form to all the separate elements without any considerable additional expense. Stone facing in many cases adds to costs but most certainly improves appearance even where used very sparingly.

Installations noteworthy for good design are the Heidelberg am Neckar plant built of red sandstone (architect, Professor Bonatz), and the Marburg mountain-river plant with granite facing (architect, Professor Haas).

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Construction of Jablanitza and Mavrovo Dams in Yugoslavia

MINISTRY OF WATER ECONOMICS OF THE FEDERAL PEOPLE'S REPUBLIC OF YUGOSLAVIA

ABSTRACT

In view of favourable climatic and geographic conditions, the Federal People's Republic of Yugoslavia has a significant hydrologic regime, with a hydro-electric potential of 13 million hp. Prior to 1941 only 2 per cent of this potential was utilized.

At present there are 37 hydro-electric plants under construction in Yugoslavia, which will produce 1 million hp., with dams of the following heights : 8 over 25 metres, 4 over 50 metres, and 1 over 70 metres. In this manner about 1,160 million cub. metres of accumulation space are obtained, which is also utilized for general improvements (irrigation, etc.), a factor which is being especially considered in the planning.

As the most interesting examples from the standpoint of size and construction, the dams of Jablanitza and Mavrovo are discussed herein.

Jablanitza is situated on the Neretva River, which drains an area of 2,368 sq. km., and a dam of 77.5 metres in height forms a lake of 14 sq. km. From the dam, two tunnels 2 km. in length lead to an underground establishment, creating a waterfall of 62-106 metres. The underground building houses the power-station which produces, according to the annual precipitation, from 758 to 980 million kwh. The investment is 3 billion dinars, and the cost of the power 0.20 dinars per kwh.

Mavrovo is of an entirely different type. Through the construction of a dam, 55 metres in height on the upper Radika River in Macedonia, a lake of 350 million cub. metres is obtained.

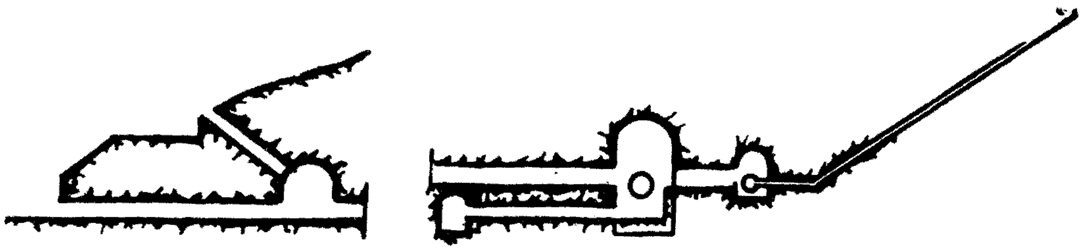
The yearly power production for the average annual precipitation consists of 343 million kwh., and the cost per kwh. is 0.75 dinars.

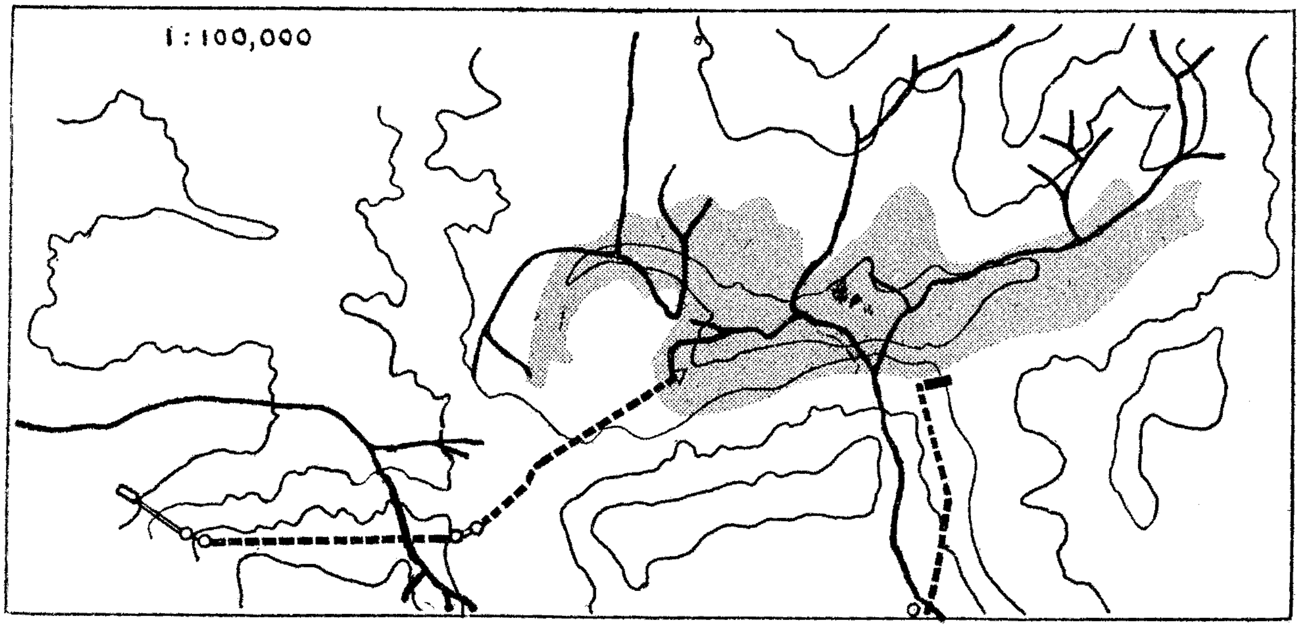
According to its water-power as well as to the possibility of its utilization, Yugoslavia ranks with those European countries which have a significant hydro-energy potential. Geographical position, configuration of the ground, climate and other factors influenced the formation of the hydrologic regime of our rivers, giving—in the case of certain rivers—a specific way in which hydraulic energy can be utilized.

According to the available data, the water-power of Yugoslavia is estimated, at an average water-level, at 13 million h.p. Until the last war only 2 per cent of this h.p. potential was utilized, which demonstrates how backward Yugoslavia was. Since the accomplishment of political and economic changes in Yugoslavia, great attention has been paid to the electrification of the country as one of the conditions for raising the living standard of the Yugoslav peoples.

The hydrologic regime of the rivers is conditioned by the climate, which is changeable in Yugoslavia. Whereas western regions abound in large quantities of precipitation of the atmosphere (up to 5,000 mm.), in regions further to the east the quantities of precipitation decrease and reach only 500 mm.

Most of the rivers in Yugoslavia have their headwaters in the Dinara Mountain system which extends over almost the entire length of Yugoslavia (north-west to south-east). The basic characteristic of their hydrologic regime is high-water in spring and autumn and low-water in





summer and winter. The spring waters last longer than the autumn ones and occur regularly. Summer low-waters are also frequent while winter low-waters often do not occur. Since the higher courses of the rivers are mostly in mountainous regions they offer great possibilities for the utilization of water-power.

Owing to the above characteristics the planners of hydraulic power-stations in Yugoslavia devote particular attention to the accumulation of water in the upper courses of the rivers in order to reach a hydraulic and electric equalization. The solving of hydro-electric problems in Yugoslavia embraces other problems which appear in connexion with the utilization of water. It is impossible to reach individual solutions on any of the larger rivers until a hydro-economic solution is found for the entire system with its corresponding region. The TVA projects serve to indicate all the problems encountered regarding water systems.

In Yugoslavia 37 hydro-electric plants with over 2,000 h.p., as well as a large number of smaller plants for the electrification of villages, are now under construction. In the mentioned 37 plants, 87 generators altogether will be mounted, most of which will be put into operation towards the end of the first Five Year Plan. The total power of these plants amounts to about 1,001,000 h.p., which, in comparison with the pre-war situation, means a sixfold increase.

The construction of the planned hydro-electric plants requires the planning and building of a series of very complex and elaborate structures. Twelve dams over 25 metres high, four of which are over 50 metres high, are under construction. The total quantity of concrete used in the building of these dams amounts to 2.8 million cub. metres, and earth-work to about 10 million cub. metres.

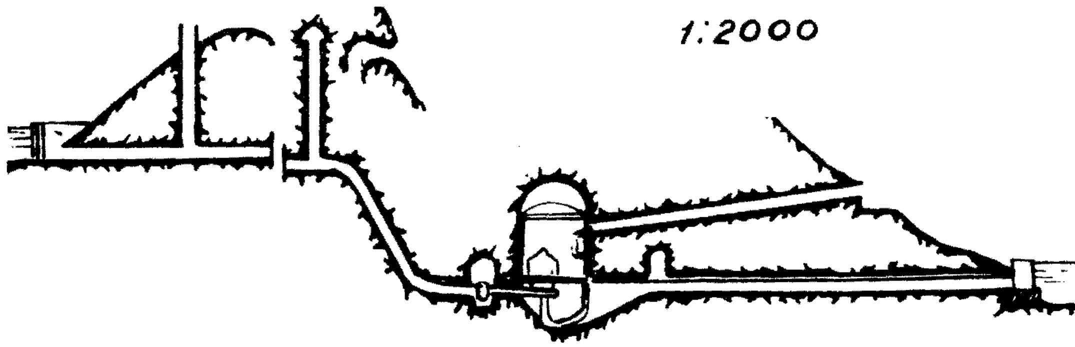
The building of these dams will give 1,160 million cub. metres of useful accumulation space which will be of manifold use to Yugoslavia: the obtaining of energy, improvement of adjacent areas, and flood control.

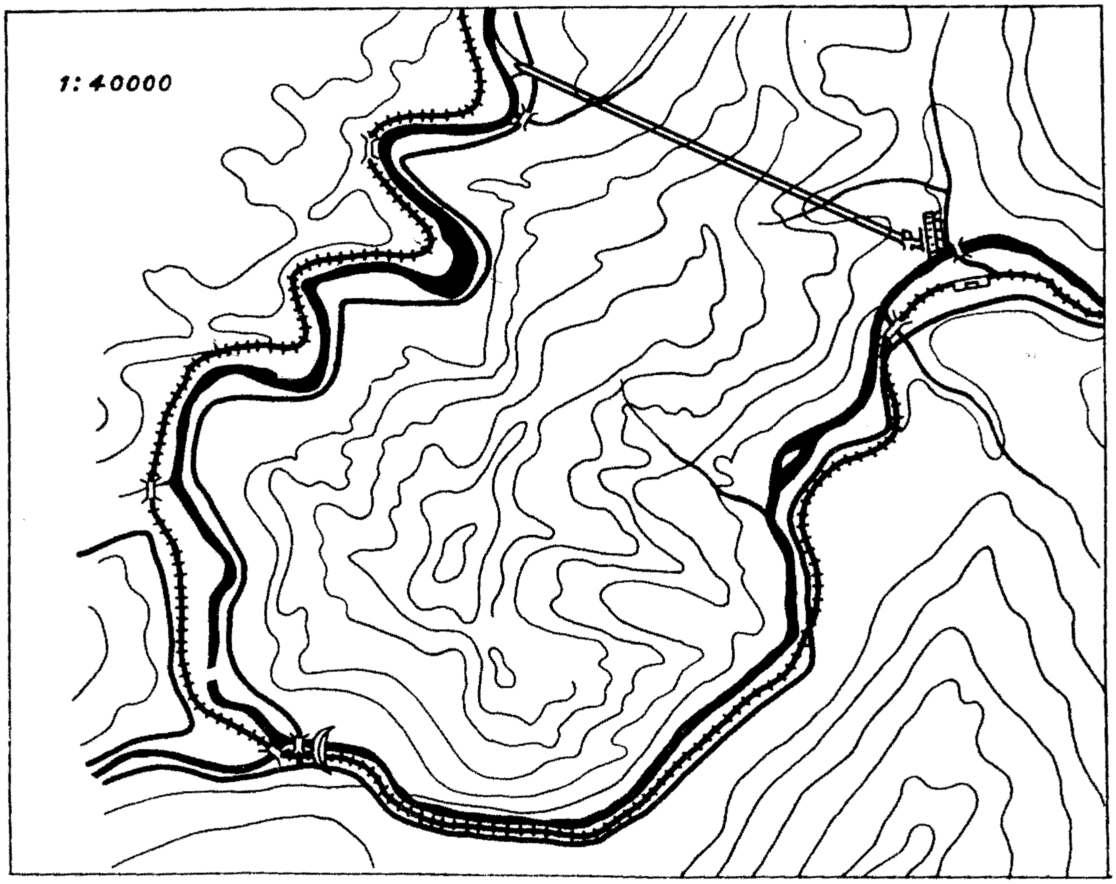
The following is a description of two major plants—the hydraulic power-stations of Jablanitza and Mavrovo, among the largest structures of the first Five Year Plan.

The hydraulic power-station at Jablanitza, in view of its power and the amount of power produced, is the largest plant in the Five Year Plan. It also ranks with the largest hydraulic power-stations in Europe.

The plant is on the Neretva River, which drains a region of 2,368 sq. km. into the dam. The plant utilizes the natural curve of the Neretva River through which two tunnels with a diameter of 5 metres (2,000 metres long) are constructed, thus creating an artificial waterfall from 62 to 106 metres according to the oscillations of the water-level in the lake.

Across the Neretva River an arched gravitation dam,





constructional height 77.50 metres, is built. This dam forms a lake of huge dimensions (surface about 14 sq. km.) which stretches to a length of 50 km. The capacity of the lake is 300 million cub. metres. This lake makes possible the equalization of the water level in different seasons, which offers the possibility of better utilization of the inflowing water and better exploitation of the plant. The water accumulated in the lake flows through the two tunnels and actuates the turbines.

The building of the power-station is underground, together with all the hydraulic and electric equipment. The underground hall for the plant is of huge dimensions. The excavations in the rock together with the tunnels amount to 900,000 cub. metres which clearly illustrate the size of this underground building. The motive power in the station itself is divided so that it actuates eight turbines of Francis type for an average mathematical fall of 93 metres and with a total power of 165 mw. The total annual energy in a rainy year amounts to 980 million kwh. and in a year of medium precipitation it amounts to 758 million kwh. The natural conditions of this power-station make the cost of one kilowatt, in spite of huge investments (3 billion dinars), 0.20 dinars only, which is very cheap energy to be rationally utilized for the industrial development of Bosnia, Herzegovina and Dalmatia.

The hydraulic power-station at Mavrovo is of another type. It is on the watershed between the Adriatic and the Aegean river systems. At an altitude of 1,200 metres there is a valley which is being transformed into an accumulation basin. Around this valley there is a chain of mountains through which cuts a narrow gorge. Through this gorge flows the Radika River which is a confluent of the Crni Drim River (Adriatic river system.)

The chief waters are supplied by the Radika River. In addition there are other small rivers which are introduced into the accumulation basin. On this narrow place a dirt dam 55 metres high is under construction and prevents the natural flow of the water. The accumulation basin formed by the construction of the dam stretches over a surface of over 13 sq. km. The useful capacity of the basin is 350 million cub. metres. The inward and outward flow of the water is regulated by means of tunnels, canals, syphons, pipes and aqueducts. The total length of these devices amounts to 61 km. The most characteristic object in all this net of installations is a syphon with a diameter of 2 metres and a length of 892 metres. The syphon overcomes the rock which lies 230 metres under the level of inflow on this place. In view of the volume of the works and the problems which appear both during and after the construction, this syphon ranks with the most significant in the world.

The area draining into the accumulation basin amounts to 316 sq. km. and the total annual water-flow through it to 216 million cub. metres, at the rate of 6.85 cub. metres per second.

From the lake the water flows through an adit to the turbine. The length of the adit amounts to 6 km. Then come the turbine, pipes under pressure, and the engine-house, which are also placed underground. The plant is designed for 160 mw. The average energy production per year of medium precipitation is 343 million kwh.

The construction of the plant was preceded by great preliminary works (roads, accomodations for workers, organization of the working ground, etc.) The total investment for the construction of the hydraulic plant Mavrovo amounts to 2,500 million dinars. One kwh. of this energy is valued at about 0.75 dinars.

The hydraulic plant at Mavrovo represents a huge project. It makes the two-year equalization of the annual flow of all its water-systems possible. In this way, the production of energy is possible at a time when all the neighbouring plants are left without water.

Besides its significance as a source of power, in the summer months the Mavrovo accumulations will serve the purposes of irrigation of large surfaces in Macedonia which otherwise have a very low amount of precipitation.

The Use of Models in Planning Structures for Measuring and Dividing Water[1]

F. J. DOMINGUEZ

ABSTRACT

The paper is confined to the problem of measuring and dividing water in Chile. This consists in determining or separating a constant percentage of a yield varying in time. After a long period of inadequate measures this problem has been solved in the last thirty years by what are called rapid acceleration dividers and gaugers (or measures), which are isolated from any possible tailwater variations.

The rapid acceleration is produced by means of local dams or contractions introduced into the current. Measurements were made using models of contractions (1917), dams with rectangular cross-section (1922), and triangular cross-section (1942). The results of the tests were confirmed and perfected by professional experience. The type most frequently used both for dividers and for measures is the triangular cross-section dam combined with contraction. The results are quite satisfactory, with less than one per cent error.

Graphs are provided for calculating the heights of dams, the widths of contractions, and the volume-of-flow coefficients for the backwaters produced by these devices.

The water carried by canals, particularly in irrigation works, must be supplied either in a volume that is constant over a period of time that may be limited or indefinite, or in a constant proportion of a volume of flow varying over an indefinite period. In our country, Chile, the imperative necessity for irrigation (since there is no rain during the spring and summer) in the Central Region has from the very beginning required the development of canals and has not given time for the construction of control works on the rivers. These rivers, of glacial origin, that is, derived from the melting snows, are subject to variation in yield not only from month to month or from day to day but even in considerable measure within a single day. The water quotas, which have been poorly defined since colonial times, have for the most part come to consist at present of aliquot parts, that is, a fixed proportion such as a third or a tenth of the total yield of the river. In practice these quotas vary considerably even from hour to hour of the same day. Consequently all the devices invented in Chile have been designed to deliver a volume which although variable would remain at all times in constant proportion to the total volume carried by the canal. In addition to this water divider a measurer or gauger has been developed on the same principle. We shall touch upon this briefly later, but shall devote our attention primarily to the water divider, which we believe to be originally and almost exclusively Chilean.

It is interesting to observe the historical development of the water divider, usually called the "frame divider structure", which has followed the development of hydraulics during the latter years of the colonial period and throughout our era of independence (150 years).

[1]Original text: Spanish.

Originally the branch was led off from the main canal at an angle of 30 degrees by means of a dividing point so placed as to form rectangular openings with widths proportional to the quotas. The poor results of this construction, which did not take into account the hydraulic characteristics of the branches and was often unfair to the smallest quota that was diverted at an angle, led to rectifications. Both branch canals were given the same slope and consequently, as their walls were of the same degree of roughness, it was assumed that the shapes and dimensions of the channels of the two branches would, given the same head of water, bear the relation:

$$\frac{Q_1}{Q_2} = \frac{A_1 \sqrt{R_1}}{A_2 \sqrt{R_2}}$$

This assumed that the basic widths were proportional to the quotas. Naturally, since the coefficient C of the formula $Q = AC\sqrt{RS}$ was not identical for both branches, as the above ratio assumes, their slopes were equal only for a few metres' length, so that the heads in the branches were not the same. Hence, this solution was not practical.

The idea, which was also tried, of obtaining the same head by lining a section of from 100 to 150 metres of both branch canals and making openings in the dividing wall between them throughout that length, aggravated the fault which it was intended to correct. Obviously, if one branch had less head than the other, the reason was that its hydraulic qualities below the divider were better than those of the other; and so the branch which was already carrying more than its quota was given more still.

In 1914, Prof. Ramón Salas conceived the idea of using a broadcrested weir in water dividers of the lowest height that would permit the critical flow over the crest. If we call *a* the height that we must make the dam, and remember that with a rectangular bed, (for the sake of simplicity, the only one used) the specific energy corresponding to the critical flow is $\frac{3}{2}$ h_c, and take the bottom of the canal below the dam as the base level, the energy per unit of weight at the dam should be $a + \frac{3}{2} h_c$. Conditions downstream determine the specific energy in the current of each branch; if, assuming the same bottom level, we call H_1 the sum of that specific energy plus the loss of head or loss of energy caused by the broadening (Figure 1) that is $H_1 = h_1 + \frac{U^2_1}{2g} + \Lambda$ the equation giving us the height of the dam will be:

$$\frac{3}{2} h_c + a = H_1 \text{ or}$$

$$a = H_1 - \frac{3}{2} h_c$$

This equation (2) assumes that the loss of head Λ is known; we may ascertain this by analytical or experimental means, the results of which should coincide. We cannot enter into greater detail here especially as regards the first means, which can be referred to in our "*Curso de Hidráulica*" (1)[2] The experimental method was also tested in Chile (2) in 1922 on a small-scale model, the results on which coincided completely with a number of tests made on large canals. It can be said that both methods give the same result, and the calculation is made assuming h_1 to be the tailwater head (Figure 1). Naturally the calculation is governed by the branch with the greater specific energy. The branches are separated by a thin sheet of steel (Figure 2) inserted in the broad crest of the barrier. The thickness *e* of this sheet is determined by calculation in such a way as to produce on the crest the wave velocity $\sqrt{gh_c}$, which is the critical velocity and which therefore affords insulation against any variations downstream such as sluice gates, silt deposits, weed growth in the branches, etc., which are duly taken into account in the calculation of h_1. Many estimations and discussions have dealt with the impossibility of producing over the broad crest the "critical flow" which assumes the existence of parallel filaments. In our opinion demonstration of this fact on models in 1922 and in numerous cases in practice over approximately thirty years bears more weight than certain isolated experiments cited in modern works on fluid mechanics. The dam also produces a rapid acceleration of the current between A and B (Figure 2) which results

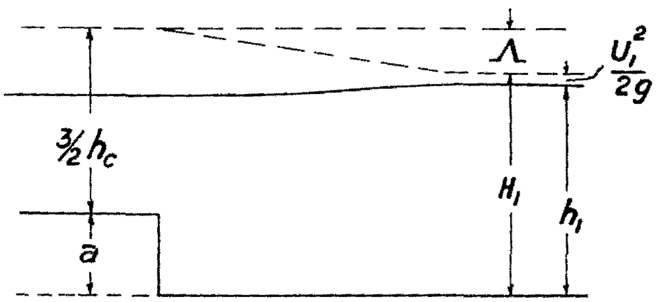


Figure 1

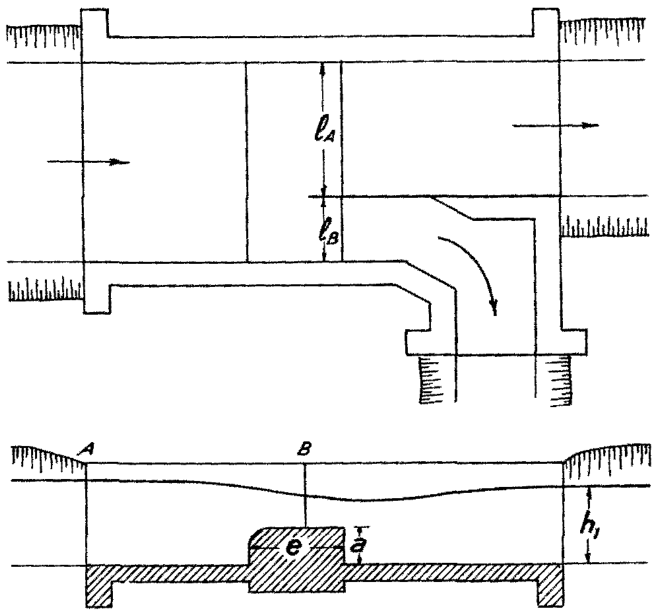


Figure 2

[2]Numbers within parentheses refer to items in the bibliography.

in the equalization of the velocities. This fact was demonstrated theoretically and the calculations have been confirmed by models (2). It is thus possible to give the divider widths of branches over the dam l_A and l_B (Figure 2) proportional to the quotas.

In 1917 we experimented on the production of the critical flow in models by means of local contractions of the current (3) of a type analogous to the Venturi and Parshall flumes and the De Marchi gauger which appeared later. On this occasion we experimented with the equalization of velocities brought about by the rapid acceleration of the current. The model indicated that if the acceleration created by contractions was excessive, the wall speeds become greater than those in the centre; and that the optimum equalization of velocities is obtained when the acceleration is seven times the average initial velocity—in other words, for practical purposes, when the width of the contraction is half the width of the approach channel.

In our country the local contraction was not as successful in practice as the dam in water division, nor in the measurers and gaugers, for reasons that are hardly logical, still less technical. The combination of dam with contraction, however, has been very widely used.

The formula for calculating the width of the contraction is similar to formula (1):

$$\frac{3}{2}\, h_c = H_1,$$

in which H has the same meaning as before and the critical height as a function of the total volume of flow, the sum of that in the two branches, is in this case $h_c = \frac{\sqrt{Q^2}}{l^2{}_g}$. This formula indicates the value of l, the width which should be given to the contraction.

For both dams and contractions the specific energy of the determining branch, $h_1 + \frac{U^2{}_1}{2_g}$, is a function that may be complex because it depends upon extremely diverse conditions; nevertheless it can be stated that in general *a larger volume of flow gives a higher dam and a smaller volume of flow a narrower contraction.*

In the dam of rectangular cross-section (Figure 2) it is impossible to determine the point at which the velocities of all parts of the current are equal to the critical velocity, which insulates against variations downstream. This place is known to depend upon the pressure of the nappe at the instant of leaving the crest, which is equivalent to saying that it depends upon the form of the nappe. As the head of water for a given volume of flow differs in the two branches, as a rule the forms of the nappes on each side of the dividing point will always be different. The place of the critical height also varies if the volume of flow varies, and consequently it is not fixed for each branch at the crest. It is necessary to seek a shape of dam in which the section serving as insulation against tail-water variations will be the same at all times for both branches and, as far as possible, for all the volumes of flow that occur. This is achieved by making a dam with a triangular cross-section, a rounded crest (Figure 3), and gentle slopes. Woodburn's experiments in 1928 and 1929 at the University of Michigan with dams which had gentle slopes but not rounding at the top led us to believe that they could also be used as measures or gauges since the position of the critical depth indicated in each experi-

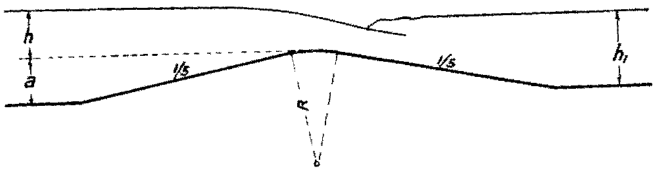


Figure 3

ment did not vary greatly with the volume of flow, and the form of the nappe was constant. It was observed that when the volume of flow was increased the position shifted downstream, clearly because of the narrowing of the nappe below. It seemed to us advisable to test crests with gentle slopes but rounded tops. The tests were carried out on models in Chile in 1942 by E. Lemaitre and V. D. Jara in the laboratory of the Catholic University[3] on dams of various heights and with three different widths (1 metre without contraction, 0.8 metres and 0.5 metres with contraction). Both the upper and the lower slopes had an incline of 1 in 5, which previous tests had indicated to be the most suitable to the purpose in view, as we shall explain below.

It cannot be claimed that over the highest point of the rounded top of a triangular cross-section in which the tail-waters have no effect there is critical flow—that is, minimum specific energy with velocity $\sqrt{gh}$ and piezometric point at the free surface. For that to occur there would have to be parallel filaments, and the hydrostatic law of the distribution of pressure would have to be applicable within the nappe. There is minimum specific energy, but it is accommodated to the curvature of the filaments produced in a dam arranged in this way. The section of minimum energy below the crest is succeeded by a turbulent or rushing current which depends upon conditions upstream, constituted in this case by the crest, and also upon the slope and roughness of the walls, in this case the slope of the dam. This turbulence will not change even though the tail-water conditions may vary, and it will spend itself by means of a backwash, passing into the calm stream. The site of this backwash for a given volume of flow will be a function of the conditions of the river below the dam and of the height of the dam. If the beginning of the backwash is brought near the top of the dam, all or part of it will develop on the inclined bed of the dam facing. Above the beginning of the backwash, as we have stated, the form of the flow remains unchanged; if we move the backwash higher and higher, the moment will come when, very near the crest and beginning almost at the crest, any further alteration that we make will change the distribution of pressure and the curvature of the filaments of the flow at the crest; the depth of flow and the head *h* (Figure 3) of the weir will be altered. We can state that at this instant the insulation between the head-waters and the tail-waters is destroyed and the weir is affected.

[3]Actually, these systematic experiments confirmed our practical experience of this type of dam in water measurers and dividers since 1934.

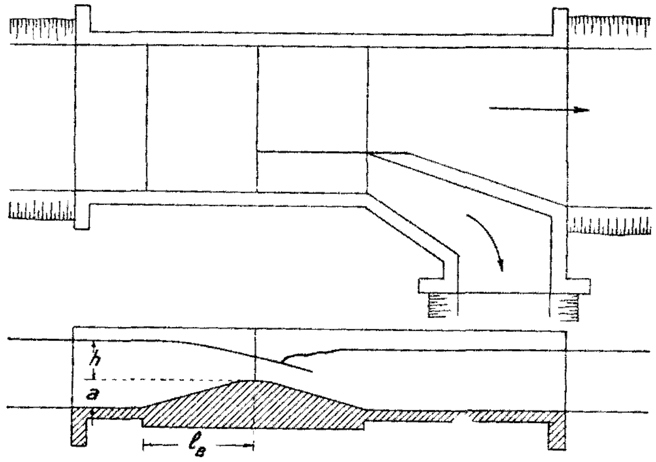


Figure 4

It is clear that under certain tail-water conditions—or, in the terms of Figure 1, when the sum $h_1 + \frac{U^2_1}{2g}$ has a certain value—the higher the dam the further from its crest the backwash will begin. Consequently it is necessary to know the minimum height that we can give the dam and still produce turbulence sufficient to ensure insulation from tail-water variations, since the minimum energy itself does not neutralize them. The distribution of pressure in such turbulence must be the hydrostatic distribution, because the water must run in parallel filaments[4] and we can obtain this condition only by experiment. Everything we have been saying has been worked out in systematic experiments on dams of the form indicated, with slopes 1: 5, heights 0.20 metre and 0.30 metre with curvature 0.125 metre radius, 1 metre wide without contraction; and contracting the channel by a funnel-type structure to 0.80 metre and 0.5 metre at the crest, with gradual widening terminating at the end of the dam[5]. The pressures in the central vertical line over the crest and the velocities were measured in a sufficient number of experiments. The same pressure and velocity measurements were made in the turbulent portion of the stream at equal distances and at a critical depth $1.5h_c$ below the crest. All volumes of flow were gauged by computation of volume, and the cross-section of the hydraulic axis was taken at levelled points; the bottom was also measured each time.

The experiments showed that throughout the width of the channel the vertical distribution of velocities was identical, which signifies that the volume of flow per unit of width is the same in any vertical line at the crest. Hence this is an unsurpassed device for water dividing. The division is made with a dividing point which is inserted up to the top of the dam with widths in proportion to the quotas (Figure 4). It does not matter if the backwash begins at a different distance from the crest provided that it does not do so at a distance less than the critical height.

[4]Under these conditions this turbulence, which is faster than the wave, cannot be altered even though tail-water conditions vary, as long as the backwash does not enter it.

[5]The form of the funnel used to produce the restriction is that described in our "*Curso de Hidráulica*", 1945, page 392 (in the note), a form which we had previously tested in the laboratory and in canals.

The curve of the crest should be given a radius greater than $3h_c$; in this way the critical height remains at the crest for all volumes of flow.

As the distribution of pressure at the crest is not hydrostatic, the level of the water at the crest cannot be measured piezometrically to deduce the volume of flow; this can be done only by direct reading. On the crest the head is for practical purposes equal to the critical head. The volume of flow could be measured and recorded by means of piezometers placed at the entrance, which give the head, h, the formula $Q = ml_0 h\sqrt{2gh}$. The experimental value of the coefficient *m* can be confirmed theoretically if the friction over the length l_B[6] is estimated. When this device is used as an indicator of the volume of flow and is planned with a contraction at the crest, then if the volume of flow is determined with the height at the crest, the same width as that at the crest must be used until the backwash begins (1 hc below the top), so that the pressure and hence the head along the walls will not fall, through the walls being further apart.

The height of the triangular dam which serves as insulation against tail-water variations can be calculated if the contraction used is not that of Figure 5 but of Figure 6. Both are summaries of experiments on models. As under these conditions (that is, of high Reynolds numbers and negligible

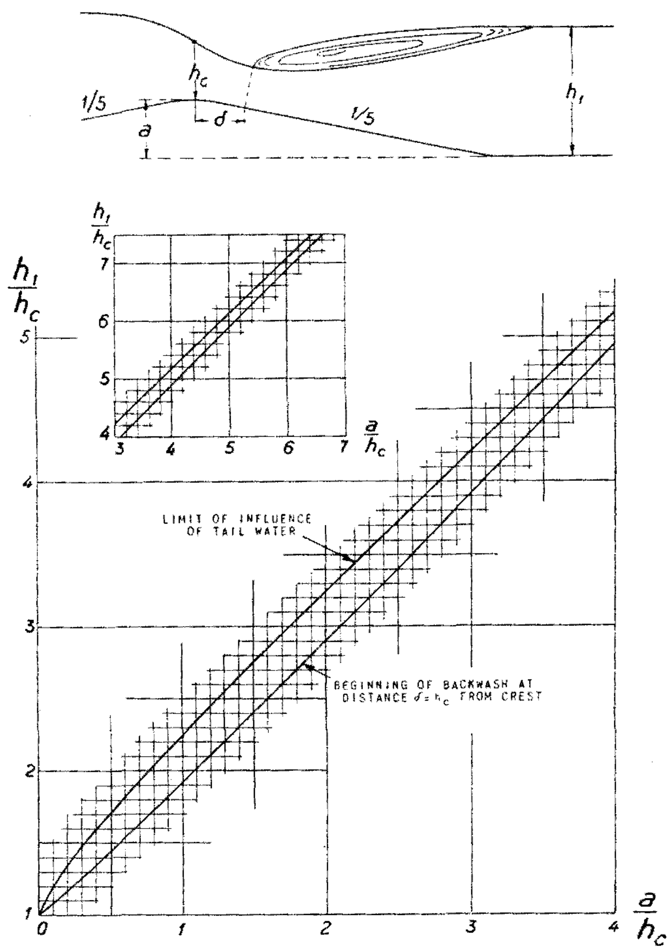


Figure 5

[6]For these details see (1), pages 431 *et seq.*

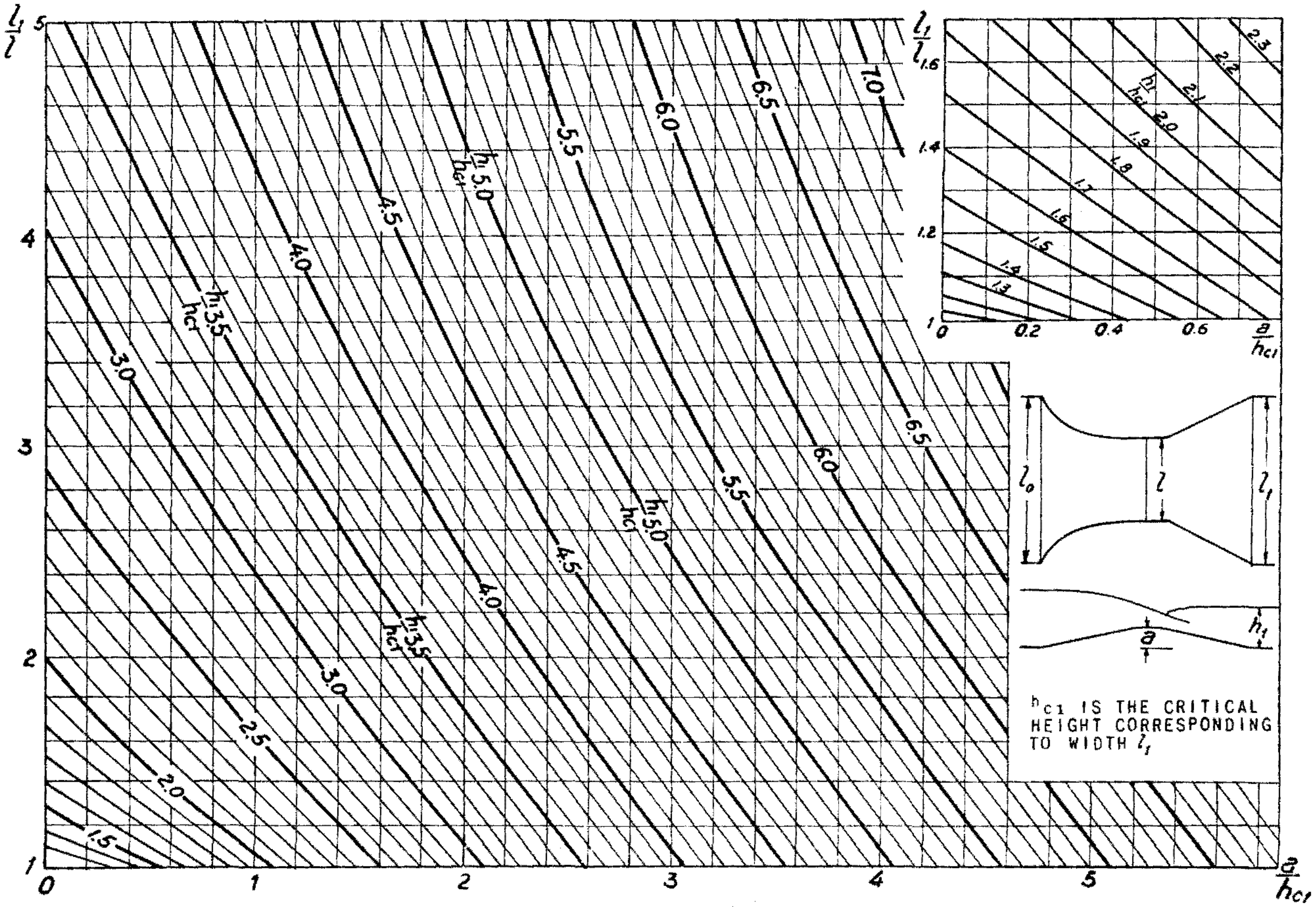


Figure 6

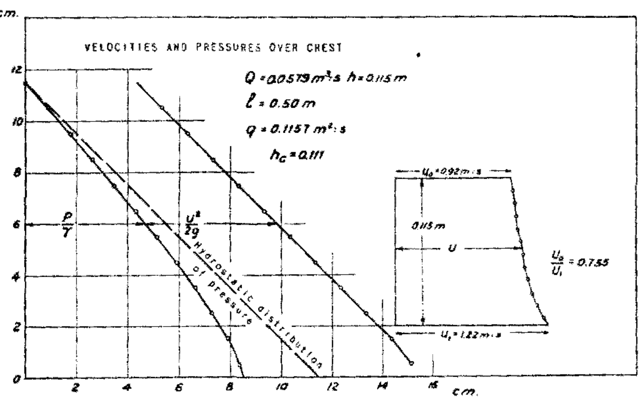


Figure 7

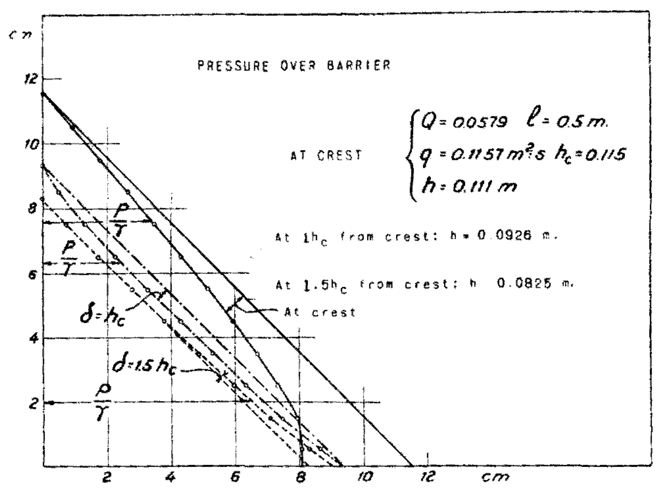


Figure 8

friction) viscosity plays no part, the graphs are true for any actual magnitudes.

Figures 7 and 8 show velocity and pressure distribution in the models at the crest and below.

A type frequently used today in Chile for dividing and measuring is the combination of the triangular dam with contraction.

The errors of division produced by these devices are less than 1 per cent, even in very small branch channels with quotas of 10 per cent of the whole. The measurers give curves that hardly exceed 1 per cent of the critical height.

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The Use of Scale Models in the Planning of River Engineering Works[1]

E. MEYER-PETER

ABSTRACT

To secure mechanical similarity between two liquid flows, the relationship between the homologous forces of the model and of the prototype must be constant. This requirement is satisfied with sufficient accuracy if the flow is definitely turbulent and if the relative roughnesses are the same. The results of experiments may be interpreted on the prototype by use of the generalized Froude's law of similarity.

In the case of river experiments, the question of similarity is more complex, as the floor of rivers is mobile and solids are carried along. Before the results of the experiments can be interpreted, the laws governing conveyance of bed-load must be known. With this end in view, the Zürich Laboratory has carried out systematic experiments. Sand of the same specific weight as that found in nature may be used in a model geometrically similar to the prototype. Froude's law applies. However, when the natural materials carried as bed-load are fine, reduction of the particles to the scale of the model becomes impossible. Moreover, the time scale becomes prohibitive in the case of the observation of long-term phenomena. It is therefore advisable in such cases to use as gravel material lighter than natural gravel. The report indicates the procedure to be followed and describes the applications of this type of experiment.

PROBLEMS OF SIMILARITY

Experiments on scale models may as a rule be divided into two groups:

1. *Purely hydraulic experiments*

This group comprises experiments in connexion with works the contour of which is not affected by currents. There is neither erosion nor silting with solids. The hydraulic structures to be considered, generally have one or more free surfaces so that the predominant factor is gravity. When other physical forces, such as frictional forces, come into play, exact similarity cannot of course be achieved (1, 2).[2] The laws of mechanical similarity require that the relationship between the homologous forces of the model and of the prototype shall be constant, and this requirement leads to a contradiction. In the case of gravity, Froude's number $\frac{v}{\sqrt{gl}}$ must be the same for the model and the prototype (v = velocity, g = acceleration of gravity, l = a characteristic linear dimension); in the case of frictional forces, the Reynolds numbers must be the same: $Re = \frac{vl}{\nu}$ (ν = kinematic viscosity). This difficulty can be eliminated, at any rate roughly, if instead of the local velocities at any given time, their time average is considered. Further, Prandtl has demonstrated (3) that when the motion is definitely turbulent, frictional forces are proportional to the square of the velocity gradient. According to the same author, the dimensions of eddies caused, for example, by irregularities in the shape of the channel, are proportional to those of the irregularities (bridge piers, weirs, etc.). This implies that head losses due to friction are proportional to the square

Figure 1. Systematic experiments on bed-load.

Figure 2. Correction of the Rhine above Lake Constance. Comparison of gravel banks in the prototype and in the model.

[1]Original Text: French.

[2]The figures in parentheses refer to items in the bibliography.

of the mean velocity (4), as Nikuradse has clearly shown by establishing that the ratio factor is constant after the Reynolds number exceeds a certain value, itself dependent on the relative roughness. The discovery of this important fact justifies the use of scale models but limits the choice of scale.

Because of these facts, the results of experiments on scale models can be interpreted on the prototype by means of a law of similarity which may be called the generalized Froude's law (5). Some difficulties remain when the facings of the canal or conduit are very smooth. Head losses measured on the model may then be corrected, for example, by means of the Gauckler-Manning-Strickler formula which provides a ratio factor that, in the case of marked turbulence, is dependent only on the relative roughness. When it is impossible to construct a model with walls of the same relative roughness as the prototype, the formula immediately provides the correction factor. These remarks apply to models which are geometrically similar to the prototype and which in general produce satisfactory correspondence for practical purposes. As regards distorted models, the author is sceptical; Prandtl's findings regarding the similarity of eddies does not seem to be applicable.

Figure 3. Correction of the Rhine above Lake Constance. Model scale 1 : 100 (brown coal dust).

Figure 4. Regulation of the Rhine between Strasbourg and Basle. Model on scale 1 : 50 (natural sand).

2. *River experiments*

The question of similarity is complicated by the fact that rivers carry solids and have a shifting bed liable to changes. Before undertaking an experiment of this kind, the type of manner in which these solids are carried along should be ascertained on the basis of systematic experiments. In river hydraulics, a distinction is made between conveyance in suspension and conveyance by rolling (bed-load). The materials transported are made up of particles varying in diameter in accordance with a certain granulometric scale. As the materials are heavier than water, they can be carried along only if the motion is turbulent.

The object of the systematic experiments is to determine the solid deposit under given hydraulic conditions (fluid discharge, width of channel, depth of water and energy gradient) and for a known granulometric size. The following experimental conditions must be observed: prismatic test channel, uniform flow of water and uniform mean flow of the solid materials. The last-named requirement does not exclude the study of the conveyance of solids with gravel banks when the solids are deposited periodically, a circumstance which complicates the experiment and necessitates a long period of observation. For the moment, conveyance in suspension must be disregarded; although quantitatively large, it does not determine the fall of the river as does conveyance by rolling.

As a result of experiments carried out in the Zurich Laboratory, it has been possible to establish an empirical formula expressing the solid deposit (time average) as a function of the tractive force (shearing tension per unit of bed surface), the specific weight of the gravel and a mean diameter. It also allows for friction on the banks and the configuration of the bottom (gravel banks and scouring) (6). Very useful data on bed-load problems can be obtained by direct observation of the movement of the solids and by still and motion photography. (Figure 1).

The formula makes it possible to solve *by calculation* certain problems of river hydraulics, including that of determining the width of the minor bed of an Alpine river carrying a great volume of solids, which cannot be solved by pure hydraulics (7).

Figure 5. Verbois Plant on the Rhône.

Figure 6. Model on scale 1 : 100 (brown coal dust).

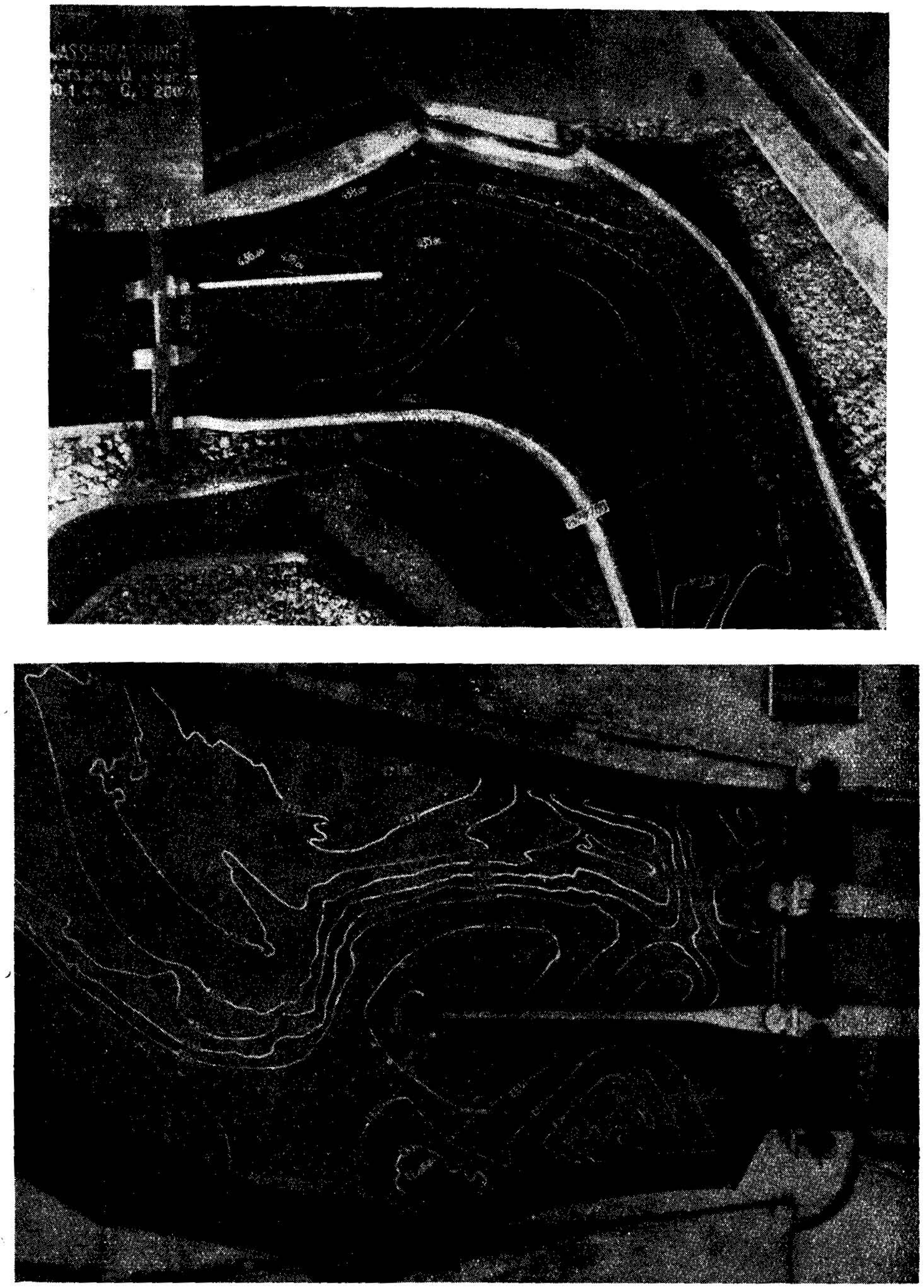


Figure 7 and 8. Lavey Plant on the Rhône, dam and water intake. Comparison of results of two models 1 : 100 and 1 : 25.

There are, however, many other problems which can be solved only by experiments on a scale model, especially where local phenomena are involved. If the solids are still stationary (low water) the use of the generalized Froude's law seems to be wholly justified provided that the scale of the model offers the certainty of sufficient turbulence and the relative roughness of the facings are the same as those found in nature. The second requirement implies that the model should reproduce the granulometry of the prototype, the diameter of the particles being reduced to scale. If the resistance of the particles to conveyance is to correspond to that of the prototype, the specific weight of the gravel used in the model must be the same as that of the natural gravel. Now, reducing the particles to the scale of the model becomes practically impossible when the river carries very fine solids. Another difficulty arises from the fact that Froude's law lays down a time scale which is out of the question for the study of phenomena of long duration; and a long-term study is absolutely necessary if a state of equilibrium is to be obtained.

Some laboratories have made use of distorted models. The author's doubts regarding the use of such models for purely hydraulic experiments seem to be even more justified in the case of bed-load experiments. By contrast, the laboratory use of materials sensibly lighter than the natural gravel seems advisable in certain cases. The law governing bed load movement then becomes an essential basis for the study of similarity. The results are as follows (8, 9): there should be geometrical and granulometric similarity; the diameter of the particles is however a multiple of that required in the use of natural sand. To offset the increased friction which results from this last requirement, the longitudinal fall of the model must be slightly increased. For a model on a scale of 1: 100 the use of brown coal dust (ratio of specific weights measured under water 1: 6.6) results in the following scales: scale of the diameter of the particles 1: 7.5, time scale for bed-load phenomena 1: 360, scale of slopes 1: 0.66. The other ratios are governed by Froude's law; the scale of fluid and solid discharge will therefore be 1: 100,000 and the time scale for the flow of water 1: 10. A special experimental technique is then required to represent sudden variations of the fluid discharge in the model. It is also found that in certain cases the increase of the longitudinal fall affects the accuracy of the cross falls of the water-level. These cross falls play a part in certain local phenomena.

APPLICATIONS AND EXAMPLES

The experiments carried out in the Zurich Laboratory make it possible to discuss some problems of river engineering.

1. *Regulation of Rivers*

The problem may be one of silting or of erosion.

Silting. Silting occurs in practically all Alpine valleys where the main river receives large quantities of solids at the junctions with numerous tributary mountain streams. To avoid a gradual rise of the bed and the danger of flooding, the bed must be regulated in such a way as to increase the carrying capacity. Either the course is shortened by means of cuttings or the cross-sections are "normalized". The lower course of the Rhine above Lake Constance has been regulated. It was planned that the minor bed should be of constant width with a fall decreasing from 1.35 per 1,000 to 0.81 per 1,000 over a distance of 25 km. (7). After the works were completed, the bed rose considerably, particularly in the middle section. Experiments on models, checked by calculation, made it possible to make an adjustment by progressively reducing the width of the minor bed as the river proceeded downstream (Figures 2 and 3).

Erosion. The Rhine between Strasbourg and Basle was made navigable when the low-water level was regulated by means of groins. A marked tendency to erosion became apparent in the upper part of the regulated sector near the mouth of the exit canal from the lock and plant at Kembs. The erosion caused a marked decrease in the low-water levels in relation to the sill of the downstream gate of the lock. Several schemes to halt the erosion were studied on two-dimensional scale models. The effectiveness of the final scheme, which called for an artificial pavement on the bed over a distance of several kilometres, was then checked on a three-dimensional model on a scale of 1: 50. Figure 4 shows the upper section of the model with the protected bed.

2. *Silting of retention reservoirs of hydro-electric plants*

The marked decrease of the energy gradient from the upstream end of the backwater towards the dam causes

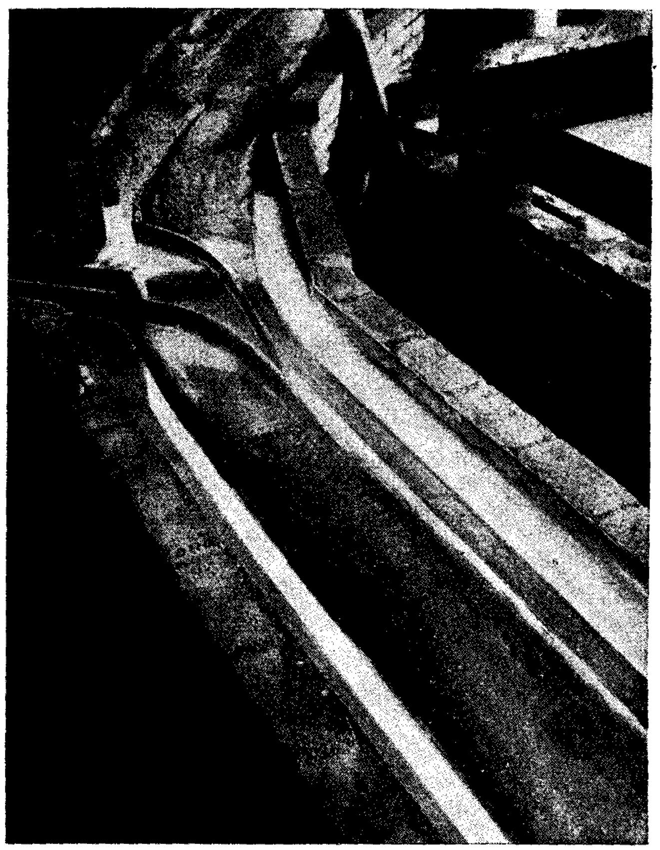


Figure 9. Wägital Plant, tail race and bypass for gravel. Scale 1 : 50 (natural sand).

silting of the bays. The settling of materials is characterized by a separation of particles according to size. Only the fine solids are transported to the dam and discharged through the sluiceways, even if the reservoir is drained. Flushing has no effect on the large stones deposited at the upper end of the bays. This phenomenon, for long a subject of discussion, was verified when experiments were carried out on a scale model for the Verbois plant at Geneva. Figure 5 illustrates the plant dam and the reservoir in its normal condition; Figure 6 shows the reservoir still silted up after 72 hours flushing.

3. *Water intakes in rivers carrying bed-load*

The water intakes and channels in many old installations have a tendency to silt up specially when the backwater is relatively small. The tendency is accentuated if the intake causes a cross slope of the water-level towards the channel. The tendency is reduced if the angle between the axis of the channel and that of the bay is very acute. It is of advantage if the axis of the intake is almost at a tangent to the outer bank of a natural curve (Figures 7 and 8). The effect of the curve can be accentuated by a separation wall prolonging the first pier of the dam. A cross fall of the water carrying the gravel towards the open sluiceways is caused if the first sluiceway is closed and the flood-water is released through the other openings. Figure 7 (scale 1: 100, brown coal dust) and 8 (scale: 1: 25, natural sand) show the correspondence between the two experiments carried out in connexion with the Lavey plant.

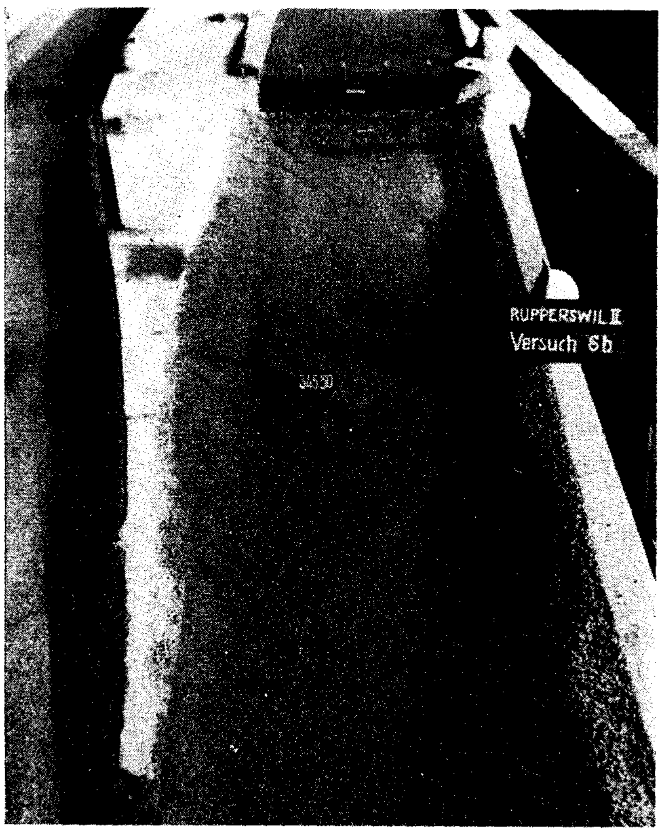
4. *Tail Races*

The dredging of a tail race, parallel with the river, can often be avoided with advantage if the natural bed's fall is reduced by dredging. This has caused the sanding-up of the Siebnen plant race (Wägital). Experiments on a model show how an artificial channel with a steep fall (10 per 1,000) completely removes the solid materials from the stream (Figure 9).

At the Rupperswil plant (Aar) the mouth of the tail race is 1.1 kilometres upstream of the concession boundary. The fall of the Aar was reduced to 14 per 1,000 by dredging. The resulting break in the longitudinal section necessitated the construction of a reinforced concrete sill 0.4 km. upstream of the mouth to eliminate erosion upstream and the silting of the new bed. Figures 10 (natural sand) and 11 (brown coal dust) show the old bed with the sill and the mouth of the channel. The retention of gravel in the bays of the plant destroys the balance and causes slight erosion of the old bed at the downstream side of the dam, which causes the bank of gravel seen on the photographs.

5. *Correction of mountain streams*

Figure 12 illustrates an experiment relating to a series of dams at the outlet from a dump of gravel and rocks carried down by the Durnagel stream (Glaris). The object was to protect the bed of the Linth against erosion and silting.



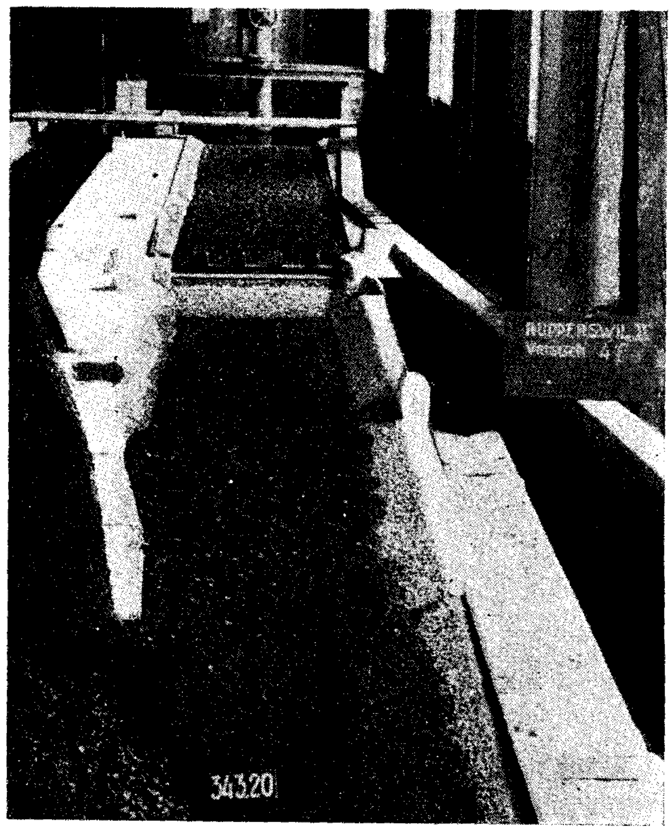


Figure 10 and 11. Rupperswil Plant on the Aar, mouth of tail race in the Aar.
Comparison of two experiments using natural sand and brown coal dust, Model scale 1 : 100.

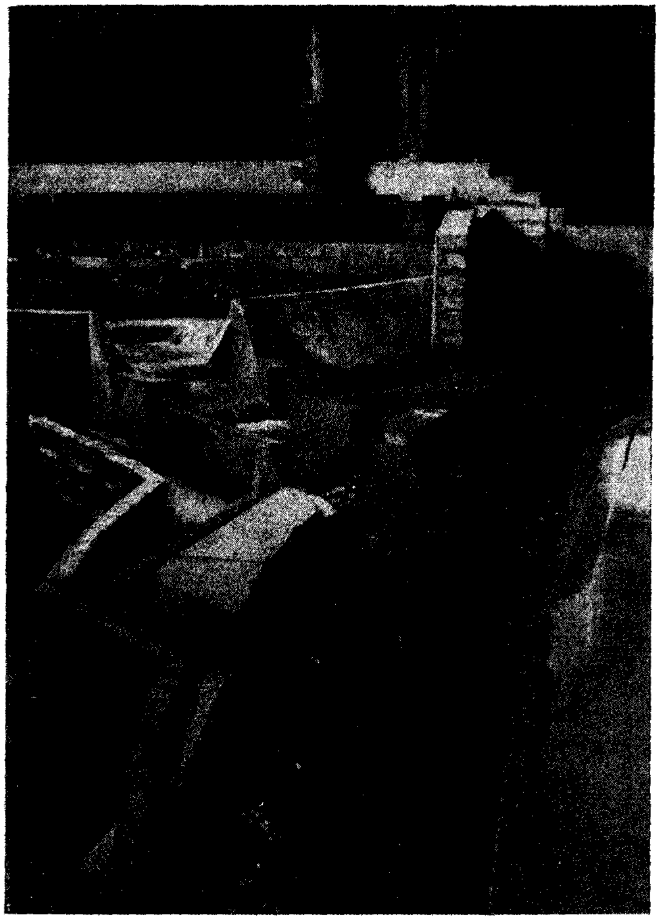
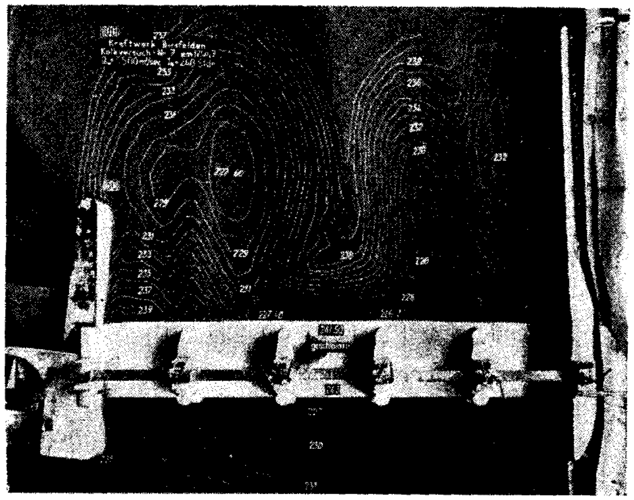


Figure 12. Durnagel, mountain stream, exit from dump. Scale model 1 : 40 (natural sand).



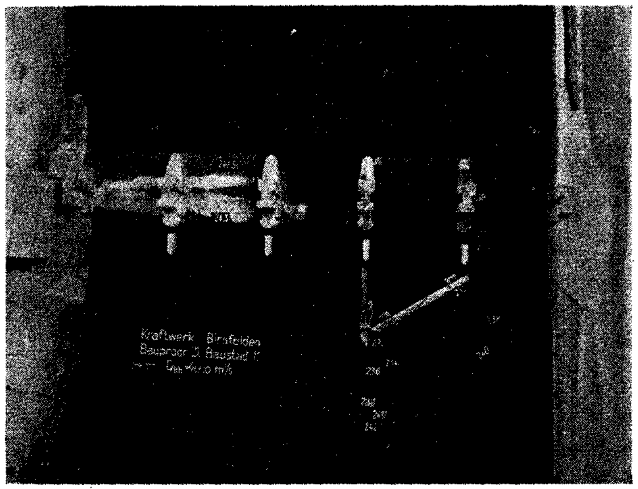


Figure 13 and 14. Birsfelden Plant on the Rhine, dam and stages of construction, scouring, scale model 1 : 100 (natural sand).

6. *Scouring at dams*

Many laboratories have studied the phenomena of scouring *downstream* from dams. However the phenomenon of erosion upstream of the sluiceways is not generally known. This occurs chiefly during the passage of flood water when one sluiceway remains closed. This causes marked and frequently asymmetrical scouring downstream of the dams as well (Figure 13). Increasing use is being made of models to study the various stages of construction as well as the completed dam. Constriction of the river by the building of coffer dams causes marked local erosion and currents which may hinder navigation. Figure 14 shows a stage in the construction of the Birsfelden plant on the Rhine.

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The Use of Models in Planning Water-Control Works

INAYAT HUSAIN and K. J. KABRAJI

ABSTRACT

Models are defined, and their varieties and characteristics described. They need not necessarily be exact and smaller replicas of prototypes ; the reliability of models in water-control planning is discussed ; and the need for their use wherever possible is stressed.

The progress made by various countries in this respect is outlined, the share of these research institutions and experiment stations in undivided India that has accrued to Pakistan is stated, and the intention of Pakistan to make much more use of this method and the manner in which it is hoped to do it are indicated.

A model is defined as a system by whose operation the characteristics of other similar systems may be observed and predicted. This definition does not—and should not—imply that a model is necessarily a small and complete reproduction of the system with which it is to be compared, or that all its dimensions are reduced in the same degree. Thus there have been instances of models having been made to the same scale as the prototype, or even to a larger scale, but of some cheaper or lighter or easily replaceable material. Nor need any but the essential details be reproduced. Also, a particular dimension like height or depth may advantageously be reproduced on a different scale than the other dimensions.

VALUE OF MODELS

The large majority of models in engineering works are, however, made to a much smaller scale than the prototype. Investigation by means of models is in most cases a much happier alternative to the theoretical—which is usually a highly mathematical—solution of a problem, or to empirical or rule-of-thumb formulae applied to it. In many cases, moreover, theoretical analysis is impossible or too difficult and lengthy, and the application of empirical formulae requires too many assumptions, not all of which may be quite justifiable.

RELIABILITY OF MODELS

Where all the dimensions and other physical properties of the prototype are well known, a model on a reasonably small scale can give a very accurate picture of the working of the prototype and can permit a very accurate prediction of what would be the result of certain changes in the prototype. It is only where the data concerning the prototype are insufficient or no longer obtainable, as, for instance, due to destruction of the prototype or unknown changes having taken place in it since its dimensions were recorded, that the results may not be so well relied on.

INVESTIGATIONS BY MEANS OF MODELS IN THE LEADING COUNTRIES

The value of models for this specific purpose is no longer in doubt, and most advanced countries make extensive use of them. Pakistan, however, has comparatively few facilities in this regard, as will be seen from the following.

The United States of America, with its numerous universities, technological institutions, and the U.S. Bureau of Standards, the U.S. Waterways Experiment Station (Vicksburg, Mississippi), the U.S. Bureau of Reclamation and the Tennessee Valley Authority, have a very satisfactory system of model experiment stations all over the country. The U.S. Waterways Experiment Station has developed probably the largest river-model in the world, that of the Mississippi River Basin. It has constructed an outdoor model of the entire drainage area (1,243,600 square miles) on a large plot of land, and all prominent features of the area are suitably represented. The Bureau of Reclamation and the TVA have their own hydraulic laboratories, where they carry out planning and research on their own problems and on problems referred to them by other agencies as occasions arise.

Among European countries which have employed models for water-control planning works, England, Switzerland and France take the lead today. But hydraulic engineers in pre-war Germany have also done much valuable work with them. Undivided India also has made good use of models in the last decade, and there have been the Irrigation Research Institute at Lahore and other Experiment Stations in the Punjab, Sind, in the United Provinces at Lucknow and Bahadurabad, in Bengal near Calcutta, and the Central Irrigation and Hydrodynamic Research Station (now known as the Central Waterways Experiment Station) near Poona in Bombay Province.

INVESTIGATIONS BY MEANS OF MODELS IN PAKISTAN

Of these only the Irrigation Research Laboratory at Lahore and the small Sind Government Experiment Station at Karachi have come under Pakistan. The former, however, has been collecting hydraulic data from all over the undivided province of Punjab and has been carrying on research and investigation on a large variety of hydraulic problems by various experimental methods and techniques.

The time at the disposal of the writers is too insufficient to obtain from these institutions anything like a comprehensive report of their work and their findings.

The Government of Pakistan intends to establish experiment stations at various points distributed over the country, and particularly in East Bengal, where the need at present is greatest. It will also encourage the various engineering colleges in Pakistan to have good hydraulic laboratories where investigation by models will have a prominent place. Thus a great need of those engaged in planning irrigation and other water-control works will be filled, future developments and progress will be greatly facilitated and much economy of time and money and a general increase in prosperity, it is hoped, will result.

The Use of Small Scale Models in River Research

M. DANEL

ABSTRACT

Many complex problems are entailed in the utilization of the benefits afforded by rivers as well as in the protection required against their detrimental effects. The usual answer to these problems takes the form of widely varied constructional works, such as dams, desilting devices, coffer-dams, locks, dykes, dredging, spur dykes, meander cutting, etc.

A small-scale model of these works allows an inexpensive representation of natural phenomena, the evolution of which is slow (silting-up), or the occurrence rare (large floods).

Public administrations and private organizations have created numerous hydraulic laboratories for the study of such problems. The latter are, however, of such a complex nature that a detailed study is only possible in such laboratories as possess varied and efficient material, capable of being adapted to all techniques.

Such laboratories are staffed by experienced technicians, specializing in pure and applied mathematics, theoretical and experimental physics, chemistry of water, chemistry of corrosion, electronics for measuring apparatus, geology, geophysics, hydrology, hydro-geology, soil mechanics, potamology, meteorology, photography, cinematography, civil engineering, resistan ce of materials and topography; a library is also provided for the study of books and other publications in all languages.

With such material resources, it is then possible to undertake and solve all types of river-research problems.

The scope of this subject is so vast that here we can give only some general aspects of the problem without delving into technicalities, however interesting they may be, for the problems a river presents to the river engineer are complex and multifold. These problems fall into two general inter-related categories—firstly, the development of a river's natural resources, and secondly, the prevention of destruction to property and resources that a river may sometimes cause.

The flow of a river may be rendered beneficial in various ways; it may be used for the production of power, for navigation, for supplying irrigation water, or even for supplying communities with water. On the other hand, a river may sometimes be used for the disposal of sewage and various industrial wastes.

In many cases, fish from rivers supply a fair amount of essential food. Rivers often afford recreational facilities of growing social importance, especially near large cities.

On the other hand, river waters may cause havoc and disaster, as in the case of major floods that destroy valuable property, if proper engineering provisions have not been taken in due time.

Many rivers are heavily laden with silt or carry an important bedload of coarser material. In silting-up their beds, they raise the mean water-level, gradually rendering inadequate protective works, such as levees. The adjoining water table rises in turn, and valuable agricultural land may be turned into boggy marshland.

The silting-up of reservoirs, either natural or artificial, is also a serious menace. Much land may have been reclaimed through irrigation from reservoir water, and just when it has reached full production, after painful toil and hardships, it may have to be gradually abandoned owing to the dwindling capacity of the reservoir.

The silting-up of canals results in excessive maintenance costs, since certain silts are detrimental to agriculture and must be removed from irrigation water before use.

Often the river engineer must also take measures for mosquito control.

Again, the encroachment of salt water within fresh water in certain estuaries may be a menace.

Or, in estuaries with fairly high tide ranges, the hydraulic bore may be a great navigation hazard.

These are some of the important problems that confront the river engineer.

The answer to these many problems must be sought by means of river works of various nature. To achieve the best engineering and the most economical results, the answer must be based on adequate research in an up-to-date and outstanding laboratory where the experience and science of both the civil and the hydraulic engineer combine to achieve the best results. Among the hydraulic works thus studied, will be:

Dams of many types, with accompanying works, flood-spillways, intakes, bottom outlets, diversion tunnels, tail-race, power-house, fish ladders, etc.

Desilting devices for irrigation or power canals.

Coffer-dams, often to be built in running water.

Navigation locks which must be provided at minimum cost for a future increase in navigation traffic.

River control-works by means of levees, bank revetment, groins, spur dikes, dredging, cut-off of meanders etc., these control works being either for navigation purposes or flood control.

Hydraulic laboratories have been gradually developed in many countries by various governmental agencies, such as the laboratories at Vicksburg, Miss. (U.S. Engineers), Denver, Colo. (U.S. Bureau of Reclamation), or Chatou (Electricité de France, Ponts et Chaussées). Many others have sprung from initially small university laboratories, and some of these have grown to be fairly important research institutions.

Some laboratories are privately owned and are operated on a consulting engineering basis. This, for instance, is the case of the Neyrpic laboratory in Grenoble, France, which has probably the largest engineering and scientific staff devoted to hydraulic research of the type here considered.

In many cases, research is conducted by means of scale models, where the various conditions are faithfully reproduced. Due to the correspondingly reduced time scale, it is possible to study, at relatively small cost and in a short time, problems that it would sometimes be impossible to study in nature in a lifetime. For instance, major floods can be reproduced at will without having to wait for the occurrence of a major catastrophe in nature.

As well as scale models, the laboratory studies, by appropriate means, some basic laws, such as bed-load problems, waves, waterhammer, etc.

Many of the river problems that come to the laboratory are very involved, and instances where they could be efficiently handled by small, "one-man" laboratories are probably rare except for a few chosen items. A modern laboratory comprises a fairly large staff of scientists and technicians.

Although the general direction of the research projects undertaken has always to do with some branch or other of applied hydraulics, it has become necessary to make use of a wealth of knowledge, usually classified under various headings.

1. Mathematics, pure and applied. The laboratory will come across problems which, more often than it would like, are new even to highly-trained professional mathematicians.

2. Physics, theoretical and experimental, in its various aspects; in this field a project is often considered from a new angle even when the subject matter is classic.

3. Chemistry of water, chemistry of corrosion, etc.

4. Electronics, as applied to measuring apparatus and various controls which have to be devised in the laboratory.

5. Geology, geomorphology, hydro-geology, hydrography, potamology, meteorology and various related sciences.

6. Photography, still and moving pictures with various special effects, according to the nature of the research.

7. Civil engineering, covering not only all phases of hydraulic works, but also applied to strength of materials, surveying, field practice, etc.

8. Documentation. The laboratory must have an up-to-date library at its disposal where its staff can follow all useful technical papers that are published, whatever be the language. The laboratory must therefore have a staff of engineering linguists.

These are some of the important branches of knowledge for which the laboratory must have first-rate personnel. This list, of course, is by no means limitative.

The consulting job now undertaken by these large research laboratories has become of vital importance to enable mankind to make the best use of the resources afforded by natural waters, or to avoid destruction of resources or property that these natural waters may sometimes cause.

The Use of Models in Planning Water-Control Works

L. G. STRAUB

ABSTRACT

A great variety of problems arising in the planning and design of water-control works can most effectively and economically be solved by techniques of the modern hydraulic laboratory. Innumerable types of hydraulic structures required, for example, in river-development programmes for navigation, irrigation, water-power and flood control come under consideration.

The broad concept of the hydraulic laboratory as an adjunct to planning and design is set forth rather than the limited consideration of models in the narrower sense of small-scale reproductions of projected structures. The application of the broad concept can almost invariably lead to great improvements and economies in final developments; the narrower concept is less fruitful and frequently inapplicable.

Emphasis is placed on the importance of a basic knowledge of fluid mechanics and the mechanics of similitude. Approaches to the experimental analysis of a number of classes of hydraulic structures are described and photographically illustrated, including standard designs for soil conservation works, flood spillways, embankments, coffer-dams and navigation works; also discussed and illustrated are questions of entrainment of air in water at high velocity flow, erosion and sediment movement, repair of existing structures and rigid bed models.

INTRODUCTION

Water-control works planning encompasses a great segment of the total sphere of activity of the civil engineer, particularly when one considers the subject in its broader aspects. Thus, for example, included is the planning of innumerable types of hydraulic structures required in river-development programmes for navigation, irrigation, water-power and flood control. These in turn are manifested as dams, canals, ship locks, desilting works, channel contraction works, shore protection works, penstocks, surge tanks, spillways, flow diversion works, movable gates of many descriptions, coffer-dams and the like. But water-control works are not confined to river development; also involved are hydraulic structures for sewerage systems, municipal water-supplies, highway and airport drainage, seaport development and coastal protection structures, to mention only a few.

All of these classes of hydraulic structures subject themselves, with various degrees of limitation, to experimental analysis in the properly equipped hydraulic laboratory. But lest I be misunderstood, I here emphasize that by experimental analysis I do not confine my reasoning to small-scale models but rather include the whole gamut of techniques that the modern hydraulic laboratory can place at the disposal of the engineer.

In approaching the planning and design of a water-control structure, let us not confine our thinking to the question, "Can the structure be designed by means of a small-scale model experiment?", but rather let us ask, "Can design problems of the structure be economically subjected to laboratory analysis?" To the first question, namely applicability of small-scale model experiments, we must frequently reply in the negative; to the second question, which is definitely of wider scope, we can almost invariably reply in the positive in the case of major projects.

In the discussions of this paper, the foregoing introductory statement will be exemplified and elaborated upon.

FUNCTION OF THE HYDRAULIC LABORATORY

The popular concept among practising engineers, and this concept is not entirely erroneous in fact, is that the planner can carry his troublesome hydraulic designs into the laboratory to be checked and corrected by small-scale models. Investigations are made on miniature rivers, harbours, overflow works and so on, modelled precisely to resemble mighty watercourses in nature. Floods, tides, waves and winds can be produced at will. Control works such as spur dykes, spillways, flood gates, with all possible variations are built into miniature watercourses. Studies are made to learn what effects may be expected by such structures when actually built in nature.

Now the foregoing statement is quite acceptable in fact, provided it is also recognized that not all hydraulic motion conditions met with in practice can be imitated by means of a small-scale model, nor solved by the similarity principles. Actually only in a relatively few hydraulic design problems can one achieve perfect similarity in a model. Thus discernment must be exercised as to whether or not the specific motion occurrences involved can be strictly subjected to the requirements of similarity, or whether the natural force systems influencing the flow condition act against the possibility of similarity in the model and permit only approximate similarity—more or less adequately for practical purposes depending upon the nature of the case.

Because of the inherent limitations imposed upon small-scale model experiments by the principles of similarity, another approach to the problem is often necessary. Frequently one finds recourse in full-scale experiments on elements of the structure and by making use of basic information arising from fundamental research. A specific typical example of an experiment might be cited.

Involved was an earth dam to impound a municipal water-supply. The dam was to be approximately 60 ft. high and a mile long. A flood-flow spillway, capacity of 650,000 sec.-ft., had to be provided. The stream-bed was of medium-size sand and extended to a depth of about 20 ft. to the underlying clay stratum on which the spillway had to be founded. Now the cost of the earth dam was estimated to be about \$20 per foot length, while the cost of the spillway was approximately \$200 per foot length.

From the foregoing brief description, it is evident that from an economic point of view it is desirable to keep the spillway as narrow as possible because there is a saving of approximately \$180 for every foot reduction in its length. However, for high flows, the velocity of approach to the spillway was estimated to be in the order of 16 tt. per second over the sand-bed of the stream, which would result in major erosion in the approach channel. If this erosion was to be prevented, then the spillway would have been almost the complete length of the dam and at an enormously greater cost. The important consideration was that the structure should be safe for all flow conditions of the river but as economical as possible.

Now in the foregoing condition, the spillway itself could be readily designed and analysed by means of small-scale models. However, in the case of the small-scale model, the approach velocity and corresponding tractive forces on the stream-bed were so small that the erosion of the sand in the approach to the model dam could not be simulated. Experiments on the sand itself, in a special test channel, could establish its erodibility for the various velocities determined for the actual river. It was not considered serious for the sand to be scoured out on the upstream side of the dam but the clay foundation should not be scoured in the approach channel or the structure might be undermined. Several undisturbed large specimens of the clay strata were therefore brought to the laboratory for full-scale tests of the resistance to erosion for various velocities and durations of flood-flow conditions. It was thus determined that the approach velocity on the clay strata should not exceed 12 ft. per second, at which velocity the clay quite abruptly began to disintegrate. The over-all length of the spillway was thereby established by full-scale tests on the clay, while the details of the spillway and spillway apron could be established by means of models constructed to a scale of 1: 60.

KNOWLEDGE OF FUNDAMENTALS REQUIRED

Space here will not permit a complete and detailed treatment of the analytical reasoning involved in the experimental design of a hydraulic structure, nor is this the purpose of our discussion. Suffice it to say that introductory and indispensable to either model experimental work or supplementary large-scale hydraulic laboratory experimentation, is a basic knowledge of the mechanics of similitude. Presupposed, of course, is a knowledge of fluid mechanics. I here purposely distinguish fluid mechanics from hydraulics in that I emphasize the need of a knowledge of the mechanical properties of fluids and their influence in motion occurrences of fluids under the action of natural forces. The properties of water—the value of its viscosity at different temperatures, its surface tension, compressibility, vapour pressure—are important parameters in the experimental approach to the design of hydraulic structures.

At this point I shall discuss, in more or less general terms, a convenient approach to the mechanics of similitude so as to show a method of providing a framework for planning a laboratory research study. Several schematic ways of establishing this framework for guiding experimental studies and the interpretation of test data are available. However, I wish to say that I have no brief for any special procedure; rather, I would emphasize that it is important for the researcher to visualize the physical factors involved in the flow problem under consideration.

By setting up so-called "model laws" one provides a systematic way of considering flow problems from a similarity point of view. This procedure shows clearly, at least qualitatively, the limitations in applying the mechanics of similitude to the interpretation of observations on an experimental model.

Customarily, one speaks of three kinds of similarity, namely, (*a*) geometrical similarity, which relates to similarity in form, that is, two systems are geometrically similar if the ratios of all homologous distances in the two systems are constant; (*b*) kinematic similarity, or similarity in motion patterns in two geometrically similar systems without regard to the force system which produced those motion patterns, so that the time ratios for all homologous motion cycles in the two occurrences are constant; and, (*c*) dynamic similarity, in which the motion patterns of the two kinematically similar occurrences take place under the influence of natural forces.

If we consider the systems of forces producing a characteristic motion of any particle in a fluid medium, we find that the forces can be classified into those which are inherent in the properties of the fluid, such as gravitation (characterized by the unit weight of the fluid), internal fluid friction (characterized by viscosity), capillarity (characterized by interfacial tension between different mediums), and elasticity (characterized by compressibility of the fluid medium). These are referred to as physical forces, each force being defined by a physical coefficient. On the other hand, the magnitude and direction of the resultant force on any particle of fluid determines the direction of its motion. Inasmuch as the physical force influencing the motion is included as a component in the resultant force for any single particle or system of particles, the ratio of the mass accelerating forces in the model and prototype respectively, must be equal to the ratio of the physical forces in the model and prototype. From this concept, we are able to establish the relationship for true similarity in flow conditions in an actual structure and a small-scale model.

A SUMMARY OF MODEL LAWS

Important in an analysis of the kind presented in the foregoing is that for each different physical force, a corresponding special model law shows that the operation of the model for similarity should be at a different speed relationship. If we use the subscript *m* to refer to a magnitude in the model, the subscript *p* to refer to a corresponding magnitude in the prototype, and the subscript *r* to designate the ratio of corresponding magnitudes in the model and prototype, then in setting up a "model law" for similar motion occurrences in the model and prototype, the time ratio:

$$T_r = \frac{T_p}{T_m}$$

is determined as a function of the length ratio; so that

$$T_r = \Phi (L_r).$$

This ratio is then referred to as the model law for the particular occurrence.

In case only inertia forces of the flowing medium influence the motion pattern described by the fluid particles, then we need not adhere to any particular model law. For such cases the pattern followed by the fluid particles will be the same regardless of the speed of operating the model, that is, Tr is no longer fixed by a controlling physical force and the scale of the model.

A summary of the model laws more frequently met with in fluid flow problems is given in Table I. The so-called dimensionless number can be derived directly from the model law by dividing the model-law equation by the right hand side of the equality and dimensionally interpreting the result. The dimensionless number associated with each model law is also characterized by a "kinematic factor" which I have arbitrarily introduced in our nomenclature at the bottom of Table I, under the characteristics of the various physical forces.

Table I. Fundamental Expressions in the Mechanics of Similitude for Fluid Motion

A. Principal Classes of Forces

		Dimensionless number	Model law
I. Physical forces			
Gravitation . . .	$\frac{V^2}{Lg}$	(Froude) Fr	$T_r = \sqrt{\frac{L_r}{g_r}}$
Fluid Friction . .	$\frac{VL}{\nu}$	(Reynolds) Re	$T_r = \frac{L_r^2}{\nu_r}$
Elasticity.	$\frac{V^2}{E/\varrho}$	(Cauchy) Ca	$T_r = \frac{L_r}{\sqrt{E_r/\varrho_r}}$
Capillarity. . . .	$\frac{V^2L}{S/\varrho}$	(Weber) We	$T_r = \frac{L_r^{3/2}}{\sqrt{S_r/\varrho_r}}$
II. Inertia Forces . .	$\frac{F}{\varrho V^2 L^2}$	(Newton) Ne	Indefinite

III. Forces having no influence upon motion occurrence within definable limits, such as atmospheric pressure, static forces on sides of vessel in which motion takes place and other forces statically counterbalanced by equal and opposite force.

B. General Dimensionless Equation of Fluid Motion

$$Ne = \Phi \text{ (Fr, Re, Ca, We)}$$

or

$$F = \varrho V^2 L^2 \Phi \left(\frac{V^2}{Lg}, \frac{VL}{\nu}, \frac{V^2}{E/\varrho}, \frac{V^2L}{S/\varrho}\right)$$

C. Characteristics of Physical Forces

Physical Force	*Kinematic Factor*	*Name*
Gravitation	$g = W/\varrho$	Kinematic weight
Fluid Friction	$\nu = \mu/\varrho$	Kinematic viscosity
Elasticity	E/ϱ	Kinematic elasticity
Capillarity	S/ϱ	Kinematic surface tension

Table II is an interesting comparison of how the various controlling physical forces influence the operational requirements of a model to obtain similarity with the prototype. The tabulation is based on the criterion that the fluid in the model is the same as in the prototype, for example, water at the same temperature in both.

TYPES OF HYDRAULIC WORKING MODELS

There are many types of working models that find a place in experimental design of the innumerable kinds of hydraulic structures encountered in practice. Just as there are hardly two major hydraulic structures alike, so hardly

Table II. Conditions Which Must Obtain in Model for Similarity of Occurrences with Prototype for Various Types of Physical Forces

Assuming the Medium in the Prototype the Same as the Medium in the Model, Scale Ratio of Model = 100

Type of physical force	*Name of model law defining occurrence*	*Model Law (Relation of time ratio to length ratio)*	*Time periods* $\frac{T_p}{T_m}$	*Velocities* $\frac{V_p}{V_m}$	*Accelerations* $\frac{ap}{am}$	*Forces* $\frac{F_p}{F_m}$	*Stresses* $\frac{S_p}{S_m}$	*Typical types of occurrences*
Force of gravitation	Froude	$\frac{T_p}{T_m} = \left(\frac{L_p}{L_m}\right)^{1/2}$	10	10	1	1,000,000	100	Flow over dams, pendulum motion, falling bodies, some types of waves, seiches, machines, pumps, turbines, etc.
Force of fluid friction	Reynolds	$\frac{T_p}{T_m} = \left(\frac{L_p}{L_m}\right)^{2}$	10,000	$\frac{1}{100}$	$\frac{1}{1{,}000{,}000}$	1	$\frac{1}{10{,}000}$	Flow through pipe lines, motion of submarines and aircraft, resistance of smooth surfaces, etc.
Force of elasticity	Cauchy	$\frac{T_p}{T_m} = \frac{L_p}{L_m}$	100	1	$\frac{1}{100}$	10,000	1	Waterhammer and other oscillating and vibrating influences, depending upon the elasticity of the fluid. Also for conditions of fluid involving velocities near that of sound in the fluid.
Force of capillarity	Weber	$\frac{T_p}{T_m} = \left(\frac{L_p}{L_m}\right)^{3/2}$	1000	$\frac{1}{10}$	$\frac{1}{10{,}000}$	100	$\frac{1}{100}$	Phenomena due to surface tension at plane of separation between two different fluids, such as ripples on lakes.

two model studies are planned alike. The model should always be designed to achieve special objectives as regards the planning of the actual structure. Only very rarely, if ever, can a single model be made to duplicate completely all features of an entire water-control works. More frequently, several independent models are required to establish various design features of a major structure, each model being especially planned for the analysis of a limited number of important features of the control works.

CLASSIFICATION OF MODELS ACCORDING TO THE CONTROLLING PHYSICAL FORCE

As a major classification of types of models, the controlling physical forces are of special significance. Thus the force of gravity most frequently is the physical force predominating in the flow or motion pattern encountered in water-control structures. But to a more or less degree, and sometimes in a predominating role, one or more other physical forces influence the discharge relationships and flow patterns. The model is then built and operated in accordance with the model law defined by the algebraic formulae involving the controlling physical force.

If no other than the predominating physical force influenced the flow pattern, then there would be theoretically no lower limit in the scale of model applicable to simulate the actual structure with great accuracy. But such singularly ideal conditions are almost never met in practice. We are usually confronted with one or more "secondary force" influences—frequently fluid friction in cases where gravity controls the occurrence—producing what is referred to as "scale effect" in the model. This causes the flow pattern in the model to deviate from that in the full-scale structure, more or less depending upon the degree of influence of the secondary physical forces. If the model is made too small, the secondary forces might influence the motion pattern to such an extent that the flow in the model no longer even approximately simulates that in the actual structure. Experimental results from such a model, although it may be precisely geometrically similar to the prototype, would not be applicable to predicting flow conditions in the latter.

From the foregoing, it will be recognized that the working model must be designed and operated to conform to the model law defined by the controlling physical force, and the scale reduction must be limited by the stipulation that the pattern of flow of particles of fluid must be similar in the model to that in the full-scale structure.

Let us now consider a number of special types of hydraulic structure design problems and the laboratory approach to their solution.

STANDARD DESIGNS FOR SMALL SOIL CONSERVATION STRUCTURE

In soil conservation work, the control of run-off is essential to prevent erosion. Where such structures are not properly designed, a serious localized damage may develop by undermining of various parts of the structure. Analytical methods of design are quite inadequate and unsatisfactory.

While the cost of such control structures is not large for each unit, in the aggregate many millions of dollars are spent annually in the United States for these structures. It has therefore become important to establish standard designs applicable to all conditions for which the control structures are to be used. This design problem resolves itself into obtaining and cataloguing field information to establish the range of conditions under which such structures are used. This information must include the variations in height of drop, discharge, tailwater elevation and general character of the terrain. With such basic information as to operating conditions and with the aid of past experience as well as theoretical considerations, hydraulic models are constructed and tested repeatedly with various discharge rates and tailwater elevations.

Changes are made in the standard structure until optimum designs are obtained both with regard to economy and performance.

Models of this sort are operated in accordance with the Froude model law, inasmuch as gravity forces control the occurrence and establish the flow pattern. The criterion for quality of design in the case of most soil-conservation structures is the dissipation of energy as manifested in lessened degree of scour downstream of the structure. A standard sediment is used in all tests, and the study is based upon the comparative erosion occurring in the different designs. The end result is a manual of standard designs which is available to field engineers concerned with the planning and construction of these water-control works.

EROSION CONTROL BELOW SPILLWAYS OF DAMS

Spillways for major dams are now usually analysed by means of laboratory models. The dissipation of energy of the water flowing over the spillway is important in order to prevent damage to the structure by scour of the foundation below the spillway. Where sufficient precaution has not been taken in such structures, serious damage has resulted, even in some instances where the dam was constructed on bedrock.

The flow occurrence over a spillway is brought about by the force of gravity, and the model is therefore constructed in conformity with the Froude model law. In the majority of instances, considerable advantage and economy is obtained by making two spillway models: (*a*) a section model to a fairly large scale; and subsequently, (*b*) a full model (or so-called "three-dimensional model") of the spillway in its position in the dam.

The section model is constructed into a glass-sided channel with a standard sand forming the stream-bed material at the toe of the spillway. In the case of a gated spillway, it is sometimes convenient to include one full bay flanked by two half-bays. Most hydraulic laboratories concerned with the experimental analysis of hydraulic structures have available a glass-sided channel for such purposes.

The objective of the experiments on the section model is to establish an optimum design which will result in the dissipation of energy of the high-velocity flow from the spillway in a hydraulic jump or by means of special energy-dissipating devices usually in the form of massive concrete piers or dentations.

The pattern of erosion below the spillway depends largely upon the flow pattern of the high-velocity jet issuing from the spillway. This flow pattern can be varied by changing the baffles or other energy-dissipating arrangement of the apron or stilling basin.

In most cases, the erosion pattern in the model simulates that in the prototype quite satisfactorily. The size of the sediment used in the model is usually not of major importance, provided it is readily erodible by the issuing stream. The nature of the scour-hole below the spillway develops nearly the same for a quite wide variety of sediment sizes; however, the speed with which the scour-hole develops is dependent upon the size and therefore on erodibility of the sedimentary material.

In the case of high dams, the flow pattern at the toe of the spillway is probably considerably influenced by the entrainment of air in the water. There is thus induced a limit of applicability which has thus far not been established. Some fundamental research is required regarding this limitation.

The full model, which usually would include the entire spillway and the adjoining ends of the flanking dam, is normally constructed to a smaller scale than the section model and is used to determine conditions of three-dimensional flow, such as eddy formation along the wing walls of the spillway and similar conditions related to the spillway as a whole. In general, the construction of the three-dimensional model should not be undertaken until the general form of the spillway and apron have been established by experiments on the section model.

STUDIES OF EMBANKMENTS

Dams built of sand or earth may advantageously be subjected to a number of types of laboratory analysis, including model studies. Experiments on such structures in the laboratory require careful planning and more than ordinary discernment on the part of the investigator.

Section models of embankments of homogeneous materials can be built into glass-sided channels to establish the pattern of seepage flow lines through the structure, the equipotential lines and similar data if the models are properly designed for this purpose. The influence upon the seepage pattern of toe drains, cut-off walls, and other design features can also be established; likewise, the effect upon the amount of percolation through the dam.

Special criteria for similarity between model and prototype arise. Thus consider the case of similarity in lines of seepage of a scale model and the prototype. The seepage pattern through the embankment is materially affected by the capillary rise of water in the embankment material; however, except for the capillary rise influence, the lines of seepage are not changed by a change in permeability of the medium provided the permeability change is proportional throughout the structure. It will be evident, therefore, that in order to obtain similarity in seepage patterns in the model and prototype, the ratio of the capillary rises respectively in model and prototype, must be proportional to the ratio of homologous linear dimensions in the two. Therefore the pores between grains of the model medium, and consequently also the grains, must be coarser than those in the prototype medium. Similarity as regards sloughing of the embankment introduces still other factors. If constructed of the same material, a large-scale model will develop downstream slope deterioration earlier and more seriously than a smaller-scale model. This is more particularly attributable to the greater seepage water concentration at the tailwater intercept with the slope, although the percolation velocities through the two different scale models will be the same. Suffice it to point out that the design of embankments can be effectively aided with model experiments, but much inductive reasoning is required, supplemented by basic soils mechanics experiments on the characteristics of the medium of which the embankment is to be constructed.

ESTABLISHMENT OF COFFER-DAM DESIGNS

Although not normally a part of the completed structure, in many large undertakings the coffer-dams needed to unwater the river-bed during construction operations are a major cost item in the completed project. It also usually is a primary construction hazard because of the very fact that it is intended as a temporary control works for achieving the end result.

The objective of studies on working models is to obtain the most economical total construction cost of the eventual water-control structure. This requires careful observation on the model for various coffer-dam designs placed at the construction site (in the model). Although not always, usually erodible river-beds are involved.

At the outset, a movable bed model of the stretch of river including the projected construction site is set up in the laboratory. An important consideration in such a model is the criterion that for the flow condition in question, if bed sediment motion takes place in the river, it should also occur in the model and the latter must be designed accordingly. Various verification tests between model and river should be made, if at all possible, before the proposed scaled coffer-dams are tested in the model. Such verifications might consist in comparing flow patterns, point velocities and bed erosion. The model coffer-dam, when results are properly interpreted, can then be expected to lead to a good prediction of conditions at the actual construction site for various coffer-dam layouts. However, this class of model study requires more than ordinary background for accurate discernment on the part of the investigator.

ENTRAINMENT OF AIR IN WATER AT HIGH VELOCITY FLOW

The insufflation of free air into water flowing at high velocities takes place in many situations in water-control structures. The condition is manifested, for example, in the occurrence of "white water" or foaming of the water flowing down steep chutes and spillways, and also through closed conduits at high velocities of flow where air is accessible to the flowing stream. The entrained air results in increased bulk volume of the discharging stream and provides special analytical problems in hydraulic design.

Laboratory models of water-control works, such as spillways, do not simulate the air insufflation occurrences found in full-scale structures. Thus a model of a spillway and apron of a major structure, operated in accordance with the Froude model law, will probably entrain little or no air, while the prototype might, for example, entrain as much as 50 per cent or more air in the total flow.

This situation involves passing a critical stage in the flow conditions which can be reproduced only to a relatively large scale, and accurately simulated in its complete form only in the full-scale structure. From basic research conducted at the St. Anthony Falls Hydraulic Laboratory in recent years, it appears that the insufflation process is dependent upon the intensity and pattern of turbulence of the flowing stream as regards the amount and distribution of entrained air, and upon the limiting value of the interfacial tension between the air and water as regards the start of the insufflation process. In small-scale models, the intensity of turbulence is usually very low as compared to the surface tension, the numerical value of the latter being the same for prototype and model when the fluid mediums are the same.

In view of the foregoing, it now appears to me that the air entrainment phenomena can best be predicted in the laboratory for a structure such as a spillway by observing the development of the turbulent boundary in scale-model tests and by making use of the basic laws of the insufflation process from large-scale idealized laboratory tests. The use of these two classes of data in combination will provide a basis for inductive analysis of the bulking phenomena which will occur in the projected prototype.

EROSION AND SEDIMENT MOVEMENT BY FLOWING STREAMS

There are a great variety of problems arising from the construction of water-control works which concern the erosion, transportation and deposition of sediment. Approaches to the hydraulic laboratory treatment of some of these questions are treated in this paper under separate headings. The laboratory in its broader aspects is a very important, if not indispensable, adjunct in connexion with achieving adequate solutions to such problems, largely by establishing basic information on the transportation of sediment by flowing water and on the transportation characteristics of various types of sediment.

With the present state of knowledge, scale models must be used prudently in predicting qualitatively the conditions involved when sediment transportation takes place. In special types of design problems where the flow pattern is dependent primarily upon the configuration of a rigid structure, such as the apron of a spillway, the pattern of erosion in the stream-bed immediately below the rigid structure can be quite well established by the model. However, when the stream-bed pattern in a fairly long stretch of erodible river comes into consideration, various limitations arise as regards applicability of a model to the prototype. Thus, in case the model is operated in accordance with the Froude law, the tractive force of the flowing water on the stream-bed will vary directly as the scale ratio; e.g., if the model vertical dimension is 1/100 of that of the prototype, the tractive force on the model bed will be only 1/100 that on the prototype. In case of an alluvial river with a fine sand bed, the sand in the model could not possibly be changed in transportability to 100 times that in the actual river by a change in material size. An expedient has been to use granulated coal or other low specific gravity material with some degree of success.

We are also met with degradation of the stream-bed where the natural movement of the sediment is interrupted by a dam, likewise aggradation upstream of the dam. Further problems include predicting of new equilibrium conditions in movable bed channels as a result of channel contraction works, deflectors of the stream and the like. Small-scale models for many of these problems are quite limited in applicability in the establishment of quantitative results; however, fundamental laboratory experiments serving to establish basic relationships, including the transportation characteristics of the specific sediments involved, are extremely useful directly in inductive analytical studies. The basic experimental data regarding transportability of various sediments by flowing water are also helpful in planning the model experiments.

A further guide in choosing sediment for an experimental model is the principle of fixing the model sediment size distribution such that the ratio of sedimentation velocities of the model sediments in still water to that of the prototype sediments in still water is equal to the ratio of the flow velocities in the model to homologous velocities in the prototype.

In conclusion, it can be stated that while there is no singular laboratory approach to the general solution of erodible-bed open-channel problems, the hydraulic laboratory when expertly used does by all odds present the most expedient practical aid.

DESIGNS FOR REPAIR OF EXISTING STRUCTURES

Hydraulic models in many instances are particularly well adapted as an aid in planning revisions in the design of existing structures or for correcting ill-designed features that have led to damage in full-scale structures. Existing conditions are normally first reproduced in the model that caused the damage in the prototype and a verification of similarity of the model is thereby obtained. Corrective measures are then tested in the model to determine the optimum design both as regards hydraulic improvement and economy in cost of repair.

In the case of overflow structures such as spillways, the damage is usually due to excessive scour downstream of the structure or damage to the energy-dissipating part of the apron. An improved design can invariably be established by the model tests.

RIGID-BED OPEN-CHANNEL STUDIES

A great variety of water-control works problems are concerned with rigid-bed channels or situations where the bed sediment movement is of minor importance. Such is true, for example, of flood routing studies, many river navigation improvements, particularly where canalization is involved, tidal studies in river estuaries and the like. Usually the model is designed to operate according to the Froude law because the force of gravitation controls the motion occurrence. However, where fluid friction also becomes a controlling factor in the motion pattern, Manning's formula sometimes is adapted to define a "special model law" for the relationship between the model and prototype.

The basic limitation in reduction in model size for rigid-bed models is that flow in the model should be turbulent wherever this is true in the prototype, and vice versa, otherwise similarity in the motion patterns of the model and prototype will not be alike and the model tests not applicable. Rigid-bed models are among the simplest to handle provided the controlling and critical limitations are understood. In many instances, the roughness of the model wetted surfaces must be adjusted to conform to conditions in the prototype before new structures such as navigation improvements are introduced into the model. The amount of this change in roughness is empirical and is guided by comparisons of flow patterns in the model with those in the prototype for corresponding discharges.

CONCLUSION

The brief review presented in this paper could be expected to introduce the use of models in planning water control works only in a general way. The techniques of the hydraulic laboratory in the present generation are proving to be a powerful adjunct to the design of hydraulic structures, an approach which we cannot possibly afford to disregard. But these techniques must be accepted in their entirety for greatest practical effectiveness.

EXPERIMENTAL STUDIES FOR THE DESIGN OF WATER CONTROL WORKS

Figures 1 to 9 on the following pages present a number of examples of model studies and other hydraulic laboratory methods for the design of water control works.

All are of projects conducted at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota in Minneapolis. The work is for and in co-operation with various government and private agencies.

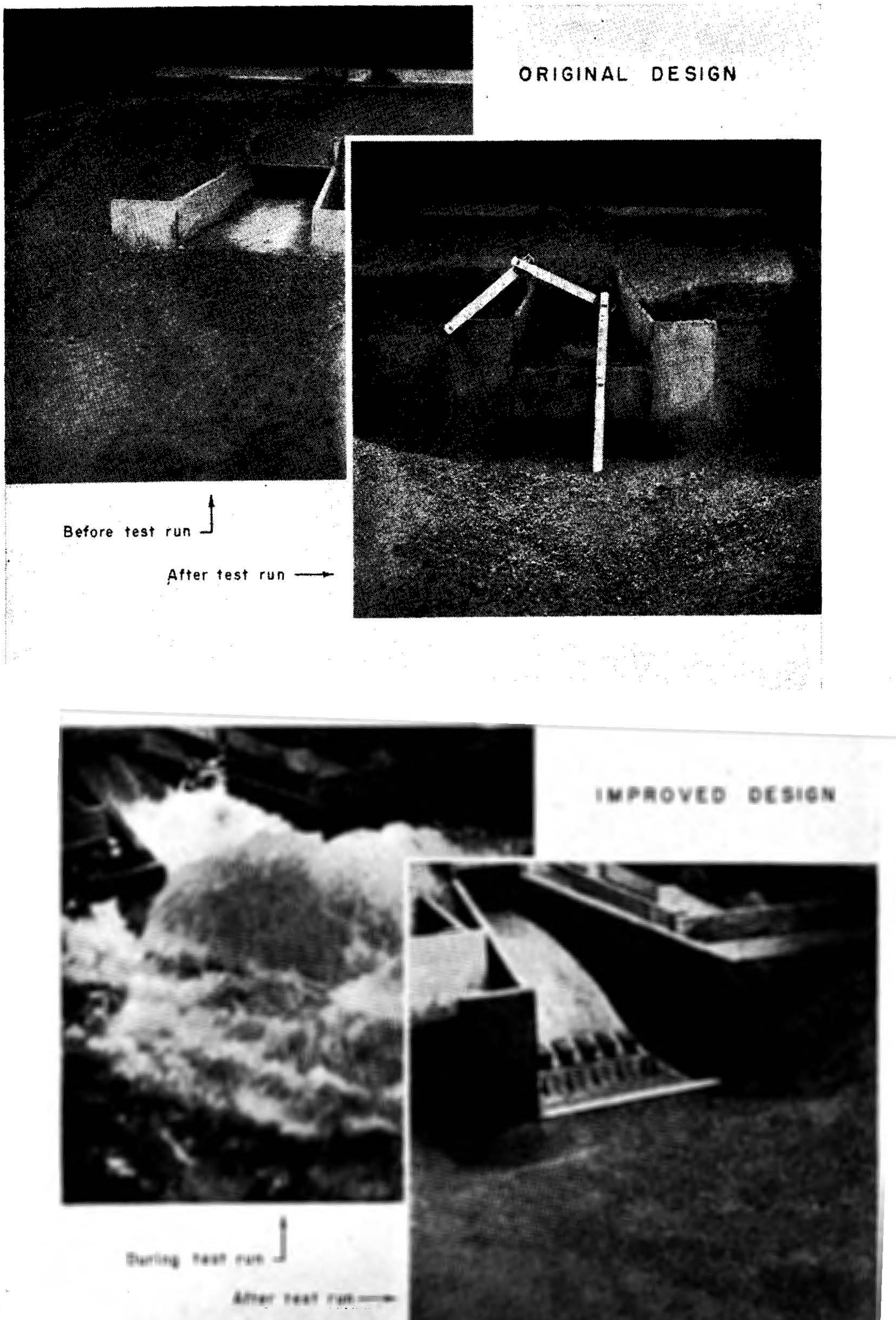


Figure 1

STANDARD DESIGN FOR SMALL SOIL CONSERVATION STRUCTURES

Soil erosion control work involving use of small structures is aided by establishing standard types and dimensions for various flow ranges. Starting with a model of a computed design (above) experimental studies are made of design variations in the model for a range of flow conditions until an optimum result is obtained (below).—U.S. Soil Conservation Service Project.

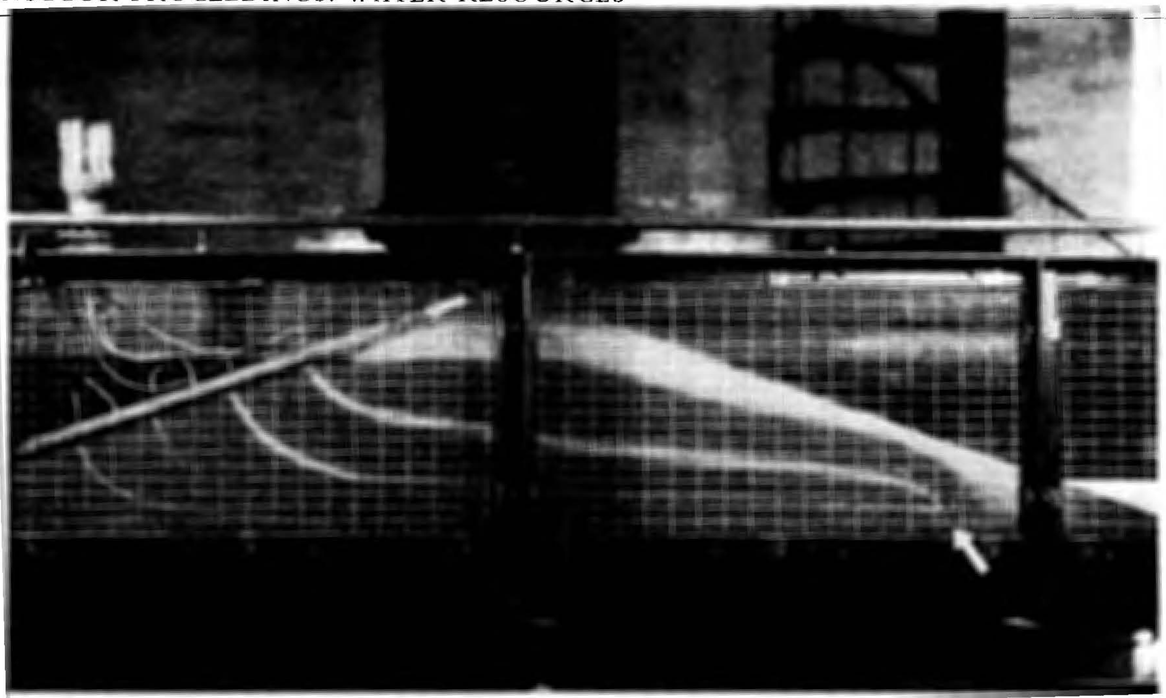


Figure 2

WORKING MODEL OF SAND EMBANKMENT

Methods of increasing stability of sand embankments against failure due to sloughing of downstream slope and piping failures. Photograph shows beneficial effect of toe drain (arrow) by eliminating most of seepage from downstream face of dam (lines of seepage are traced by dye in water).

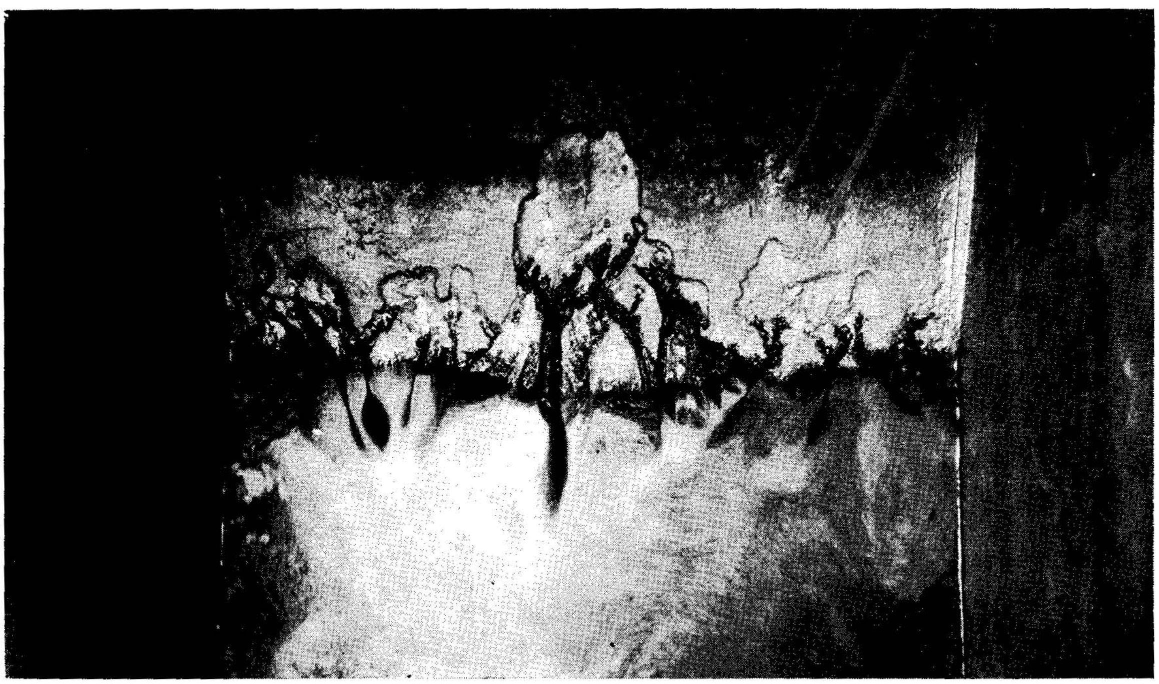


Figure 3

PARTIAL FAILURE OF DOWNSTREAM FACE OF SAND EMBANKMENT

View vertically downward on embankment slope and tailwater pool (no toe drain). Failure occurs more rapidly than when toe drain is used (bronze powder on dam near water line aids in photographically recording points of initial piping and sloughing).

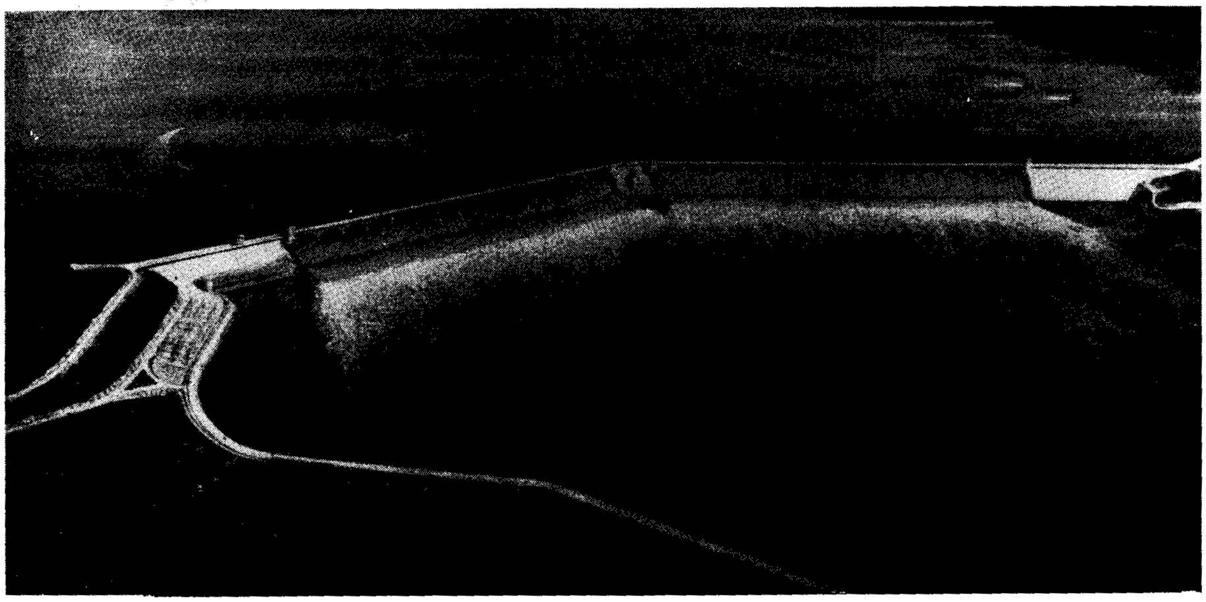


Figure 4(*a*)

PLANNING COFFER-DAMS FOR CONSTRUCTION OPERATIONS

The Ramapadasagar Dam (architectural rendering above) projected on the Godavari River in Southern India for a 265 million dollar power and navigation development, with the rock foundation ledge 200 ft. below the stream bed and river flood flows exceeding 2 million sec-ft. with velocities about 20 ft. per second, presents exceptional construction problem. Coffer-dam models (shown subsequent to test run below) guide establishment of optimum economic designs and the prediction of amount of erosion. (White cord across model shows location of axis of dam.)—Project for Government of Madras, India.

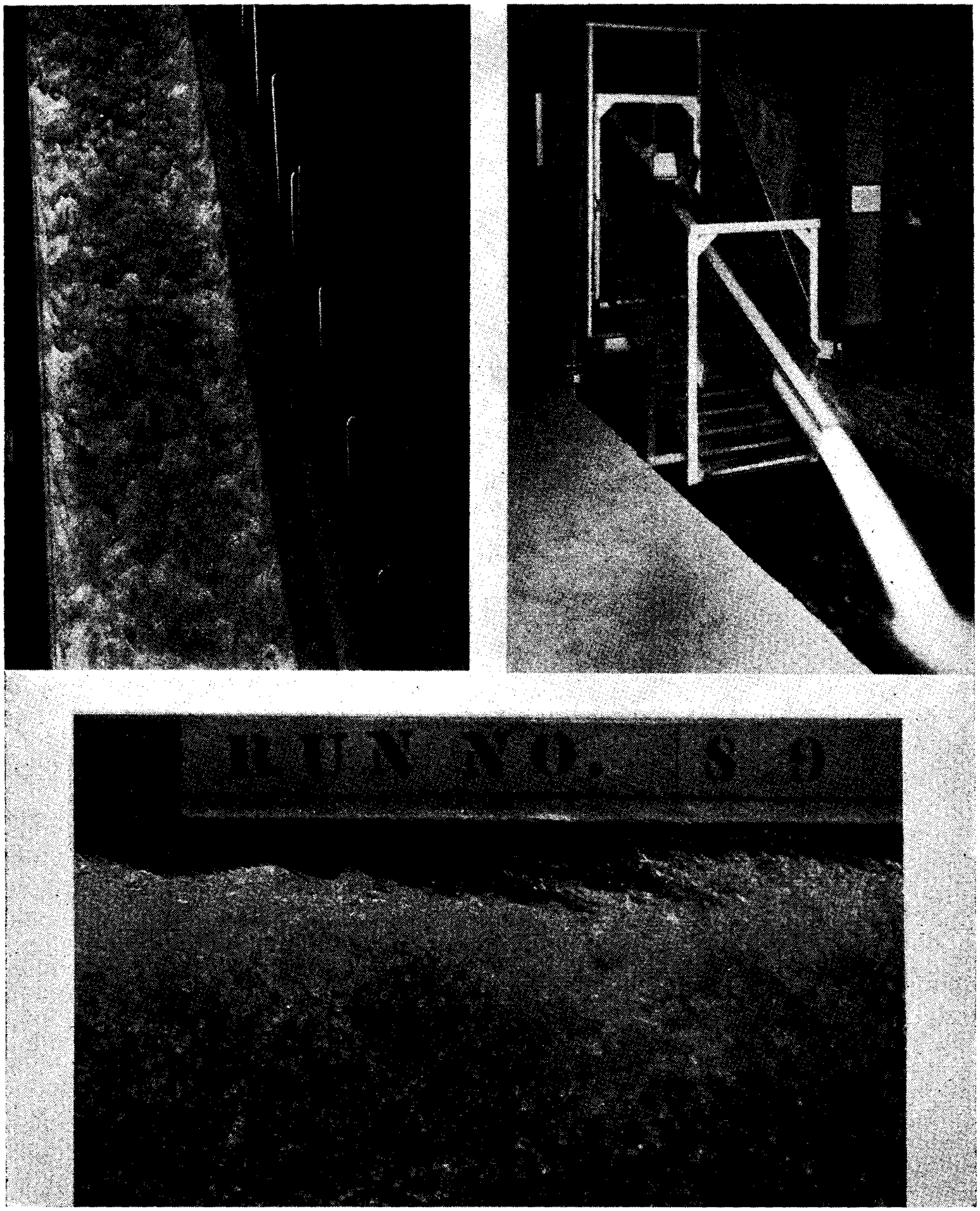


Figure 5

AIR ENTRAINED WATER AT HIGH VELOCITIES

Bulking of volume of flow over spillways and in steep channels due to air insufflation cannot be simulated in small scale models. Studies of basic laws in controlled tiltable channels (upper right) permit analytical prediction of field conditions. Photographs at 1 : 100,000 seconds exposure "freeze" insufflation process looking vertically downward on water surface (upper left) and in profile through transparent channel sides (bottom). (For scale of lower photograph: height of letters is $^3/_4$ inch.)

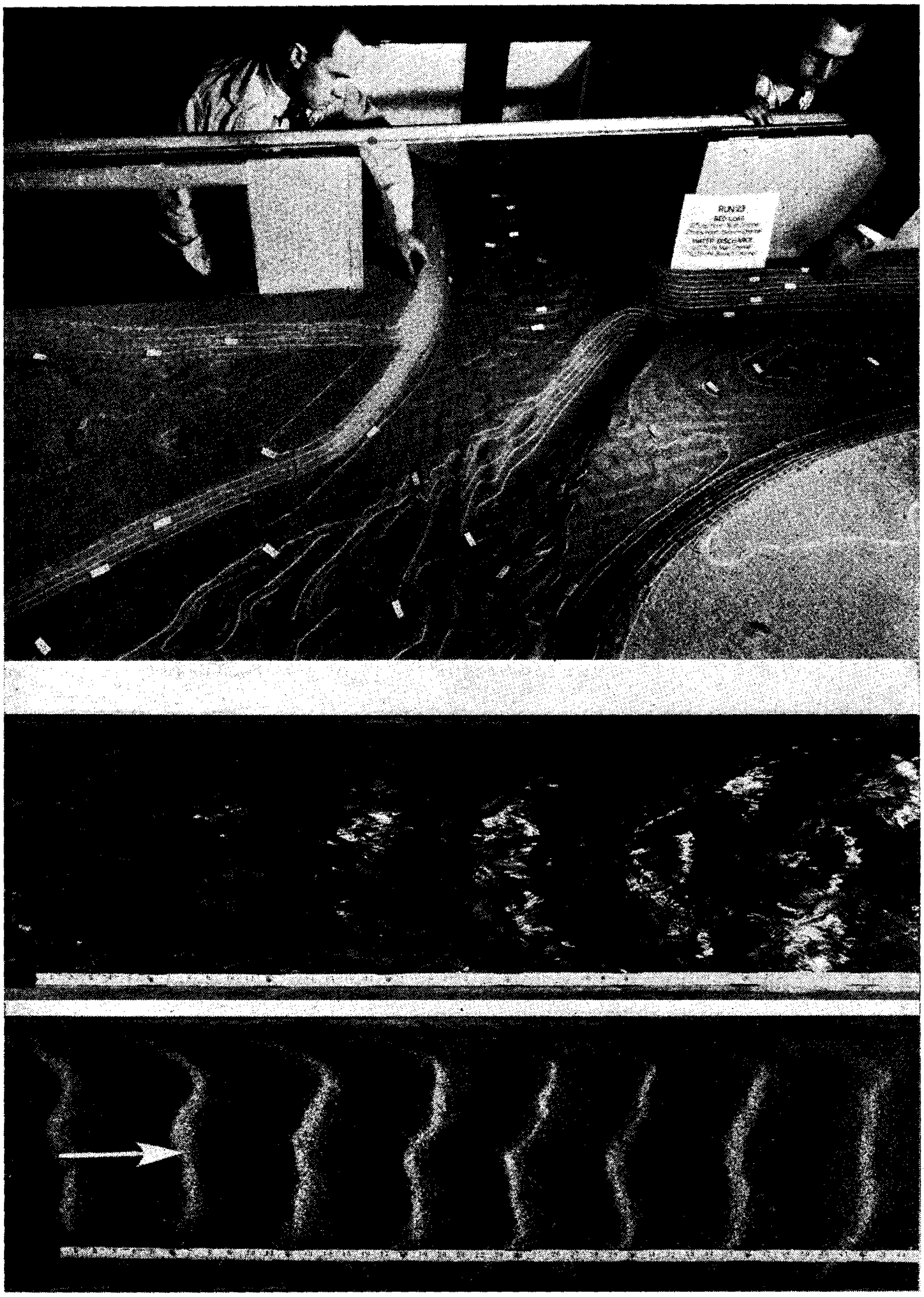


Figure 6

EROSION AND SEDIMENT MOVEMENT BY FLOWING WATER

Laboratory studies involved in establishment of basic natural laws applicable to conditions in rivers. Above shows test result to establish stream bed at confluence of two rivers. Below shows respectively water surface and stream bed in straight channel for arbitrary rate of sediment movement and water discharge.

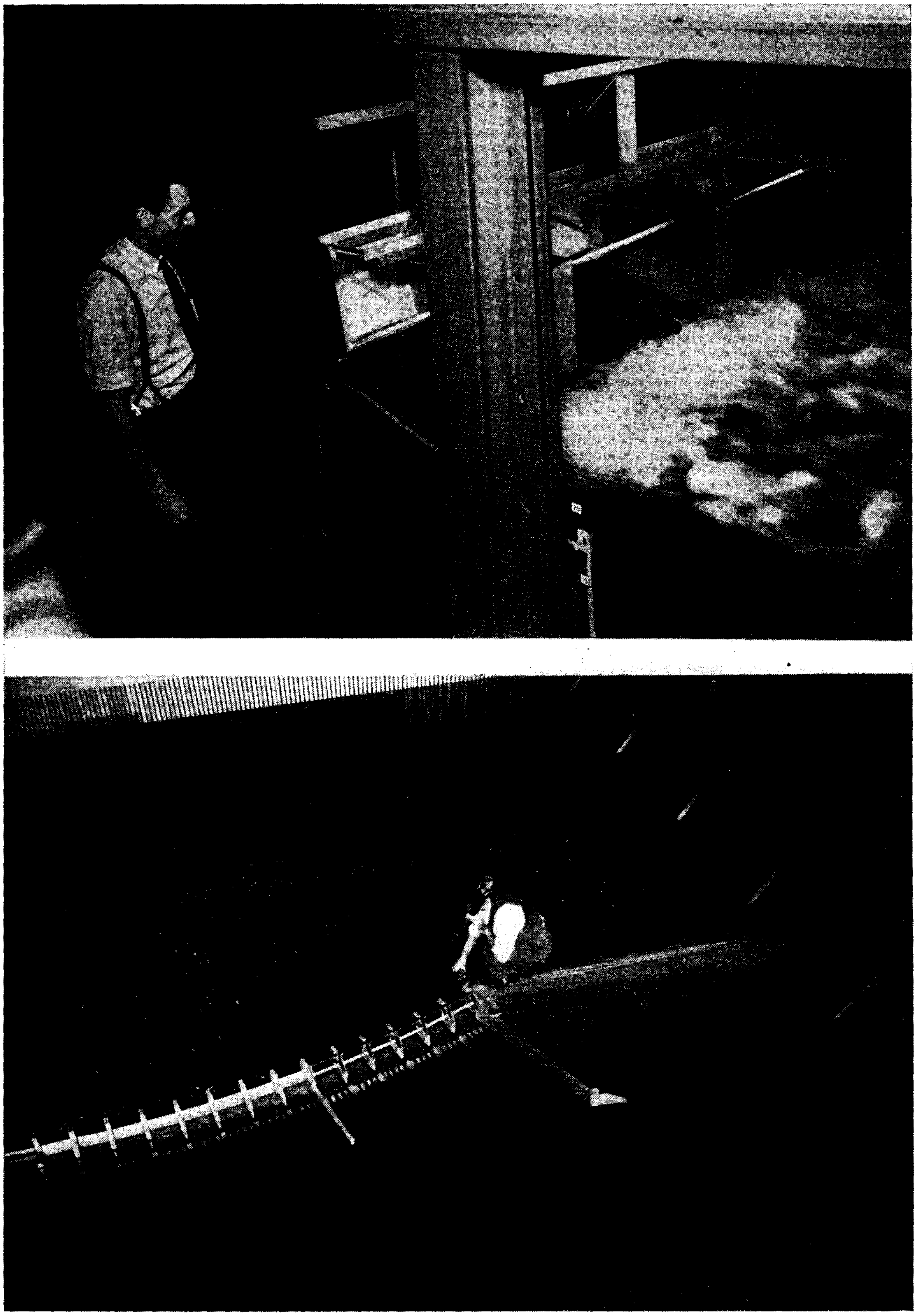
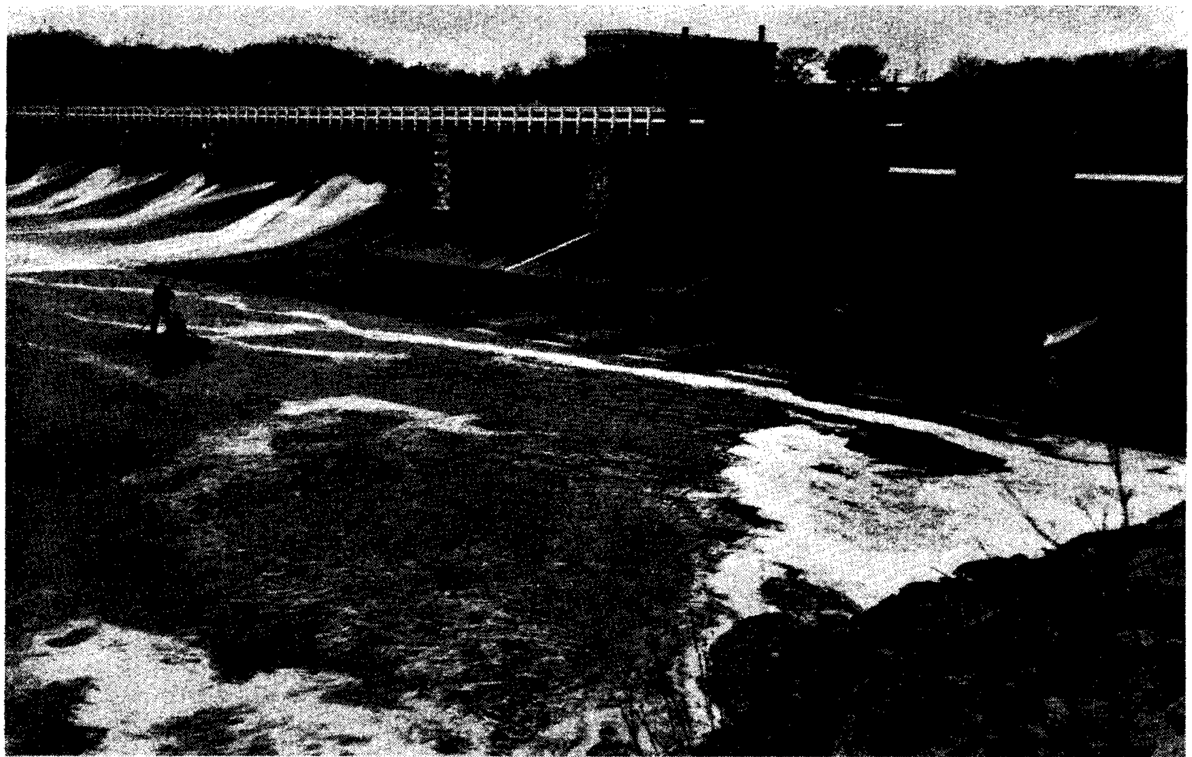


Figure 7

SPILLWAY AND APRON DESIGN

Dam on San Jacinto River, for City of Houston, Texas water-supply impoundment, is typical of flood release problem. Above is a 1 : 15 scale section model used in tests of design of spillway and apron section; below is a 1 : 55 scale "three-dimensional" model of spillway and part of flanking embankment. Flood flow: 650,000 sec.-ft.



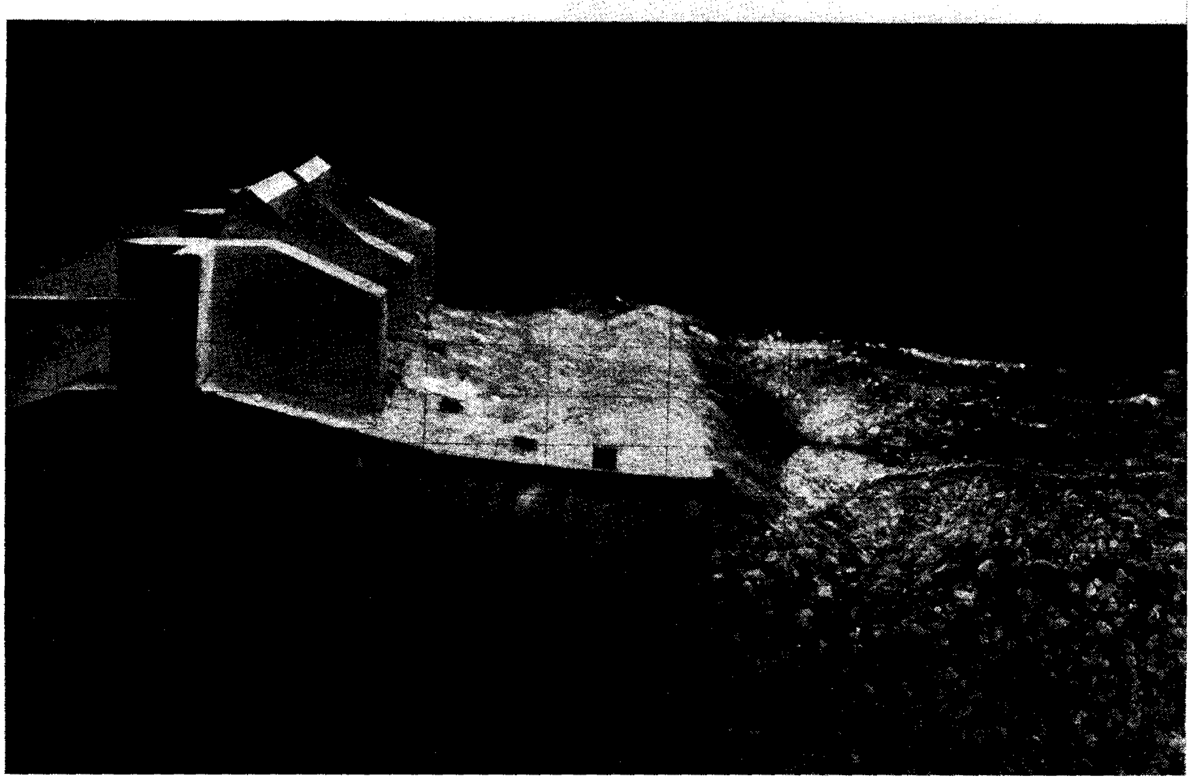


Figure 8

MODEL TESTS TO FIX DESIGN FOR REPAIR JOB

Faulty designs of completed water control works can frequently be improved by model tests. This was done on the Mississippi River dam at St. Cloud, Minnesota (above), where serious underscour occurred at toe of spillway, by means of models (below) built into a glass-sided channel.—Project for Northern States Power Company.

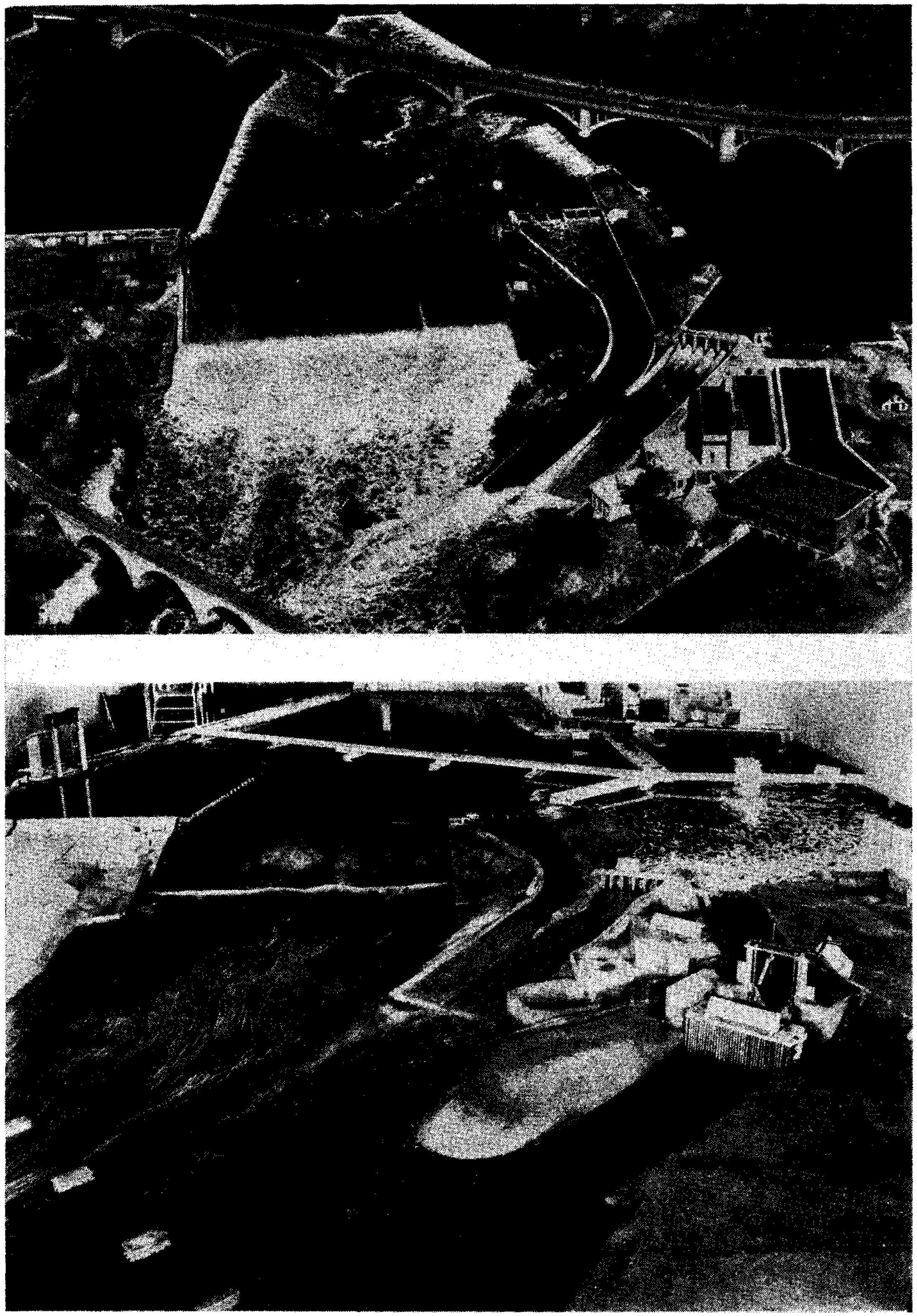


Figure 9

TYPICAL RIGID-BED MODEL STUDY

Comparison of flow conditions in prototype (above) with 1 : 50 scale model (below) for navigation structures on the Mississippi River at St. Anthony Falls.—U.S. Corps of Engineers Project.

The Measurement and Control of Silting

A. N. KHOSLA

ABSTRACT

The silting of reservoirs is a matter of vital concern for any undertaking depending on stored supplies. The rate of silting in a reservoir can be estimated from the silt load carried by streams leading to the reservoir or on the basis of experience gained from existing reservoirs.

The suspended load of streams is capable of fairly accurate measurement but no satisfactory means have been devised for the measurement of bed load. It appears, however, that the latter is not of much consequence in large reservoirs.

Catchments vary widely in silt production depending upon their size, geology, topography, vegetation, rainfall and other factors. The most important single determining factor is the area of the catchment. The relative silting of reservoirs is, therefore, best measured in acre-feet per annum per 100 square miles of catchment area. For catchments over 1,000 square miles in area, the upper limit of annual silt deposit is not likely to exceed 75 acre-ft. per 100 square miles of catchment area. For catchments less than 1,000 square miles, this limit appears to increase inversely as the area of the catchment.

There are a number of methods for controlling the silting of reservoirs. The method going to the root of the problem is watershed treatment. A certain amount of control is also possible by means of outlet works. In this connection the potentialities of density currents need to be investigated more fully.

THE ORIGIN OF SILT[1]

Silt is stream borne material derived from the disintegration of rocks and soil. The main factors causing disintegration are the diurnal and seasonal variations in temperature, wind and rainfall and the chemical agencies in air and water. Disintegration, erosion, transportation and sedimentation are the various stages leading to silting in a reservoir.

The speed of weathering is affected materially by the nature of the country rock. Igneous rocks, in general, are hard, dense and crystalline and do not disintegrate easily. The older sedimentary rocks are likewise relatively dense and offer resistance to weathering. The younger sedimentary deposits, particularly recently laid alluviums are specially susceptible to rapid weathering. Consequently, other things being equal, regions of igneous and precarboniferous rocks are regions of clear-water streams, and regions of recent sedimentaries and valleys of alluvial deposits are most likely to give rise to streams heavily laden with silt. Among the younger sedimentary rocks, difference in texture and cementation are reflected by differences in speed of weathering. Loosely cemented sand-stones and friable sandy shales are readily susceptible to weathering and are prolific producers of silt.

The chemical composition of rock material is likewise important. Rocks that contain high percentages of aluminium silicate weather into clay with fine flaky particles readily susceptible to corrosion and water transportation. Regions of such rocks are likely to be regions of cloudy, although not necessarily heavily silt-laden, streams.

Vegetation, an incidence of climate, is another important factor. By disruptive action of roots and chemical action of organic solvents, vegetation aids weathering. By protection of the land surface from the action of wind and water, it retards corrosion or the tearing away and placing in motion of disintegrated material. Rainfall, if it comes in erratic cloud bursts, will accelerate erosion and transportation of silt. If, however, it is gentle and spread evenly over the catchment area and over the seasons, weathering, erosion and transportation of silt will be reduced owing to the sustained vegetable cover made possible by such distribution and the stream-flow will be less heavily silt-laden. In general, an arid climate will cause excessive weathering and torrential rainfall will carry this excessive weathered material and result in heavy though sporadic flows of silt.

Snow-fed supplies do not appreciably add to the silt load of a stream but supplies derived from rainfall do, more or less, in proportion to such supplies. Glacial supplies are silt laden.

Steep hill sides will part with debris much more quickly than those with a gentle slope. Land treatment for agriculture plays an important part in soil erosion.

SILT LOAD OF STREAMS

The catchment characteristics, as indicated above, are a general guide to the relative degree of silt production in various regions. In some areas, the sediment produced may be deposited on fans and flood plains without ever reaching the main stream channels whereas in others it may be carried by streams either in suspension (suspended load) or rolling along its bed (bed-load).

Suspended load: The magnitude of suspended material carried by a stream is capable of fairly accurate measurement by standard methods of sampling and analysis. A number of experiments carried out in the United States of America (6)[2] led to the conclusion that (i) a sample taken from six-tenth depth gives the mean percentage of suspensions in the vertical and (ii) that the mean of the results obtained from three verticals, at the centre of the section, and at distances of one-sixth the width from each edge of the stream, gives the mean percentage for the cross section.

Experiments carried out in Egypt (12), on the Nile, indicated that (i) the clay and silt were fairly constant throughout a vertical, the variation being almost entirely in the coarser part of the sand portion of the suspended solids, and (ii) the mean concentration at half depth bore a constant ratio to the mean concentration in the water passing the whole cross section of the river.

[1]The word "silt" has been used here in a general sense to mean all detritus and other matter carried by streams.

[2]Numbers within parentheses refer to items in the bibliography.

Experiments carried out in India have shown that the depth of mean silt point on a vertical increases with an increase in the average particle size in suspension. The position of this point can be determined by taking a number of samples all along the vertical, taking due account of the velocity of flow at each point. There is also some variation in sediment concentration across the channel particularly in wide channels of non-uniform section.

Where the bulk of the suspensions is less than .075 mm. in diameter in small channels and .1 mm. for large channels, a sample taken at 0.5 depth is considered sufficient for the determination of the average suspended silt load on the vertical. But for grades exceeding these, the number of sampling points on the vertical would depend on the nature of the investigation and the grade of material to be sampled. For routine measurements, the number of verticals for taking samples is recommended[3] as follows:

Width of channel	*No. of verticals*
Less than 50 feet	1
50 to 300 feet	3
300 to 1,000 feet	5
Over 1,000 feet	7

Each vertical should be located with respect to transverse distribution of stream discharge so that it forms the centroid of a section of equal discharge; alternatively its mean concentration should be weighted suitably.

In the rivers of northern India, the percentage of suspended load has been found to increase with an increase in discharge. The bulk of the coarse material thus moves during the flood season in the monsoons, the streams being relatively clear of suspended material during the rest of the year. The annual suspended load in small flashy streams is carried within a small number of days out of the year and it varies considerably within a short time on the rising or falling stage of a stream. The reliability of the estimates of suspended load is thus dependent on taking samples at the proper time.

Bed-load: No practical means of measuring the bed-load of a stream so far have been devised. Fortier and Blaney (6) estimated the bed-load of the Colorado River at Yuma as 20 per cent of the suspended load. Humphreys and Abbot put it at 11 per cent for the mouth of the Mississippi River. Follett from a study of the Rio Grande believed it to be 25 per cent. Davis as a result of studies of the San Carlos River in Costa Rica arrived at percentages between 1.7 and 7.1. Stevens (14) found that in the Coeur d'Alene river at Rose Lake, Idaho, the bed-load might be anywhere between zero to 100 per cent of the total load. R. C. Hemphill (12) is inclined to believe after investigations in Texas streams that the quantity of sediment transported as a true bed-load comprised a much smaller percentage of the total load than is generally assumed.

Simaika (12) from a study of the distribution of silt in a vertical concluded that the bed-load could not be heavy. If the bed-load were considerable and not all carried through the sluices of the Aswan Dam, one would expect a continual rise of the bed upstream of the solid part of the Aswan Dam, of which there is no evidence.

[3]Full details are given in the Central Board of Irrigation (India) publication "Determination of Detritus Load in Rivers and Canals". (In the press).

It will thus be seen that information about the relative proportion of bed-load and suspended silt is meagre and very conflicting. So far as known, no successful attempt has been made to measure the material transported as bed-load. It appears, as stated by Simaika and Hemphill that the bed-load is not really so important a factor as it is sometimes made out to be.

A study of the methods used in measurement and analysis of sediment loads in streams has been the subject of a series of reports issued in the United States. (11). In India a technique for measuring bed-load by using a trench with a cross grid flush with the bed has been tried on small artificial channels. The experiments are not yet conclusive but it appears that it may be possible to measure the load in small channels by this method.

Silt concentration. "The concentration of sediment of a given size which can be transported by a given stream is unlimited, except by the fluidity, if the vertical component of the stream velocity is greater than the velocity of free fall of the same sediment in the same fluid when the fluid is at rest.... In normal stream-flows these vertical currents are the vertical components of the turbulent motion." (8)

The extent of weathering of a particular catchment, other factors being normal, is a function of time. A certain quantity of weathered material is made available for transportation during the year. If the rainfall is more or less evenly distributed over the period, this weathered material will be moved gradually and the silt concentration will be low. If the rainfall is torrential and erratic, the entire run-off will be in the form of a few freshets and the silt concentration will be heavy. But this heavy silt concentration during flashy periods should not be interpreted as an indication of abnormal silt production of the catchment. The rate of silt production will be governed more by the area of the catchment than the total amount and intensity of rainfall.

SILTING OF RESERVOIRS

Reservoir silting results from the deposition of material carried by a stream when the transporting power of the stream is suddenly diminished by flowing into the deep impounded waters of a reservoir. A correct knowledge of the probable rate of silting of reservoirs is of vital importance to any undertaking requiring the construction of a storage dam. The height of the dam is to be determined by a consideration of the necessary useful storage and the additional capacity required for silt reserve. If a reservoir is constructed for purposes of irrigation, the silting, if not adequately provided for, may start depleting the useful capacity of the reservoir just when the areas dependent on it approach their maximum development. This may not only impair the financial prospects of the scheme, but may spell disaster to the colonies and communities which owe their existence and subsequent prosperity to such undertakings. In the case of reservoirs for flood control, the depletion due to silting will progressively reduce their flood absorption capacity and to that extent expose the country-side to increasing flood damage. In the case of those for hydro-electric development, this depletion will interfere with the equalization of supplies which enables the generation of maximum firm power for any given stream-flow.

In view of the stakes involved, the subject of silting of reservoirs assumes great importance and justifies a programme of systematic and thorough investigation. Steps have also to be taken to control the excessive rate of silting of existing reservoirs for reservoir sites are natural resources limited in extent as are other resources such as coal, oil or iron.

SEDIMENTATION SURVEYS

An estimate of the rate of silting of an existing reservoir is necessary in order to determine the useful life of the reservoir and to see if any measures of silt control are called for. The data collected can also be used for estimating the probable rate of silting of proposed reservoirs in similar basins.

A reconnaissance survey may first be made to ascertain the approximate extent of loss of capacity and to decide whether a more detailed survey is needed. It consists in measuring the thickness of sediment at a few well distributed locations (varying from 15 ft. to 100 ft.) in the reservoir by means of a spud or by taking soundings from the water surface and comparing these with the original contour map of the reservoir basin. The results provide a satisfactory basis for estimating the order of magnitude of the remaining useful life of the reservoir.

There are two methods of making detailed surveys known respectively as the Contour Method and the Range Method. The choice of the method to be followed depends on the amount and distribution of sediment as indicated by reconnaissance and on the availability and character of previous base maps.

The Contour Method consists in the mapping of contours of the present silt surface over the entire lake area and is best applied when 50 per cent or more of the original area of the lake is silted and the ground surface on the delta deposits is above the level in the reservoir. The Range Method is more rapid and consists in measuring actual silt depths on ranges. It is used when the deposits are largely below the water-level in the reservoir.

A combination of the two methods may also be adopted by setting up measuring ranges over the lower part of the lake where penetrations with a sampling spud are generally obtainable and by mapping contours on the delta portions of the lake, provided previous contour maps are available for comparison. Detailed instructions for carrying out surveys by both methods are given in *Technical Bulletin No. 524* of the United States Department of Agriculture (5).

In India, the Central Board of Irrigation has recommended the laying down of permanent sectional lines at suitable intervals for all reservoirs, the sectional lines being marked by concrete pillars on the flanks and the section measured annually either by levelling if the reservoir dries out or by soundings.

ESTIMATING THE PROBABLE RATE OF SILTING OF A PROPOSED RESERVOIR

The rate of silting of a proposed reservoir may be determined either on the basis of silt-load carried by the main and tributary streams or by comparison with sedimentation rates in other reservoirs exposed to similar conditions.

Estimate on basis of silt-load observations. The annual deposition of silt in a reservoir will depend on the annual silt-load brought in by the stream and the extent to which this will be retained in the reservoir. Carl B. Brown (2) has found that reservoirs trap from 70 to almost 100 per cent of the sediment delivered to them by inflowing streams.

An assumption must also be made with regard to the probable density of the silt deposited in the reservoir. It has been known to vary from 18.7 lb. of dry material per cubic foot of deposit, possessing prominent colloidal characteristics, to the cobble like formation containing 106.1 lb. of dry material per cubic foot of deposit. Between these two extremes, all intermediate values are found.

In a reservoir used for flood control only, the water is stored temporarily and the deposited material, subject to shrinkage during long periods of time, has an average ultimate weight of dry material per cubic foot of deposit, approximating 90 lb. In a reservoir for storage of water for future use, dry periods and increased demands for water result in lowering of the water-surface and exposure of silt deposit for periods of time, resulting in an average ultimate weight of dry material per cubic foot of deposit of approximately 70 lb.; and in a reservoir for power generation where the head is maintained practically constant, exposure and the resulting shrinkage do not take place and the average ultimate weight of dry material per cubic foot of deposit approximates 30 lb. Faris recommends 70 lb. for the average ultimate weight of dry material per cubic foot of deposit.

It has been pointed out above that whereas suspended load is capable of fairly accurate measurement, no satisfactory means of measuring bed-load have been devised. It is, however, generally felt that bed-load in the case of large reservoirs is not of much consequence. Coarse material like shingle will normally be deposited at the headwater of the reservoir where the velocity slackens on entering the reservoir, and will progressively build up a delta, thus causing a gradual aggrading of the stream-bed and a reduction in the silt depositing in the reservoir.

Estimates based on the actual rate of silting of existing reservoirs. The rate of sediment production of a drainage basin depends, as already explained, on the nature of the catchment, its geological formation, topography and vegetable cover. Other factors which affect this rate are the size or area of the catchment basin, the annual run-off and its relation with storage capacity, the period of storage in relation to silt-load of the stream, the location of sluices and outlet works and the method and purpose of release of supplies through the dam.

The silt characteristics of different catchments vary within wide limits. The Columbia River above the Grand Coulee Dam with a catchment area of 74,000 square miles, most of it highly timbered, is believed to run practically silt free. The River Nile above the Aswan Dam carries approximately 100 million tons of silt per year but the silting in the reservoir above the Aswan Dam is negligible owing to the large sluicing capacity at bed-level and to the storage capacity being only 6.7 per cent of the mean

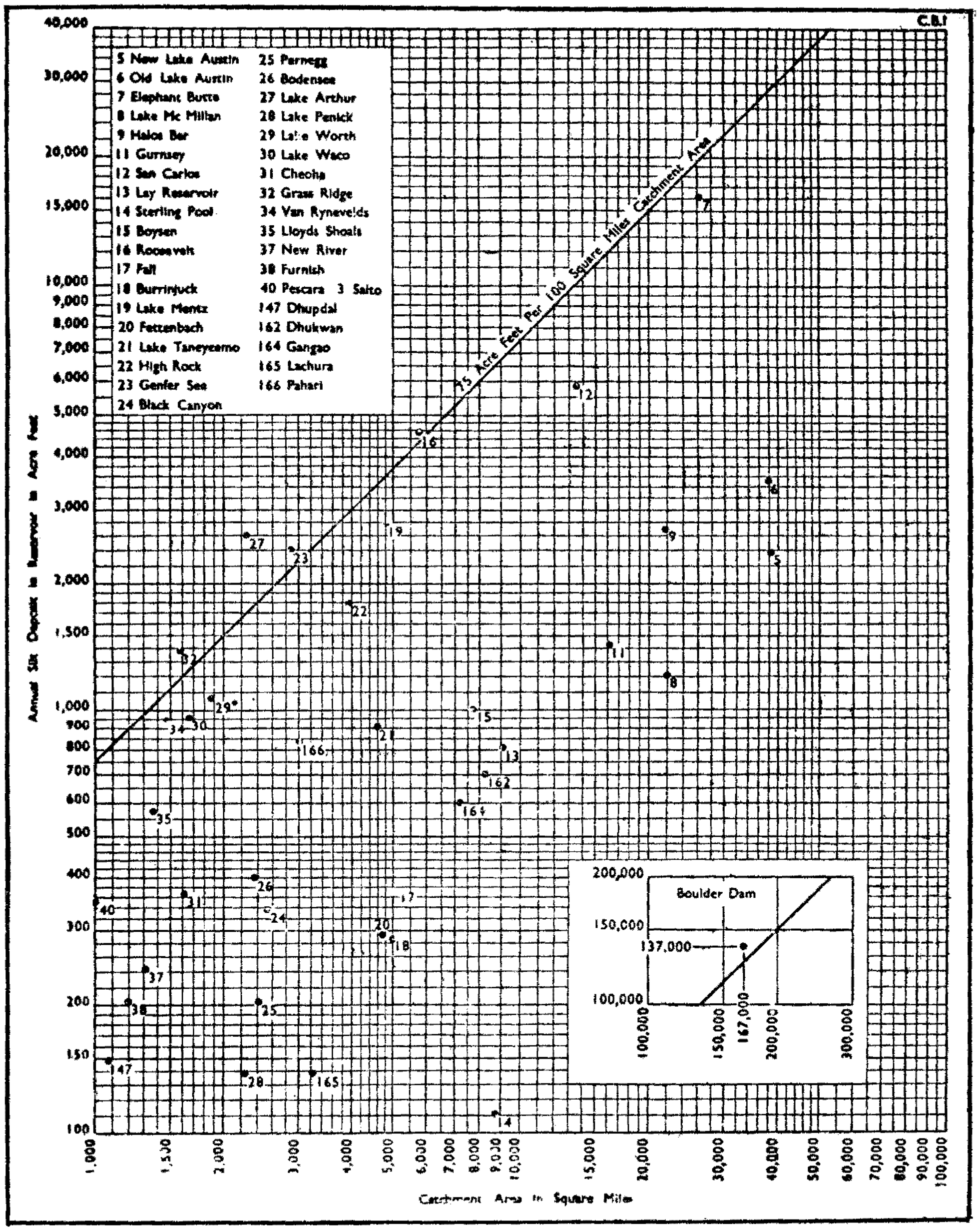


Figure 1: showing rate of annual silt deposit in reservoirs with catchment areas above 1,000 square miles.

annual run-off which enables the requisite storage to be obtained during the period of low silt concentration. Numerous reservoirs in southern India and Ceylon have been in existence for centuries without material loss of capacity. On the other hand there are many reservoirs where the rate of silting is very high.

It is easy to appreciate the difficulty of correlating the rate of silting in a reservoir with the numerous contributing factors, widely varying in their effects—geology, topography, vegetation, run-off and capacity and the method of its operation. Wide divergence in rates of silting under similar natural conditions is caused by artificial interference with the normal characteristics of the catchment such as construction of check dams in tributaries, large scale afforestation, denudation, etc.

The rate of silting also decreases with the age of a reservoir. One of the main reasons for this is the settlement and shrinkage as a result of superimposed load of additional silt and exposure to weather. Also deltas progressively form at the mouths of tributaries so that a portion of the silt is trapped in these above reservoir level, resulting in a process of aggrading of their beds.

It is comparatively simple, however, to correlate the rate of silting in a reservoir with the area of its catchment, the most important contributing factor. The data of over 200 reservoirs spread all over the world has been collected and the result of studies carried out by the author is printed in the form of two diagrams attached to this note. It will be seen therefrom that for major catchments of over 1,000 square miles (Figure 1) the rate of annual

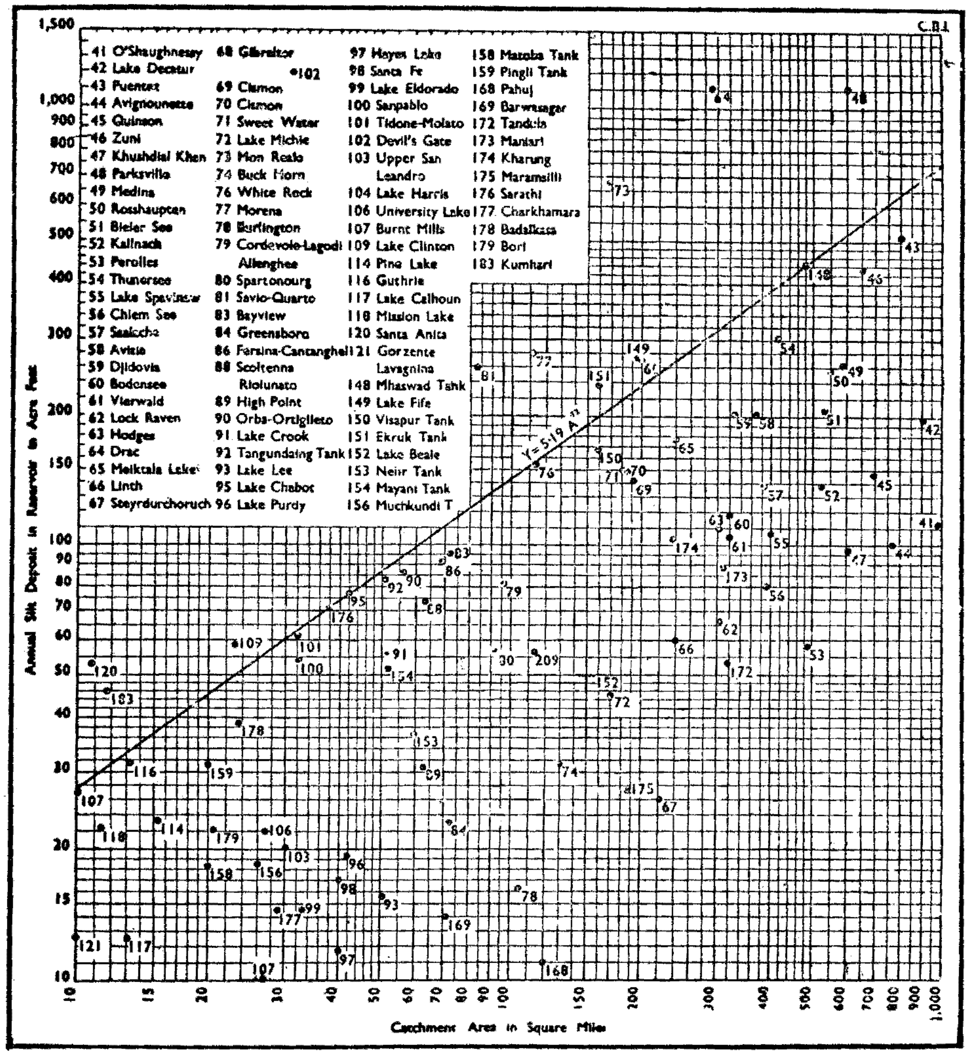


Figure 2: showing rate of annual silt deposit in reservoirs with catchment areas below 1,000 square miles.

sedimentation per 100 square miles of catchment has a normal upper limit of 75 acre-ft. For minor catchments the annual normal sediment deposition (figure 2) can be represented by the equation:

$$Y. = 5.19\, A^{\cdot 72}$$

Where Y is the annual silt deposit in acre-ft. and A the catchment area in square miles. The rate of annual silt deposit per 100 square miles of catchment area may be expressed as:

$$Y_1 = \frac{519}{A^{\cdot 28}}.$$

This gives a rate of 75 acre-ft. for a catchment of 1,000 square miles increasing to 272 acre-ft. for a catchment of 10 square miles. In metric units the results obtained above can be expressed as follows:

For catchments over 2,590 sq. km., the annual normal silt deposit has an upper limit of 357 cub. metres per sq. km. For catchments less than 2,590 sq. km., the annual silt deposit per sq. km., Y_2 in cub. metres has an upper limit of

$$Y_2 = \frac{3226}{A_1^{\ \cdot 28}}$$

where A_1 is in sq. km.

Attempts have been made to correlate the rate of silting of reservoirs with other contributing factors described above but with little success. It is, therefore, not proposed to examine them in this brief note.

METHODS OF SEDIMENTATION CONTROL

Before concluding this brief note, it appears necessary to review the manner in which the problem of silting of reservoirs affects the design and operation of a reservoir at all stages.

Selection of reservoir site. A careful study is made of the quantity and type of sediment load that will be produced by a drainage basin. The possibility of choosing an alternate site is, however, limited in most cases.

Design of the reservoir. Three factors have to be considered in the design of a reservoir from the point of view of silting control; (i) the total capacity, (ii) the design of outlet works, and (iii) the dead storage or the capacity to be reserved initially for sedimentation over a number of years. Outlet works must of course be designed with a view to the removal of the maximum amount of silt, and wherever possible, a portion of the total capacity must be reserved for the deposition of silt over as long a period as possible without affecting the usefulness of the dam.

Control of silt inflow. The inflow of silt to a reservoir may be reduced by (i) the construction of settling basins, (ii) the improvement of vegetable cover on the catchment and (iii) the provision of by-pass channels, if possible, to escape heavy silt-laden flows without passing through the reservoir. The first of these, viz., settling basins, have only a temporary utility.

Control of sediment deposition. Whenever and wherever possible, the outlet works must be operated in such a manner as to permit selective withdrawal of water having a high silt content. An attempt has also to be made to pass density currents through small openings in the dam. A special mention of the density currents is necessary as a proper understanding of the phenomenon might be of considerable benefit in the control of reservoir silting.

When relatively muddy water approaches a reservoir, the stream expends a large amount of energy due to the shock losses involved in the change of momentum. This results in the mixing of turbid water with the clear impounded water. The energy available is, however, not large enough to cause complete mixing and the diluted turbid water, because of its greater density, plunges beneath the reservoir surface and continues to flow along the sloping bottom of the reservoir as a separate muddy stream. In the process of going down it drags along with it some of the reservoir surface water and induces a corresponding counter flow. The result is that all the floating debris, whether brought down by the river or by the reservoir surface current, tends to accumulate at the "plunge point" thus giving a surface indication of the underflow.

Once a density current has been formed, it can be stopped only if the kinetic energy is dissipated, or the density difference has been destroyed through the deposition of material. Observations so far made in the United States of America indicate that density currents are not easily destroyed. They are known to have travelled for 100 miles through Lake Mead and for 35 miles through Elephant Butte Reservoir.

A density current can also move as an overflow or as an interflow. For instance, if the impounded water is colder or more saline than the incoming water, the density current would move as an overflow. But if the lake contains stratified layers differing in temperature, salinity or silt content, the density current may move as an interflow between the less dense and more dense layers.

A muddy underflow may flow over the spillway. But if the lake is deep and outlet works relatively high, it comes to rest at the lower end of the lake and the suspended sediments settle slowly over a period of weeks or months. The fine-sized material carried by a density current wastes about four times as much space as a non-cohesive deltaic material of equal weight.

Though the phenomenon of density flows has been observed and reported at a number of reservoirs, the data available with regard to their behaviour are not sufficient for formulating any general rules on the number, spacing and distribution of outlet works for the most effective venting of the density currents. Model experiments in this respect are being undertaken in India.

Watershed treatment. Watershed treatment consists in afforestation and forest management including control of grazing, fire protection, improved cultivation practices, halting gully growth by check dams and planting, proper treatment of highway embankments and cuts and stabilization of stream banks.

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Recent Experience in Lift Irrigation and Drainage in Egypt

ABDEL AZIZ AHMED BEY

ABSTRACT

The irrigation systems of Egypt are outlined and the effects on the soil of the extensive conversion of basin to perennial irrigation are discussed.

Two large electricity schemes for lift irrigation and drainage are described, and their mechanical and electrical features briefly explained.

Expansion of the cultivable area by means of lift irrigation is envisaged on a large scale, and the water and power requirements are estimated from the experience gained in the operation of the above mentioned electricity schemes.

Finally, it is shown that by proper conservation and harnessing of the Nile water, as well as the development of the available power resources the cultivable area could be increased, in the first instance, by about 45 per cent of the present area under cultivation.

In the course of the last century the methods of irrigation in Egypt have undergone radical changes. From the days of the Pharaohs irrigation used to be carried out under a system which parcels up the land into large areas surrounded by banks to form basins. The basins are annually inundated with silt-laden flood-water to a depth of about one metre for a period of six weeks which enables it to deposit its silt contents. The water is then run off back into the falling river and one winter crop is grown, and receives no more water between sowing and harvest. Thereafter the land lies fallow until the next flood.

No attempt was made to change the basin system which suited admirably the crops then cultivated, which were mainly cereals, until the introduction of cotton plantation into Egypt in the last century which marks the era for the creation and development of the "perennial" system of irrigation, by which the land receives water all the year round, and two or three crops are grown annually.

Briefly explained this system consists in raising the level of the river by barrages, and upstream of the barrages are derived canals which are thus enabled to receive water at all times. The slope of these canals is less than the river and the land, so that as they run northward they gradually rise relatively to the land and after some distance the land is watered by free flow or "flush" irrigation. Perennial irrigation began on a large scale after the construction of the Delta Barrage about 20 km. north of Cairo. It covers now practically the whole of Lower Egypt and the greater part of Upper Egypt, amounting to about 5,973,000 feddans[1], there being still about 1,017,000 (1)[2] feddans in Upper Egypt under basin irrigation.

Extensive networks of canals have been created all over the country and provided with the necessary constructional works such as regulators, syphons, tunnels and culverts to enable full control of irrigation water and its equitable distribution to suit the seasonal requirements of the various crops. For size, efficiency and management this system of irrigation is considered unique.[3]

The free flow system of perennial irrigation has saved Egypt enormous expenses which would otherwise have been necessary for lift irrigation by means of motor-driven pumps which would have involved large capital outlay and considerable expenses in fuel, which until recently had to be imported entirely.

As a result of the conversion of basin to perennial irrigation the cropping capacity of the land has increased, but some doubt has been expressed as to whether the fertility of the land will remain at the original level. In the first place the subsoil water-level is generally higher under perennial than under basin irrigation, causing deterioration of the soil unless efficient drainage is provided. Second, the conversion of basin to perennial irrigation has deprived the land of the mud deposit, which the river brings annually from the highlands of Abyssinia, and which is deposited in the basins during their annual inundation. It is believed that this mud contributes largely to the fertility of the basins, although our knowledge on this point at present is somewhat vague.

It is well known that the alluvial deposits of volcanic materials, such as brought down by the Nile, form the most fertile soils on the face of the earth. Practically the whole of the Nile Valley is formed of mud, which has accumulated to a considerable thickness in consequence of the river having for thousands of years annually overflowed its banks and deposited suspended matter on its flood plains.

In the Sudan the land irrigated by the red water of the Blue Nile is much more fertile than that watered from the White Nile. In Egypt the muddy flood-water when supplied annually to desert land converts it gradually into good cultivable soil which improves with the lapse of years as the supply of muddy water continues. The general practice is to run all canals brimful during flood and to supply the land with as much red water as possible.

It may be of interest to record the following incident which shows the effect of the annual mud deposit in the basin area on cultivation.

During the high flood of 1946, which called for impounding a large volume of flood-water in Aswan reservoir as a protective measure against flood devastation, thereby causing the water to deposit the bulk of its mud contents in that reservoir, and so the basins had to be inundated by comparatively clear water and the crops grown in the basins that year have greatly suffered in consequence.

The proportion of suspended matter in the Nile water entering Egypt varies widely throughout the flood season and reaches in August its maximum concentration of about 2.5 grammes per kg. Since the basins are usually

[1]One feddan = 4,200 sq. metres = 1.038 acres.
[2]Numbers within parentheses refer to items in the bibliography.
[3]It is interesting to mention that in Lower Egypt alone the total length of the irrigation canals is roughly 40,000 km.

flooded to a depth of about one metre, it follows that the maximum quantity of silt deposited annually amounts to 10.5 tons per feddan, which corresponds to a layer 2.1 mm. deep spread over the basin area. Actually the average thickness of silt deposits is about 2 to 3 mm. as may be observed in fresh excavations especially in Upper Egypt which generally reveal distinct flakes representing on average the annual rate of silt deposition in past centuries.[4] (2)

We shall now investigate the fertilizing properties of the Nile mud. As regards chemical composition it is found to contain the following principal plant nutrients:

	Per cent
Phosphoric anhydride P_2O_5	0.24
Potash K_2O	1.07
Lime CaO	4.16
Organic matter	2.42
Nitrogen (included in organic matter)	0.13 (3)

Taking the maximum annual rate of silt deposit as 10.5 tons per feddan as shown above, the corresponding amount of plant nutrient deposited annually would be

	Kg.
Phosphorus	25.2
Lime	430.6
Potash	112.5
Organic matter	254.1
Nitrogen	13.5

Thus while the Nile mud is fairly rich in lime, potash and phosphates it is relatively deficient in nitrogenous contents. However, it provides suitable conditions for the life and activities of the soil micro-organic population, particularly the nitrifying bacteria which supply the crops with nitrogenous plant food.

Observations recently made in the basins of Upper Egypt show that when the soil is tested for nitrogen contents immediately after the basin water has been allowed to escape back into the falling river, only the smallest traces of nitrogen are observed in the surface layers but soon afterwards the nitrogen contents increase with extraordinary rapidity with the development of plant life, by the action of the nitrifying bacteria. Furthermore these bacteria, dwelling as they must have been from time immemorial in the Egyptian soil, have apparently adapted their life to the basin system of irrigation, which is as old as Egypt itself.

Any deviation from the regular annual routine of the basin regime is invariably attended by undesirable effects on cultivation. For instance, if a premature emptying of a basin takes place accidentally after the basin has been filled with muddy water, and then filled up again and allowed to remain full for the rest of the flood season as usual, the basin is known to produce in general but a poor yield of crops that year, and is said to have been "exposed".

Finally, it was proved that the organic contents as well as the nitrogen percentage in land under basin irrigations are on the whole greater than in perennially irrigated land. Furthermore the depth distribution of organic matter and nitrogen contents falls less rapidly in the former case than in the latter, although there is a slight increase of both in the surface layers of the latter, as a result of the agricultural system under which the land is farmed. The results obtained show clearly that the subsoils of land under perennial irrigation are becoming steadily poorer in organic matter and especially in total nitrogen. (4)

The reduction of nitrogen contents may be due to the rise of subsoil water-level in perennial irrigation. This question will be referred to again in this paper, when dealing with the question of drainage.

It may be said, in general, that although the conversion of basin irrigation to perennial irrigation has deprived the land of the annual deposit of the highly fertile Nile mud, yet on balance this conversion is economically justifiable, since under perennial irrigation the land produces two or three good crops annually, while basin land unaided by pumping produces one crop only.

As mentioned above perennial irrigation has been in general effected by means of free flow canals. Until 1933 lift irrigation had been limited to a few scattered areas whose configuration did not permit of their irrigation by means of free flow canals.

The first lift irrigation scheme to be carried out on a large scale in Egypt is the Upper Egypt Electricity Scheme in the Province of Aswan, for the irrigation of what is known as the Isolated Basins. The scheme was carried out by the author in 1933. These basins comprise a number of plateaus, separated from each other by highlands, and whose configurations or levels do not permit of planning out continuous free flow canals, except at a very great cost. The area served amounts at present to about 55,000 feddans. Fourteen electrically driven pumping stations have been installed at the sites shown in Figure 1,[5] being fed from a generating station installed at Edfu by means of a 66/33 kv. transmission line system.

The generating station contains two 2,500 kva. turbo-alternators with 25 per cent continuous overload capacity. Each turbo-set has its own tube boiler for firing with pulverized coal or crude oil. The turbines are of the two-cylinder type having steam inlet pressure of 30 kg./sq. cm. abs. and 350 degrees C. The turbines run at 3,000 r.p.m. and are directly coupled to 3-phase turbo-alternators of 3,300 v., 50 cycles at p.f. 0.8. The voltage is stepped up to 33 kv. to feed the overhead transmission line system, which consists of a single circuit of copper conductors, 50 sq. mm. section, and one steel earth wire 35 sq. mm. section, being supported on steel truss towers, the upper part of which is galvanized.[6]

The lift varies in different districts from about five to eight metres. It remains fairly constant in a given district throughout the months of low Nile. As the river rises

[4] Estimation of the rate of silt deposition in the Nile Valley, based on observation of the rise of flood as shown by its water mark on ancient building, shows that it is about 12 to 13 cm. per century, assuming that the amount of flood rise remained sensibly constant.

[5] The Scheme also includes three pumping stations for lift drainage, viz., Iqlit, Daraw and Binban, and operating only during the flood season, serving an area of 5,000 feddans.

[6] The transmission line crosses the River Nile twice at Edfu (span 690 metres) and at Silwa (Span 720 metres) with a minimum clearance of 50 metres above flood level for sailing boat navigation.

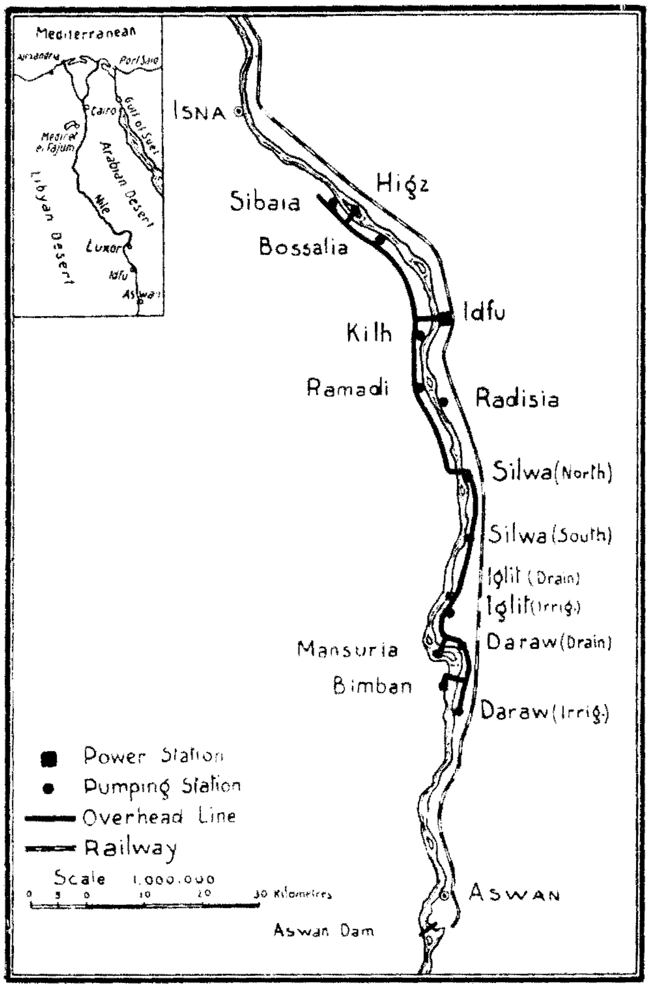


Figure 1

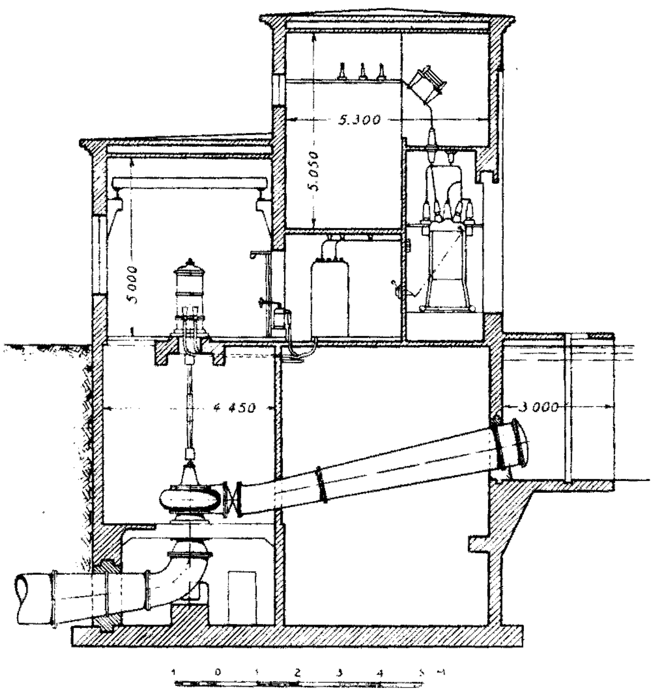


Figure 2

in flood the lift decreases and may drop to zero or even become reversed to free flow in normal flood years.

The speed of the pump is varied according to the lift by means of a variable resistance inserted in the rotor circuit of the driving motor, which improves the overall efficiency of the motor-pumping set. Figure 2 gives a section of a typical pumping station.

All the pumping stations run continuously throughout the months of low Nile, and are mostly shut down in the flood season in normal flood years. Only in exceptionally low floods do all the pumping stations run in the flood season. Such a flood took place in 1941, which year has been selected for the present study. The monthly discharges as well as the monthly energy consumption in kwh. per feddan are shown in Figure 3. The following remarks are worthy of note.

During low Nile the kwh. curve runs more or less parallel to the discharge curves since the lift is practically constant. During the flood months the kwh. consumption decreases relatively to the discharge, owing to the rise of the river and consequently the reduction of lift.

The high discharge during July is due to the first heavy watering of fallow land for sowing the maize crop, known as "Sharaki".[7] (11). During September the land is given a plentiful supply of muddy water which accounts for the peak shown in the figure.

The drop in the discharge curve in January is due to the deliberate curtailment of the irrigation water by partially or even totally closing the canals in order to enable the removal of silt deposits accumulated therein from the previous flood. This operation is carried out annually all over Egypt during January when the demands for irrigation water are minimum. The subsequent rise of water in February is to partially make up for January deficiency.

The areas of the discharge and kwh. curves give the total annual quantity of water and energy consumption per year per feddan, which amount to 9,947 cub. metres and 221.2 kwh. respectively. The former figure gives an average water duty of 27.3 cub. metres per feddan per day all the year through.

In a normal flood year, however, the conditions in the flood season are somewhat different. The monthly consumption of the electric energy in the irrigation pumping stations as well as the monthly discharges of irrigation water lifted are shown in Figure 4 which has been plotted from the latest returns of the annual reports 1946-1947. In this figure the discharge during the flood season represents only that delivered by the pumping station, the free flow discharge not being included since no means are provided for its measurement. The discharge and kwh. curves however represent a typical case where water is pumped direct from the Nile in a normal flood year.

[7]The "Sharaki" or fallow period has the effect of restoring the fertility of the soil. At the end of this period the available nitrogen is greater than at the beginning of the fallow. The increase is mainly in ammonical nitrogen, not nitrate, because bacterial activity ceases in the dry soil. When watering takes place, there is a rapid biological conversion to nitrate. It is this mobilization of reserve nitrogen as nitrate which accounts for the increased fertility of the soil after the resting or fallow period.

The total annual discharge (pumped) and the kwh. per feddan during that year amount to 7,661 cub. metres and 173 kwh., respectively.

Some districts in these regions actually combine the basin system of irrigation where land-levels permit of their inundation during flood, together with the perennial system for the rest of the year.

Six more pumping-stations are projected in order to serve an additional area of about 30,000 feddans thus raising the total area served by the scheme to 85,000 feddans. For this purpose an extension of the Edfu generating station amounting to 7,200 kw. has been contracted for and is actually under construction.

The expansion of perennial irrigation whether by free flow or lift has so far given excellent economic results. Cultivated areas under this system produce regularly two or three harvests a year. The whole country will ultimately be under perennial irrigation. However, the expansion of perennial irrigation has resulted in a general rise of the water table, though its detrimental effect upon the soil was not realized until many years afterwards. Some of the best lands of Menoufia and Beni Suef, once as fertile as any land, have been reduced to a deplorable condition. Unfortunately drainage was provided, generally, after the land had already deteriorated. Only in comparatively recent years has drainage engaged serious attention.

In the extreme case, when the interstices of the soil are completely filled with water, the soil becomes waterlogged. Such soil asphyxiates ordinary crop-plants. The root hairs die from want of air and the whole plant suffers. The most satisfactory growth is maintained when the amount of water present is not more than forty to sixty per cent of what would saturate it.

The amount of water in the soil also affects the life of bacteria living therein. There are two kinds of bacteria, those which nitrify the soil and so provide plant food and those whose action is contrary. The former cannot work in waterlogged soil, but need air; the latter on the contrary can only work in waterlogged soil. This question involves biochemical and biological studies which are outside the scope of this paper. However, on the rise of the subsoil water-level su ı ciently to bring about the infertility of the soil our knowledge at present is somewhat vague[8]. (2)

Extensive field investigations have been carried out in Egypt with a view of fixing the minimum difference between ground-level and water-table level which is necessary for efficient drainage. There is as yet no generally accepted figure. Some authorities claim that 1.5 to 2 metres should be sufficient, which is average lift for which drainage pumping stations are generally designed. Others maintain

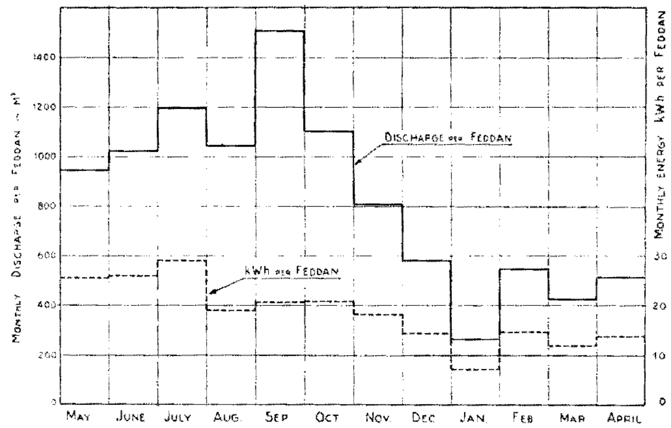


Figure 3

that it should be increased to 2.5 metres. It is obvious however that the drainage lift must ultimately depend on the composition of the soil such as clay or sand, and the plant to be cultivated, or rather the depth to which its roots penetrate in the subsoil.

The conditions and methods of drainage in Lower Egypt differ essentially from those in Upper Egypt.

In Lower Egypt, which consists of a large expanse of land with a gentle slope of about 7 cm. per km. towards the north, drainage is effected by two different systems. The southern parts of the Delta are served by gravity drains which run northwards to the Mediterranean Sea. The northern parts, consisting of land whose levels lie between sea level and 2 to 3 metres above, require lift drainage. These two parts are separated by a definite belt running across the Delta having contour of 2 to 3 metres above sea level.

The only outlet for the drainage water in Upper Egypt is the Nile which acts as a natural drain, except during flood when it rises above the land.

The water-table level is sensibly affected by the rise and fall of the Nile even at some distance from the river, with a certain time lag. This is shown clearly in Figure 5. (6) The chosen points of observation were within a kilometre from the river bank. At points further inland other factors interfere with the readings, such as the presence of canals and drains or basins or even the kind of crop such as rice which takes a lot of water.

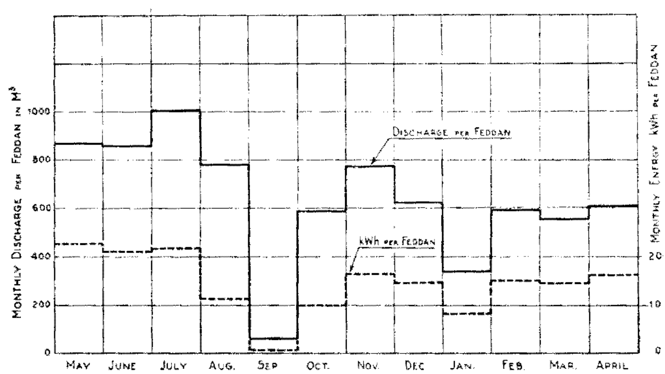


Figure 4

[8]It appears from the researches of the Ministry of Agriculture that waterlogging of the soil favours the growth around the roots of plants of a bacterium (a variety of *Microspira desulphuricans*) which reduces the sulphates in the soil to sulphides and utilizes the oxygen so obtained for the oxidation of organic matter, thereby causing a marked increase of alkalinity of the medium in which it grows; and this increase of alkalinity, by depressing the solubility of the calcium and magnesium salts present, permits of exchange taking place between the sodium of the sodium salts remaining in solution and the exchangeable calcium and magnesium contained in the clay fraction of the soil, thus rendering it highly impermeable to irrigation-water.

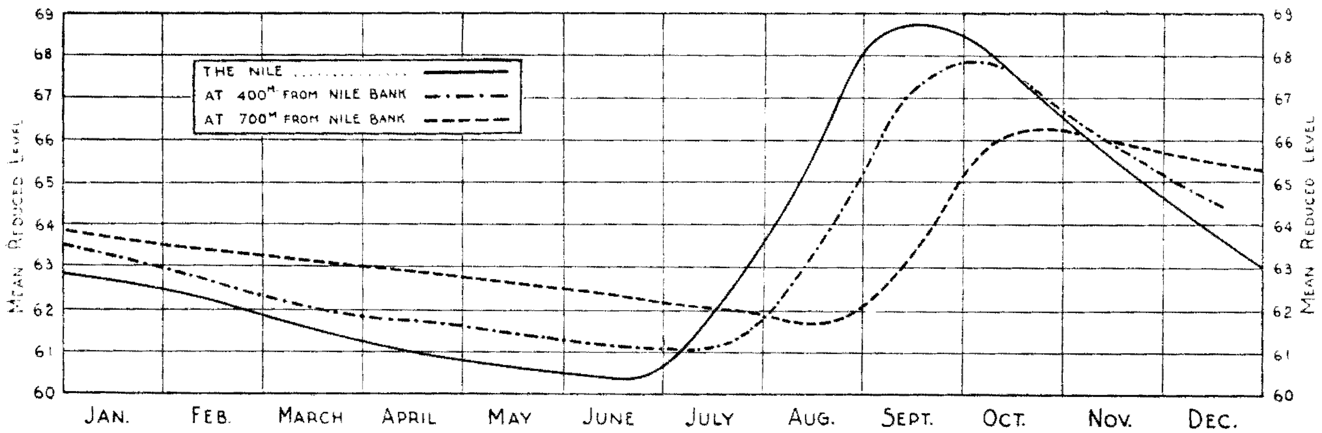


Figure 5

In what follows the different conditions and methods of drainage in Lower and Upper Egypt will be dealt with in their respective places.

During 1931-1933 the author carried out an electrical scheme for the drainage of North Delta land (see figure 6). It includes nineteen electrically driven pumping stations having a total installed discharge capacity of 421 cub. metres per second serving a total area of 910,000 feddans. The scheme includes in addition three irrigation stations.[9]

Power is generated in three central stations situated at Atf, Belquas and Serw (total installed capacity 22,000 kw.). They are interconnected by a 66 kv. transmission line (operating at 33 kv.) feeding the pumping stations.

The Atf generating station includes one 5,000 kw. and three 2,500 kw. turbo-alternators with 25 per cent continuous overload capacity. Each turbo-set has its own water tube boiler for firing either with pulverized fuel or crude oil. The turbines have a steam inlet pressure 28.3 kg./cub. metres abs. and 350 degrees C. They run at 3,000 r.p.m. and are coupled directly to 3-phase alternators 3,300 v., 50 cycles, stepped up to 33 kv. for transmission.

Belquas and Serw generating stations contain diesel driven alternators.

The transmission line system consists of double circuit copper conductors and one 35 sq. mm. steel earth-wire, supported on galvanized steel truss towers. It includes a main trunk line about 200 km. long, having a conductor area of 75 sq. mm. and an average span 200 metres and branch lines of total length 170 km. 35 sq. mm. conductor area and an average span 150 metres. The minimum ground clearance is 6 metres.[10]

The pumps installed in the nineteen drainage stations are inclined at an angle of 45 degrees and are driven by similarly inclined motors by means of reduction gears. There are altogether seventy-six pumps, being standardized at 2.5, 5 and 10 cub. metres per second. Provision has been made for increasing the discharge of the 2.5 cub. metres per second pumps to 5 cub. metres per second when required by changing the impeller and the driving motor. Figure 7 gives a section of a 10 cub. metres per second pump and figure 8 shows a typical pumping station.

The inclined pumps used in this scheme are probably the first of this type to be installed anywhere. They present good hydraulic flow-path, and require no priming since they are always submerged.

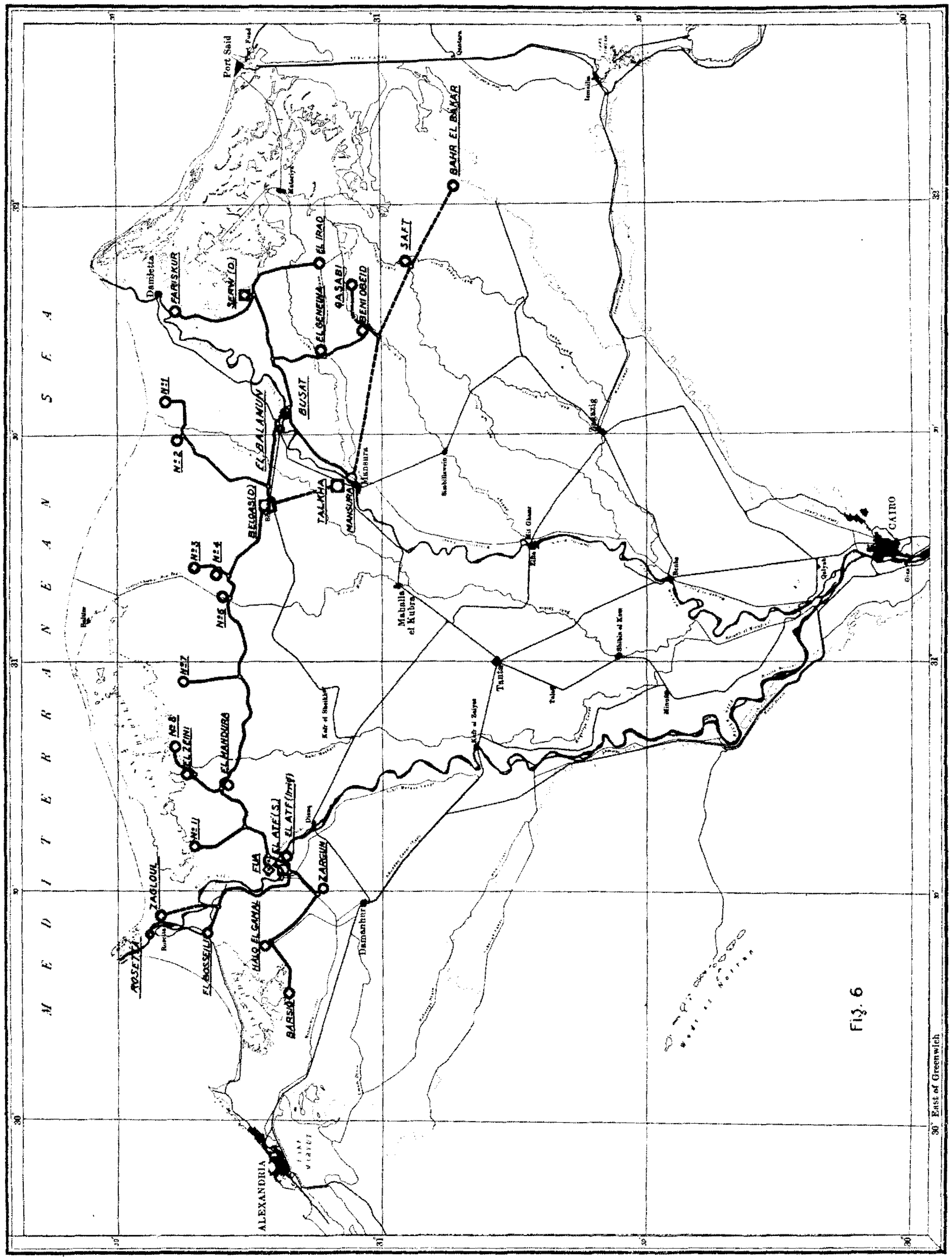
The pumps are provided with Mitchell combined thrust and journal bearing at the top end and lignum vitae journal bearing at the bottom.

This drainage scheme was put in operation in 1933 when land reclamation of the areas served by the various pumping stations commenced. Figure 9 gives the annual consumption of electrical energy in the drainage stations from the commencement of operation until last year 1947-1948, this energy being a measure of the drainage water lifted by the pumps. The figure shows a progressive increase of energy consumption as land reclamation advances.

Reference has been made previously to the effect of the Nile flood in raising the subsoil water-level. This is further increased in Lower Egypt by infiltration water from the vast network of canals since they carry during the flood season as much muddy water to the land as possible. In Figure 10 the peak of the Nile flood is shown together with the total kwh. (which is a measure of the drainage discharge). The influence of the flood on the drainage discharge is evident, particularly for 1939 onwards. During the previous years reclamation of the land was in progress and the kwh. consumption in any particular year is a measure of the extent of reclamation effected. Obviously the relation is not a straight line law, owing to the presence of other indeterminate factors, such as the duration of the flood-peak, time lag, and the area reserved for rice cultivation which varies from year to year. However two points on the curve are particularly worthy of mention, namely the year 1941 which had one of the lowest, and 1946 which had one of the highest floods ever known in Egypt. In both cases the total drainage discharge appears to follow the flood peaks with remarkable proximity.

[9]These are Foa, Balamon and Busat which operate only for a few months during low Nile.

[10]The transmission system crosses the Nile twice as follows:
Rosetta branch span: 800 metres, height of tower 119 metres, and Damietta branch: 600 metres, height of tower 96.2 metres. Minimum clearance above flood level in both crossings is 50 metres.
In addition there are 13 crossings over navigable canals with an average span of 11 metres and height of tower 50 metres.



EXISTING TRANSMISSION LINES
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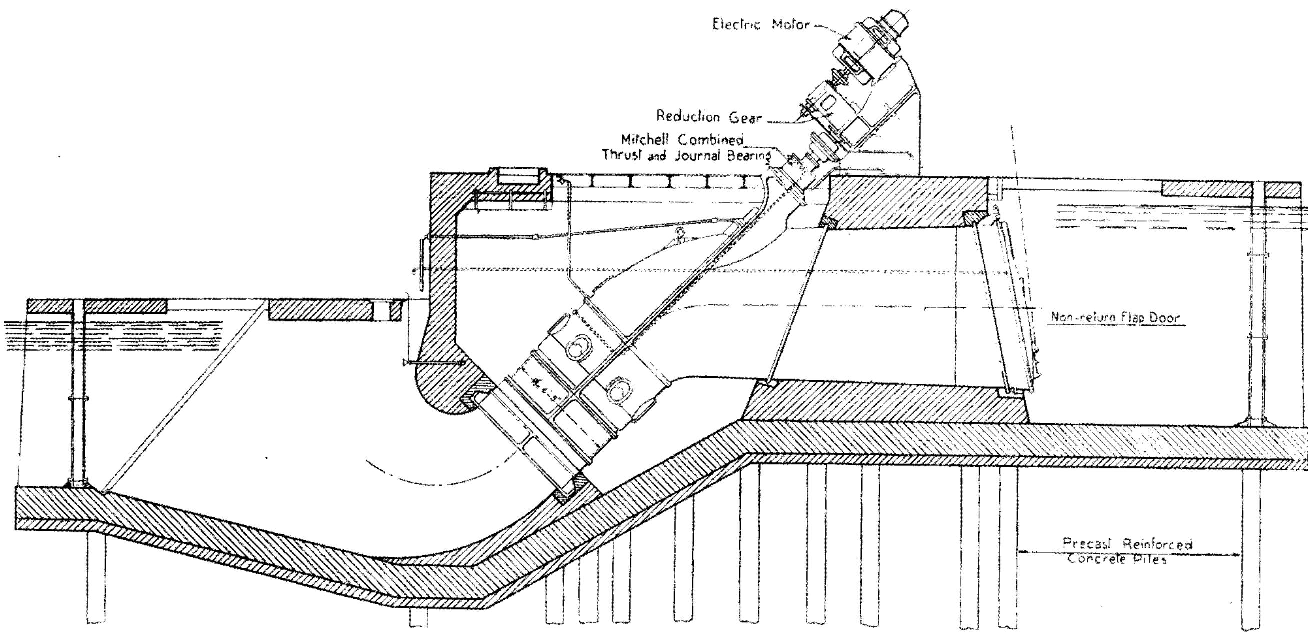

Figure 7

Furthermore, since the amount of subsoil water is a function of the irrigation water, being the percentage thereof that penetrates into the subsoil, and the infiltration water from the Nile and irrigation canals, the quantity of drainage water varies all over the year, reaching its maximum during the flood season with a certain time lag behind the flood peak. This is shown in Figure 11. The drop in the discharge in January is due to the curtailment or interruption of irrigation supply to which reference has been previously made.

The area of the discharge curve which represents the annual amount of drainage water per feddan per annum amounts to 6,133 cub. metres, giving an average drainage duty of 16.8 cub. metres per day. Similarly the annual energy consumption amounts to 51 kwh. per feddan.

The total amount of drainage water lifted by the pumping station amounts annually to 5,500 millions cub. metres or little over the capacity of Aswan Reservoir.

An extension of the North Delta drainage scheme has now been projected. It includes the addition of five more drainage stations, and tenders have actually been invited for the erection of a new generating station at Talkha (see Figure 6) having an installed capacity of 38,700 kw. The ultimate area which will be eventually served by lift drainage in Lower Egypt has been raised to 4,141,000 feddans or about 90 per cent of the whole area which is under perennial irrigation.

In the Isolated Basins of Upper Egypt Electricity Scheme described above, the river acts as a natural drain except in flood when its level rises in some districts higher than that of the land, thus calling for lift drainage during the flood season. Three such drainage stations have been in operation for the last ten years. A fourth station is under construction, and thirteen others are projected, covering practically the entire area served by the irrigation pumping stations. These stations, which would operate only during the flood season with an average lift of 5 metres, would be shut down during the rest of the year. Figure 12 represents the operation of a typical drainage station in the isolated basins scheme.

Besides, there are several engine-driven drainage stations both in Lower and Upper Egypt. However since they run only a few months in the year, the running expense of the personnel, which is characteristic of thermal stations, is high in relation to the actual drainage discharge. It is anticipated that when hydro-electric power becomes available at low price, lift drainage will be much more widely used.

It has been mentioned previously that some of the districts served by Upper Egypt Electricity Scheme for lift irrigation combine basin with perennial irrigation. There are roughly about 200,000 feddans in Upper Egypt under the semi-basin regime as it is commonly called, perennial irrigation being obtained from the subsoil water by means of engine-driven pumps. It is claimed that lowering the subsoil water-level in this way provides efficient drainage of the land so that it needs no further drainage measures. Recently the Egyptian Government has budgeted for the conversion of about 250,000 feddans in the province of Qena into the semi-basin regime, by means of electricaly-driven pumps fed from a thermal generating station, each motor pumping unit serving an area of 250 feddans.

FUTURE EXPANSION OF CULTIVABLE AREA

Egypt embraces a total area of almost exactly one million square kilometres. The whole country is warm, dry and almost rainless. The average rainfall over the country as a whole is only about one centimetre a year. With so scanty a rainfall it is no wonder that with the exception of the Nile Valley the greater part of Egypt consists of barren and inhospitable deserts.

The cultivable areas of the Nile Valley consist of narrow strips of alluvial land on either side of the River Nile and over the broad expanses of the Fayoum depression

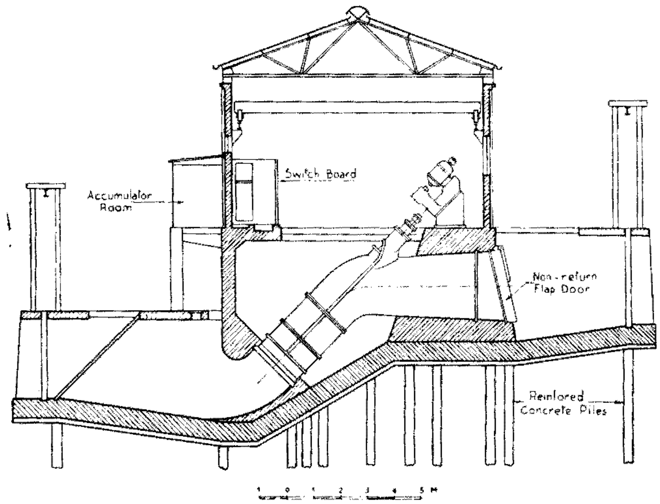

Figure 8

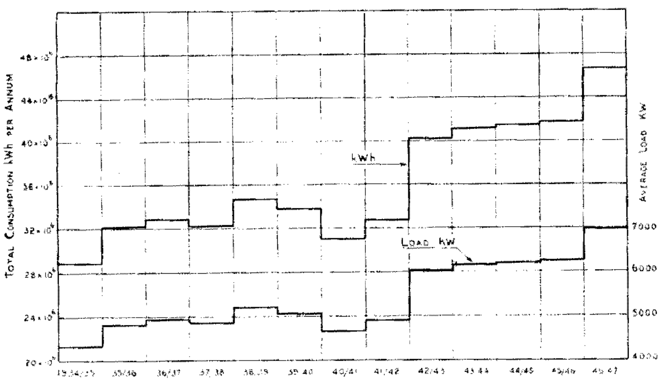

Figure 9

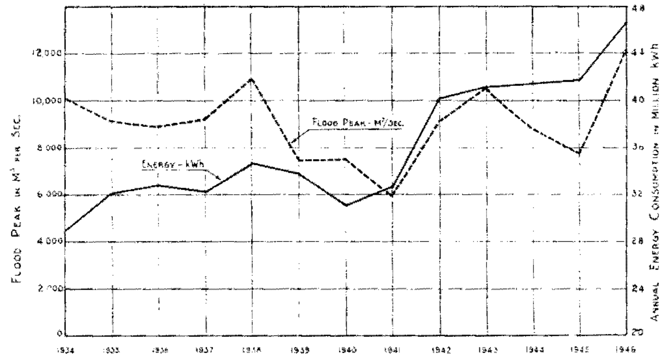

Figure 10

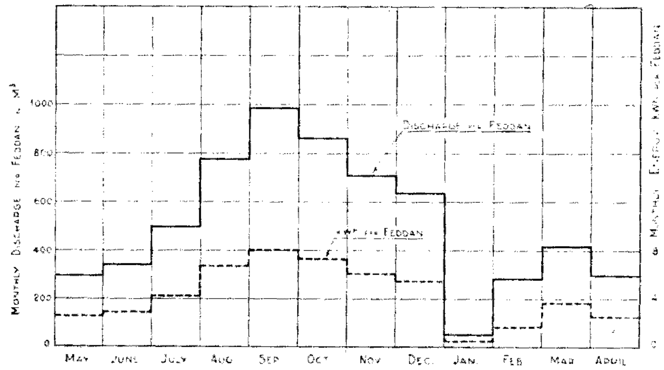

Figure 11

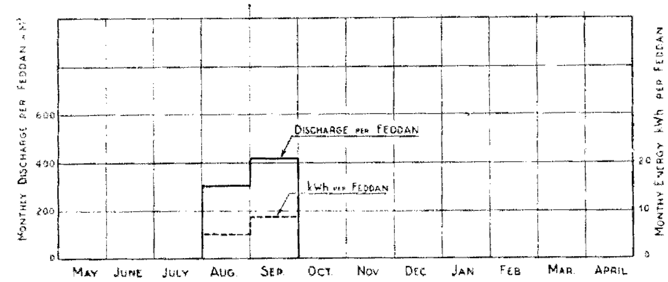

Figure 12

and the Delta, comprising in all roughly 30,000 sq. km. or about three per cent of the total area of the country, as fertile as any land in the world.

In general it may be said that land can be cultivated if it can be supplied with water. If it is salty like some of the lands of northern Egypt, washing and drainage will make it fertile. If it is desert sand, it will gradually improve as crops are grown, especially if it is watered with the muddy water of flood-time as Nile silt is added.

The area actually under cultivation at present is approximately six million feddans, but the area which can be cultivated depends mainly on the level of the land in relation to the nearest water-supply, and the availability of power for lift irrigation.

The area which can be cultivated by free flow within the borders of the Delta amounts to 7.1 million feddans. To this may be added 663,000 feddans in the Eastern Desert, east of the Suez Canal, (6) which can be irrigated mostly by free-flow and partly with a lift varying from 5 to 8 metres.

There is also an area of 430,000 feddans bordering the Delta with a lift up to 10 metres (1) extending to Alexandria. This may be increased by 47,000 feddans along the west coast.

Furthermore there is an area of 357,000 feddans in the Western Desert which can be increased to 440,000 feddans or more with a lift of 10 to 20 metres, making up a total of 1.58 million feddans. These areas added to the free flow area given above would amount to 8.68 million feddans or more. Additional areas lying at still higher levels can be cultivated if required. It may be stated in general that the problem of increasing the cultivable area beyond the free flow land of the Nile Valley resolves itself into first harnessing the Nile water so as to obtain optimum conservation and utilization thereof, and second, providing electric power in sufficient abundance and at moderate rates for lift irrigation. (7)

When estimating the water requirements of Egypt, only the water required during low Nile, i.e., February—July (usually referred to as Summer water) need be taken into consideration. The estimate has so far been based on a cultivable area of 7.1 million feddans, amounting to 28 milliards cubic metres.

The summer water available at present amounts to about 22.9 milliards, being made up of: Natural River, 15.4 milliards; Aswan Reservoir, 5 milliards; Gebel Aulia, 2.5 milliards; total, 22.9 milliards. Hence the deficit is 5.1 milliards.

This deficit, however, refers to the river discharge in an average year. In order to make allowances for low years and for possible errors of forecast of river discharge and the necessity of keeping in hand a reserve therefor, the deficit to be provided for is usually taken as 8.4 milliards.

Various schemes have been put forward for providing the above mentioned deficit. They fall under two categories. First, the conservation of the waters of the Equatorial Lake Districts, which in substance amounts to the regulation of the water flow into the Nile and the cumulative storage of surplus water for use in bad years. This scheme has been worked out for regulation extending over a hundred years and hence it is called the "Century storage" (1). It involves the excavation of a large canal to divert some of the Nile water from Bahr el Gebel, which spills over its banks into the swamps known as the "Sudd" region, with a consequent loss of water estimated at 14.5 milliards annually. The same object can be attained at lower cost and much shorter time by a scheme proposed by the author, which involves the utilization of a reservoir dam at the inlet to the swamps for the generation of power, which would be transmitted several hundred kilometres north to a point on the White Nile, where electrically driven pumps would be installed for lifting water from the swamps (8).

The second category consists in the harnessing of the flood-water of the Blue Nile, by means of two dams similar to Aswan Dam to be erected respectively at the second and fourth cataracts on the Nile, having a combined storage capacity which is adequate not only for providing all the water requirements of Egypt, but also for protecting the country against high floods. It is claimed that by proper choice of dates for filling these reservoirs, the required water quantities can be stored during the lowest flood years. (9)

As an alternative to the fourth Cataract project the author has developed a scheme for the storage of flood-water in Wadi Rayan, a large depression south-west of Fayoum province. Water would be led from the Nile to the depression during flood by means of a canal to be excavated, and stored, to the extent of 8 milliards. When the flood subsides about 2 milliards would flow back into the Nile by free flow, and the rest would be pumped out by means of electrically driven pumps (10).

There is at present a sharp controversy as to which of these schemes or rather group of schemes should be adopted. It is not proposed to discuss them here in any detail, and the reader is referred to available literature relating thereto. It may be mentioned that, generally speaking, these schemes are technically sound, and with certain modifications they can be made quite acceptable. The Lake district would cost more and take more time to carry out[11], (8) but provides more guarantees of water-supply under all conditions including years of extremely low water-supplies.

In the author's opinion the conservation of both the Lake districts and flood-waters are needed for the long-term irrigation policy advocated in this paper. The question as to which should be adopted first would depend upon available finance and the time they require to carry out, or rather the dates by which they should be completed to meet the needs of a rapidly growing population. The total summer water available from these two schemes together would amount to about 20 milliards or maybe even more. The total water requirements including those required for the areas given above, namely, 1.58 million feddans, amounts to 17 milliards.

[11]The time would be greatly shortened by the adoption of the author's scheme.

ELECTRIC ENERGY REQUIREMENTS

The electric energy requirements have been computed from the returns of large electricity schemes for irrigation and drainage previously described. The energy required for the expansion of cultivation may be summarized as follows: irrigation of elevated land, 463,088,000 kwh.; drainage of all free-flow areas in both Lower and Upper Egypt, 276,800,000[12] kwh.; total, 739,888,000 kwh., say, 740 million kwh. in all.

These figures do not include the electric losses in transmission and transformation which depend, among other factors, on the distance from the generating to the consuming centres.

The main potential sources of water-power in Egypt are the Aswan Dam, the Second Cataract and the Qattara Depression, which are capable of producing altogether 1,130,000 kw. (10). The Aswan Dam scheme is under construction; the other two projects are under examination. The estimated energy output of these three schemes amounts to 8,000 million kwh.

The benefits to be gained from the extra cultivable area cannot be over-estimated. Not only will it provide labour for the population of a productive kind, to which they are admirably suited, but would also practically fulfil the country's needs as regards food and clothing, and probably leave a surplus for export. Moreover, as mentioned previously, this system of irrigation is capable of further expansion into the desert on a long term policy. For instance, it can be extended to cover the shores of the Mediterranean almost as far as the western boundaries of Egypt. This region has excellent climatic and geographical conditions for habitation and sea-side recreations, as well as industrial and commercial activities. It only lacks water, which, being provided in the manner described above, for domestic uses as well as for a certain amount of cultivation, would transform it gradually into an ideal residential area.

In conclusion the author wishes to thank Sayed Bey Abdel Gawad, Director-General of the Mechanical and Electrical Department for permission to use the returns of the annual reports in the present study.

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The Importance of Sediment Control in the Conservation and Utilization of Water Resources

E. W. LANE and OWEN G. STANLEY

ABSTRACT

Problems involving sediment are becoming increasingly important in water-resource development and control. In some sections regional development is limited by the water resources, and the filling of reservoirs by sediment is a serious problem. The filling of stream channels by sediment deposits caused by excessive soil erosion and the withdrawal of water from streamflow is a similar problem. Although an absolute remedy is not now known for many of these cases, certain steps to improve the situation can be taken, and future developments of science can be expected to bring assistance along lines not now completely visualized.

A problem closely related to sedimentation is the debris-flows which have caused great damage and even loss of life in certain areas, especially in the vicinity of Los Angeles, California. Another closely allied problem was the debris from hydraulic mining operations in the Sierra Nevadas of California in the latter half of the last century. This debris was carried down into the Central Valley, causing serious aggradation of river channels, which impeded navigation and caused widespread inundation from floods. Aggradation reached its peak stage about 1905, but since that time the river-beds have gradually receded until the channels now approach their original condition.

Sediment control as a factor in the conservation and utilization of water resources is receiving more and more recognition as water resources become more completely developed. However, it has not yet received the attention which its importance warrants. In the present state of our scientific development, sediment difficulties place definite limitations on the life of many of our hydraulic projects and the cultural improvements related to them. In semi-arid regions, such as the western part of the United States, growth in population and industry is definitely limited by the water resources available. In some sections, development is already approaching its limit. Full utilization of water resources necessitates storage of water in times of excess stream-flow for use in times of deficiency. But, in water storage reservoirs, deposition of sediment is gradually reducing effective capacity and eventually will destroy their usefulness unless means of sediment control are evolved. Therefore, the length of the useful lives of reservoirs, means by which the lives can be prolonged and the possibilities of alternative reservoir sites are matters of great importance.

The reduction of storage space by sedimentation involves much more than the loss of investment in the reservoir and appurtenant facilities. As a result of the construction of reservoirs, cities are supplied with water without which they could not exist, and irrigated areas are developed which are absolutely dependent upon the reservoir. Also, in many instances, the growth and development of industry are dependent upon the electric power which the reservoir makes possible. In the light of present knowledge, if sedimentation cannot be eliminated or if alternative storage or sources of power are not provided, these cultural developments will be imperilled. It is therefore imperative that in planning water utilization, the possibility of such an eventuality be adequately appraised.

The rate at which reservoirs fill with sediment varies greatly. The rate depends upon the quantity of sediment in the water and upon the ratio of the volume of the reservoir to the volume of water which passes through the reservoir and drops its load of sediment. There is a great range, both in the quantity of sediment carried by streams and in the ratio of storage volume to flow volume. Consequently, there is even greater range in the useful lives of reservoirs. At one extreme are reservoirs having small storage capacities in comparison with the volume of flow and which are located on streams carrying heavy sediment loads. Such reservoirs may be filled in a single flood. At the other extreme are reservoirs having large storage capacities in comparison with the stream-flows and which are located on streams with very low sediment content. The useful life for such reservoirs may be measured in thousands of years. Fortunately, by making sediment measurements it is possible to collect data in a few years which permit reasonably accurate predictions of the rate of sediment accumulation, provided conditions of the drainage area do not change in such a way as to alter the rate of sediment production. With a knowledge of the rate of sediment accumulation it is possible to estimate whether a project should be constructed, or whether its construction would be economically infeasible because of short life.

What are the remedies to the sedimentation of reservoirs? The most obvious one is excavation of the sediment.

But, except under most favourable conditions, costs appear prohibitive. Another remedy is flushing out of the sediment. This plan is practicable only under favourable conditions and requires considerable water, which decreases the amount available for other purposes. Another possibility is to build new reservoirs or increase the capacity of present reservoirs when they are filled. In many cases alternative sites are available, but since the most economical sites are developed first, the alternatives will be more expensive than the original reservoirs. The eventual result of continued development under such circumstances is obvious. A fourth remedy is soil-erosion control. A great deal of work has been done in this field of endeavour.

In regions where rainfall is adequate to support considerable vegetation, soil-erosion control measures can result in considerable benefit within a relatively short time. In semi-arid regions the growth of vegetal cover is slow and improvement through soil-erosion control is likewise slow. Without doubt, though, great efforts should be expended in soil-erosion control since such work usually has important benefits besides the prevention of sediment accumulation in reservoirs. However, even with the best erosion control streams still will carry sediment which will accumulate in reservoirs.

The reduction of effective storage space in reservoirs is only one of the difficulties caused by excessive deposition of sediment. Valley aggradation is also a resulting problem. A typical case of valley aggradation is the Middle Rio Grande Valley in New Mexico, United States of America. In past geological time, this valley had probably reached a condition of substantial equilibrium between sediment inflow from the tributaries and sediment outflow in the main river. In recent years, however, men have diverted for irrigation a large part of the clear-water inflow and at the same time have increased the sediment inflow by over-grazing parts of the drainage-area. Consequently, there has been an increase in sediment inflow with a decrease in stream-flow available to transport it, with a resulting deposition of sediment in the river-bed. This has already raised the bed above the level of the streets of the principal city of the valley, and is now threatening the agricultural productivity of lands along the river by raising the ground-water level. In this case reservoirs for the combined purpose of reducing flood flows and storing excess sediment, together with channel contraction which will increase the sediment transporting capacity of the river, are planned by the United States Bureau of Reclamation and the Corps of Engineers, U.S. Army. These improvements should remedy the situation for many years, after which reservoir enlargements or new reservoirs may be necessary. There is, of course, a definite limit, a long time in the future, beyond which these remedies may not be effective, and other valleys may not be so fortunate as the Rio Grande in having reservoir sites. In many ways the valley aggradation problem is similar to the reservoir problem previously discussed, and the long-range aspect is practically the same.

The importance of sediment or debris-flows is not confined entirely to their effect upon water-storage reservoirs or river aggradation. In some instances the control of sediment is vital in the solution of flood problems. A large proportion of the major flood problems of China are caused by the deposition of sediment. In several locations in California debris-flows have caused great damage and even loss of life, particularly in the vicinity of Los Angeles where a portion of the City's metropolitan area lies at the base of the San Gabriel Mountains. In a distance of one to three miles these mountains rise abruptly from a base elevation of about 2,000 ft. to an average crest elevation of 7,000 ft. The face of the mountains is very rugged, being characterized by precipitous canyons. The mountains are composed of shattered and badly-weathered rock overlaid by a thin mantle of coarse, rocky soils that support a growth of brush and shrubs of varying density. This vegetal covering is extremely susceptible to fires, which often entirely denude large areas. Accumulations of material have formed below the canyon mouths and, where canyon mouths are adjacent to each other, they have merged to form large alluvial fans with slopes of two to ten per cent. During long intervals between major storms, these alluvial fans have become inhabited, in many places quite extensive developments having taken place.

In general, major storms sweeping this area originate in the North Pacific, move south over the ocean and inland over the San Gabriel Mountains. As the moisture-laden air masses are deflected upward by the precipitous mountains, the rainfall from them increases rapidly both in intensity and quantity. For instance, the average annual rainfall varies from about 20 in. at the base of the mountains to more than 40 in. at their crest. The intensity of rainfall during major storms varies in about the same manner. Consequently, when these storms strike, flood-waters literally pour down the mountain sides. Flowing over material that is readily eroded, especially so if the area just recently has been burned over, they pick up and transport debris ranging in size from fine sediment to boulders of several tons. The debris-laden waters accumulate rapidly in the steep canyons, rush down on to the flatter alluvial fans and into shallow, poorly defined channels. There, because of the flatter slopes and consequently decreased velocity, much of the debris load is dropped, clogging the channels and often causing change in course. In many instances, the changed paths have been directed through residential developments, carrying away houses and other improvements and resulting in great property damage and often in loss of life. Such catastrophes occurred in 1934 and again in 1938.

The Los Angeles River Drainage Area flood control project, being prosecuted jointly by the Corps of Engineers, U.S. Army, and the Los Angeles County Flood Control District, is designed, as one of its objectives, to alleviate conditions resulting from these debris-flows. In general, the solution entails catching the debris in basins constructed on the alluvial fans at the canyon mouths. These debris basins have concrete spillways, and often concrete inlet structures, and are supplemented by paved channels to carry away the water after deposition of the debris. When the project is called into action, deposition of debris starts at the upper end of the basin and proceeds toward the spillway, and the basins are designed, as to length, width and depth, so that when the deposition of material reaches the spillway, the fill has extended fully to the sides of the basin. Usually, the basins are designed to contain the output of one major flood, with provisions for excavating the deposited material after each flood. In instances, the basins are designed to hold the debris from several floods; in other instances, the basin is sufficiently large to hold the debris for the estimated economical life of the whole project; and, in a few instances, debris storage is accomplished in reservoirs built primarily to regulate stream-flow to prevent inundation by water.

The intensity of debris-flows varies greatly, influenced principally by the character of material in the watershed, the steepness of its slopes, the condition of the vegetal covering and the quantity of run-off. Very recently burned-over areas, naturally, produce the most debris. Flows during a single storm up to 85,000 cubic yards per square mile of tributary area have been observed, while it has been estimated that under very adverse conditions flows during a single storm up to 200,000 cubic yards per square mile may be attained.

In the Central Valley of California, a man-made flow of sediment has taken place that, together with the treatment thereof, has had a marked influence upon the development of all northern California, and especially upon the Central Valley itself. It is the debris from hydraulic mining operations on Sierra Nevada streams to obtain gold from the gravels of both present day and ancient river channels. These operations consist of applying water under pressure to banks of gravel to separate out the gold. They began soon after the Gold Rush in 1849, and increased rapidly in magnitude and extent until 1884. In the hey-day of hydraulic mining, great water systems with ditches many miles long were developed. Large mountains were washed away, the small gravel and finer materials being carried into the stream channels and thence on down to the navigable rivers below. The channels of these lower rivers became choked with debris, so that navigation thereon was almost impossible, and their flood-carrying capacity was so impaired that even moderate floods caused widespread inundation of valley lands. For example, the bed of Yuba River in the vicinity of Marysville was raised about 20 ft., until the low-flow water-surface was some ten feet above the ground surface in the town. Only the construction of high levees permitted the town to continue in existence.

In 1884, hydraulic mining was stopped by a Federal court ruling, based primarily upon the injury to navigation being caused by the debris. It has been estimated that some 1,540 million cubic yards were hydraulically mined during the time hydraulic mining was uncontrolled. Although the court decision halted uncontrolled hydraulic mining, much mining debris had become lodged in mountain canyons as a result of these operations and for years it continued to be carried down in great quantities, the aggradation of river channels in the valleys reaching its peak about 1905. Since then, the beds of the lower rivers have gradually receded until they now approach their 1849 condition.

Although uncontrolled hydraulic mining was stopped in 1884, investments in the industry were so great, and developments dependent upon it were so large, that great efforts were exerted for its resumption. Accordingly, in 1893 the Federal Congress created the California Debris Commission, a Board consisting of three officers of the Corps of Engineers, U.S. Army, to regulate hydraulic mining and to assist in its revival. Since that time, hydraulic mining has been prosecuted, under licence by the Commission, where provision is made for retention of the debris. In fact, the Commission itself has built two reservoirs for the retention of hydraulic mining debris. One of these is the 71,000 acre-ft. Englebright Reservoir on Yuba River, and the other is the 12,700 acre-ft. North Fork Reservoir on North Fork of American River. The capacities given are water capacities. The debris capacity is estimated at 118 million cubic yards for Englebright Reservoir and 25,100,000 cubic yards for North Fork Reservoir, being calculated on the basis of the probable slope the debris finally will assume. Operators who mine on the watershed above these reservoirs pay the Government for the privilege of depositing their debris therein. The storage rate for the Englebright Reservoir is 2.3 cents per cubic yard, and for the North Fork Reservoir, 3.11 cents per cubic yard, quantity measurements being made in the mine pits.

Despite all efforts to revive hydraulic mining by having it operate under Federal control and with some Federal aid, the industry has not even approached the magnitude and importance it held prior to the court decision of 1884. Because of high prices for both labour and materials, at present it is almost dormant.

For the solution of the sediment problems discussed in this paper and the many others which now confront the hydraulic engineer, a new branch of engineering, which may be called "sediment engineering" is being developed, which promises to grow in importance as these problems become more accute.

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The Silt Problem in the Basin Development of the North China Plain

C. T. FONG

ABSTRACT

The rivers flowing out of north-west China, of which the Yellow River and the Yungting Ho are first and second in importance, have the highest silt content in the world. So great is the load of silt that they are unable to carry all their burden to the sea, and consequently they drop a part on their way. Thus was formed originally, and is still being laid down, the vast North China plain that now supports a population of a hundred million. Yet the river conditions that produced the plain also produce the floods that periodically cause great devastation and loss of life.

The control of the rivers' water volume and silt content has long been a problem for which various solutions have been tried. To confine the streams within their channels, dykes and embankments have been built in the past but these have proved only a temporary solution. As the river-beds have risen owing to the deposit of silt, the dykes have had to be raised so that the Yellow River and the Yungting Ho are for considerable stretches elevated above the plain ; when a breach in the dyke occurs, the havoc is immense.

Soil and water conservation measures, particularly in the upper courses of the rivers, are, of course, a fundamental means of flood and silt control, and also help to prolong the life of the reservoir downstream. In addition, the writer proposes the building of a gorge-type reservoir with two large-capacity outlets to discharge silt into a series of desilting basins for which the lowlands parallelling the elevated river-beds would be used. These lowlands would gradually be raised by silt deposition and could be drained during a certain period of the year for use as one-crop farming land. In the periods when the basins are under water, clarified water could be drawn off to irrigate the adjacent dry land. A further benefit from the construction of a high dam would be the generation of power, an urgent need in connexion with the industrialization of China.

The writer's proposals differ in principle from older desilting-basin projects in that the plan is to operate under artificial controls both with regard to the time of operation and to the amount of water and silt that is admitted.

INTRODUCTION

The North China plain, extending south to the Huai River and north to the Great Wall, is the gift of the rivers which flow out from north-west China, among which the Yellow River is the most important and the Yungting Ho the second. The plain is still undergoing extension at the rate of about 1/8 km. annually at the mouth of the Yellow River (1)[1] and 21,600,000 tons of silt have been deposited near Daikou, the mouth of the Yungting Ho (2).

So great is the load of silt carried by the rivers that they are unable to carry all their burden to the sea and consequently they drop a part on their way. To prevent inundation of the plain, dykes or embankments have been built from time to time, thus making the river-bed higher and creating a higher potential of dyke breaches. Thousands of square miles have occasionally been flooded and millions of lives have been lost. Those who escape death by water die by famine or are at least impoverished and weakened by privation.

A great deal of thought has been given to elimination of floods, some attempts being partially successful and temporarily effective. Evidently the flood control of such rivers is a hard task, involving the solution of the complicated problem of water and silt combined, in which silt is the predominant factor.

It is the silt that once developed the vast plain and attracted and benefited the people who live on the plain. But silt is now one of the main factors causing serious floods which result in great loss of life, famine and suffering. The same silt that now is a scourge was beneficial in the past.

This paper suggests the general principles which may be adopted to solve the complicated problem of flood control, and pays particular attention to the distribution and economical utilization of both water and silt. Both have been the cause of devastation but they can be converted into use.

The principles herewith described are not new or epoch-making. They are threefold: checking of floods by a storage reservoir, disposal of silt in a desilting basin and utilization of the clarified water for irrigation. Special emphasis is given to the disposal of silt from the reservoir, since this is generally considered as the vitally important problem in the construction of the reservoir, and one which is not yet perfectly solved.

GENERAL DESCRIPTION OF THE RIVER-BASIN AND THE ALLUVIAL PLAIN

The North China plain is about 125,078 square miles in area, excluding East Shantung. It has a striking uniformity in level and in colour; even the roofs are made of the same yellow mud that covers the plain. It sustains a population of over one hundred million and is one of the most intensively used regions of its size on earth.

The rivers, originating in the mountains and upland regions of north-western China and all of them flowing in an easterly direction, have the highest silt content in the world. Their present beds in the plain are several metres above the adjacent land; the Yellow River near Kaifeng has a maximum elevation of 15 metres above the plain, and the Yungting Ho below Chen-Macha, 5 metres' elevation. Consequently the river-beds are ridges in themselves, and serve as watershed lines dividing the alluvial plain.

The surface of the plain is composed of river alluvium and soil deposited by the wind; it is highly fertile and

[1]Numbers within parentheses refer to items in the bibliography.

thus favourable for agriculture. A few long stretches of sandy soil mark the course of some ancient river. As recorded in history, the Yellow River has seven times shifted its lower course, and the Yungting Ho has also changed its banks many times.

Because of the flatness of the plain, the water table is relatively high and drainage is poor. The soils along the lower stretch of the rivers are mostly of high salinity. The white colour of sodium chloride and sodium sulphate, a result of excessive evaporation, appears on the lower lands and swamp areas when they are dry.

An equitable distribution of rainfall is the key to prosperity, for too little rain brings crop failures and excessive rain, flood and famine. Artificial irrigation may be the basic means of achieving prosperity both for the watershed basin and the plain. Ningsha, Sianyuan and Kuanchuan along the Yellow River, and Sin Bou An along the Yungting Ho, where there are both old and new irrigation systems, have been proved to be the richest regions in agricultural production.

Over the plain rainfall averages 600 mm. decreasing from 800 mm. at the coast, to 300 in the interior. It has been roughly established that about 60 per cent of the annual precipitation falls in the months of June, July and August, while the remainder is scattered over the other nine months. In amount and in distribution, the rainfall is obviously too uneven for full harvests.

On account of cold weather, low rainfall and insufficient fertilization, "three harvests in two years" is the general cropping practice; winter wheat is the principal crop, and buckwheat, millet and Indian corn are auxiliary crops. In Shangtung Province and to the south, kaoliang can be planted as the winter crop. Rice plantations are limited to the region in the Huai River basin, the east Hopeh region and scattered places of the upper basin where plentiful water is available. The western part of Liu Pan Shan and the northern regions of Shensi and Shansi lie in the spring wheat belt, where buckwheat, millet and rapeseed are the summer crops. Rapeseed, the only crop planted at elevations above 2,500 metres, is widely spread over the upland.

The forests, being of limited extent and scattered throughout the basin, are of little utility as a means of regulating river discharge. Reafforestation is a difficult undertaking because sufficient moisture is lacking. Most parts of the mountainous districts are entirely bare of vegetation.

The flood damage wreaked by the Yellow River is immense. *The Yellow River Chronicle* (3) records dyke breaches on 1,170 occasions during the past 4,224 years, i.e., once in two and a half years, on an average. The river has overflowed its banks on 422 occasions. As a result of dyke breaches, the river's lower course has shifted seven times. Where its outlet was once at Tientsin, and it flowed southward to the Huai River, it later found its way to the sea with an outlet near Shanghai. The uncontrolled regime of the river has led to the impoverishment of the hundred million people who live on the plain and has harassed the whole country. The average annual property loss has been estimated at $US 8 million.

As for the damage caused by the Yungting Ho, 124 occurrences of flood have been recorded within 1,681 years. The area flooded by this river and the adjacent Ta-Ching Ho has reached a maximum of 12,200 sq. km. while the average annual inundation is 1,670 sq. km. On the assumption of an annual agricultural yield of $US 2,000 per sq. km., the tangible flood loss for each year amounts to $US 3.3 million.

For the whole North China plain, a total of $US 12 million is a conservative estimate for average annual flood damage. (See the following table.)

RIVER-REGULATION MEASURES ADOPTED AND PROPOSED IN THE PAST

Earth embankments and spur dykes

Both for the Yellow River and the Yungting Ho, the earth embankment is the principal means of flood control, a means adopted many centuries ago. The total length of the dyked section of the Yellow River from Mengtsin to Litsin is 720 km. and that of the Yungtin Ho is 140 km. from Macopola Bridge to the junction with the Pei-Yung-Ho (North Canal). A tremendous load of silt, exceeding the carrying capacity of the river, is deposited on its bed, thus raising the flood-level higher and higher and necessitating higher and higher embankments to carry the same volume of flood discharge. As stated earlier, the present maximum elevation of the Yellow River is 15 metres above the adjacent land near Kaifeng, and the Yungting Ho is 5 metres above the plain near Chen-Ma-Cha. As this process of silt deposition is by no means stopped, the difference in elevation will gradually increase from year to year, and so will the potential of flood damage. Earth embankments are evidently not a permanent solution but rather a temporary expedient that puts off the evil to the second generation.

A confinement system with spur dykes has been widely adopted for regulation of the lower sections of both the Yellow River and the Yungting Ho. These, too, have not proved to be a practical solution. Because of the tremendous amount of debris that ceaselessly flows into the river from the watershed, the fixed channel can hardly be traced. The present purpose of the spur dykes is only for the protection of the embankments, not for scouring the silt deposits from the bed.

Soil and water conservation work

Soil and water conservation work has been generally considered as the basic means of flood control, and a means of prolonging the life of the reservoir downstream. A lower silt content in the rivers would, it is reasonable to assume, tend to cut down their beds, thus confining their currents in definite channels and greatly decreasing the possibility of dyke breaches.

Lowering of the silt content of the rivers, of course, requires control of erosion in the river-basins. The principal types of soil erosion are classified as sheet erosion and gully erosion. Sheet erosion is the process of removing top-soil from land into adjacent tracts or gullies. Conditions conducive to gully erosion are steep slopes, an abundant amount of water and the presence of silt in great quantities. The lower reaches of sloping land frequently develop

Basic Data Concerning the Yellow River and the Yungting Ho

	Yellow River	Yungting Ho
Geographical and topographical data		
Total drainage area	771,574 sq. km.	54,040 sq. km.
Loess soil area	288,234 sq. km.	—
Length of main river	4,635 km.	500 km.
Length of dyked section	720 km.	140 km.
River slope of lower course	1 : 6370	1 : 2750
Meteorological data		
Average annual precipitation over the basin	470 mm.	428 mm. in mountainous region
Minimum annual precipitation over the basin	286 mm.	518 mm. over the alluvial plain
Hydrological data		
Max. flood peak (CMS)	at Shenhsien 29,000	at Sancha-Tien 5,000
Av. annual discharge	1,375	
Min discharge	245	0.8
Max. flood run-off (M^3)	at Shenhsien $3,200 \times 10^6$	540×10^6
Max. annual run-off	$71,201 \times 10^6$	
Av. annual run-off	$42,991 \times 10^6$	
Min annual run-off	$20,711 \times 10^6$	
Max. silt content	46 per cent by weight	55.73 per cent by weight
Max. annual silt run-off	$2,643 \times 10^6$	
Av. annual silt run-off	$1,890 \times 10^6$	30×10^6
Flood damage data		
Max. inundated area	29,600 sq. km. (1938)	12,200 sq. km. (1939)
Av. annual inundated area	2,318 sq. km.	2,330 sq. km. (including swamp area)
Average annual loss	$US 8 million	$US 3.3 million

numerous rills which induce gully erosion. New gullies by the thousand are developed every year, and the erosion problem becomes more acute as the year progresses.

In the Yungting Ho basin, 11 checkdams for the purpose of saving the soil were proposed above Kuanting (5). No definite similar plan exists for the Yellow River but experimental work has been undertaken on a small scale with the view of studying the soundness and effectiveness of the different methods that could be employed.

A practical method of gully control is to build a dam across the rills, thus providing a small reservoir to check the run-off and silt. Such dams have proved to be very effective just after their completion, but they gradually cease to serve their function. The gully-control work, designed with emphasis on the deposition of silt, does nothing to prevent the process of soil erosion from land, and indeed tends to destroy the land along the shore-line of the smaller reservoirs. That no direct benefits return to the farmer may, however, be the principal obstacle to wide adoption of the method.

Sloping terraces as a means of erosion control appear to be very popular in the upper basin of the Yellow River and Yungting Ho. It does not seem possible to extend the work greatly. Level terraces have been suggested as a means for checking the run-off and for encouraging the deposits of silt from upper land. By way of gradual deposition on the lower end behind the retaining ridge, the land will become rather flat, and the flatter the slope the less is the loss of soil through erosion. But retaining ridges proved to be unsuitable for loess soil districts due to the impounding of water behind the ridges, a result that increases the possibility of sink-holes and land-sliding. Experimental data (6) on the cohesion and the friction angle of loess in different districts ranges from 0.045 to 0.18 kg. per cm. and from 20 degrees to 35 degrees respectively. Under saturation conditions cohesion suddenly drops to naught and the friction angle still remains unchanged.

A general conclusion can be drawn from the above statement that the engineering method either of soil-saving dams or retaining ridges is not the basic means of soil and water conservation, but is at most a temporary method, not a fundamental solution.

The land, entirely covered with snow in winter, and successively frosted in spring, becomes more susceptible to erosion. Fortunately, the precipitation before May is scanty, and such soil erosion as occurs is very slight and without injurious effect upon the river downstream. Heavy precipitation falls in the months of July, August and September, when most of the principal crops are harvested and the winter crop is just seeded but has not reached the flourishing stage. Heavy precipitation and poor coverage, the two main factors which cause erosion, occur concurrently and lead to serious erosion throughout the basin.

Strip-cropping or overlap-cropping, usually effected by planting a row of taller crop with a row of lower crop, or by seeding one crop before another crop is harvested, is a practical method eliminating the hazard of poor coverage and checking sheet erosion from farming land, and a method that is peculiarly effective in the periods of heavy precipitation. In this method, the annual yield per unit area will be somewhat increased, a result that should induce the farmer to carry out what the hydraulic engineer wants to accomplish. Based on the principle of a definite and guaranteed benefit to the farmer, the method may well be widely adapted and practised over the whole basin.

Reservoir system

For rivers of limited flood volume, such as the Yellow River and the Yungting Ho, detention reservoirs or storage reservoirs, if topographically suitable, should be considered as the most effective method of flood control. The method has since 1933 been under consideration for the Yungting Ho by the North China River Commission, which proposed building a dam at Kuanting (5). For the Yellow River, Mr. Elliansan first initiated the idea of a detention basin at Shenhsien (7). The Japanese, after careful field investigation, proposed constructing a dam at Sanmen with a total storage capacity 40×10^9 cub. metres—enough for storage of the total flow of the Yellow River. Later the Yellow River Consulting Board suggested shifting the dam-site to Pulihutung where there would be less flowage damage than at the Sanmen site (8).

Owing to the tremendous amount of debris flowing into a reservoir, the storage reservoir project will immediately meet with strong objections. When a reservoir becomes so full that it has no further value for storage, not only is the investment therein entirely lost, but an irreplaceable national asset is forever wasted.

THE NEW PROPOSALS

For the flood control of the lower plain and regulation of the lower river-course, for improvement of the swamp areas and the saline land, for irrigation of the belt area along the river and the prevention of silting up of the reservoir, the writer suggests that a gorge-type reservoir be built with two large-capacity outlets to discharge silt into a desilting basin from which clarified water will be re-utilized to irrigate the adjacent dry land. The silt flowing out through the outlets would be deposited upon the lower land, which would act as the desilting basin and, when drained, would become one-crop farming land. Thus water and soil, once wasted and destroyed, would be converted into use.

In these new proposals, the principal works would consist of the following items:

1. The building of a dam at the lower end of the gorge forming a gorge-type reservoir, with a view to flood control. Say that the dam for the Yellow River would be at Pulihutung and for the Yungting Ho, at Sankiatien about 50 km. west of Peiping.

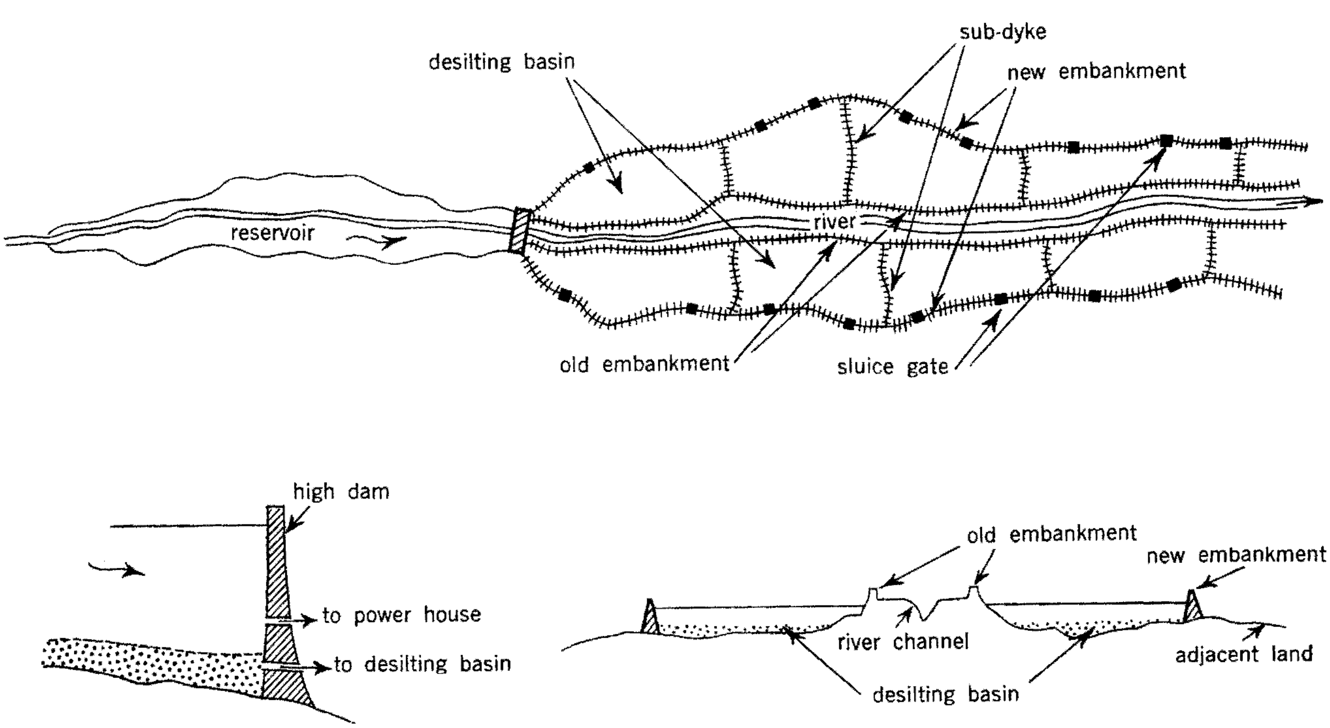
2. The construction of two parallel earth-embankments on both sides, with the original dyke and some new sub-dykes forming a series of desilting basins.

3. The provision of two large-capacity outlets in connexion with two canals in order to lead the water and soil from the reservoir to the desilting basin which originally would be much lower than the river-bed.

4. The building of a great number of sluice-gates, acting as intakes of the irrigation canal, at proper locations along the new embankment so that clarified water could be supplied to adjacent dry land.

Such works would be widely scattered over the belt plain and could be executed within the same period. Native labour and material could be utilized to the maximum extent. All these works, each with its individual function, would become an integral part of the basin development. A diagrammatic sketch follows as a brief illustration.

DIAGRAMMATIC SKETCH OF THE NEW PROPOSED PLAN



The following observations, based on field investigation of many reservoirs, may be considered as generally characteristic of reservoir sediment. They indicate that the effectiveness of the reservoir may possibly by improved with artificial treatment.

1. The sediment profile is more or less in parallel with the original bed. The decrease of reservoir capacity can be roughly estimated from the original volume by subtracting therefrom the volume of silt calculated from the average value of depth throughout the whole length of the deposit.

2. With the dam height below 100 metres, analysis of conduit capacity averaged 5 to 8 per cent by weight.

3. The initial discharge contains a large proportion of sediment, but after a short period of continuous flow, the discharge becomes relatively clear. The operation reopening the conduits at certain intervals will effectively increase the scouring amount of sediment. In a large number of cases the percentage of sediment in the outlet water is the same as that of the initial flow, though actually a maximum of 10 per cent has been obtained.

4. Water of low temperature will effect an increase in the scouring power of the deposited layer.

The desilting-basin principle was first suggested by K. C. Lee (5) in the Ching Dynasty; it was later systematically proposed by Mr. S. A. Hardel (5) and finally adopted by the North China River Commission for the Yungting Ho (5). There is a strip of land adjoining the dyke, about 5 km. or 6 km. in width and several metres lower than the river-bed, which is favourable for use as the desilting basin because it is mostly akaline and swampy. Functioning to some extent as a flood basin, the construction of a series of sluice gates has been proposed along the dyke, in order to divert a part of the flood-water to the lower land to allow the silt contained in the diverted water to be deposited there; in this way the land will gradually be raised and improved as a reclamation measure.

From the technical point of view, this scheme will encounter many strong objections:

1. In general, the higher silt content occurs in the time of flood, i.e., in the months of July, August and September, and the diverted water would be injurious to the crops already planted in the region.

2. The existence of a series of sluice gates would increase the possibility of breaks in the dykes.

3. The outflowing of a great amount of discharge of lower silt concentration and silt of fine particles, means that the coarser sand would be retained in the river and less would be transported to the sea. Both results would worsen the flood conditions.

In the new plan, the flood discharge is temporarily storaged in the reservoir. The water to the channel proper is to be of lower silt concentration, or rather it is to contain a controlled quantity of silt. The basin scheduled for inundation will be in use for five months from December to April of each year, while clarified water will be delivered from the desilting basin to the adjacent land whenever the crops need to be irrigated. In the months from May to October the desilting basin would be drained for farming, when the adjacent land as well as the desilting basin can also obtain water from the reservoir, thus benefiting the land irrigated and achieving flood control through storage.

The old desilting-basin project and the desilting-basin principle adopted in the new plan, though they are the same in effect, are quite different in principle. The new plan is to operate under artificial controls both with regard to the time of operation and to the amount of water and silt that is admitted. Besides admitting coarser silt into the desilting basin, the new plan has special advantages in that the river channel downstream and the general drainage of the basin are favoured.

The following figures, though not very accurate, may be considered as on the conservative side. Our studies indicate that the new plan will be in continuous operation on the Yellow River for 720 years and for 933 years on the Yungting Ho. If a desilting basin should be constructed upstream or should soil conservation work be undertaken throughout the watershed, the projected works would last much longer.

1. *Yellow River*. Length of dyked section, 720 km.; average difference in elevation between river-bed and the adjacent land, 5 metres; average width of the desilting basin on both sides, 10 km. The total volume of the desilting basin is therefore—$720 \times 1{,}000 \times 2 \times 10 \times 1{,}000 \times 5 = 72 \times 10^9$ cub. metres. Suppose that 200×10^3 tons of silt are delivered annually into the desilting basin and the density of the silt deposit in the basin is twice that of water. Then the number of years for continuous operation is—

$$\frac{72 \times 10^9 \times 2}{200 \times 10^6} = 720 \text{ years}$$

2. *Yungting Ho*. $140 \times 1{,}000 \times 2 \times 5 \times 1{,}000 \times 1 = 1.4 \times 10^9$ cub. metres. Suppose that 3×10^6 tons of silt are delivered annually to the basin; then similarly the number of years for continuous operation is—

$$\frac{1.4 \times 10^9 \times 2}{3 \times 10^6} = 933 \text{ years}$$

PROSPECTIVE BENEFITS

The river-flow, after regulation by reservoir, would have a lower concentration of silt and the silt would consist of comparatively fine particles. Degradation would suddenly take place near the downstream part of the reservoir but the material removed would be deposited somewhere downstream. It is reported that 150 million cubic yards of silt have been moved downstream during the eleven years following the closure of Boulder Dam. The degradation as it progresses for the river of water and controlled silt, will be continued in action and gradually extend downstream farther and farther. This, of course, will be a very long time, but the performance of the deep channel will be secured in the long run.

As the result of degradation of the channel proper and of the sudden drop of the flood-peak due to regulation by reservoir, the possibility of dyke breaches downstream would be eliminated, thus protecting all the properties in the alluvial plain and the lives of the inhabitants.

The benefits that may be derived from releasing the large amount of water clarified in the desilting basin are obviously threefold: irrigation of the adjacent dry land, reclamation of adjacent lowlands and their conversion into fertile land, and reinforcement of existing dykes.

Take the Yellow River as an example. Suppose that the average annual silt deposit of 200×10^{6} tons of relatively coarser particles is suctioned out through the outlet and diverted to the desilting basin where the average silt concentration is 5 per cent. The water that could then be drained out is estimated at $3{,}800 \times 10^{6}$ cub. metres or approximately one-tenth of the annual run-off, which is enough to irrigate 8 million mou of farm land.

As the desilting basin would be under water from December to April of each year, the crop of winter wheat would be entirely lost. But drainage permits the use of swamp or water-logged land, and such land is usually very fertile. The area is suitable for the planting of certain crops of higher value, such as cotton which is harvested at the end of October. It is probable that the loss of winter wheat would be compensated by crops of higher value planted in fertile land.

The construction of a high dam would, of course, have great importance for the generation of power, the most urgent need in connexion with the industrialization of China.

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Costs and Benefits of Canal Linings

T. V. WOODFORD

ABSTRACT

Costs of linings in irrigation canals range from about $ 2.50 per square yard for unreinforced portland cement concrete to as low as 12 cents per square yard for silt or loosely placed earth linings. Pneumatically applied portland cement mortar and hot-mix asphalt linings are about equal in cost and somewhat less than portland cement concrete. Linings of compacted earth with and without bentonite have proven effective in seepage control at costs averaging 50 cents per square yard where suitable materials are available in the immediate vicinity. Rather limited experience with thin buried membranes of asphalt cement indicates excellent possibilities for a positive seal with long life at costs from 60 to 80 cents per square yard.

The chief benefits and the greatest justifications for canal linings are the conservation of water and the prevention of land waterlogging. Often the water saved as a result of reduced seepage losses will make possible the irrigation of enough additional land to repay the cost of lining. If additional land is not irrigated, the size and cost of storage and distribution facilities may be reduced. Other benefits are better hydraulic properties and lower maintenance costs resulting from reduced weed growth and less erosion.

INTRODUCTION

The water in our streams and rivers which is utilized for irrigation, power, and domestic consumption is recognized as an important and valuable natural resource. In conveying this water through unlined canals, a large portion of it seeps into the ground or through the banks and is, for the most part, wasted. Such losses through unlined canals often amount to one-third of the total inflow. Where losses are found, or expected to be excessive, linings of appropriate materials are placed over the wetted area to stop the seepage or reduce it to a satisfactory minimum. Although there are other benefits, which will be discussed later, the chief function of a canal lining is to control seepage and therefore it should be of low permeability, if not watertight.

TYPES OF CANAL LININGS AND THEIR COST

The types of canal lining in most common use in the United States are portland cement concrete, pneumatically applied portland cement mortar, and selected earth placed either loose or compacted.

Engineers and irrigationists in this country have for many years considered linings of portland cement concrete the most permanent and dependable, but they are, in general, the most expensive in first cost. A typical concrete-lined canal of medium size is shown in Figure 1. On current Bureau of Reclamation jobs of considerable size, contract prices for 2-in. to 4-in. thick unreinforced concrete linings range from $2 to $2.75 per square yard. These prices include the cost of final trimming of the earth section and all materials and operations that are a part of the lining, but not the canal excavation. Under special conditions where reinforcement steel is required in concrete linings, the cost of furnishing and placing the steel increases the total cost of the lining about 10 per cent. Prices within the range stated are made possible by arranging the work for large contracts so that full advantage may be taken of completely mechanized equipment, thereby reducing hand labour to a minimum. Concrete linings can be, of course, and have been, satisfactorily placed by hand methods; and in countries where wage rates are lower and labour is plentiful, the capital investment in mechanized equipment may not be justified.

Pneumatically applied portland cement mortar is more commonly termed shotcrete or gunite. As these names imply, it is a sand-cement mortar applied by compressed air through the nozzle of a large hose. Figure 2 shows this type of lining under construction. Shotcrete for lining canals is usually placed 1-1/2 in. thick and seldom thicker than 2 in. The placing of shotcrete requires special equipment and experienced operators, is a relatively slow process, and the finished lining is little, if any, lower in cost than concrete. Shotcrete has been used rather extensively and with success in irrigation canals of our southwestern states where winters are mild and freezing temperatures are seldom encountered. This type of lining is particularly adaptable on smaller installations, requiring only small construction crews, or for the repair of old concrete linings. Shotcrete is often reinforced with woven steel wire, but reinforcement is believed unnecessary for the average installation.

Earth linings of selected cohesive materials have been placed at costs ranging from 12 cents per square yard for loose earth to $1 per square yard for heavy, compacted lining on the side slopes. Heavy, compacted linings (4 ft. to 5 ft. thick) are placed in shallow lifts and compacted by horizontal rolling. Such a lining is very effective and durable and may be installed for about 50 cents per square yard if suitable materials are available without excessive haul. Thin, compacted earth linings (6 to 12 in.) should be protected with a 6-in. to 8-in. gravel cover, as illustrated in Figure 3, and will usually be lower in cost than the heavy lining if materials are as readily available. However, the compaction of thin linings on the side slopes usually presents additional construction difficulties and sometimes becomes an item of excessive cost.

At the lower end of the cost range are the loosely placed earth linings which are usually only partially effective, are costly and difficult to maintain, or are of questionable value after a few years if not properly maintained. These may be and have been placed by a variety of methods including that of dumping selected material over the canal bank or sluicing it into the canal while in operation. The latter results in a thin lining of silt which settles out over the canal bed and forms a partial seal. Because of the instability of this fine material, such a treatment is only a temporary remedy and must be repeated every year or two if seepage is thus controlled.

Bentonite is a special type of earth material which has been used rather extensively in limited areas where natural deposits of this material occurred. Bentonite is a colloidal clay, with high-swelling characteristics, which is very effective as a water seal. It may be used as a membrane covered with a protective blanket of gravel or other stable material, or it may be mixed in a predetermined proportion with a gravelly soil. If available locally in a grade and form requiring little or no processing, a satisfactory lining may be installed within the range of 35 to 75 cents per square yard.

The use of asphaltic materials for lining canals in the United States has, until recently, been very rare and of limited success. In the last few years, as a result of an organized effort by the Bureau of Reclamation, more interest has been indicated in asphaltic linings and a number of large-scale trial installations have been made. Several miles of 2-in. thick hot-mix asphaltic concrete were recently placed by contract on Bureau of Reclamation projects in the states of Washington and California at prices 10 to 20 per cent less than portland cement concrete of the same thickness. Figure 4 pictures a newly constructed hot-mix asphaltic concrete lining. Placing was done by hot-ironing the asphalt mix with a sub-grade guide slip-form built for the job. The asphalt used and the desing of the mix was such as to obtain the maximum toughness and durability with a reasonable degree of flexibility. As asphaltic concrete has greater flexibility than is possible to obtain in portland cement mixtures, it is expected that

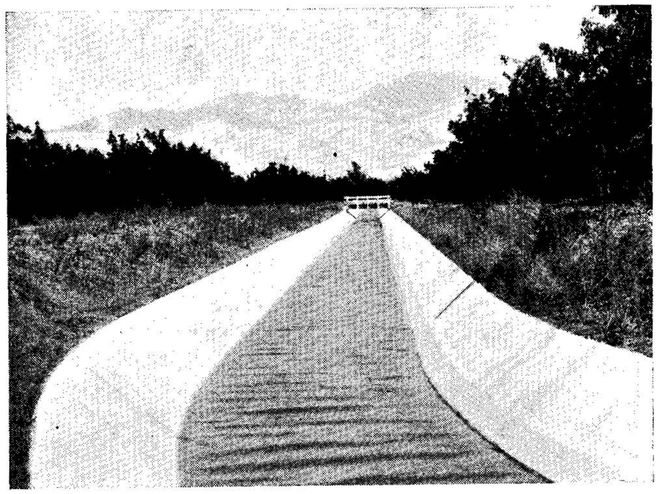

Figure 1. Unreinforced portland cement concrete lining, 3 in. thick—Contra Costa Canal, California.

Figure 2. Placing shotcrete lining in Pasco Pump Lateral, Washington.

Figure 3. Six inches of gravel cover over 6-in. compacted earth lining—Rathdrum Prairie Project, Idaho.

this type of lining will conform to minor changes in the sub-grade due to settlement or frost heaving without rupture. However, this type of lining has not yet been in service long enough to prove its merits or its probable life.

An entirely different type of lining recently developed by the Bureau of Reclamation is the buried asphalt membrane. This type of lining consists of a hot, sprayed-on membrane of asphalt cement applied to the over-excavated canal section (see Figure 5) which, upon cooling, is covered with about a 1-ft. thick cover of gravelly soil or thinner covers of both earth and gravel. The membrane is placed about 1/4 in. thick and is protected from weathering and mechanical injury by the cover material. Such a lining forms a positive seal for seepage control and has been installed for as little as 30 cents per square yard when Government forces prepared the sub-grade and placed the cover using material excavated from the canal, and the asphalt was supplied and placed by contract. No lining of this type has as yet been installed entirely by contract, but it is estimated that costs on the average job will range between 60 and 80 cents per square yard. This type of lining holds most promise for satisfactory seepage control at low cost, but experience with it is very limited, and its life, like that of the asphaltic hot mix, has not as yet been determined.

BENEFITS OF LINING

As mentioned in my introduction, the chief benefit of canal lining is the reduction of seepage losses. The value of irrigation water in the western United States varies from $1 per acre-ft. in some areas to as much as $18 in others, depending on a number of factors such as the supply available, the value of crops grown, and whether the water is pumped. In many cases the value of the water saved is justification alone for the cost of lining. However, seepage water is worse than wasted because it usually collects in the lower lands, rendering them unproductive or requiring the installation of costly drains. The installation of an effective lining in canals that seep badly will usually prevent the waterlogging of adjacent land and eliminate the need for a drainage system. In some instances, the cost of a suitable lining will be little, if any, more than the cost of the drainage system. Often the water saved as a result of lining a distribution system is sufficient to put considerably more acreage under irrigation, and the revenue therefrom may pay for the costs of lining.

Seepage losses from canals and laterals represent a loss not only of valuable irrigation water that should be conserved for productive agricultural use but also a considerable loss in additional costs of construction from which no return is received on the investment. Storage reservoirs and dams must be constructed of sufficient size to impound not only the useful water but also the water that will be lost in transit to the farms. Canals and laterals must be designed with capacity not only to transport the useful water but the water that will be lost through seepage as well. Often the canal cross-sectional area required for the lost water is equal to that required for water that will be delivered to the users. Canal structures (bridges, weirs, drops, check, and chutes) must likewise be of increased size. Thus the seepage losses require a considerable increase in construction costs—an increase which could be

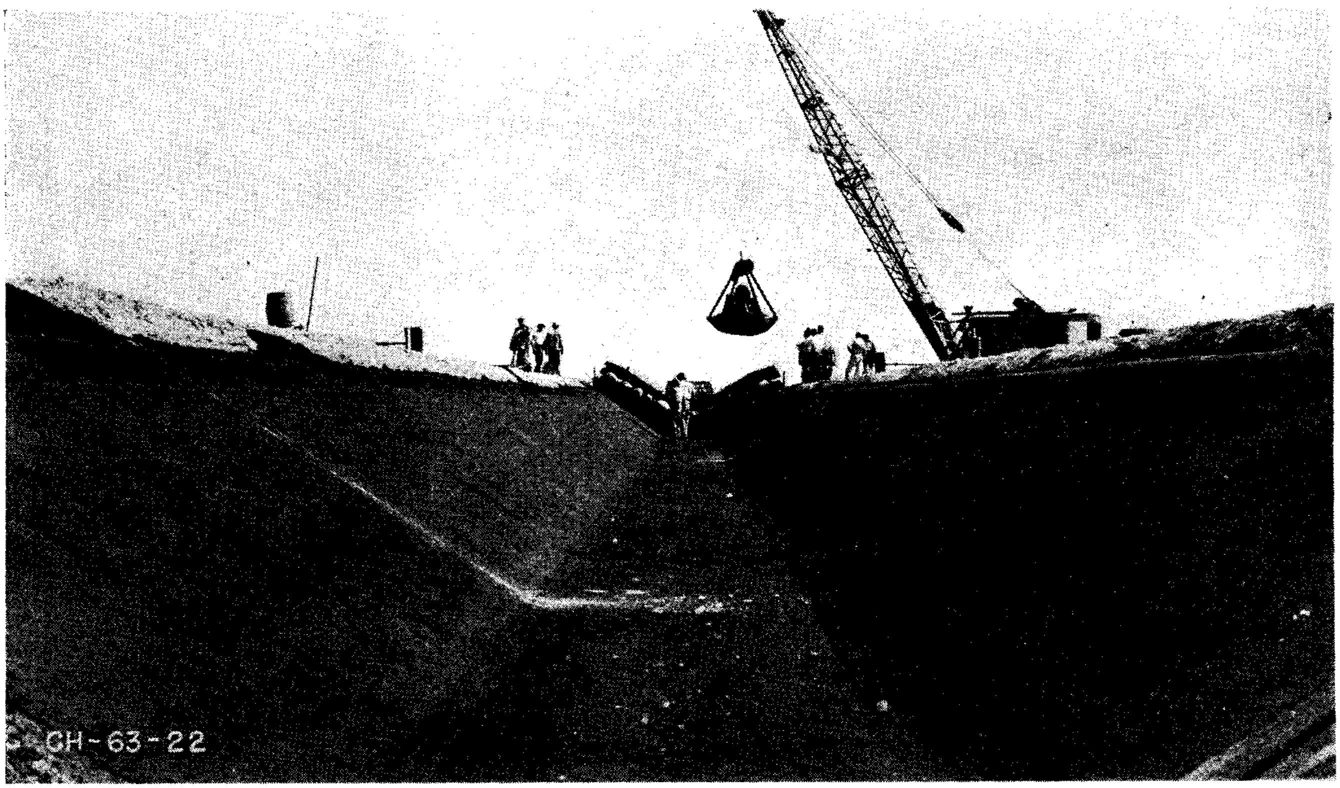

Figure 4. Newly constructed asphaltic concrete lining and placing operations in background—Pasco Pump Lateral, Washington.

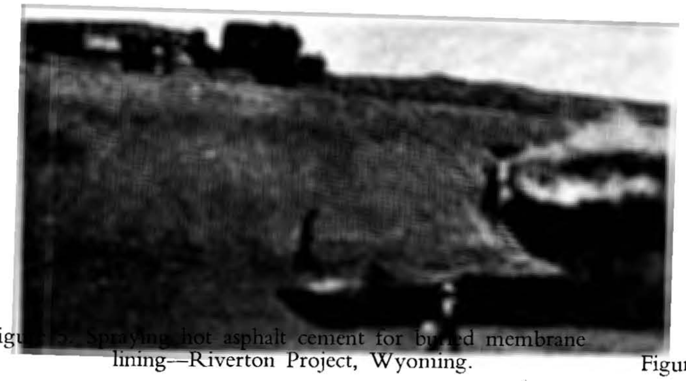

Figure 5. Spraying hot asphalt cement for buried membrane lining—Riverton Project, Wyoming.

Figure 6. Weeds in unlined section choke flow of water and reduce capacity.

obviated by the installation of an impervious canal lining at the time of original construction.

Linings having a low coefficient of friction, such as concrete, permit the use of smaller canals by virtue of the improved hydraulic properties. The average unlined canal of 100 cub. ft. per second capacity, as designed by the Bureau of Reclamation, has a water-surface width, or wetted perimeter, of 15 ft. whereas a concrete-lined canal of the same capacity has a wetted perimeter of only 12 ft. Thus construction of the canal requires less excavation and right-of-way requirements are reduced. In certain cases, it may be important to use as flat a gradient as possible to serve the maximum area, since only the land below the canal can receive water without expensive pumping. A canal lining having a low coefficient of friction will permit a much flatter slope than is possible in an earth section, thus bringing a larger area under irrigation. Conversely, the maximum permissible velocity in an unlined canal is limited because of its low erosion resistance. Also, canals must often traverse slopes which for unlined canals require the use of drops or chutes to avoid destructive erosion. A permanent erosion-resistant lining, however, will permit the use of higher velocities and steeper gradients and so eliminate the need for many of the structures which may, in some instances, cost almost as much as the lining.

Another very important benefit of most canal linings is the reduced cost of maintenance as compared to unlined canals. In areas through sandy or other unstable soil, bank erosion of an unlined canal is so severe that it becomes very difficult, if not impossible, to maintain any reasonable section. Under such conditions, canal breaks sometimes occur at critical periods which result in crop losses exceeding the cost of a lining. Even a gravel cover over an earth or buried membrane type lining will aid materially in resisting erosion and preventing breaks.

Weeds which grow profusely in unlined canals choke the section and reduce the flow. The unlined section of the canal shown in Figure 6 typifies this condition. The periodic removal of weeds is costly but necessary in such cases in order to maintain a reasonable carrying capacity. Most linings resist, and some prevent, the growth of weeds, thereby reducing or eliminating the problem and expense of their removal.

Silt deposited in the bottom of slow-moving unlined sections presents another maintenance problem. In areas where the water carries a large silt load periodic removal of the silt deposit becomes a necessary item of considerable expense. Those linings which have lower coefficients of friction permit higher velocities. Higher water velocities tend to keep the silt in suspension and less is deposited in the canal. Thus, maintenance costs are again reduced.

CURRENT INVESTIGATIONS

Because of the increasing urgency of conserving water lost from unlined irrigation canals in the western United States, the Bureau of Reclamation, in 1946, inaugurated a programme of laboratory investigations and field trials to develop lower-cost linings. A progress report was issued in June 1948 for the purpose of summarizing and bringing up to date all available data on costs and general information on canal linings, to present economic studies and results of the programme, and to describe new developments in equipment and methods of construction. The report, entitled "Lower-cost Canal Linings", contains some 85 illustrations and a complete bibliography of 180 references on all phases of the subject. As stated in the report, the final answers to many of the problems cannot be determined until after years of continued research and further observation of lining installations. To this end, the Bureau of Reclamation plans to continue such activities as are necessary.

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Summary of Discussion

The CHAIRMAN declared the meeting open and said he wished to make a few remarks on the situation in Mexico, the country he represented.

Owing to the geographic, orographic, hydrographic and climatic conditions, 90 per cent of the country was arid. Irrigation was the only means of assuring the existence of the 24 million inhabitants of those areas. In the rest of the country, the climate was humid and the authorities were faced with numerous problems of another kind. Over 50 per cent of Mexico's water resources, which were estimated at some 200,000 million cub. metres annually, were to be found in that humid area.

As far back as 1926, Mexico had been carrying out a vast irrigation programme so as to bring approximately 10 million hectares under irrigation. Up to date, 2 million hectares had been irrigated, which had necessitated the construction of dams with a capacity of some 15,000 million cub. metres. To irrigate the rest of the proposed area, works, with a capacity of 60,000 million cub. metres, would have to be constructed.

Earlier meetings had been devoted to the discussion of water resources, their distribution through the various seasons, their geographical distribution and the need for water conservation by scientific means. The current meeting was to deal with water-control structures which would make such water conservation and control possible.

The Conference would, therefore, be told of the experience acquired by various countries in the construction of such works, and it would be able to examine models of some of them. Finally, it would deal with special techniques of water control, and would study in particular the problems of sedimentation, and the reduction of the capacity of dams which resulted, in all the arid and semi-arid countries of the world.

Mr. AUBERT presented his paper on "Latest Development in Design, Construction and Operation of Major Water Control Structures, including Dams, Canals, Locks and Desilting Works". He pointed out that the French word *barrage* used in his text corresponded to both the English words "dam" and "weir".

Two essential questions arose in connexion with the modern technique for the construction of weirs; (*a*) the height of the works had to be increased (the Tennessee weirs were a brilliant example of the way in which that problem might be solved); (*b*) the relation between the movable and the fixed parts of structures had to be determined. In the construction of movable dams, either lifting gates or cylindrical roller-gates, or small parts called "wickets" were used. French engineers had perfected a new system of iron wickets which would last indefinitely without maintenance. That system, which had been tested twenty years ago at Vives-Eaux and Suresnes on the Seine, had given complete satisfaction. Among its advantages were: (*a*) vessels could go safely through the dam even when the wickets were raised; (*b*) a dam under this new system, with wickets, dispersed energy and prevented eddies, thus considerably reducing the cost of the upkeep of the protection works below the dam. Thus, at Suresnes the protection works put up below the wickets had not as yet had to be repaired, whereas those which had been constructed below the lifting-gates erected in the other arm of the Seine had already had to be repaired twice; (*c*) the cost of construction of dams with wickets was half that of dams with big lifting-gates; (*d*) dams with wickets made it possible to leave a space between piles which was of immense importance to navigation—on the Mississippi, for example, United States engineers, who were not familiar with that system had had to content themselves with putting up a large number of closely-spaced piles; (*e*) finally, iron wickets could be electrically controlled by one man, a fact which might be of particular interest to the United States.

A similar dam was being built on the Rhône where the effective vertical height of the wickets would be over 7 metres.

After concluding his talk, Mr. Aubert showed a film of the working of the Vives-Eaux Dam.

Mr. RAUSHENBUSH briefly summarized the paper by Mr. Coyne on "Water Control Structures: Dams", and the paper on "The Preliminary Comparison and Selection of Dam Sites", by Mr. Speedie.

In reviewing the various types of dams, Mr. Coyne had pointed out that the gravity dam used in the United States required a specialized staff and powerful equipment. European countries, which had to economize in materials, had ruled out that type of dam in favour of arch-works. When the width of the valley became really too great it was possible to save still more material by means of thick arch construction.

The author had described "ski-jump" spillways which, according to Mr. Raushenbush, was beginning to be used in the construction of stone-bedded dams.

Speaking of Mr. Speedie's paper, he pointed out that it provided a brief formula which made it possible to select locations for dam sites on the basis of parameter K variable.

Mr. MCCLELLAN presented his paper on "Deterioration of Large Dam Structures". He explained that the protective measures which he recommended had been worked out by the United States Bureau of Reclamation during the forty-seven years of its existence. The best way of preventing foundation leakages was by drainage and grouting. Cracking of concrete dams could be prevented by contraction joints and by careful control of the rate of cooling. Leakage in horizontal joints could be prevented by proper joint "clean-ups" and by the use of mortar seal for new concrete.

The expansion of concrete, due to chemical reaction, was one of the difficulties which could be overcome by refraining from mixing reactive aggregates with alkaline cement, or by using pozzalan.

In an earth dam, slumping of the upstream face was caused by rapid drawdown of the reservoir. By zoning embankments and providing free draining material at the upstream face, that type of deterioration was eliminated. Wave damage was prevented by using riprap backed up by graded material that would not be washed out through the riprap. To preserve freeboard in earth dams, consolidation of the foundation and embankment was essential. Examples were cited of damage to appurtenant structures and facilities from cavitation and erosion. Skilfully designed and constructed water passages were required to avoid the destructive effects of cavitation.

In the absence of Mr. Simaika, Mr. El Samny presented the paper prepared by him on "Preservation of the Aswan Reservoir".

In view of the vital importance of that reservoir to Egypt, its use for power generation and protection against flood had been the subject of extensive research.

When in flood the Nile brought down large quantities of silt which formed the fertile soil of Egypt but which made it impossible to keep the reservoir full throughout the year. The maximum concentration was estimated at 3,600 parts per million. To remove the danger caused by silting it had therefore been decided to open the reservoir during the flood season.

Apart from the danger of silting, there was a tendency for the silt deposits to hinder navigation immediately above the dam.

Mr. El Samny briefly outlined the result of silt experiments carried out over a number of years. Those experiments proved that the manner of regulating the sluices influenced the accumulation of silt upstream of the dam.

The reservoir was surveyed periodically and the results confirmed those obtained from the silt experiments.

To scour out the reservoir the lower sluices were opened.

In conclusion Mr. El Samny pointed out that the paper did not deal with the question of bed-load. He had studied the movement of the latter and worked out a method for gauging its importance. The results of that study would be published shortly.

Mr. Raushenbush summarized briefly the paper submitted by Mr. Grzywienski, professor at the Technical University of Vienna, on "Modern Principles for the Construction of Hydro-Electric Stations and River Development Projects".

The Chairman drew attention to another paper which had been prepared for the meeting but which had been received too late for reproduction and distribution to participants. This paper had been submitted by the Ministry of Water Economics of Yugoslavia, and was entitled "Construction of Jablanitza and Mavrovo Dams in Yugoslavia".

The Chairman called upon Mr. Karpov who wished to make a few observations on Mr. Coyne's paper on "Water Control Structures: Dams".

Mr. Karpov observed that the largest and most costly river engineering works in the world were being built in the United States. As one aspect in that country, gravity dams were being built recently with too liberal cross-sections, which are much more expensive than they should be. The dams built twenty years ago, although entirely satisfactory, seemed very light in comparison with those constructed at the present time.

On account of the danger from earthquakes, the United States had established completely arbitrary criteria for enlarging the cross-section of dams. No one knows the behaviour of earthquakes, however, if an earthquake acted otherwise than was anticipated, those dams might prove less advantageous than lighter ones.

Mr. Karpov agreed with Mr. Coyne that by building arch dams a considerable economy in material might be effected. At the same time, such dams are better able to withstand the effects of earthquake than gravity dams.

In regard to arch dams, in the United States only circular dams were built. The engineers, however, neglected to take advantage of the economies which could be effected by adapting the shape of the dam to the configuration of the valley.

Mr. Karpov then discussed the observations made in Mr. Coyne's paper on the methods of construction used in the United States. That country possessed a big cement industry as well as railroads having a very large freight capacity so that there was no need to accumulate large stocks of cement on the construction site.

In most other countries, on the other hand, especially in the under-developed areas, vast supplies of cement had to be procured before beginning a large construction scheme. It was easy to understand the difficulties which resulted in warm and humid countries.

The United States was as extravagant in its flood-control projects as it was in the cross-sections of its dams. It had made tremendous progress in the construction of water engineering works, but these results had been achieved in a unique kind of economic system where labour was very costly and highly skilled and where, in government projects, money was no object.

For that reason, other countries should guard against purely and simply copying American methods and should seek rather to adapt the experience acquired by the United States to local conditions. It would be better for them not to use too heavy machinery and to entrust as much as possible of the necessary work to unskilled labour.

The relatively under-developed countries should use local building materials and local labour accustomed to handling those materials. They should take into consideration climatic conditions, build works of simple construction and bear in mind the difficulties of transportation. Where there are no navigable rivers and no broad-gauge railroads, it might be difficult or impossible to transport heavy machinery. They should furthermore build rockfilled or earth dams rather than concrete dams.

The success of any country and its development will depend on how the country could adapt the experience of the United States to its own conditions.

The Chairman asked the section to present its views on Mr. McClellan's paper.

Mr. Karpov said he had read Mr. McClellan's paper with interest. He approved of the latter's frank exposition of the various difficulties which the Bureau of Reclamation had encountered.

Expressing doubts in regard to the introduction of the paper, Mr. Karpov remarked that in certain regions which he had visited the lack of protection of the dams and of the irrigation system had in the ancient past caused the total disappearance of the population.

To avoid damage due to temperature phenomena, he recommended that the study should be continued of the cements to be used and of the economy of methods used for cooling the mass concrete. Further, the method of building lifts of five feet, used by the Bureau of Reclamation for such a long time, seemed to him insufficient. If improved cement and cooling are used the height should be raised to ten or fifteen feet in order to reduce the number of horizontal joints and minimize the damage to which the dams described in Mr. McClellan's paper were subject.

Passing on to arch dams, Mr. Karpov said he did not share the fears expressed by Mr. McClellan on that subject. He thought that the modern constructions of that type of dam were a sufficient proof of their safety. The lack of water-tightness of the foundations presented a much more serious problem. In the case of a limestone foundation for example, the fact that insufficient grouting had been done in preparing the foundation of a large dam built in the United States on such foundations had led to great difficulties and considerable expense after the dam had been put into operation. Mr. Karpov attributed the other problems described in the paper to improper designs rather than to the behaviour of the materials.

In the section dealing with earth dams, Mr. McClellan had indicated that it was necessary to wait until the foundation had attained final consolidation before putting the dam into operation. Mr. Karpov, however, did not think there was any need to wait till the final consolidation of the foundation before completing construction and putting the dam into operation. Some settlement may occur, but that can be easily taken care of.

Mr. Kalinski asked Mr. Aubert for additional information on the method used in the Rhône basin to cut off the flow.

Mr. Aubert was ready to furnish Mr. Kalinski personally with detailed information on the method used. For the moment, he would merely point out that it was a special method which had been selected for the Génissiat-Dam on the Rhône where the problem was to cut off an enormous flow of 600 cub. metres per second. Whereas in the case of the great Zuyder Zee dyke in Holland, it had been decided to close it by dumping a large volume of materials very rapidly into the current, the use at Génissiat of metal tetrahedrons secured by cables had reduced the necessary volume of rock-filling by approximately three-quarters. A constant and permanent equilibrium was achieved by means of that method. The submerged tetrahedrons weighed 100 kg. and were 6 ft. high. Their function was to hold the rock-filling in place and to break the kinetic energy.

Mr. Sain asked Mr. McClellan for some additional information on the method used to avoid the destructive effects of temperature rise on concrete dams, and, more especially, to prevent cracking.

Mr. McClellan replied that the Bureau of Reclamation had succeeded in lowering the temperature and consequently the variation in volume by reducing the quantity of cement used and by the installation of cooling pipes.

Mr. Papanicolaou asked Mr. Aubert to give him further details on the construction of dams in chalky soil.

Mr. Aubert thought that the members of the Bureau of Reclamation were better qualified than he to explain the problem. He himself had only built a large dam at Génissiat where the soil was calcareous, but of good quality. There cement had been added in order to obtain a sufficient imperviousness. It had likewise been necessary to use that method in the construction of several dams in Algeria where the ground was particularly bad. Mr. Aubert added that the method was a costly one.

Mr. McClellan stated that the TVA had solved some of the problems of calcareous soil by drill holes and by the addition of cement in the foundations.

Mr. Blee spoke on the problems which had arisen during the construction of dams in the Tennessee Valley. Where it was not certain that the soil would prove impervious, cement grout was injected under pressure. Holes 36 in. in diameter were drilled to give access to deep strata of unsound rock or open cavities so that these might be cleaned out and filled with concrete. The drainage had shown an insignificant outflow which proved that the work had been completely successful.

Mr. Raushenbush presented briefly the paper on "The Use of Models in Planning Structures for Measuring and Dividing Water", prepared by Mr. Dominguez, who was absent. The paper was a technical study of the development of the water divider or "frame divider structure" and of different works for which the divider had been used.

In the absence of Mr. Meyer-Peter, Mr. Fornerod presented the paper on "The Use of Scale Models in the Planning of River Engineering Works" which the former had prepared. The document contained certain technical observations on the problem of similarity and concluded that the law of mechanical similarity could not be conclusive until experiments had been made on the prototype.

After reviewing the work of Drs. Prandtl and Nikuradse on frictional forces and the factor of proportionality, Mr. Meyer-Peter mentioned the results of certain experiments on models and the use of the generalized Froude's law. The question of similarity was complicated by the fact that rivers carried solids. Studies were made to determine the solid deposit under given hydraulic conditions, account being taken of the diameter of the particles carried (granulometry). For the moment, conveyance in suspension must be disregarded; although quantitatively large it did not determine the fall of the river, as did conveyance by rolling.

As a result of experiments carried out in the Zürich Laboratory, an empirical formula had been established whereby it was possible to solve by calculation certain problems of river hydraulics that could not be solved by pure hydraulics.

Mr. Meyer-Peter said many problems could be solved only by experiments on scale models, and he pointed out the difficulties to which application of the law of mechanical similarity might give rise. In conclusion he mentioned certain experiments made in the Zürich Laboratory in connexion with the regulation of rivers, the silting of retention reservoirs, water intakes in rivers carrying bed-load, tail races, the correction of mountain streams and the scouring at dams.

Mr. HAMID presented the communication on "The Use of Models in Planning Water-Control Works", prepared by Messrs. Husain and Kabraji, both of whom were absent. The paper set forth the advantages of using small-scale models as compared with seeking a theoretical solution or using empirical formulae. A model could in most cases give an accurate picture of the working of the prototype and show exactly what the results of certain changes would be.

Whereas the United States had an excellent network of experiment stations throughout the country, which were connected with numerous universities, Pakistan had only a relatively small number of such stations. Those at Lahore and Karachi, however, had been able to do research work on many of the hydraulic problems with which the country was faced.

Messrs. Husain and Kabraji stated that the Government of Pakistan intended to establish experiment stations throughout the country, especially in East Bengal.

Mr. AUBERT presented the report on "The Use of Small Scale Models in River Research", prepared by Mr. Danel, in the absence of the latter. It was a general document which dealt with the origin of the use of small-scale models and showed the use to which such models could be put in the control of river basins. The study of the works by means of small-scale models made it possible to determine at little cost what would take place in reality, as well as the consequence of the damage caused to dams and dykes by a phenomenon such as silting-up and heavy flooding.

Several hydraulic laboratories had been developed in France. In particular, the Chatou laboratory had been established by *l'Electricité de France et les Ponts et Chaussées*. Numerous others had been originally small university laboratories. Others again—as in the case of the Neyrpic Laboratory in Grenoble—were privately owned and operated on a consulting engineering basis.

Mr. Danel maintained very close relations with the laboratories of the United States. He stated in his paper that the performance of the tests with small-scale models required the collaboration of experienced technicians, specializing in pure mathematics, theoretical and experimental physics, the chemistry of water and corrosion, geology, hydrology, etc. Moreover, each experiment station must include extensive libraries containing works in several languages from all the countries which had used small-scale models in the study of river problems.

In presenting his paper on "The Use of Models in Planning Water Control Works", Mr. STRAUB wished to deal rather with the philosophical aspect of the problem under discussion than with the details of the construction of small-scale models. While it was true that the control of watercourses involved a great deal of construction of all kinds, hydraulic research covered other problems as well, such as the drainage of roads and airports and the protection of coasts. All such hydraulic structures might be profitably studied in the laboratory, although not solely with small-scale models but also with full-scale experiments. It was possible to reproduce on a small-scale not only dams, dykes and reservoirs, but also natural phenomena such as floods, landslides and erosions. Not all hydraulic phenomena, however, could be reproduced in the laboratory to a small scale. Most of the limitations were due to the fact that it was difficult to apply the rule of mechanical similarity.

A model should be a faithful reproduction not only of the geometry of the prototype but of the flow pattern itself. Account should be taken of fluid-mechanics as against empirical hydraulics. If those precautions were not taken, the similarity principles could not be applied. A model should reproduce exactly the movement and behaviour of fluids. Otherwise, it would be valueless.

Special studies should, moreover, be made of critical factors and of certain natural phenomena. The various forces which acted on water-control works when reduced in the model, did not always correspond in effect to those met in practice. That was particularly true in the case of critical situations. For example, it had proved impossible to obtain in the laboratory exact results on certain sedimentation phenomena and on a number of conditions of hydraulic equilibrium. Experiments on small-scale models should therefore be supplemented by field studies and sometimes by full-scale laboratory studies.

In most cases in which laboratory experiments had not given satisfactory results, the behaviour of the fluid in the models had not been studied sufficiently.

Mr. SAIN presented Mr. Khosla's paper on "The Measurement and Control of Silting".

Silting of reservoirs was a matter of vital concern for any undertaking depending on stored supplies. The rate of silting was sometimes such as to reduce considerably the life of the reservoir. A distinction should be made between suspended silt and bed-load. Although the annual suspended load of material carried by streams could be measured fairly accurately, so far as he knew, no satisfactory means had been devised to measure bed-loads.

In India, attempts had been made to measure bed-load by means of a trench with a cross grid which was flush with the bed; although experiments made so far were not conclusive, it might prove possible to measure the bed-load carried in small channels by that method. The way in which silting took place should be studied in order to determine the useful life of existing reservoirs. The rate of silting should be estimated to determine whether any preventive measures were called for. The data collected from experiments on existing reservoirs could be used also for estimating the probable rate of silting in reservoirs which it was proposed to construct in similar basins.

There were two methods of making detailed surveys, known respectively as the contour method and the range method. The contour method was best applied when 50 per cent or more of the original area of the lake was silted and the ground surface on the delta deposits was above the water-level in the reservoir. The range method was more rapid and consisted in measuring actual silt depths in certain sections. A combination of the two methods could also be adopted by mapping contours on the delta portions of the lake (provided previous contour maps were available for comparison) and by measuring ranges over the lower part of the lake where penetrations with a sampling spud were generally obtainable.

In India, the Central Board of Irrigation had recommended the laying down of permanent sectional lines at suitable intervals for all reservoirs, such lines being marked by concrete pillars to be measured either by levelling, should the reservoir dry out, or by soundings.

Mr. Khosla had made a special study in order to determine the rate of silting of reservoirs. After studying the data of over 200 reservoirs situated in all parts of the world, he had worked out a formula showing the rate of annual silt-deposit per 100 sq. miles of catchment area. This gave a rate of 75 acre-ft. for a catchment of above 1,000 sq. miles, increasing to 272 acre-ft. for a catchment of 10 sq. miles. In metric units, the results would be that for catchments over 2,590 sq. km., the annual normal silt deposit had an upper limit of 370 sq. km. For catchments less than 2,590 sq. km., the author had worked out another formula giving the annual silt deposit per square kilometre.

In certain cases, the life of a reservoir would be very short if we assumed that the entire silt would be deposited in the reservoir. Fortunately, such an assumption would not be correct. Numerous reservoirs in southern India had been in existence for centuries without material loss of capacity.

The flow of silt into a reservoir could be reduced by the construction of silting basins, the improvement of the vegetation cover on the catchment or by the provision of by-pass channels to allow heavily silted flows to run by without passing through the reservoir.

There was no doubt that conservation was best achieved through the proper management of watersheds by reafforestation when necessary, by controlling the exploitation of forests by adopting protective measures against overgrazing, improving farming methods, halting gully growth by check dams, and by proper treatment of highway embankments and cuts and the stabilization of streambanks.

The Chairman drew attention to the paper on "Recent Experience in Lift Irrigation and Drainage in Egypt" by Mr. Ahmed Bey. This was available to the participants.

The Chairman then called on Mr. Lane and Mr. Stanley, the two authors of the paper on "The Importance of Sediment Control in the Conservation and Utilization of Water Resources".

Mr. Lane said that the importance of sediment control has not yet been sufficiently recognized, although it is beginning to be realized. The welfare of the western part of the United States is absolutely dependent on water stored in reservoirs subject to more or less filling with silt. Some rivers are capable of filling an entire small reservoir with sediment in a single flood, and on others sedimentation is so slow that the probable life of a reservoir is practically unlimited. By carrying out the necessary investigations before building reservoirs, a good idea can be formed of how they will behave, but not necessarily how sedimentation can be prevented. The most obvious remedy for such sedimentation is the excavation of the sediment, but costs are prohibitive, except under favourable conditions. Another remedy is flushing out the sediment, but that is practicable only under favourable conditions, and requires considerable volumes of water which means that much less is available for other purposes. Another possibility is to enlarge existing reservoirs or to build new ones, but such reservoirs will cost more, as the ones built first have been on the most economical sites. Finally, there is soil-erosion control. A great deal has been done to that end. In regions where the rainfall is adequate to support considerable vegetation, soil-erosion control measures can be very beneficial within a relatively short time. In arid regions progress is necessarily slow, but no measures of erosion control can entirely prevent streams from carrying sediment which will settle in reservoirs.

Mr. Stanley drew attention to the aggradation due to floods in the middle Rio Grande Valley. The danger was greater than would be believed at first glance. Debris-flows have caused great damage, particularly in the vicinity of Los Angeles, and even loss of life. The faces of the mountains were very rugged and furrowed by precipitous canyons. The slopes were composed of boulders overlaid by a thin mantle of pebbly soil which supported a growth of shrubs. They could not arrest the waters which rushed down the face of the mountains after heavy thunderstorms. Those waters could carry along with them even boulders weighing several tons. Debris accumulated rapidly in the steep canyons and came to rest on the gentler slopes, obstructing the outflow channels and even causing changes in the courses. After every storm these canyons had disgorged up to 65,000 cub. metres of measured debris per square mile, with possibilities up to 150,000 cub. metres per square mile. Such catastrophes had occurred in 1934 and 1938, when several inhabited areas had been destroyed.

After the Gold Rush of 1849 a process of obtaining gold by hydraulic mining operations had led to the construction of great water systems with ditches many miles long in the Sierra Nevadas of California. Small gravel and silt were carried into the channels and thence down to the navigable rivers below. The river-beds became choked and their flood-carrying capacity impaired. In 1884 hydraulic mining was prohibited by decision of the Federal Court, primarily because of the injury to navigation caused by the accumulation of debris; between 1849 and 1884, however, 180,000 cub. metres of debris had been shifted from the river-basins and had accumulated in river-beds.

Mr. Raushenbush made a few introductory remarks on the paper by Mr. Fong which dealt with "The Silt Problem in the Basin Development of the North China Plain". After mentioning the author's description of the conditions prevailing in China and the fact that the rivers of China had the highest silt content in the world (the bed of the Yellow River near Kaifeng had an elevation of 15 metres above the adjacent land), Mr. Raushenbush drew attention to a new method proposed by Mr. Fong for guarding against silting as explained on page 9 of his paper. He added that the author wished to have the opinion of those participating in the conference on the value of the method he proposed.

Mr. Woodford read a paper on "The Costs and Benefits of Canal Linings". He presented information on the costs of linings in irrigation canals which, however, owing to economic conditions, could not serve as a guide for the future since they were subject to marked variations. His statement was only useful in that it contained data concerning the past and gave information on present conditions. The current cost of lining with unreinforced concrete ranged from $2 to $2.75 per square yard.

Mr. Woodford pointed to the benefits of lining canals of which the most important was the reduction of seepage losses. The value of water thus recovered was often sufficient to justify the cost of lining. In addition it must be remembered that seepage water was not only a waste, but that it harmed the land where it collected, rendering such land unproductive and necessitating the installation of a costly drainage system. Water saved as a result of lining might often be used for additional irrigation and thus defray the lining costs entailed. Canals dug out of unstable soil often deteriorated so rapidly that it was very difficult if not impossible to maintain them in proper condition. Linings also eliminated or reduced to a minimum the growth of weeds.

The CHAIRMAN opened the general discussion.

Mr. KARPOV wondered whether Mr. Hussain and Dr. Kabraji had not been over-optimistic in their paper. The papers of Mr. Straub and Mr. Danel showed how difficult it was to obtain conclusive results from the use of models. To set up good laboratories competent personnel was needed, which was difficult to find, since such personnel must possess not only advanced theoretical knowledge but must also be able to carry out practical experiments and very often do manual work. Even in the United States the choice was limited. To establish a new laboratory, specialists would probably have to be drawn from laboratories which already existed. In these circumstances it might be better for Pakistan to have say only two laboratories. In addition to the existing one in Western Pakistan, to establish only one new laboratory in East Bengal and gather the best talent there instead of trying to increase the number of experimental laboratories.

It should always be remembered that experiments with models made under imperfect conditions, could only mislead the engineer. If experiments of that kind did not offer every chance of success, it was much better not to carry them out.

Mr. LANE commented briefly on the paper by Mr. Fong. The greatest contribution the hydraulic engineer could make to the welfare of the world is to bring the Yellow River under control. If it behaved like other rivers, the modern technician could probably easily control the floods by flood control reservoirs, but the great quantity of sediment carried makes this difficult.

Three methods can be used to control the sediment: the soil from which the sediment is derived can be kept in place on the land; the sediment can be carried to and deposited in the sea; or it can be deposited in any other place where it causes relatively little inconvenience. All of these solutions mean recourse to methods to a large extent untried. The first requires the adaptation of soil-conservation methods to Chinese conditions and applying them on a much vaster scale than has heretofore been attempted. For the second method, the carrying capacity of the current will have to be increased, which possibly may be done by narrowing the channel, or by flushing from time to time by releasing water stored behind dams. Narrowing has not been carried out under similar conditions, and flushing has not previously been applied.

The method of deposit of sediment on the plain recommended by Mr. Fong should be studied, particularly regarding the ability of the river to transport the sediment to the depositing areas. The bearing on Yellow River control of the results of narrowing of the channel of the Missouri River should also be studied. If reservoirs are used, they should be provided with gates for emptying them, so that the deposits could be scoured out and flushed downstream.

Flood Control and Navigation

29 August 1949

Chairman :

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iscussion :

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s. RINGERS, HATHAWAY, GOLDSCHMIDT, WEBER, SAIN, WING, DARLING, APANICOLAOU, BURGER, DAWSON, FABREGAT, GONZÁLEZ MOLINA

cer :

GOLDSCHMIDT

Flood Control

C. J. WITTEVEEN

ABSTRACT

A. *System used in the Netherlands to prevent flooding*

In the past the Netherlands suffered much damage from flooding, when the main dykes of rivers failed in periods of maximum discharge of water, or as a result of the impounding of water behind ice dams.

Conditions along the Rhine and the Maas were improved by the following measures:

Regulating the summer bed so that the result was a single deep, streamlined channel.

Removing obstacles in the winter bed that would hamper the discharge of water and ice, and strengthening the main dykes.

Giving both the Waal and the Maas a new separate outlet to the broad tidal river Hollandsch Diep.

Breaking the ice artificially before the thaw sets in.

The supervision and maintenance of the big rivers is under the jurisdiction of the Government; but the main dykes are cared for by local boards which are controlled by higher authorities.

B. *Improvement of the Maas below Grave*

The main purpose of this work was the prevention of periodical inundation in areas totalling 50,000 acres south of the river (spillway Beersche Overlaat).

To enable the Maas downstream from the Beersche Overlaat to carry off the whole of the river-discharge, the stretch between Grave and Blauwe Sluis was shortened by one third by cutting out many bends; in addition the summer bed was enlarged and the winter bed improved.

The cost of the work amounted to fl. 22 million. The benefit to shipping which resulted from the canalization of this part of the river is estimated to be fl. 200,000 to fl. 300,000 per annum.

GENERAL DESCRIPTION OF THE SYSTEM USED IN THE NETHERLANDS TO PREVENT FLOODING

A big area in the south-west part of the Netherlands consists of low-lying islands separated by broad tidal streams; in this estuary three big rivers, the Rhine, the Maas and the Scheldt, discharge their water. The Rhine and the Maas reach the delta after courses of 75 and 160 miles, respectively, through somewhat higher ground sloping down from the German and Belgian frontiers. High banks occur only along part of these rivers, especially along the Maas before it changes its course in a westerly direction.

The low-lying land in the estuary, and also that along the broad higher reaches of the Rhine and the Maas, are protected against high water by dykes. The function of and requirements for the dykes in these two areas are not the same.

In this paper attention will be given to the latter region only.

The Rhine, when crossing the frontier, has a maximum-discharge of $\pm$ 13,000 cub. metres per second, against only $\pm$ 3,200 cub. metres per second for the Maas, 460,000 and 115,000 cub. ft. per second respectively. The minor bed of the Rhine is 1,100 ft. wide, and that of the Maas below Grave (Figure 2) 450 ft.

The Rhine soon divides into three branches called the Waal, the Neder Rijn and the IJssel; the Waal taking by far the greatest part (about two-thirds) of the total Rhein discharge.

The layout of the river-dykes has generally been devised in such a way that the left and right main dyke enclose a major bed (winter bed) which for the Waal is from 0.6 to 1.2 miles wide. The areas between these main dykes and the minor bed (summer bed) of the river are usually—not always—protected against high water in summer by low dykes, say 10 to 12 ft. above the mean summer level (summer polders).

When the river is in flood, by far the greatest part of the discharge is carried off by the summer bed. The summer polders and the unembanked alluvial areas, which constitute part of the river's major bed, also account for a portion of the river-discharge, but are hampered in this respect by their comparatively high level and by the summer dykes. The winter bed now makes an important contribution to security through the utilization of its storage capacity to lower the high water levels during winter floods.

In the past, the Netherlands suffered much damage from disastrous flooding, the inundated areas often being very extensive. The breaking of the main dykes was sometimes caused by their not being high enough, especially in places exposed to heavy wave attack. Sometimes waves would curl over the top of the dyke and erode the inside slope. The greatest danger, however, was the result of the formation of ice dams following the break-up of the ice, thereby raising the upstream level by several metres, and causing the water to discharge over the embankment which might then fail.

Of late the measures taken have been improved, and by now the danger of the big rivers flooding vast and rich areas can be considered a thing of the past, provided the necessary watchfulness and activity are maintained.

General outline of the protective system

The essential idea is to regulate the river in such a way that the summer bed will take the shape of a single deep, streamlined and continuous channel, which does not allow an accumulation of sand and assures its transport downstream. In the absence of bars and acute bends, the danger of the piling up of ice-barrages is much less than in a

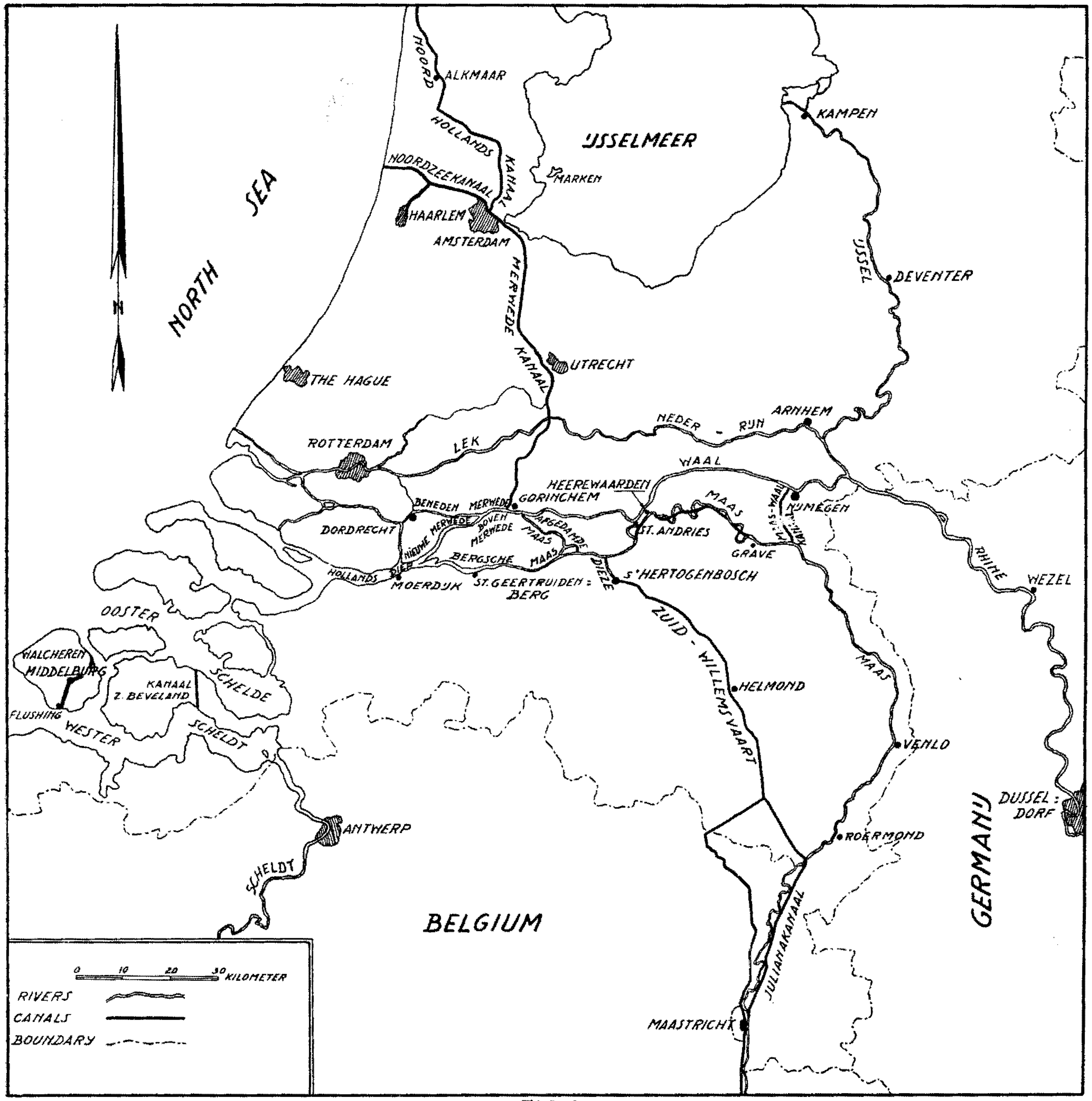


FIG. 1
MAIN RIVER-BRANCHES IN THE DELTA OF RHINE, MAAS AND SCHELDT

wild river. In addition, the ice is removed artificially by ice-breakers working upstream from those parts of the estuary which never freeze.

The winter bed is maintained in a state suitable for taking part in the discharge of flood-water, while of course the main dykes must be kept in good condition, or improved if necessary.

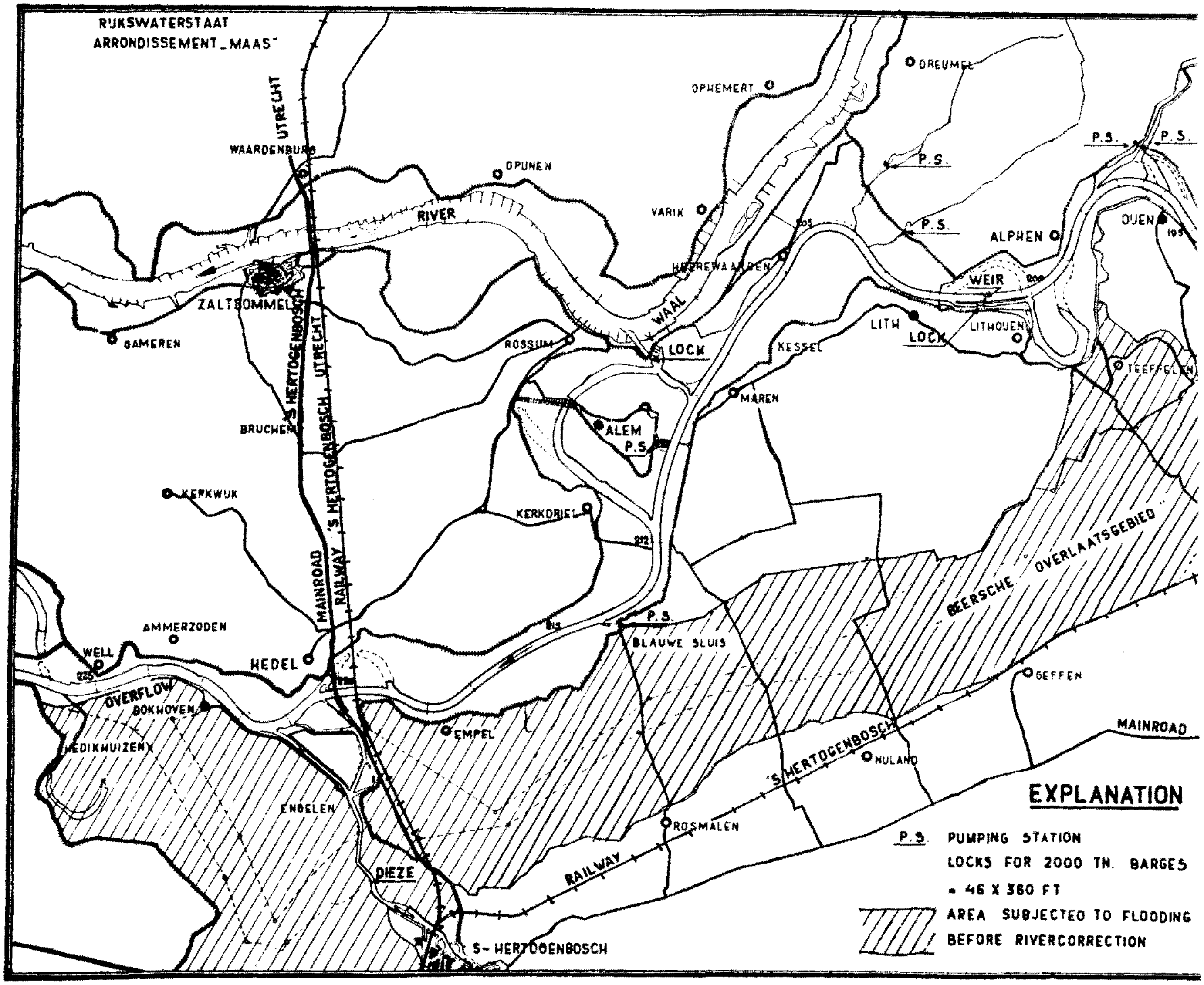
Regulation of rivers

In the Netherlands all big rivers have been regulated and are now in good condition.

The first series of works regulating the Waal, which is 53 miles long, was undertaken in 1852-1889 at a cost of about fl. 10,800,000[1] to the Government. The work was undertaken in the first place to ensure a safe discharge of flood-water and ice; but navigation, of course, also profited from the improvement of the summer bed.

Later on, as the demands of navigation increased, the work was continued with a view to establishing greater depth in the channel, while at the same time the discharge capacity was improved anew.

[1]$1 = ± fl. 2.50.



At present no dredging is necessary for the maintenance of the regulated rivers. On the contrary, dredging of sand and gravel in the river bed, by private firms, has for some time been allowed only by arrangement, with the contractor paying compensation to the Government, while of late dredging has in many places had to be stopped altogether.

The cost of maintenance of the Waal in 1938 amounted to not more than fl. 86,000.

Improvement of the Waal and the Maas by altering their outlets in the estuary

The Waal and the Maas formerly joined near Gorinchem (Figure 1), while there was a spillway in the dyke between the two rivers at Heerewaarden, about 16 miles upstream, where they draw near to each other. These connexions tended to increase the danger of the forming of ice dams, and floods in one of the rivers would influence the other; the water of the Maas especially used to be impounded as a result of high water on the Waal.

The difficulties were solved by altering the course of both rivers, providing the Maas with a new outlet, the Bergsche Maas, 20 miles long, to the broad and deep tidal river Hollandsch Diep (1908), and closing the old connexion at Gorinchem and the spillway at Heerewaarden. The Waal was improved by a new connexion, the Nieuwe Merwede, 12 miles long, with the Hollandsch Diep (1890).

The expenses involved were fl. 25 million, for the Bergsche Maas of which amount fl. 3 million, was provided by local authorities; and fl. 12 million for the Nieuwe Merwede.

Strengthening of the main dykes

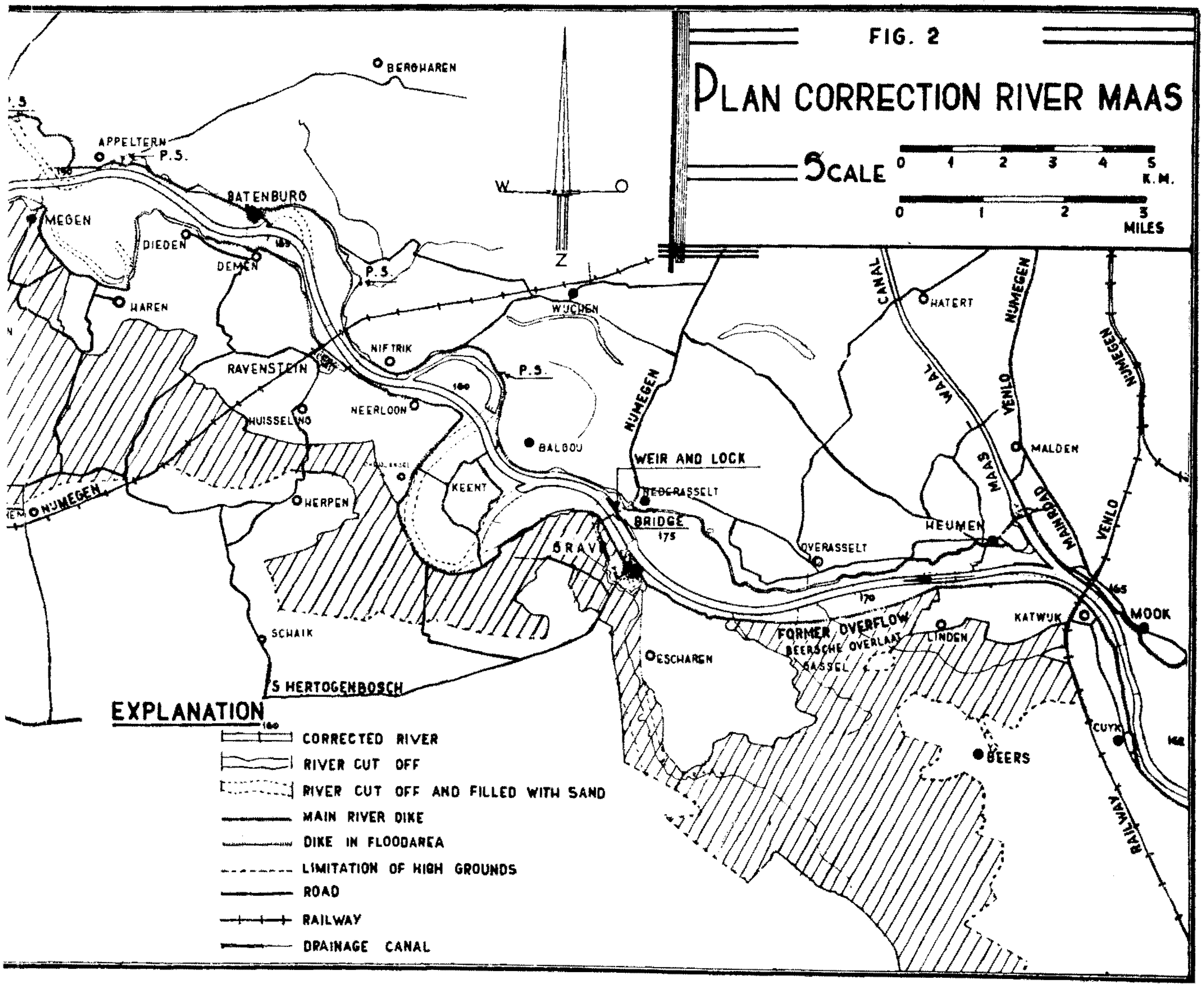
The main dykes have been and, when necessary, still are being strengthened; the incline of the slope being from 1: 2 to 1: 3, while the top may reach from 3 to 5 ft. above the highest high water.

On dangerous stretches the slope has to be protected by stone pitching, rubble etc.

The expense of these improvements is borne by the local authorities, sometimes subsidized by the province.

Artificial clearing of ice

The use of explosives to remove ice dams has not given satisfaction and this method has been abandoned.



At present powerful ice-breakers can be summoned, and clearing of the dangerous river stretches is achieved on the following lines. As soon as the ice begins to pack, it is attacked by a small fleet of ice-breakers working upstream from the lower stretches of the tidal rivers which are still open; three or four powerful ice-breakers go ahead and break up the ice into big floes which are in turn smashed into blocks by three or four smaller ice-breakers coming up some hundreds of yards behind. Below this fleet, which continues to proceed up-river, the already broken-up stretches are kept open by another shift of six or seven ice-breakers, one powerful.

In this way the authorities succeeded, in the very severe winter of 1939-1940, to break the ice from the Hollandsch Diep upwards along the Merwede and the Waal for 57 miles, clearing several ice dams with a height up to 28 ft. on the way, well before it started thawing. When after 29 days a thaw set in, the ice caused no difficulties.

The expense of breaking the ice is borne by the Government. The amount involved on the Waal in 1939-1940 (the case mentioned above) was fl. 91,000.

Financial aspects

The works undertaken for the improvement of the big rivers were, on the whole, necessary in the common interest (i.e., protection against flooding and the creation of better shipping possibilities, navigation on the rivers being open to everyone and free of taxes). They were indispensable for the common welfare; therefore, as already stated, the expenses were in large part paid by the Government. In a number of cases, however, and principally with reference to the strengthening of the main dykes, the cost or part thereof has had and still has to be borne by those immediately concerned who are organized in public local boards. The boards are often subsidized by the provinces concerned, and they have the right, subject to supervision by the provincial authorities, to impose taxes on the owners of real estate within their jurisdiction.

Supervision

The supervision over the rivers, and consequently their maintenance and improvement, is the task of the Govern-

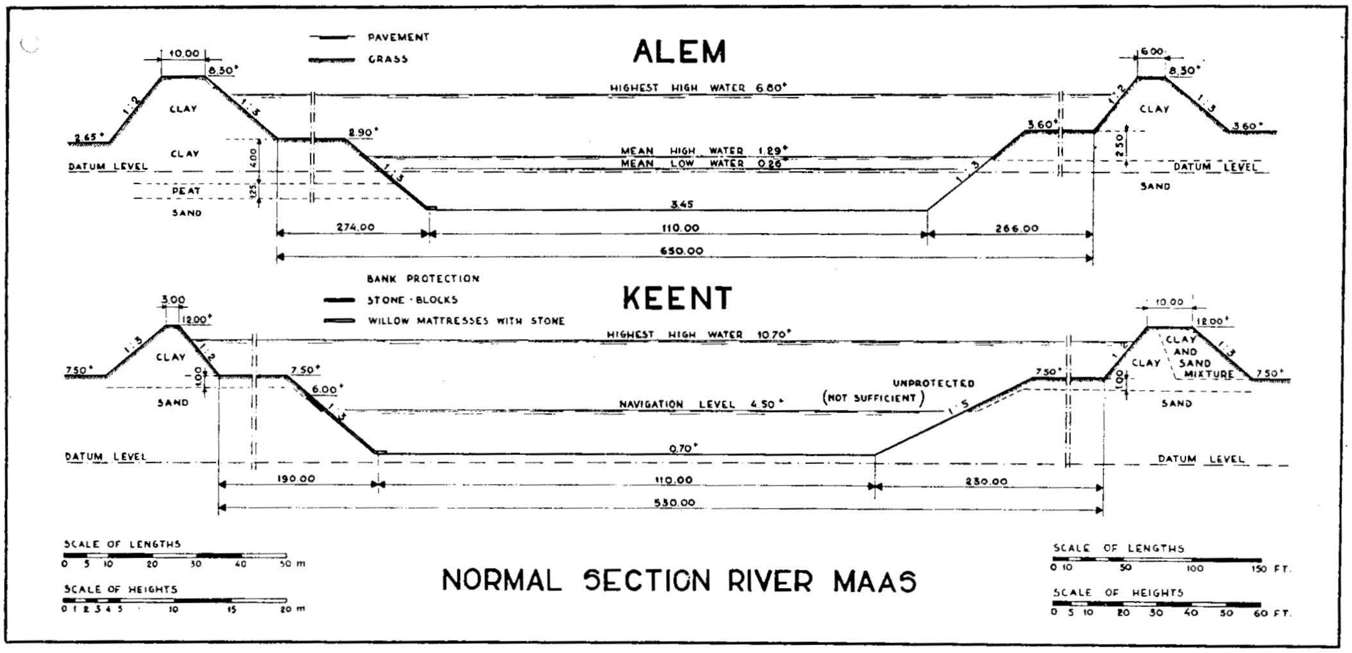


Figure 3

ment (*Rijkswaterstaat*). *Rijkswaterstaat* also controls the activities of the local boards mentioned above in so far as the activities are connected with the main dvkes.

The *Rivierenwet* (River-law) prohibits, unless permission is obtained, the construction of any earth-work or building or the planting of any trees that might hamper the free discharge of the river between the main dykes.

In winter, during periods when danger threatens from ice or high floods, a special service, organized each autumn, is set into motion to guard the dykes. *Rijkswaterstaat* engineers are in charge and personnel from this organization and from the local boards are stationed in suitable places, each having control of a well-defined stretch of dyke. Provision is made for the storage of adequate supplies of materials and tools for repairs, which are acquired and maintained by the local boards.

In a case of emergency the *Rijkswaterstaat* officials have wide powers, such as the right of expropriation, of taking over materials and tools needed for the defence, and of summoning the population to help guard and defend the dykes.

IMPROVEMENT OF THE MAAS BELOW GRAVE

Formerly the Maas below Grave could not, when the river was in flood, discharge all the water coming downstream, because of its many bends and the small fall in this lower part of the river.

A spillway about 2½ miles long used to exist, therefore, in the southern main dyke near Grave (Beersche Overlaat) by which the surplus water was discharged in a westerly direction through a broad false channel, finally joining the Maas again many miles downstream, partly via the River Dieze north of 's-Hertogenbosch, and partly by the Bokhoven spillway in the southern main dyke (Figure 2). The area thus periodically inundated measured some 50,000 acres—between 1882 and 1920 water was discharged over the Beersche Overlaat during 48 periods—and although the whole area was not flooded each time, the situation was very unsatisfactory with regard to agriculture, housing and traffic.

A serious flood in 1926, when the inundations in the region of the Maas were extended to about 130,000 acres, gave the impulse to the devising of radical changes. The purpose was to improve the river-bed (below Grave) in such a way, that the whole discharge could be led through it. The new outlet of the river to the Hollandsch Diep, described on the first part of this paper, had already been effected.

The discharge capacity of the river below Grave had for this purpose to be increased by about 75 per cent. This was attained by the cutting out of several bends,

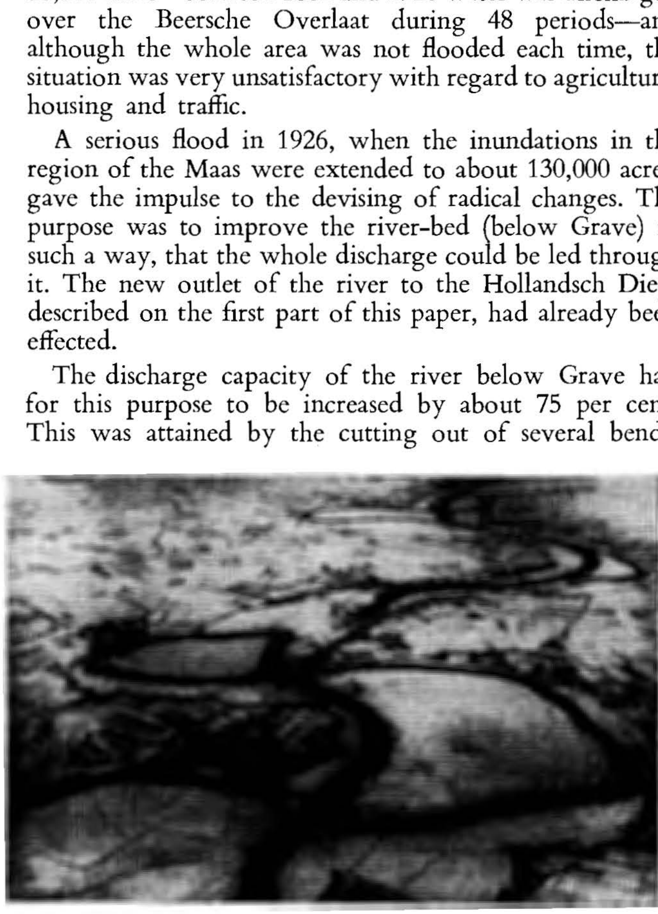


Figure 4. View on the River Maas showing its former curves and its present course.

by the enlargement of the minor bed, and by improving the major bed.

The channel already was too shallow for shipping, and as the depth would (in summer) further decrease as a result of these works, measures had to be taken to assure a waterway suitable for the 2,000-ton barges which could already navigate the canalized Maas upstream from Grave.

To obtain this result a weir with a shipping lock was built at Lith.

The regulation of the river between Grave and Blauwe Sluis (Figure 2) could for the greater part be effected within the existing major bed. Only the cut-offs at Balgoy and at Alem required the building of new main dykes (Figure 3), the cost of which amounted to $\pm$ fl. 75 per metre (fl. 68 per yard). The new summer bed measures only two-thirds of its former length and has been shortened by about 12 miles.

The enlargement of the summer bed on this stretch of the Maas was attained by increasing the bottom-width from 75 to 110 metres (from 250 to 370 ft.). Farther downstream, beginning at Hedel, (Figure 3) the channel required only deepening, but it was found necessary to enlarge the cross-section of the summer bed from the Beersche Overlaat upstream as far as the village of Mook. The material, mostly sand, was removed by dredgers and deposited in the cut-offs.

The winter bed was improved by the removal of hedges etc. The main improvement was gained by lowering areas which lay too high to fulfil their function properly. This required excavation on a fairly large scale, which was effected in this way: that the top layer of ground was put beside the excavation and brought back again after completion; the yield of these areas and of those mentioned below (nearly all grassland) after a few years was back at its former level. The new elevation of these areas between Lith and Grave was fixed at between 2 and 2½ metres (6½ to 8½ ft.) below the highest high water. The excavated material was used (as far as suitable for the purpose) for covering the sand in the cut-offs and for strengthening the main dykes; furthermore, several pools and watercourses existing inside the winter bed were filled with it.

The total cost of the Maas regulation, amounting to fl. 22 million, was paid by the Government except for a contribution of about 10 per cent which was borne by the provinces and the local boards concerned.

From 1933 to 1940 about 46 million cub. metres (60,500,000 cub. yards) were removed at a cost of fl. 0.30 per cub. metre (fl. 0.24 per cub. yard).

Although no extremely high discharge of the Maas has occurred since the completion of the work, it may be concluded from the gauge-readings during normal floods that the result of the regulation will answer the expectations.

The benefits gained from regulating the Maas below Grave are as follows:

1. The periodical inundations south of the river have been stopped and in the area involved, which measures about 50,000 acres, there can now be much better development in every respect;

2. A far higher security is ensured for all areas bordering on the river, as a result of lower high-water levels and improved main dykes; the quantities of water leaking through and under the dykes are substantially less than before;

3. A very useful canalized waterway capable of carrying 2,000-ton barges, has been established between Lith and Grave. It is now carrying a fairly heavy traffic, especially of empty barges moving upstream, which thus avoid the parallel course by the Waal where there is a strong current. The savings resulting from the use of the Maas route are estimated at fl. 0.08 per ton or fl. 200,000 to fl. 300,000 yearly. It is of course not possible to calculate exactly the money-value of the regulation of the Maas. It is evident, however, that the whole scheme has been a great success.

Flood Control

GEORGE L. BEARD

ABSTRACT

Flood control has become necessary because man has elected to utilize for numerous advantageous purpose the flood plain area required for the periodic overflow of rivers. In the absence of desirable restraint in the use of such areas, effective means for control of floods sufficient to permit beneficial use of flood-threatened zones have become highly developed and constitute an important phase of the conservation and use of land and water resources.

The problems associated with control of floods are interrelated with problems of other uses of river-basin resources and centre principally around evaluation of the benefits and costs of flood control and related developments.

The effects of flood control include advantages and disadvantages which are difficult to evaluate in economic terms, but no other basis for evaluation as yet devised shows promise of affording a complete and accurate appraisal of flood control benefits and costs in terms comparable to the related factors in river-basin development.

Important problems in the evaluation of flood-control benefits and costs are: the adjustments necessary to put benefits and costs which occur at various times on a common time basis; the problem of price levels applicable to future benefits and costs; and the difficulties of assigning benefits among projects or purposes of projects which are functionally interrelated and interdependent and which contribute mutually to common effects.

Intensive study of benefit-cost problems is a major requirement of current flood control planning.

Floods are phenomena of nature which would present no problem to man if he could or would elect to avoid or limit use of the flood plains of rivers and other water bodies for the numerous purposes for which he has found it necessary or desirable to do so. Through all history, however, man has chosen to utilize the flood plain because of advantages to agriculture, transportation, and other activities. The flood problem has grown with the increase of man-made developments. Flood control has rarely been applied prior to development of use of an area subject to flooding but is usually undertaken only after it has been demonstrated by experience that the cost of permitting flood damage to continue is greater than some feasible measure to prevent or reduce it. A procedure for control of the type and amount of development of areas subject to flooding, consistent with the extent to which necessity or advantage clearly outweigh the disadvantages, would be a desirable goal in an over-all programme for maximum conservation and the best utilization of resources. The establishment of justifiable control of floods prior to or concurrent with the development of such areas would also be desirable.

With the types and amount of development existing and in prospect today along our rivers, flood control is an important need and is related directly to many other phases of conservation and use of water resources. Flood control serves two main purposes: First, to prevent loss of life and damage to the health, welfare, property and economic activities of the people in areas subject to flooding; and second, to make possible a beneficial new use or higher use of the areas in which the flood hazard has prevented or retarded desirable development.

The determination of the need for flood control and the justification of any available measures for its accomplishment require consideration of many economic and social factors of the region affected as well as of the related problems of water and land use and conservation. Perfectly balanced programmes for river basin development in which the interrelation of all pertinent factors has been adequately considered can be achieved only if satisfactory means are devised for evaluating the several factors on comparable bases. This would appear to be a reasonable objective for attainment in so far as strictly economic factors are concerned. In flood control, however, and probably in other phases of water and land use, there are many important considerations which are impossible or, at least, difficult to evaluate in economic terms. This difficulty confronts us as a limitation on our ability to devise water and land use plans which are adequately balanced with respect to the numerous interests affected. Our only recourse is to make our bases for planning as complete and as comparable as possible, utilizing suitable economic terms and all other useful aids to judgment for that purpose.

In so far as flood control is concerned, the basis for planning and evaluating projects should include consideration of the benefits and costs attributable to the proposed flood control measures and the relative need of flood control as compared with the need or desirability of any alternative developments of the land and water resources involved. Full discussion of the problem of determining the relative needs for flood control and other developments is beyond the scope of this statement but an important factor in such determinations is the evaluation of benefits and costs which is the keystone of flood control and multiple-purpose water-use planning.

ANALYSIS OF BENEFITS AND COSTS OF FLOOD CONTROL

The principal purpose of an analysis of the benefits and costs of a project is to determine if the accomplishment of the project is warranted in the light of all advantages and disadvantages that will result. The benefit-cost analysis is also useful for comparing the relative effectiveness of alternative projects and the relative desirability of various degrees of possible development.

In view of these purposes, it is apparent that the accuracy of the evaluation procedure depends on its ability to give weight to all effects of the project, both advantageous and disadvantageous, in comparable terms. What are the benefits and costs, or advantages and disadvantages, of flood control measures which must be evaluated?

The advantageous effects, or benefits, of flood control projects may be grouped into three general classes:

(1) The benefit of preventing losses, damages, or impairments of all kinds that result from floods.

(2) The benefit of improving the utility of property over and above the value of any flood damage prevention involved.

(3) Collateral or incidental benefits through improvement of navigation, irrigation, power development, pollution abatement, water-supply, sedimentation control, fish and wild-life conservation, recreation and other activities which may be associated with projects involving flood control.

This statement is limited to discussion of the first two of the foregoing classes. The third class includes types of benefits which can be more appropriately discussed under other topics of the programme of this Conference.

The "prevention-type" benefits of flood control may be identified in terms of the kinds of losses or impairments prevented. These include: Loss of life; impairment of health, damage to property; disruption of business, industry, transportation and communication; diversion of effort and materials for flood-fighting; rescue, evacuation and reoccupation; impairment of general welfare, impairment of economic security; impairment of national defence ability; and similar losses or impairments attributable to floods. It is apparent from even a general listing of the types of losses to be prevented by flood control that it will be difficult to evaluate the benefit of preventing some types of losses in any terms and that it will be even more difficult to evaluate all benefits in comparable terms.

Many, if not most, flood losses can be evaluated readily in monetary terms. Some, such as loss of life and impairment of health, can only be expressed inadequately or not at all in such terms. In flood-control planning those benefits which cannot be adequately expressed in monetary equivalents are often of primary importance in the analysis of justification of the project. The problem of taking such benefits into account is not insurmountable in so far as analysis of the justification of flood control alone is concerned, but it is as yet unsolved with respect to economic comparison of flood control with other activities which may be related to or affected by flood control projects. This is a major problem which should engage the attention of all concerned with the formulation of land and water resource-development programmes.

The second general class of flood-control benefits, i.e., improvement in the usefulness of property and resources now hampered by floods, is exemplified by the increase in the wealth-producing capability of property which is made suitable for a new or higher use by removal of the flood hazard. The immediate benefit of this effect can be evaluated readily in economic terms, but secondary benefits such as the effect on the well-being of a community and stimulation of economic activity are not conclusively identifiable or measurable. How far we can and should go in tracing and evaluating these secondary effects as flood-control benefits is a question which deserves considerable thought and requires correlation with procedures adopted for analysing flood-control costs and the benefits and costs of other resource developments.

The costs of providing flood control may be classified in two general groups: First, the resources, or goods and services, that are needed to establish, maintain and operate the projects; and second, the adverse effects of the project on utilization of other resources. The first group of costs can be evaluated in economic terms with considerable accuracy. The second group may include such effects as disruption of established economic activities, destruction of aesthetic values and other effects which are difficult either to identify or to evaluate or both.

For both benefits and costs, it would be of great aid in flood control planning if a procedure could be devised to permit comparable evaluation of all effects from the broadest possible viewpoint. Such a system might involve placing monetary values on effects now evaluated in non-monetary terms or might involve adoption of a non-monetary basis that could reflect both economic and social values adequately. Accomplishment of this objective would probably require many years. Meanwhile, attention should be given to improving and expanding the coverage of evaluation procedures which are now in general use and which are centred around economic value concepts.

TIME FACTORS INVOLVED IN ESTIMATING BENEFITS AND COSTS

One of the most important factors affecting evaluation of flood-control benefits and costs is the time of occurrence. In general, benefits accrue from time to time in varying amounts of unpredictable sequence depending on the occurrence of flood-producing conditions of various magnitudes. Costs accrue principally during establishment of the projects and periodically during the maintenance and operation of the project over its period of useful life. The benefits and costs must be reduced to a common time basis to permit comparison for economic analyses.

The lack of predictable sequence of flood-control benefits can be overcome by expressing the benefits as the average amount expected in a given unit of time. This is done by determining the probability of occurrence of floods of all magnitudes in a given unit of time (say, one year) and the amount of damage that would be caused by floods of those magnitudes. From these data the amount of damage to be expected, on the average, in any selected unit of time can be computed. The accuracy of the computation is limited, of course, by the amount and character of the hydrologic and economic data on which it is based. Collection and analysis of basic data which are of fundamental importance in water-resource development are being discussed in other parts of the conference programme.

The problem of adjusting flood-control benefits of types other than damage-prevention benefits to a common time basis is similar for benefits of all water-resource development projects. Various methods have been used, ranging from a summation of benefits into a total over a given period of time to a reduction of all benefits to a present worth basis as of the beginning of a project. One of the methods most commonly used is to express benefits as an amount equivalent to the average per year over the assumed useful life of the project. The assumptions as to the period of time over which the project will be useful are particularly important. Most flood control works are of types which will endure physically for very long periods of time or can readily be maintained in good condition for long periods or in perpetuity. The length of time over which they can be expected to be necessary or desirable is dependent principally upon the economic future of the area affected. On this point alone, the assumption of a useful life of a hundred years or more might appear warranted but because the same period should be used for analysis of costs, there is a tendency to limit the assumed useful-life period to fifty years or less. Study of this problem is needed in order that a period can be selected for economic analyses which will be acceptable in the light of factors affecting both benefits and costs of all water uses.

Another factor of importance in reducing flood-control benefits to a common time-basis is the rate of discount or interest on money. It would appear logical that the economic value of any beneficial effect should reflect the viewpoint of the beneficiary and that discount or interest rates should also reflect the beneficiary's viewpoint. This question is complicated by the practical difficulty of identifying the beneficiaries of flood control.

EFFECT OF PRICE LEVELS ON ESTIMATES OF BENEFITS AND COSTS

Estimates of the benefits and costs of flood-control and other water-resource development projects involve assumptions as to the levels of prices expected to prevail over the period in which benefits accrue and costs are incurred. For flood control, this presents a complex problem. Benefits accrue more or less uniformly throughout the life of the project, but costs are incurred principally at the outset and to a lesser extent during the life of the works. In order for estimates of benefits and costs to be on comparable bases it is necessary to anticipate probable price levels throughout the expected life of the project. This is especially difficult in estimating flood control benefits because of the variety of goods and services involved. This phase of economic analysis merits careful study to determine if forecasts of future price levels can be made with sufficient accuracy to justify their application to flood control-benefit estimates or if some other procedure can be devised to ensure comparability of estimates of benefits and costs which will occur at different price levels.

EXTENT TO WHICH SECONDARY BENEFITS AND COSTS SHOULD BE MEASURED

In addition to the more immediate or direct effects of flood control projects which are readily identified as benefits or costs, there are numerous secondary or extended effects which must be considered if the economic analysis is to be complete. For example, if a project prevents loss of a crop, the activities of food processors and marketing agents may be affected. Several questions arise, however, as to whether these secondary effects should be evaluated as benefits of the project. In some cases the effects may be of a type that would occur whether or not the project is built. Also, they may be effects that could be realized by alternative measures. Costs as well as benefits that stem out of the initial impact of a project must be considered. The offsets, cancellations, and alternatives involved become complex. This phase of economic evaluation of projects requires intensive study.

INTERRELATION OF THE SEVERAL ELEMENTS OF A FLOOD CONTROL SYSTEM

Analysis of the justification for flood control works is often made more complex by the fact that there are two or more projects contributing to the control of floods in the same area. The costs of each of any interrelated and interdependent projects which form a flood control system can be estimated separately but it is difficult to assign the benefits to each of the projects for a number of reasons. For example, in a system of ten flood control reservoirs, each of the ten reservoirs will theoretically effect a larger amount of benefit if constructed as the first unit of the system than if constructed as the second or a later unit of the ten. Nevertheless, each successive unit added to the system improves the ability of the group to control floods resulting from an infinite variety of flood-producing conditions. This situation defies precise mathematical solution but must be taken into account by some means. An equitable apportionment of benefits of a system of reservoirs can be approximated by assigning to each reservoir the proportion of the total system-benefit that the individual-reservoir benefit bears to the total of the benefits of each reservoir assumed to be acting alone. Such proportioning, however, fails to take into account the relative weight that should be assigned to each reservoir because of various physical factors such as probable greater frequency of flood-producing conditions over one reservoir area as compared with another. The various physical and economic factors involved in apportioning system benefits among the several elements of the system deserve intensive study and analysis.

INTERRELATIONSHIP OF THE SEVERAL WATER USES WHICH MAY BE INVOLVED IN FLOOD CONTROL WORKS

In addition to the complications involved in apportioning benefits among the several interrelated projects of a flood control plan, there is need for evaluating the usefulness of individual projects and groups of projects on comparable bases with respect to other water uses which those projects served or could be made to serve. This requirement is particularly difficult to satisfy for projects involving flood control because of the many important benefits of flood control which cannot be readily evaluated in monetary equivalents and because most of the collateral water uses are more susceptible to appraisal in economic terms. Uses of water for power and irrigation, for example, have economic values which can be identified and measured more readily than flood control. Nevertheless, effective river-basin development depends on evaluation in comparable terms of the possible alternative uses of the limited water resources of the basin. This phase of evaluation of water use and conservation is among the most pressing problems facing those who plan river-basin development.

METHODS OF PAYMENT FOR FLOOD CONTROL

The foregoing discussion has been concerned primarily with the evaluation of the benefits and costs of flood control works. Another problem which depends for its solution largely on benefit and cost studies is the method of financing flood control.

In theory it is possible to identify most, if not all, of the beneficiaries of flood control and to evaluate the extent of benefit to each. In practice such identification and evaluation can be carried out to a reasonably complete extent only for the smaller projects and cannot be accomplished satisfactorily for projects of average or greater scope. Furthermore, the recipient of some types of benefits could be identified only as a community, a region or a nation rather than as a single individual or comparatively small group of persons. In the face of these circumstances, assessment of beneficiaries for the costs of flood control cannot be made with precision. Another factor to be considered is whether any activities or developments not benefited by the project are partly responsible for the flood conditions and, therefore, liable to assessment for part of the cost of flood control.

In some cases, the benefits accruing to readily identifiable recipients may be more than sufficient to cover the direct costs of establishing, maintaining and operating the project. These known beneficiaries may be willing to bear the entire costs of the project. Only a fraction of the necessary and justifiable control of floods could be undertaken, however, if it were necessary to finance the cost of the works by direct assessment of the beneficiaries. The answer to the question of the proper method for repayment of the costs of flood control lies in the perspective that will be available when the nature and incidence of benefits and costs have been more completely defined than they are today.

CONCLUSION

The control of floods is an activity which is typical of numerous other activities of man in his advance towards mastery of his world. The means for accomplishment of any particular objective, such as flood control, are capable of development more readily than the means for adjustment and correlation of the accomplishment with other concurrent developments. Our need today, therefore, is not so much for improvement of the procedures and facilities for control of floods, on which great advances have been made and demonstrated, but on principles and procedures for evaluating the role of flood control among the several interdependent factors in the over-all conservation and use of land and water resources.

Development of the Rivers and Other Waterways of the United States for Navigation

CLARENCE C. BURGER

ABSTRACT

The experience of the writer has been essentially that of effectuating in accordance with national policies the control, planning, and accomplishment of navigation improvements. The control by the National Government over navigable waters of the United States is derived from the Constitution. The national policy for navigation improvements is formulated by Congress and includes an enunciation that all navigable waters shall be free from tolls and unrestricted in use. Beginning with the initial national improvement in 1824, navigation improvements have been planned and supervised by the Corps of Engineers, United States Army. The accomplishment of such improvements has followed a plan of development continually revised and modified to keep pace with the economic growth and general development of the country. Notwithstanding rapid strides in recent years in such development, much remains to be done. Expenditure for construction on 1,300 existing navigation projects exceeded 2,000 million dollars; and for maintenance, over 1,000 million dollars. Projects in the planning stage have an estimated construction cost of 5,000 million dollars. With the experience gained, within the United States and from other nations, continuing advancement in the methods and techniques of waterway development is assured and will be fostered by exchange of information among the United Nations.

INTRODUCTION

Throughout world history the waters over which man has sailed in peace and war have been steeped in romantic adventure. Those persons who engage in water transportation problems best realize their good fortune from day-to-day participation in this romantic, yet realistic, field. In the United States, we of the Corps of Engineers who work for the improvement of rivers and harbours are among the fortunate ones. The peoples of the world who deal in imports and exports have a working knowledge of the port and harbour development of the United States. Unfortunately, much less is known regarding our inland waterway development and the blueprints which we have for future progress. Also important for world understanding is the way in which democratic processes in the United States work in giving vibrant life to our river and harbour development. This paper will highlight these lesser known facts as we cite some of our experiences in that development.

HISTORICAL BACKGROUND

The United States has been generously blessed with natural resources, including its river systems and harbour potentialities. These natural gifts have been a predominant factor in its growth. From modest beginnings, in ocean ports, on inland waters and inland ports, steady progress has been made. With comparatively few exceptions, the improvement and maintenance of harbours and waterways in the United States have been financed from public funds. In this connexion, the control by the National Government over the navigable waters of the United States is derived from the Constitution (1),[1] which provides that the Congress shall have power:

"To regulate Commerce with foreign nations, and among the several States, and with the Indian Tribes."

The policy with respect to national improvements of rivers and harbours in the interest of navigation has been formulated through laws (2) enacted by the Congress over a span of many years. Following a decision of the Supreme Court in 1824 (3), it was generally recognized that the lifting of a snag, the removal of a sand bar, or the building of a breakwater is a national work, with a national character and a national consequence, and a proper subject for appropriations of national funds. This policy, limited in scope at first, has grown and broadened from year to year with the advance of population and the increasing needs of commerce and navigation. The first distinct national legislation for improving navigation was an Act of Congress in 1824 (4), which appropriated funds for removing sand bars from the Ohio River and snags from the Mississippi River.

National appropriations for the improvement of natural waterways expanded from 1826 to 1866, and during that period a large proportion of the inland commerce of the country was carried on inland waterways. Then, with the development of the railroads throughout the Midwest, the volume of water-borne commerce steadily receded. However, at the turn of the century a growing demand from industry and agriculture for low-cost transportation gave impetus to a revival of the use of waterways. Thereafter, a substantial growth in water transportation has prevailed. In keeping therewith, the National Government has maintained a consistent policy to improve the inland waterways and to foster the development of water transportation. Throughout the same period improvement of highways for truck traffic and the railroad network occurred. While these modes of transportation are competitive all three have prospered throughout this period.

It has been the policy of the United States to maintain all navigable waterways free from tolls (5) and unrestricted in use to all, including foreign as well as domestic commerce and navigation. While some early canals constructed as private enterprises were subject to tolls, Federal waterway improvements have always been free with one exception—the Panama Canal, an artery of international commerce.

SUPERVISION OF RIVER AND HARBOUR PROGRAMME

Beginning with the initial national navigation improvement in 1824, such improvements have been planned and supervised by military engineers. In early years, there were but few professionally trained civilian engineers in the country. Therefore, it was only natural for the National Government to utilize available trained engineers for the

[1]The numbers within parentheses refer to items in the bibliography.

work—the military engineers. All work of improvement of rivers and harbours for navigation, and for flood control, is today carried out under the supervision of the Chief of Engineers, United States Army, at the direction of the Secretary of the Army, in accordance with specific authorizations by Congress. The organization consists of about 200 officers of the Corps of Engineers, 6,750 civilian engineers, and over 30,000 other civilian technical and administrative personnel. The term "Corps of Engineers" embraces both military and civilian personnel. The organization is decentralized into 40 districts, the boundaries of which conform roughly to watersheds. The districts in turn are grouped into 11 divisions which are so arranged that they embrace related works. Each district and division is under the charge of an army officer of the Corps of Engineers as District or Division Engineer.

INLAND WATERWAY DEVELOPMENT

In carrying out such planning and supervision, the national improvement of inland waterways has followed a definite plan of development which we continuously revise and modify in order to keep pace with the economic growth and general development of the country. From natural channels improved only by removal of snags to provide for the needs of shallow-draft packets of relatively small power and carrying capacity, we have developed our inland waterways to accommodate towboats having up to 3,200 h.p. moving as many as 20 barges with 20,000 tons of freight, the equivalent of 400 loaded 50-ton railroad cars.

Our experiences in the development of the upper Mississippi River for navigation demonstrated the need for continuous study and progressive improvement. Early improvements of the river were limited to the removal of snags and closure of sloughs to confine low-water flows to the main channel. Then in order to provide a more dependable channel, a waterway with a minimum of 6 ft. was authorized by Congress in 1907 (6). However, in time it was apparent that greater depth was required in order to provide for the accommodation of larger tows so as to achieve economical movement of the traffic on this waterway. Congress in 1927 authorized a study of a 9-ft. channel. Our investigations concluded that reliable and economical navigation would be assured by a 9-ft. channel and Congress authorized such a modification of the project (7). Since the completion of a 9-ft. channel by a series of twenty-six locks and dams, extending 650 miles from St. Louis to St. Paul and Minneapolis, traffic on the upper Mississippi River has steadily increased. In order to keep abreast with water transportation, we have underway an investigation of this reach of the upper Mississippi River as well as its principal tributaries to determine the advisability of extending thereto the 12-ft. waterway which has already been authorized (8) for the lower 740 miles of the river. This development is a typical example of the progressive and alternating development of both waterways and the equipment making use thereof.

In expanding upon the Mississippi River sight should not be lost of the small independent waterway improvements. While main line waterways and principal feeder channels with the same channel capacity carry the greater amount of our water-borne commerce, small independent channels serve to build up industry and develop areas that can be well served by water transportation.

PROCEDURE FOR THE DEVELOPMENT OF A RIVER AND HARBOUR PROJECT

The authorization of a navigation project follows a definite prescribed democratic procedure. The project originates in the needs and requirements of local people. At their request studies are authorized by Congress and made with a view to determining the advisability and justification of the improvements advocated. Field surveys and the basic reports are made by the District Engineers after public hearings. The reports of the District Engineers with the recommendations of the Division Engineers are reviewed by the Board of Engineers for Rivers and Harbors and the Chief of Engineers. The reports are also reviewed by the Governors of the affected States, and by other national agencies concerned in order to co-ordinate and integrate the projects with all water uses, prior to submission of the reports to Congress.

No project is recommended for construction unless the average annual benefits to accrue therefrom, as determined after careful and thorough study, are found to be greater than the average annual charges for construction, amortization and maintenance. In general, only those benefits which can be measured in monetary terms are used and compared with costs based on estimated economic life of a waterway development of not more than fifty years. About 50 per cent of proposed river and harbour projects studied and reported upon are found to be not justified. Ordinarily, local interests are required to participate in the project such as by contributing funds when benefits are local, by providing adequate terminal and other shore facilities, by furnishing necessary lands, and by releasing the United States from claims for damages that may result from the work of improvement.

Projects receiving favourable consideration are first specifically authorized by Congress. Funds with which to carry out the work are subsequently appropriated on an annual basis.

PERFORMANCE OF WORK

Once funds are appropriated, we perform our operations through private contractors as much as possible. It has long been an established policy of the Corps of Engineers to utilize the resources of private contractors to the fullest extent possible. The cost of maintaining an organization and construction equipment to carry out all construction directly by the Government would be excessive. However, careful Government estimates are made for each job prior to advertising for bids and we always reserve the right to perform the work ourselves in the event that a reasonable bid cannot be secured. Such work as is done with Government equipment and personnel is generally limited to emergency maintenance requirements. The equipment to meet these needs ranges from small survey launches to sea-going hopper dredges, the largest of which is just being completed. This new dredge will have a carrying capacity of 8,000 cub. yards of dredged material, loaded displacement of 22,000 tons and length of 525 ft. A dredge of this type and size will provide for efficient maintenance of the entrance channels in New York Harbor where a critical combination of rough water and congested traffic is involved.

RIVER AND HARBOUR PROGRAMME

A glance at any general map of the United States reveals one of the greatest natural systems of inland and coastal rivers and tidal estuaries in the world, adapted to improvement and interconnexion as continuous waterways. The accompanying map[2] of the principal waterways of the United States indicates the geographical distribution of our principal improvements and indicates projected but not yet completed projects. There are 1,300 authorized projects (9) for improving and maintaining 28,000 miles of waterways, 490 locks and dams, and 270 harbours. Total expenditures for initial construction of national river and harbour projects have exceeded 2,000 million dollars and for maintenance over 1,000 million dollars. In the planning stage, there is a backlog of authorized and recommended projects approximating 5,000 million dollars.

The improvement and maintenance of our rivers and harbours on a national basis is carried out in accordance with the most urgent requirements of navigation and is necessarily tempered in our democratic form of government by geographical considerations. While the decentralized organization of the Corps of Engineers carries out the elements of our comprehensive programme, the Office of the Chief of Engineers directs, co-ordinates and supervises the operations in order that a well-balanced, integrated programme of waterway improvements is continually underway to meet the needs and demands of the nation.

To carry out such a programme we maintain and revise annually a schedule of operations of the three principal phases, namely, surveys, construction and maintenance. The survey and construction programmes are scheduled for accomplishment based on the total amount of work, cost, urgency, the type and size of the improvement, and its relationship to the over-all programme of development subject to the status of the national economy. The survey programme is worked out on a three-year basis and the construction programme on a six-year basis. The third or maintenance and operation phase is scheduled on an annual basis. This portion of the programme dealing with the restoration of channel depths and operation of locks is carried out to serve only the most essential requirements of navigation at an annual cost of $75 million. Our determination of the requirements of the maintenance and operation is based on periodic surveys and the studies of commerce and traffic requirements.

TRAFFIC GROWTH

Our studies of traffic requirements indicate that the primary factors responsible for the growth of water-borne commerce are those of low cost and dependability. Bulk commodities are best suited to this mode of transportation and lack of speed of movement is offset by regularly scheduled volume movements. As waterway improvements are linked and integrated, through water-traffic develops. The continuing development of our waterways and the growth of traffic are illustrated by the fact that our total water-borne commerce (10) reached an all-time record of 760 million tons in 1947, and more than double the total tonnage just fifteen years before. Foreign and coastwise traffic reached an all-time high of 310 million tons, as compared with the ten-year pre-war average of 204 million tons. Total inland waterway traffic for 1947 continued at a high level amounting to 31,500 million ton-miles and on the Great Lakes shipping has increased to 112,000 million ton-miles in 1947. This increase in waterway activity in addition to recent advances in the design of towing equipment is resulting in requests for us to make many investigations for the purpose of determining the advisability of modifying our project channels to meet changing conditions.

CONCLUSION

Under democratic processes, we of the Corps of Engineers are proud of the progress we have made in the task of improving our rivers and harbours for the benefit of our country and for any influence that improvement may have on other countries of the world. However, we realize how far we yet have to travel. This can be appreciated when it is realized that the United States has over 65,000 miles of navigable waters and has improved only 28,000 miles of these. Also, considering that along a coastline of over 30,000 miles, including the Great Lakes coasts, we have only about 190 improved harbours.

While strides have been made in recent years in waterway development, much remains to be done. Great river-basins like the Columbia, the Arkansas, and many others remain to be developed as the economy of the areas may warrant. Much remains to be done in providing interconnecting channels for the fuller utilization of regional water transportation facilities. Early modernization of our older canalized waterways is imperative. Our lessons from past experience in the development of rivers point clearly to the need for the formulation of our current plans in terms of the future.

With all of the ingenuity we can summon and with the experience gained, within our country and from other nations having longer and more intensive knowledge of waterway development, we look forward to a continuing advancement in that field. Such advancement will assuredly be fostered by this beneficial exchange of information among the United Nations, and we appreciate the opportunity of participating in these discussions.

[2] *Principal Waterways of the United States*, Corps of Engineers, U.S. Army Map Service. It was not possible to reproduce this map, copies of which were supplied by the author for distribution at the Conference.

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The Utility of Inland Waterways[1]

JEAN AUBERT

ABSTRACT

This paper demonstrates the utility of transport by water.

The case of the new countries is considered first of all and the part played by rivers in opening them up is also shown.

The general organization of transport, and goods transport in particular, in the economically highly-developed countries, is then studied.

After setting out the various competing means of transportation and the reasons why the waterways have developed differently in the various countries, we consider in detail the factors governing the distribution of the traffic between waterways and all the other means of transportation. This leads on to consideration of the prime cost of transportation by water, the actual freight cost and the conditions characteristic of this particular type of transportation.

The actual distribution of the total traffic in various countries is then considered. A more detailed analysis of this distribution makes it possible to demonstrate the part played by waterways in the development of seaports and industry in general.

The final section deals with the question of the justifiability of waterways development.

The over-all conclusion is in favour of increasing the part played by waterways, a course which has moreover already been taken in the countries which are technically and industrially most advanced at the present time.

INTRODUCTION

The benefits or utility of waterways cannot be considered in an isolated manner, i.e., without reference to the part played by the other means of transportation.

As Mr. Aldous Huxley has said, one of man's principal activities is the transportation of goods from one point to another[2]. Hence, the poorer the development of land or air communications in a given country, the greater the utility of its waterways.

We shall consider in succession the case of countries whose economic organization is still rudimentary and that of countries whose transportation systems are already highly developed.

UTILITY OF WATERWAYS IN COUNTRIES WHOSE ECONOMIC DEVELOPMENT IS STILL RUDIMENTARY

Some guidance may be obtained from a study of former economy in countries which are today completely industrialized. In countries, however, whose development is quite recent, conditions can be observed directly.

Examples of both kinds will therefore be considered.

THE WATERWAYS OF ANCIENT FRANCE

According to Strabo, a Greek geographer of the first century of our era, the waterways of Gaul were already in use in Roman times. He states that goods which had been brought into the interior of Gaul by the boatmen of the Rhône and the Saône were unloaded to be taken by "portage" to the waterways in the basins of the Loire, the Seine and even the Rhine.

Various economists have recently shown that so long as the transportation system is inextensive, the development of any one of the means of transportation, far from being detrimental to the others, brings about an increase in the volume of traffic carried by them. In France, for example, railway construction has been accompanied by an undoubted development of road transport and the construction of departmental road networks.

Moreover, internal customs between provinces did not play the important part ascribed to them until recent years. If formerly certain areas suffered from famine while the harvest was satisfactory in other areas, the blame for this should not be attributed to the customs, but to the prohibitive cost of transportation, even over short distances, at a time when there were still neither roads nor railways.

The waterways of Gaul were gradually improved and still played an important part under Louis XIV, for example, in whose reign Madame de Sévigné described her experiences during a journey down the Rhône in a water-coach.

THE WATERWAYS OF THE UNITED STATES

In the early days of American history the Hudson, Delaware, Potomac and James Rivers served as routes for the opening up of the country. It was in the first half of the nineteenth century that work was begun on supplementing these natural waterways by a system of canals, among which mention should be made of the Erie canal connecting New York with the Hudson and the Great Lakes.

The Mississippi and Ohio Rivers were used by the early explorers in their travels and, a little later, served as outlets for the agricultural products of the whole basin.

Waterways continued to play a considerable part in the development of the United States until about the time of

[1] Original text: French.

[2] At the beginning of "Jesting Pilate: An Intellectual Holiday", he states the following: "Moving bits of matter from one point of the world surface to another—man's whole activity".

the War of Secession. The great period of railway expansion between 1850 and 1870 brought about the eclipse of the waterways, and the Great Lakes alone continued to be widely used.

It was later, especially in the period between the two World Wars, that the important part that waterways could and should play in the transportation system of a great modern country was realized.

ECONOMICALLY UNDEVELOPED COUNTRIES

Transport by water plays a large part in these countries, in which rivers continue to be almost the sole available means of penetration.

It should be noted, in particular, that in China the Yangtze River made it possible for industry to penetrate as far as Hankow, more than 1,000 km. from the coast.

Similarly the Congo and the Amazon constitute the sole means of access to the heart of the forests of equatorial Africa and America.

UTILITY OF WATERWAYS IN HIGHLY-DEVELOPED COUNTRIES

TRANSPORTATION OF PASSENGERS

In the highly-developed countries waterways play only a very small part in the transportation of passengers. Almost their sole use is in tourist travel, the classic examples of which in Europe are the voyage down the Rhine, or at least its mountainous section and, on a smaller scale, the voyage down the Rhône.

Formerly a number of services for the transportation of passengers by water were operated in Europe over short distances; for example, passenger steamers went up and down the Seine in Paris and environs until the First World War.

At the present time such transportation is still effected on lakes, for example, in Sweden in the archipelago made up of the countless islands of Lake Vänern in the neighbourhood of Stockholm.

CARRIAGE OF GOODS

Various competing means of transportation

In the countries now under consideration the goods traffic is divided among many competing types of transportation, whether in the case of inland transport within a country forming a political unit, or of international transport between countries not separated from each other by sea.

The means of transportation in question are the railway, the automobile, the inland navigation vessel and the aeroplane.

This list moreover is not exhaustive and, in the United States in particular, many tons of petroleum products or natural gas are transported by pipe-line.

It may even be considered that the lines for the transmission of electric current also constitute means of transportation, although the traffic over them does not correspond to material removal. The transmission of the electricity produced by a thermal station situated near a mine can replace the transportation of coal from its point of production to a more or less distant power-station.

One of the factors governing the division of the traffic between the various other means of transportation on the one hand and the waterways on the other is clearly the relative development of the latter. We shall therefore consider this point and also say something about the elasticity of the traffic before attempting to determine the factors directly governing its distribution.

Development of waterways

This development varies greatly from one country to another, even if the comparison is confined to countries whose economies may be regarded as more or less similar.

It varies first of all according to geographic location and on account of the fact that the utilization of natural waterways presents difficulties of varying degree and thus requires the employment of capital in varying amounts.

In North America, for example, the Great Lakes constitute an extremely favourable waterway on which important traffic routes are concentrated. In the case of each lake the outlay was for port installations and not the development of the waterway itself. On the other hand, expensive works were required to interconnect the various lakes (the St. Mary river between Lake Superior and Lake Huron and the Welland Canal between Lake Erie and Lake Ontario).

In Europe the waterway with the best natural conditions is the Rhine on which the improvements carried out (at least below Bingen and the extensive rock removal works at Binger Loch) have consisted only of very small alterations in the existing conditions.

Besides these immediately exploitable waterways which may be described as gifts of nature, there are others which have required large capital expenditures to make them navigable. This applies particularly to canalized streams and rivers and artificial canals.

A second factor has had a considerable influence on the development of waterways.

In most countries there is an antagonism between the railway and the waterway, and the economic principles upheld by the respective Governments of these countries have naturally affected the policy followed in regard to transportation.

In France, for example, since the First World War the waterways have not received from the State the support which they could legitimately claim in view of their economic importance, because it was feared that there would be a drop in railway receipts.

In Belgium and Holland, on the other hand, large sums have been devoted to the establishment or improvement of the system of inland waterways. This is all the more remarkable since the relative smallness of these countries limits the distances to be covered, at least in the case of national transportation. Hence it may be concluded that, contrary to the opinion of some people, waterways should not be used only for transportation over relatively great distances.

The political organization of a State undoubtedly influences its economic policy. It is therefore interesting to note that in Belgium the railways and inland waterways are controlled by two different ministries.

In France, on the other hand, these two means of communication come under the Ministry of Public Works, whose tendency to favour the railways seems to have become even stronger in the course of the last few decades.

The reason for this favourable treatment is that railway construction in France has given rise to important public works, whereas no waterways of any size have been constructed for a long time. Moreover, the railways employ a large number of engineers from the *Ponts et Chaussées*, that is to say engineers belonging to the body from which the principal directors of the Ministry of Public Works are recruited. Lastly, from the trade union point of view, the numerical strength of railway personnel makes the railwaymen's union particularly important from the political point of view.

Elasticity of traffic

It is natural to consider that at any given time the transportation requirements of a country correspond to a certain specific number of ton-kilometres. If this is so, any increase in the traffic of one means of transportation causes a corresponding reduction in the traffic of other competing means of transportation.

In certain cases this may be regarded as correct. It may be considered, for example, that the number of kilos of bread consumed annually by the inhabitants of a country does not vary appreciably according to the wheat or flour transportation rates. If the flour is carried in trucks, that amount of traffic will be taken away from the railway or the waterway.

In the same way the carriage of motor fuel (petrol) corresponds to requirements which do not vary appreciably according to the cost of the various types of transportation. This is particularly so in France where petrol is heavily taxed and where variations in transport costs can therefore amount to only a very small percentage of the total price paid by the consumer.

The position is different however for many types of raw materials of basic industrial importance and an improvement in transportation often leads to an increase in the number of ton-kilometres carried, even in countries whose economic development is already advanced.

Hence the total volume of transportation in such countries is elastic and any increase in it represents an undoubted advance. This should not be lost sight of when the conditions for distributing the traffic among the various means of transportation are examined.

Factors governing the distribution of the traffic

It should be noted at the outset that this distribution is governed not only by the carriage rates offered to the users but also by the individual characteristics of the various means of transportation.

We shall consider the following points: prime cost; freight cost; compound factors involving the particular suitability of a given means of transportation for the various types of traffic; and State intervention.

Prime cost of water transport

The prime cost is governed by a number of factors such as the output per ton weight of the vehicle used, per man employed and per unit of fuel consumed. These three points will be considered in turn.

1. *Output per freight ton.* It was commonly held in Europe in 1945 that the transportation of 1 ton of goods required:[3]

A fraction of an aircraft weighing 2,000 kg.; a fraction of a railway wagon (not including locomotive) weighing 560 kg.; a fraction of a 10-ton truck weighing 500 kg.; and a fraction of an inland navigation vessel weighing 160 kg.

It should be added that boats cost much less per ton than aircraft, trucks or even railway wagons. It should be admitted, on the other hand, that a boat travels a much shorter distance each year than an aircraft. Its useful life, however, is longer than that of its competitors.

2. *Output per man.* In regard to the personnel required to effect transportation, it is considered in France[4] that the following are required to transport the given weights of cargo: 4 tons by aircraft, 2 air crew and 7 ground crew; 15 tons by rail (10 or 20 ton wagon), 1 man (the SNCF[5] having almost as many employees as wagons or coaches); 10 tons by truck, 1 driver and 1 garage mechanic; and 280 tons by boat (Flemish barge), 1 boatman, 1 man on shore.

The load capacity per man employed is thus: 0.45 tons for aircraft; 15 tons for railway; 5 tons for road transport; and 140 tons for water transport.

Instead of comparing in this way the transport capacity with the personnel employed, we may examine the number of ton-kilometres carried.

Let us consider first of all one of the least favourable cases in regard to transportation by water: that of the small inland navigation vessels still employed on British canals. As[6] cargoes limited at times to 25 tons are involved, this traffic, which may be likened to a sort of barrowing, should be compared rather with transportation by truck than with transportation by rail.

In the days when horses were used for traction, one man (with one horse) transported daily: by cart on road, 30 ton-km.; and by boat, 25 tons over 30 miles, i.e., 750 ton-miles or 1,200 ton-km.

Output was therefore 40 times higher by water than by road.

The position changed with the appearance of the diesel engine which makes it possible for a man to transport 1,500 ton-miles or 2,400 ton-km. daily by truck.

Using the same means of traction a team of two men can convoy two small boats of 25 tons each over a distance of 35 miles. The output per man/day is therefore only 875 ton-miles or 1,400 ton-km., that is to say, less than the output of the truck.

This paradoxical result is due to the use of vessels which are obviously too small, and by making the same calculations with vessels of 100 tons (still very small) the output in ton-km. per man/day becomes double that of the truck.

[3]Figures taken from a paper read on 10 January 1945 to the *Association des Grands Ports français* by M. Brousse, then Director of the *Office National de la Navigation*.

[4]See footnote 12.

[5]S.N.C.F.—*Société Nationale des Chemins de fer* (France).

[6]The statistical data regarding these canals are taken from the report submitted by Mr. Fraser to the International River Transport Congress hold in Paris in June 1947.

3. *Fuel efficiency.* From the point of view of fuel expenditure the boat is definitely superior to the truck.

According to Mr. W. Fraser, a gallon of fuel is sufficient for the transportation of 190 ton-miles by truck and 520 ton-miles by small boat, or 2.75 times as much.

A comparison with the railway presents greater interest.

When animals were used for towing, the traction effort was 0.15 kg. per ton, while the effort required to move one ton along a horizontal railway line is 2.5 kg., that is to say 16.5 times as great.[7] The use of more modern means of traction leads—particularly in the case of the self-propelled boat—to much greater speeds and since water resistance increases very rapidly with speed, the advantage of water transportation over rail transportation from the point of view of traction effort disappears almost completely.

4. *Actual prime cost.* After considering in turn three particular aspects of transportation, it is necessary to make a synthesis: we have seen the reasons why any one means of transportation may be theoretically more advantageous than another, but the essential factor is the actual prime cost.

This clearly depends upon the vessel used, the waterway on which it travels and the nature of the cargo carried. Furthermore, only the prime costs obtained by large-scale undertakings are interesting from the economic point of view.

We shall therefore merely indicate[8] the prime cost of the Inland Waterways Corporation, a national service which operates the Federal Barge Lines in the United States, responsible for more than half the goods traffic on the Mississippi.

For bulk-cargo such as coal, petroleum, grain or sulphur, this prime cost is from \$.002 to \$.003 per short ton-mile, or fr. 0.40 to 0.60 per ton-kilometre.[9]

Freight cost

This corresponds to the prime cost plus the carrier's profit.[10] Since the prime cost varies greatly with circumstances, the freight cost by water also varies within very wide limits.

As an example of particularly low freight rates, we may quote first of all the rates in force on the great American lakes and on the Mississippi.[11]

The rate for the carriage of iron ore from the far end of Lake Superior to Cleveland, a distance of 833 miles, does not exceed 80 to 90 cents per short ton, or fr. 0.20 to fr. 0.22 per ton-km. In the opposite direction some of the boats sail in ballast so that the freight rate is even lower: in the case of coal it is as low as fr. 0.10 per ton-km.

[7]Figure taken from a report submitted by Mr. Delmer, Honorary Secretary-General of the Belgian Ministry of Public Works, to the 17th International Congress on Navigation, held in Lisbon in September 1949.

[8]On the basis of the report submitted by Mr. Paul M. Zeis to the International River Transport Congress in Paris in June 1947.

[9]Taking the conversion rate as 300 francs to one dollar.

[10]The concepts of prime cost and profit are less clear than they appear at first sight. To be strictly accurate we should have to make careful and precise distinctions but they would lead us beyond the scope of this paper.

[11]See footnote 8.

The current rate for grain is from fr. 0.16 to fr. 0.21 per cubic metre/km.

The railway could clearly never achieve such low prices.

This also applies to the best waterways in Europe.

For example, the freight rate for Alsace potash down the Rhine from Strasbourg to Antwerp was approximately fr. 0.50 per ton-km. in May 1949.

As an example of a high freight rate on a waterway with short sections and many locks, it may be stated that on the canal from the Marne to the Rhine the rate is approximately fr. 2.0 per ton-km.

Special factors

Under this head we shall consider the following points: speed of transportation; loading and unloading; warehousing; miscellaneous risks; and habits and financial connexions.

1. *Speed of transportation.* The slowness of the waterway is often contrasted with the speed of transportation by railway or truck. This is correct in principle but there are many exceptions. The following examples may be quoted in particular:

The motor-vessels which make the "Lyons-Marseilles-Lyons" run down the Rhône cover a distance of 735 km. Taking into account the time required for loading and unloading operations they can make the round trip in one week. The down-trip from Lyons to Marseilles takes only one day while the return upriver takes three days.

On the Seine, where the traffic is important, a motor-vessel of 800 tons takes three days from Le Havre up to Paris and two days if it originates from Rouen. The trip downriver takes one and a half or two days at the most.

On the Rhine still better results are obtained and the "Strasbourg-Antwerp-Strasbourg" run, a distance of 1,575 km., is frequently completed in 12 days.

2. *Loading and unloading.* The horizontal dimensions of the holds of vessels used on inland waterways are usually much superior to the corresponding dimensions of railway wagons and trucks. The result is that the use of grabs for the loading and unloading of heavy materials is much easier when a boat is used.

In the case of transportation beginning in a seaport, the use of inland navigation vessels has still other advantages. Vessels of this type can tie up to the free side of a cargo ship berthed alongside a wharf. By using the derricks on board, the cargo can be loaded into the barge while the wharf cranes work on the other side of the cargo ship. The berth is thus occupied for a much shorter period, constituting a considerable saving.

It should be added that in the transfer of the cargo from the steamer to the barge, the latter has to be moved a few times only (in contrast to a railway wagon or truck) and this movement on water is particularly easy to effect.

The unit capacity of the boats currently employed on the continent of Europe (capacity varying from 300 to 3,000 tons) is a factor which is sufficient of itself to demonstrate the superiority of these vessels over a railway wagon, the capacity of which is less than 100 tons, and over a truck the capacity of which does not exceed 20 tons.

Hence it may be concluded that the use of a boat is particularly advantageous and simple in the case of large cargoes. Conversely, the transportation by boat of smaller cargoes requires special precautions or the use of boats divided into separate holds.

3. *Warehousing.* What was stated above about the great loading capacity of a boat, whether in relation to freight tons or to the number of men employed, is sufficient to show that a boat lends itself much better than any other means of transportation to the storage of goods. At certain times inland water vessels are, in fact, frequently employed as floating warehouses.

4. *Miscellaneous risks.* Mr. W. Fraser has shown[12] that road transport causes a dreadful number of fatal accidents and that there are also fatal railway accidents, while fatalities in the carriage of goods by water are extremely rare.

The risk of breakage is reduced in the case of carriage by water—a valuable consideration in regard to fragile products such as bricks, china and pottery or even inflammable materials such as certain types of lignite or compressed fuels.

This absence of concussion makes the construction of tanks for boats much less expensive than that of tanks used for the transportation of liquid products by rail or road.

Transportation by water also provides a certain degree of security against fire which is a valuable consideration in the case, for example, of a cargo of straw, and a degree of security against theft because of the relative isolation of the boat and the small number of persons employed.

Many more examples of this kind could be given.

It should be noted in particular that cotton requires a certain degree of humidity and its transportation by water makes it possible to avoid the risks of dryness.

5. *Habits and financial connexions.* Habits clearly have much to do with the choice of transportation made by farmers, industrialists or businessmen, with the result that technical advances achieved in any particular branch are often somewhat slow to make themselves felt.

The possible financial connexions between various industries and the railway companies, for example, may also be a contributory reason for giving the preference to railways for certain special types of transportation, even if carriage by boat is intrinsically more advantageous.

The subscription rates which include a fidelity clause, offered to their clients by certain railway companies, constitute a means of creating financial relationships very similar to those referred to above.

It is often impossible to determine in advance the incidence of the various factors which we have reviewed; hence it is difficult to foresee what the traffic over a new waterway will be.

For example, since being put into service in 1938 the *Mittelandkanal* has carried a monthly traffic of 400,000 tons, more than the most optimistic estimates. German economists and engineers, however, admit that because of the unpredictable preferences of the canal's users, the density of the traffic has been far different from what was expected.

[12]*Op. cit.*, see footnote 6.

State intervention

The various means of transportation may be regarded at one time as complementary (this was noted when the case of new countries was examined) and at another as competitive. As it is possible for this competition to become immoderate, State intervention is deemed to be necessary at times.

"Co-ordination" consists in the whole of the measures employed by the State to referee this competition, that is to say, to see that it operates in the general interest. We shall show how this co-ordination may affect the distribution of traffic.

First of all it is necessary to note a first type of co-ordination which is employed in the construction stage (at least in countries where, as in France, the understructure of the various means of transportation is built by the State) and which links up with what was stated above regarding the part played by the State in the development of waterways.

The need for a second type of co-ordination at the operational stage had not yet made itself apparent at the beginning of the twentieth century. An official French report of 1901 contains the following sentence[13] which admirably illustrates the state of mind at that time:

"Once the State has laid down the main lines of development of their understructure, all the means of transportation have a definite part to play and experience allots to each of them its place in the development of the public wealth".

Ideas have progressed considerably in this respect in the last fifty years and development of the motor car after the First World War led to more or less marked intervention by the State in the operation of the various means of transportation.

Although there is lively discussion in France concerning the conditions of this intervention, there are practically no supporters of the theory that there should be absolute freedom.

It is generally recognized that a certain amount of State intervention is essential because:

For given types of transportation certain techniques enjoy, temporarily at least, a *de facto* monopoly;

The various transport companies do not always bother to organize the necessary technical and commercial co-ordination;

It is impossible for the State—in so far as it assumes responsibility for the development of the understructures—not to concern itself with the growth of the various means of transportation.

It should be added that too vigorous competition would give rise to contests that might result in suspending the operation of some of the means of transportation. The result of this would be frequent and violent changes in tariff rates to the detriment of the users.

This concept appears to accord with the ideas prevailing in the United States, where a large number of bankruptcies

[13]Quotation taken from a lecture given to the *Cercle des Transports* on 24 June 1948 by Mr. François Ollive, former Director of Transport Economy in the Ministry of Public Works. The whole section of this paper relating to State intervention is based on this interesting document.

by railway companies during the last century have demonstrated the reality of this danger.

A report presented in 1934 to the 73rd session of Congress by the Federal Co-ordinator contains the following passage:

"Uncontrolled competition in transportation would make rates and charges utterly unstable and undependable and invite much the same abuses as existed in the railroad 'rebate' days .... It would be particularly dangerous if indulged in by the railroads, because there is still a very considerable volume of railroad traffic upon which other forms of transportation do not encroach. The tendency .... would be to exact the last possible cent from such traffic and make rates on the competitive traffic low enough to stifle the competition. The other forms of transportation have no such reserves of non-competitive traffic to sustain their endurance."

State co-ordination of the various means of transport may assume widely different forms. The most primitive and ruthless method is the arbitrary division of the traffic between the competing means of transportation. In this extreme case the decision of the competent official or body is sufficient to determine the division, but this decision is obviously influenced by the other factors mentioned above.

Other less comprehensive types of State intervention may prevent a given means of transportation from developing purely in accordance with the law of supply and demand. In France, for example, before the last World War it was forbidden to put a new vessel into service without breaking up other vessels representing an equivalent tonnage.

We have no intention of attempting to determine the limits within which the co-ordinating activity of the State may legitimately be exercised, but we could not avoid noting its effect upon the distribution of the traffic between the various means of transportation.

Actual distribution of the global traffic

In the United States water traffic is considerable on the Great Lakes and very heavy on the waterways in the Mississippi Basin.

On the Great Lakes the annual traffic has exceeded 170 million short tons every year since 1941.

In 1944 the number of ton-miles carried by water and rail transport in the United States as a whole was as follows:

	Milliards
On the Great Lakes	119
On rivers and canals	31
Total	150
Rail transport	740
Grand Total	890

Hence water transport accounts for 17 per cent, not of the total United States traffic, but of the traffic carried by rail or water.

This proportion however varies considerably from year to year and the same calculation in respect of the year 1941 gives a proportion of 25 per cent for water transport.

In Europe the most important waterway is the Rhine, on which traffic exceeded 86 million tons in 1937.

In Germany, inland navigation transport accounted before this last war for approximately one-quarter of the total traffic by rail and water.

In France the proportion is appreciably smaller and varies between one-quarter and one-sixth.

In Belgium, on the other hand, the inland navigation traffic annually exceeds three milliard ton-km. and corresponds to about one-third or one-quarter of the total traffic in the country.[14]

The relative importance of water transport is still greater in the Netherlands. For example, the goods traffic in 1947 is divided up as follows:

	Tonnage in millions of tons	percentage of total
Inland waterways	41	46
Railways and tramways	17	19
Trucks	32	35
Total	90	100

The above figures[15] include traffic inside the Netherlands as well as the tonnage exported or imported via the various land frontiers.

As the various means of communication were not completely restored to normal in the course of 1947, it is interesting to note in addition that in 1938 water transport accounted for 90 per cent of the Netherlands import and export traffic via the land frontiers.

MISCELLANEOUS FACTORS

For a better understanding of the economic role of inland navigation, it is essential not to consider merely global proportions as in the foregoing; a more detailed analysis is desirable.

Development of seaports: The proportion of the tonnage moved by inland navigation transport from a large seaport is of particular significance in this regard. This percentage is given below for a number of European ports:[16]

Marseilles	3
Le Havre	25
Antwerp	40
Amsterdam	45
Hamburg	45
Rouen	60
Rotterdam	70

This question of the manner in which goods are moved is a major factor in the prosperity of ports.

The German port of Lubeck, for example, was once as busy as the two other great Hanseatic towns of Bremen and Hamburg. It has declined steadily for several decades and has been partially superseded by the port of Stettin, advantageously situated at the mouth of the Oder.

The port of Cherbourg in France, which is admirably situated purely as a port, has been unable to develop in the

[14]M. Delmer, *op cit.*, see footnote 6.

[15]Taken from the report submitted by the Netherlands in September 1949 to the 17th International Congress on Navigation, at Lisbon.

[16]Figures taken from Mr. Brousse, *op. cit.*, see footnote 3.

same way as Le Havre and Rouen because the latter are situated on the Seine.

The Belgians and Dutch have made considerable financial sacrifices in order to improve the interconnexion by water of Antwerp and Rotterdam and they have noted that each improvement has resulted in increased traffic.

Outside Europe, too, the great ports have sprung up in estuaries: this applies in particular to New York and New Orleans.

Inland waterways are therefore of great importance to the seaports of which they are the natural continuation; it has been justly said that rivers constitute the land roots of the marine waterways.

Industrial development

In a highly developed country the volume of industrial traffic is much greater than that of agricultural traffic and there is no doubt that the development of inland waterways has influenced industrial advancement.

Belgium provides a noteworthy example.

At the beginning of the industrial period the factories were established on the banks of the Rhine, the Meuse and the Scheldt, or even of lesser waterways such as the rivers Sambre, Dendre, Durme, Lys, Haine and Rupel.

These rivers or streams were subsequently interconnected by canals to form a system of 2,000 km, of waterways.

Lastly it is to be noted that all Belgian factories, with very few exceptions, are situated on the banks of waterways.

Effect on rail tariffs

In several countries the railways are compelled by tariff competition to provide special rates for rail transport effected parallel to waterways. Already enjoying the advantages of the waterway, the industrialist whose plant is situated on the banks of a river thus has a second advantage which may equal or surpass the first in importance.

This constitutes one of the beneficial effects of competition which undoubtedly leads to progress so long as it is kept within sensible limits.

Without going back on what was stated above concerning the role of the State in traffic distribution and without claiming to exhaust the question, we shall confine ourselves to noting two dangers:

The railway may, in its desire to compete, be led to agree to prices lower than what is termed its partial prime cost[17] thus causing an overall loss;

The same railway may attempt, at the cost of temporary losses, to ruin and eliminate water transport so as to introduce, subsequently, a sharp increase in rates.

International character of waterways

In Western Europe the system of waterways extends across political frontiers. Even excluding the Rhine, navigation on which is regulated by a special international régime, it may be said that the conditions in which a vessel flying a foreign flag may travel the waterways are relatively liberal. Hence in regard to transportation from one country to another, at least, it is possible for international competition to develop. This presents the same advantages—and disadvantages—as competition in general.

In this respect there is a profound difference between waterways and railways.

Justification for the development of waterways

As we have seen, the valleys of great rivers form preferential areas for industrial development and their existence constitutes a national asset.

In order to exploit this asset in the best possible conditions, it is often necessary to develop the rivers in question and the utility or justification for the works required is neither disputed nor disputable.

The fact of declaring that works which enable the maximum possible profit to be derived from a natural watercourse are justifiable involves by inference the justification for all other works for the improvement of a country's waterways, including the construction of entirely new artificial waterways. This inference may be arrived at by two different processes of reasoning.

In order to improve navigation on a river, it may be desirable and at times almost essential to connect it by an artificial canal to another waterway or to a seaport. In Belgium, for example, industrial conditions in the Liège district have been much improved by the opening of the Albert Canal which forms a direct link with the port of Antwerp.

It may, moreover, be considered that when the banks of a country's navigable waterways have been completely utilized for the construction of factories (to the extent that no more land or labour is available in the areas in question) it is legitimate for the State to consider establishing, along the banks of new waterways developed or constructed from scratch, new sites to be gradually utilized in the course of subsequent years and decades.

By such action the State extends to a fresh group of beneficiaries both the advantages of water transport and the benefits of more favourable railway tariffs.

It is here that some supporters of the railway revolt and state they are no longer in agreement. They ask why State funds should be used to favour certain categories of citizens to the detriment of the others.

To this it may be replied that the State always acts in this manner when carrying out public works. To quote only one example, it should be pointed out that technical necessities compel the State to concentrate on a small number of ports the resources allocated for the development of the country's maritime traffic. The same applies to airfields and—outside the field of the construction or improvement of the means of communication—the execution of public works in general.

The only way to achieve a little more equality among the citizens would be to compel them to contribute in reasonable proportion to the costs of the public works from which they benefit. In most countries much still remains to be done in this respect.

[17]The exact definition of the partial prime cost cannot be given in a few lines and its calculation in each individual case is only possible on the basis of a number of more or less arbitrary assumptions.

CONCLUSION

In examing the case of the new countries, we have seen that waterways have often played a unique part as a means of penetration.

In our study of the importance of waterways in advanced countries, we have considered, in particular, goods traffic conditions and have demonstrated the essential part played by water transport in the development of national ports and industries.

We have shown that in order to be able to dispute the importance of constructing or maintaining waterways, it is necessary to restrict one's field of vision to the point of identifying—as has occasionally been attempted in France—economic progress with the financial stability of a national railway system.

Our purpose was to demonstrate how a country may benefit from the use and development of the various resources in inland waterways with which nature has endowed it. It should be noted moreover that since the beginning of the twentieth century the views of economists, financiers, engineers and politicians have shown a favourable development in this regard.

Summary of Discussion

The CHAIRMAN stated that the discussion should centre round the economic aspects of flood control and navigation rather than the technical aspects. As the discussion would have to be supported by concrete examples, he was glad to have found among the papers presented one by Mr. Beard on the general economic problems of flood control and another by Mr. Witteveen on the system of flood control used in the Netherlands.

At the preceding meeting a request had been made for a continuation of the discussion on dykes with navigable channels. He therefore proposed that the discussion of the agenda of the day should close at about 12.30 p.m. so that the discussion on that question could be resumed. It was so decided.

Mr. RINGERS presented the paper by Mr. Witteveen. In it, the author discussed the technique used for flood control in the past and traced the development of engineering theory up to the time when modern techniques had been developed.

In the low-lying land the country is protected against flooding by the river dykes. Between these dykes the river is flowing in winter, but in summer the river is restricted to a summer bed, which has been regulated in such a way as to prevent the accumulation of sediment. Between the high river dykes and the summer bed lay the summer polders, protected against summer flood by lower dykes.

In spring, when ice is coming down from the upper reaches of the river, forming of ice barrages has been prevented by giving the summer bed no sharp bends. The danger of piling up of ice barrages is thus reduced. If the accumulation of ice is increasing too fast, ice breakers remove the ice.

The branch of the Rhine known as the Waal, 53 miles in length, had been dyked during the period between 1852 and 1889. The regulating work undertaken for protection against flood had been of great benefit to navigation and the dredging that had been done to keep the branch of the river open to navigation had improved the discharge capacity and facilitated flood control.

The Waal and the Maas joined formerly at Gorinchem, moreover there was a spillway in the dyke between these rivers at Heerewaarden, by which reasons the danger of the forming of ice dams increased and the Waal, when in flood, would threaten to burst the dykes of these rivers.

The Maas had been provided with an outlet to the sea some 20 miles long, which had made it possible to close the old canal. The waters of the Waal had been regulated by connecting it with the Hollandsch Diep. It was thanks to that work that the ice which had formed in those canals in the severe winter of 1939-1940 had been successfully broken with the aid of icebreakers over a distance of some 57 miles, and ice dams up to 30 ft. high had been cleared well before the thaw set in.

The author next discussed means of financing flood control and methods of supervision. He emphasized that the authorities and the people whose lands were exposed to flooding worked together in an atmosphere of mutual understanding.

At the present time 90 per cent of the expenses was paid by the Government and only 10 per cent was borne by the people who benefited from the works and who had organized local boards to handle flood control.

Mr. HATHAWAY asked Mr. Ringers if he could give an idea of the amount of sediment deposited by the Rhine during the winter rising.

He also asked whether the countries through which the river flowed had concluded agreements for the comprehensive development of the Rhine basin, for example, for the construction of retention reservoirs in the upper river to facilitate navigation during low-water periods.

Mr. GOLDSCHMIDT asked how the different countries along the river solved the problems of flood control constructions.

Mr. RINGERS replied first to Mr. Hathaway. The sediment deposited between the summer and winter dykes made that the most fertile land of the region. The deposit of sediment was not therefore a matter of anxiety to the Netherlands.

In regard to any flood control works which might be undertaken on the upper Rhine, it must be said first of all that the international regime of the Rhine, instituted by the treaty of Vienna, applied only to navigation. If a country decided to construct a large retention reservoir for use during periods of low water, the Netherlands would be only too pleased; it would not have to contribute to the cost.

He drew attention to the construction of the large canal in Alsace in France, which was to be used for power production. It was not necessary to consult the Netherlands on that type of project, since the international river regime did not allow the countries along the river to intervene unless the works endangered navigation.

Problems had arisen in regard to pollution, but they had been amicably settled through negotiations with France, and, with rather more difficulty, with Germany.

In reply to Mr. Goldschmidt, Mr. RINGERS stated that there was no system in force for apportioning the costs of flood control among the countries through which the river flowed. Each country constructed the works which seemed necessary on its part of the river, bearing the full cost itself. If such works gave rise to navigation problems it was for the International Navigation Commission of the Rhine, instituted by the Treaty of Vienna, to settle them.

The CHAIRMAN explained that the grand canal in Alsace, which would be used chiefly for power production, would also facilitate navigation on a part of the Rhine which had hitherto been difficult to navigate. The costs were sustained by France, which had asked nothing from the other countries bordering the river. It was that which distinguished the regime of the Rhine from those which it was proposed to establish for flood control of international rivers. The modern idea was to apportion the expenses among all the countries which would benefit from the projects and not to undertake them without their consent. The Rhine had not presented any serious problems in that respect; the works were comparatively modest, and the countries along the river had therefore been able to apply the existing system without the work undertaken having led to any friction.

Mr. WEBER summarized the paper by Mr. Beard, which discussed the economic problems to which flood control gave rise.

The problems of flood control were interrelated with problems of other uses of river-basin resources.

The effects of flood control included both advantages and disadvantages; it was difficult to assess them in economic terms, but no other basis for assessing them hitherto devised seemed to afford a complete and accurate appraisal of flood control benefits and costs.

It was necessary to distinguish between the benefit of preventing losses and damages, and the benefit of improving the utility of property as a result of flood control.

Most, if not all, flood losses could be estimated directly in terms of money, but it was difficult, if not impossible, to assess such losses as loss of life and impairment of health. Those benefits, however, which could not be assessed in monetary terms were often of primary importance in a critical examination of the reasons justifying the project.

The problem which arose in the analysis of the justification of flood control was not insoluble, but it had not yet been solved with respect to the economic comparison of flood control with other activities which might be related to or affected by flood control projects.

That was a major problem which should engage the attention of all concerned with the formulation of land and water resource development programmes.

The improvement in the usefulness of resources was harder to assess. The immediate benefit could be readily estimated in economic terms, but secondary benefits such as the effect on the prosperity of a community and the stimulation of other economic activities could not be conclusively identified or measured.

In addition it was necessary to consider the period of time over which the project would stimulate economic activity either directly or indirectly and to estimate the benefits which might accrue to each of those activities throughout that period.

It would be very useful to work out a method by which a comparative estimate of all effects could be made from the broadest possible point of view, but it would probably take many years to accomplish such a task. In the meantime it would be well to study the possibilities for improving and extending the scope of the evaluation methods in general use, which were based on concepts of economic values.

The author then considered the effect of price levels on estimates of the benefits and costs.

That phase of economic analysis merited a careful study to determine whether forecasts of future price levels could be made with sufficient accuracy to justify their application to flood control benefit estimates.

Finally, the author dealt with methods of payment for flood control.

Mr. WEBER pointed out that all the questions raised in Mr. Beard's paper had been studied by a federal committee established to consider all the possibilities of river-basin development in the United States. The committee would publish its conclusions at the appropriate time.

The CHAIRMAN observed that Mr. Beard's paper was all the more interesting because it was in the United States that flood control had been most extensively developed. He proposed that the two following points should be discussed:

1. Was it possible to find a comprehensive method of assessing the advantage of a flood control project which would allow a reasonable decision on whether certain projects should be undertaken or not?

2. Mr. Beard pointed out that in the United States benefits were estimated on the basis of a fifty-year period. The question whether that was a suitable period or whether a period of different length should be considered might be discussed.

Mr. RINGERS stated that the calculations mentioned in Mr. Beard's paper had been made in the Netherlands, but they had never led to a really satisfactory conclusion.

The Netherlands Government had finally adopted a policy whereby the State assumed the largest share of the costs of flood control. That policy was based on the fact the Government would benefit indirectly. There was no longer any attempt to make a complete estimate of the advantages of works which were necessitated by social considerations.

The CHAIRMAN remarked that the United States followed a policy very similar to that of the Netherlands which Mr. Ringers had just explained. No complete assessment was made in France, either, since the decision to be taken was of necessity influenced by psychological and political factors. France had not yet succeeded in estimating the benefits to be derived from flood control projects.

Mr. SAIN drew attention to cases where the land adjacent to a river was not inhabited on account of floods. On construction of flood control works the region would inevitably become inhabited by people who would consider themselves safe from floods. But what would happen when the reservoirs became clogged?

In regard to works of that type the question arose whether other reservoirs could be constructed at other places on the same stream when the first ones had been filled up. If not, it could be asked whether it would not perhaps be better to refrain from undertaking flood control projects rather than create a false sense of security which might have disastrous consequences in the future for those who came to live along the banks of a river thus controlled.

The CHAIRMAN quite understood Mr. Sain's solicitude for such psychological preoccupations, but reminded him of the experience in Italy with the control works on the Po dating from Roman times, which had continued to work satisfactorily ever since.

Mr. RINGERS asked Mr. Weber how benefits were assessed in the United States. When land which had originally been worth, for example, 100 dollars per unit increased in value to 400 dollars when the river control project was completed. Was the benefit estimated at 300 dollars or were the costs necessary to render the land suitable for new crops deducted? Experience showed that those costs accounted for almost the whole of the apparent benefit, at least during the first years.

Mr. WEBER replied that the readaptation costs were deducted.

Mr. WING pointed out that in assessing benefits, it must be borne in mind that the money for flood control works had to be provided immediately, while the benefits did not appear until later. It was like a loan, which always cost more than the sum borrowed, because the interest had to be added. That principle applied to flood control projects. Before undertaking a project it was necessary to make sure that the benefits would exceed the total of the cost and the interest on the money.

Mr. WEBER explained that the activities of the flood control services in the United States were controlled by Congress in accordance with the rule that projects should be undertaken in every case where the benefits were greater than the installation costs. There was no fixed ratio between costs and benefits. Nevertheless that factor entered into the calculation, at least indirectly. On the one hand the estimate of the benefits the project would bring was always incomplete; on the other hand the estimate of both the benefits and the installation costs allowed for interest computed at the same rate.

Mr. DARLING said that he had spent twenty-two years with the Mississippi River Commission. He could therefore appreciate the remarkable results obtained in flood control in that basin. In 1928 the United States Government had organized and financed a project of direct interest to seven states. Up to then flood control measures, which consisted of small-scale works constructed by private undertakings, had given poor results. The progress recently achieved in that direction was such that, in spite of several serious floods, the Mississippi Valley had reported very little damage during the past few years.

He then commented on a statement by Mr. Sain, in which the latter had described the danger that the development of certain fertile valleys for agricultural purposes might entail in his country, and the feeling of false security which the construction of reservoirs gave the farmers in those areas.

Thanks to flood control measures it had been possible to reclaim areas from 20 to 80 miles wide and 600 miles long in the Mississippi Valley. Those areas, discovered in 1541, had been described by certain Spanish authors of the time as lands completely flooded in spite of the existence of virgin forests and the complete lack of agricultural development. It was impossible nowadays to prevent farmers from settling on those fertile lands.

Mr. PAPANICOLAOU explained that important works on flood control had been carried out in Greece, especially in Macedonia, before the last world war, financed by the Greek Government. A total of $33 million had been voted for the purpose. Thus, 60,000 hectares of fertile land had been reclaimed in the Plain of Salonika and 180,000 hectares had been protected from floods. These works included large railway and highway bridges (some of which are about 800 metres in length), the costs of which were charged to the works. For this reason, the cost of the above works had been deducted from the estimate of the value of the reclaimed and distributed lands to the peasants. The Greek Government had itself financed all these works, apportioning the expense subsequently among owners and purchasers of the reclaimed land.

Mr. HATHAWAY thought that Mr. Sain had raised an extremely important question when he spoke of the difficulty of constructing reservoirs in the basins of certain rivers carrying a considerable amount of sediment. The Mississippi River Commission had encountered the same kind of difficulties during the construction of several reservoirs. Studies had been undertaken which would doubtless lead to the solution to that difficult problem.

Mr. BURGER, in presenting his paper on "Development of the Rivers and Other Waterways of the United States for Navigation", explained the United States policy in regard to the control and improvement of navigable waterways. The control of United States navigable waters was mentioned in the Constitution itself, and Congress laid down the general policy for the improvements to be carried out in that sphere. Since 1821, beginning with the initial national improvement in 1824, all the work had been carried out and directed by the Corps of Engineers, Department of the United States Army. All improvement projects were planned to keep pace with the country's economic and general development.

In introducing Mr. Aubert's paper on "The Utility of Inland Waterways", the CHAIRMAN stressed the importance of improving the waterways in economically underdeveloped countries. Mr. Aubert's paper gave several examples of projects carried out in China and in the valleys of the Congo and Amazon. It then dealt with the utility of waterways in the more developed countries, and listed the various competing means of transport in the interior of each country. The distribution of traffic between the different means of transport depended in each case on the importance of the waterways, which in turn depended on the river system of the country and the steps taken by the Government to develop it. He agreed with Mr. Burger that the development of waterways and other means of transport had started at the same period. There was, therefore, no conflict between the development of railways, for example, and the improvement of waterways.

The paper then dealt with the prime cost of transport by water. It showed that the tonnage thus transported per man, per ton of shipping, and per unit of fuel consumed was considerable. On the other hand, it was relatively low with regard to the distance covered, for it was still a very slow means of transport. Several examples of freight costs showed that in the United States transport by water was less expensive than by rail. Furthermore, certain conditions made it necessary to transport large quantities of raw material by boat. For example, transport of goods was less dangerous by water than by road, as it reduced the risk of breakage and provided a certain security against fire. The Chairman emphasized that waterways should be governed by a national policy.

A number of examples of the amount of water transport in several countries showed that the maximum total had been recorded in the Netherlands. It would be seen from other examples that the development of ports and the development of certain industries had a definite influence on water traffic. In Belgium, for example, all factories were built near waterways.

The paper then pointed out that in France certain expenditures involved by the improvement of waterways had been criticized by the representatives of other means of transport, in particular the railways. The Section should discuss that aspect of the problem and should define the extent to which expenditure on the development of waterways was justified.

In conclusion the Chairman asked the meeting to consider the following points: (1) prime cost of transport by water as compared to the prime cost of transport by other means; (2) the advantage of water transport from the point of view of loading and unloading of sea-going vessels, transport risks etc.; (3) economic advantages of water transport and cost of developing seaports and industry; (4) justifiability of State expenditures on the development of waterways.

Mr. Dawson thought that Mr. Burger's paper gave an admirable account of the work undertaken in the United States for the development of waterways.

The results obtained, together with the improvement of the design of barges and the considerable increase in their size, had enabled the number of ton-km. of transport on the Ohio to be doubled. The prime cost of transport by water of certain commodities such as coal, petroleum and steel had proved so advantageous that the construction of special barges was contemplated for the transport of valuable commodities such as petrol and certain chemical products. The Corps of Engineers Department of the United States Army had undertaken research on the possibility of increasing the speed of barges. That work had been made possible only by the adoption of a minimum depth of 12 ft. for canals.

He asked for additional information on the following three points:

(1) How was it proposed to ensure that the annual profits obtained from the improvement of waterways would exceed the expenditure entailed by improvement work?

(2) To what extent was the economic development of the country allowed for in the development of waterways?

(3) To what extent was it expected that water transport would be increased as a result of the carrying out of the canal construction described in Mr. Burger's paper?

Mr. Burger, replying to Mr. Dawson's questions, pointed out that navigation had contributed largely to the prosperity of industrial centres in the United States. In this connexion he stated that of the 30 principal cities of the United States, all but four are located on navigable waters and those are state capitals, and that no less than 65 of the 92 cities that had more than 100,000 population at the time of the 1940 census are located on improved waterways.

In regard to the increase in water traffic, the development of the Mississippi had raised the number of tons of goods transported by water from 5 million to 57 million. This increase, which is typical of a sound waterway project, has been accomplished by continuous study and progressive improvement. Early improvements of the river were limited to removal of snags and to the confining of low flows to the main channel. Then to provide a more dependable channel, a 6-ft. waterway was constructed and later modified to a 9-ft. waterway. At the present time there is authorized a 12-ft. channel for the lower reach of the river. An investigation for extending the 12-ft. channel to the upper reach as well as the principal tributaries to provide for the accommodation of larger tows is under way in order to continue economical movement of commerce.

Mr. Goldschmidt stated that he had read Mr. Aubert's paper with great interest. He congratulated the latter on his frank exposition of the problem created in France by the antagonism of the representatives of the railways. In his view, the section meeting should consider in particular the development of waterways in under-developed countries. Early in the existence of the United States, General Washington, who had realized the importance of internal navigation for the economic progress of the country, had convened a conference to consider the utilization of waterways. That conference was concerned with the construction of two canals, one linking the Ohio to the Potomac, and the other connecting the Great Lakes with the Hudson.

The prime cost of water transport and of other means of transport should also be studied. Such studies would show the general direction that efforts for the development of waterways should take.

Mr. Goldschmidt asked the representatives of economically under-developed countries to what extent their Governments had promoted the development of a waterways system in preference to the improvement of, say, railways or roads. It would also be interesting to know what types of construction and equipment had been recommended in particular instances.

The Chairman remarked that the question raised by

Mr. Goldschmidt was of considerable significance. It was important to know what means of transport should be adopted by under-developed countries in particular.

Mr. Burger, in reply to Mr. Goldschmidt, pointed out that waterways, even when they had been the object of important construction work and constant maintenance, did not bear the same stamp of homogeneity and uniformity as a network of railways or motor roads. There were always certain parts of streams which were difficult to navigate. Nevertheless, considerable progress had been achieved in the United States in the solution of the technical problems of river navigation, in particular through the adoption of towage systems which had made possible an extremely economical method of operation suitable for relatively shallow waters.

He was prepared to show a film on those new methods of river navigation. In conclusion, he recognized the importance of the problems indicated by Mr. Goldschmidt with regard to the need for low-cost means of transport for heavy freight in the under-developed countries.

Mr. Fabregat stressed the importance of the papers presented by Mr. Burger and the Chairman, and of the idea developed by Mr. Goldschmidt. Following Mr. Burger's review of the progress achieved in the United States in river navigation, with particular reference to the Mississippi basin, he wished to add some information on the corresponding situation in Latin America and in his country, Uruguay. He recalled the classic definition of a river "a road which moves", which was enough to show the importance of inland navigation. Utilization of rivers and waterways made it possible to develop regions in the interior. Development of waterways, however, should not cause railway and road construction to be neglected. There were four great river-basins on the American continent. All those rivers and their tributaries constituted natural waterway systems of the greatest importance. Thus the Amazon river system extended over a distance of 35,000 kilometres in Brazil.

The United States had enhanced the efficiency of its natural waterways by a judicious construction of canals. Its example should be followed in South America; in particular, as he had suggested in his book on the River Amazon, the River Paraguay and the principal tributary of the Madero should be connected by a comparatively short canal. The Amazon basin would thus be linked to that of the Plata.

It was certain that natural waterways provided a means of promoting speedy economic progress, especially in economically under-developed areas. Greater use of waterways would facilitate the extraction, export and processing of raw materials and would thus promote industrialization, which was absolutely essential for Latin America, and for Uruguay in particular.

In conclusion, Mr. Fabregat emphasized the importance of carrying out a study on the question of the economic utilization of waterways, particularly in backward regions where it would facilitate the absorption and settlement of new populations. It was also necessary to co-ordinate waterways with railways and roads, which were their natural complements. There was no conflict whatever between railways and waterways. A comprehensive policy for all means of communication as a whole would make it possible to achieve more rapid progress.

He paid a tribute to Mr. Truman, upon whose initiative the conference had been called. The agenda of the conference should also include a study of the human element, which alone gave natural resources their value and made it possible to utilize them in the interests of progress. In Uruguay the waterways represented an important instrument of economic progress.

Mr. Ringers shared Mr. Fabregat's view that waterways were always the first means of transport which could be developed; that had been proved in Europe by the experience of an already distant past, and more recently in under-developed countries.

Reverting to the question of the comparative cost of water, railway and road transport, he stated that it had been the object of detailed study in the Netherlands for thirty years: such a comparative study presented certain difficulties, in view of the fact that the general expenses of railways were much higher than those of other means of transport and did not vary according to the amount of traffic. He mentioned as an example the competition between the navigation on the Rhine and the railways of the Reich (*Reichsbahn*). The traffic on the Rhine was very considerable; in 1926, for example, a total of 77 million tons of freight had entered the Netherlands by way of the Rhine. It was then that the *Reichsbahn* had established special advantageous rates for freight going to such German ports as Hamburg, and in view of its heavy general traffic, it had been able to grant very low rates for such freight.

He cited the developments in Venezuela, a country also known to him, where the waterways had been the original means of transport of mass loads. Eventually, when the existence of mass loads justified it, railway construction became essential. He considered that once certain progress had been attained in under-developed countries, the waterways should be supplemented by feeders which could consist of either railways or motor roads.

Mr. Gonzáles Molina felt that the question of waterways was of considerable importance for under-developed countries, and pointed out that the situation in his country in that regard was particularly unfavourable. Soil erosion in the mountainous regions of the Andes caused considerable sedimentation, as a result of which all the rivers of his country, with the exception of the Orinoco, had become practically unnavigable. American oil companies had therefore been forced to construct pipelines for the transport of the petroleum they extracted, since navigation on the silted-up Maracaibo Lake would have been too costly. Even on the Orinoco, where the Bethlehem Steel Company had built a river port, navigation continued to be very difficult as the delta was silted up. In view of the irregular flow of the river, lateral canals would have to be constructed to facilitate navigation.

The Chairman stated that in view of the late hour the question of channels could not be discussed at that meeting. He proposed that those interested in the question should hold a private meeting at 2.30 p.m. to discuss the subject.

Irrigation and Drainage

30 August 1949

Chairman:

S. IRMAY, Hydraulics Laboratory, Hebrew Institute of Technology, Haifa, Israel

Contributed Papers:

Relationship of Soil Characteristics to Irrigation Programmes (Indonesia)

W. F. EYSVOOGEL, Professor, Graduate School of Agriculture, Wageningen, The Netherlands

Soils and Water Control

S. M. A. BUTT and P. B. A. SALIM, The Central Engineering Authority, Government of Pakistan, Karachi

Soil Characteristics and Salinity in Relation to Irrigation and Drainage

H. M. STAFFORD, Senior Hydraulic Engineer, Water-Resources Division, Geological Survey, United States Department of the Interior, and

M. R. HUBERTY, Professor of Irrigation, University of California, Los Angeles, California, U.S.A.

Soils and Water Control Programmes

F. HELLINGA, Professor, Graduate School of Agriculture, Wageningen, The Netherlands

Soils and Water Control by Reclamation Management

Karel JUVA, Professor at the Technical University, Brno, Czechoslovakia

Recent Developments in Irrigation

Michael W. STRAUS, Commissioner, Bureau of Reclamation, United States Department of the Interior, Washington D.C.

Development of Irrigation in a Semi-Humid Climate: The Ashburton-Lyndhurst Project, New Zealand

J. O. RIDDELL, Irrigation Engineer, Ministry of Works, Christchurch, New Zealand

Some Aspects of Irrigation in Greece

A. KALINSKI, Director of Engineering Division, Ministry of Agriculture, Athens, Greece

Recent Developments in Irrigation in Indonesia

W. F. EYSVOOGEL, Professor, Graduate School of Agriculture, Wageningen, The Netherlands

Development of Irrigation Farms with Special Reference to Irrigation and Crop Production under Desert Conditions as Observed in Saudi Arabia

J. T. SMITH, Superintendent, Hofuf Agriculture Project, Saudi Arabia

Recent Developments in Irrigation in Mexico

Antonio RODRÍGUEZ., *Director General de Aprov. Hidráulicos, Secretaría de Recursos Hidráulicos,* Mexico, D.F.

Irrigation in Pakistan

Khan Bahadur M. A. HAMID, Chief Engineer, Irrigation Secretary, Government of West Punjab, Lahore, Pakistan.

Summary of Discussion:

Discussants:

Messrs. Eysvoogel, Hamid, Huberty, Stafford, Raushenbush, W. R. Nelson, Storie, Straus, Kalinski, Smith, García Quintero, Pavlovic, Sain, Timmons, S. F. Kelly, Aull, MacKenzie, L. A. Jones, Papanicolaou

Programme Officer:

Mr. S. Raushenbush

The Relationship of Soil Characteristics to Irrigation Programmes (Indonesia)

W. F. EYSVOOGEL

ABSTRACT

Outlines are given of the influence of irrigation water on different soils in Java, referring also to the peculiarities of tropical agriculture: rice growing in water, mostly without any use of manure or fertilizers.

The three major soil types: laterite, marl and limestone soils are reviewed in connexion with water of the same or other origin. Experiments for use of water on adjacent plots are described. It seems that the favourable influence of irrigation water and silt on fertility is limited to the first and the second plot.

The experiences in irrigation of marl soils are mentioned and the principles of modern irrigation practice on these soils in Java are pointed out.

Finally the results of experiments in the General Agricultural Experiment Station on the influence of root developments on fertility are mentioned. It is probable that the relatively great depth to which the roots of dry monsoon crops and weeds penetrate, has a favourable influence on the fertility of the soil.

In the tropics the close connexion of the three factors soil-water-plant is one of the major problems in the planning of irrigation works. The irrigation water is practically the only controllable source from which the soil can replenish the constituents that are used by the plant, the other source being the decomposition of minerals by weathering, on which human effort has no influence. Manure and fertilizers are used only on a minor scale. The paddy straw is burned on the field just before water is admitted; of course this brings back only partly what was used in growing the plant. Sometimes a small quantity of manure or compost is brought to the fields, but mostly this is kept at home for the garden.

The use of fertilizers was part of the propaganda of the Department of Agriculture in Indonesia. The difficulty is that the possessor of a property of 1½ or 2 acres is not able to buy the relatively costly chemical fertilizers. Use of these fertilizers therefore means an elaborate system of credit with all the difficulties thereof.

From the point of view of economy green manuring is more advisable. In the last twenty years this kind of manuring is coming into use more and more in Java. In a paper on experiments in green manuring Van de Goor says:

"Green manuring with leguminous crops highly increases the yield of lowland rice, especially on soils lacking in nitrogen."

This means that the older laterites, a very common type of soil in Java, will profit most from green manuring. Yet other soils also will profit. Quoting Van de Goor again:

"It is made evident that the large increases of the yields are not due only to the supply with nitrogen. Also other fertilizing constituents such as phosphoric acid and potassium, which come in a more available form, will contribute to the general results of green manuring."

As will be seen, this is very important for districts where the irrigation water is lacking in nutritious qualities.

Nevertheless in the greater part of Java (and in the other islands of Indonesia where lowland rice is grown) the irrigation water is the only source from which the necessary minerals can be supplied. Strictly speaking, "water" is not an accurate expression, the sediments transported by the irrigation water being the principal source and the dissolved salts occupying second place.

Soils in Java can be classified into three major types: laterite soils, marl soils and limestone soils.

Laterite soils cover the central part of Java and Sumatra. The younger laterites are first class soils, the older laterites are deficient in nitrogen and calcium and to a lesser degree also in phosphorus.

According to Dr. Hardon the clay component of laterite soils mainly consists of kaolinite with or without some montmorillonite. The physical properties are favourable for agriculture.

When headwaters are in laterite soils, rivers supply irrigation water with good, sometimes very good, characteristics: percentage of SiO_2 and phosphoric acid, considerable; potassium and calcium, reasonable; sodium and sulphur content, not dangerous. The water is almost neutral with a tendency to acid. The silt, which is carried in reasonable quantities (200-300 milligrammes dry silt per litre, in flood periods more) has the same good quality.

The influence of irrigation water from lateritic sources on soils is practically always favourable (except in some cases of heavy acidity due to volcanic springs). Well-known is the picture of terraced and dyked rice-fields on the slopes of the volcanos. Here for ages fertility depended only on irrigation. But most things are not as beautiful as they seem to be. The agriculturist often finds phosphor deficiency in the paddy-fields, especially in the plots that get their water not directly but over adjacent plots.

The experiments of Dr. Den Berger in the General Agricultural Experiment Station at Buitenzorg are very enlightening on this subject. He led irrigation water over a row of 13 plots, as is done in the hills of Java. The total acreage was 0.44 hectares (1.1 acre), the quantity of water used: in the dry monsoon 3.4 litres per sec. per hectare (0.05 sec. ft. per acre), in the wet monsoon 2.1 litres per sec. per hectare (0.03 sec. ft. per acre).

In the dry-monsoon-experiments water was supplied during 95 days. In this period 2,718 kg. of silt was brought on the first check, 328 kg. on the second and 45 kg. on the last checks. This means that the first check got 6.29 kg. P_2O_5, the second 0.68 kg., the last 0.17 kg.

During the wet monsoon, when silt percentages are higher, the first check got 9.6 kg. P_2O_5, the second 1.96 kg., the last 0.17 kg.

Harvest on the first check gave four times as much rice as on the last check.

Of course contour-check flooding with 13 checks is a fairly excessive case, but 8 or 10 are quite normal, and it is easy to see that production is not what it could be. Even in this fertile part of the island higher yields could be obstained by the use of fertilizers.

Marl soils are found in the tertiary zone of Java, a broad belt north of the volcano line. They are frequent also in the other islands.

The hills from which the fluvatile marl soils originate consist of mudstones, soft sandstones and soft limestones. The last two are mostly found in ridges, the mudstones fill the greater part of the area.

Marl soils are heavy sticky clays with a percentage of clay (2 micron) of 50 to 60, an upper plastic limit of 60 to 70 and heavy shrinkage and deep cleavage in the dry monsoon period. According to Dr. Hardon the mineral is montmorillonite. The soils are practically always deficient in phosphorus; the physical properties are mostly very unsatisfactory.

The rivers are characterized by heavy floods; dry monsoon river-flow is negligible. Erosion is considerable; in flood the rivers carry large quantities of sediment (up to 6,000 milligrammes of dry silt per litre). The silt fraction of these sediments mostly contains a reasonable quantity of phosphoric acid; the clay fraction is very fine and has a bad influence on soil structure. The percentage of soluble salts is high as regards calcium, potassium, sodium and magnesium; the percentage of phosphoric acid is mostly very small.

When marl soils are irrigated with water of volcanic origin, the soil usually is improved slowly. As an example may be mentioned the left bank area of the *Pemalie* irrigation scheme. The 18,000 hectare area has been irrigated since 1903 with water of first class quality, the Pemalie River having its headwaters on the slopes of the volcano Slamat, which are well-known for their high content of phosphoric acid. An investigation in the year 1925 revealed a definite improvement apparent in the distribution units. This improvement, however, was limited to the fields alongside the irrigation ditches. At that time it amounted to 10 to 15 per cent of the area.

For a real improvement of these soils a far greater length of irrigation ditches is needed than the population thinks necessary for the watering of their paddy-fields. It is very difficult to make this clear to the farmers.

Irrigation of marl soils with water from the tertiary zone is an intricate problem. The population mostly prefers rain-water to irrigation water from the small rivers. The farmers are afraid of the fine clayey particles of the sediments, which tend to seal the surface. With modern irrigation works it should be possible to derive the benefit of the coarse particles of the sediments of the big rivers, these particles having a reasonable phosphor content. But the transport of coarse silt through the ditches is very difficult and the favourable influence is limited to the first checks. On the other hand the damaging influence of the fine particles is felt everywhere. This is the reason that in several irrigation schemes in this region results are not satisfactory.

Diseases (root rot and mentek) and insect enemies (rice borer) are playing a role also. It would take too much space to go into that aspect of the problem.

Metzelaar suggests that the relatively high quantity of Na-ions (100 milligrammes of Na_2O per litre is not unfrequent) leads to Na-clay (alkali damage). Usually salinity damage through irrigation water is not known in the tropics, rainfall being far in excess of evaporation. But the marl soils have a very bad subsoil drainage and leaching with surface-water is usually not very successful. If possible, water with a high percentage of sodium should be left alone.

The modern procedure in marl soil irrigation in Java is the following. Irrigation water for rice-growing is applied as sparingly as possible. Storage-reservoir irrigation is preferred to river-flow irrigation. The quantity of water needed for rice-growing on these heavy soils under tropical rainfall is very small and therefore the greater part of the storage can be used for the growing of dry monsoon crops. Water of watersheds with a high sodium, sulphur or chlorine content is not used. Fertilizing with phosphates promises good results but is usually too costly for soils of poor quality. Green manuring may be a solution because it improves the physical properties and the humus content, which is important for the dry monsoon crops.

Limestone soils cover a smaller part of Java than the other two. Also in the other islands they are of less importance; only the island of Madura is for the greater part built up of limestone. These soils are mostly clays or clay loams without the excessive characteristics of marl soils. The mineral of the clay is, according to Dr. Hardon, metahalloysite.

River water from limestone hills is characterized by a high calcium content. It is advisable to use this water in small quantities because the alkaline character (pH=7,4-7,8) has a tendency to make the extraction of P_2O_5 from the soil more difficult for the plant.

A very interesting view on the water-soil-plant connexion is given by Dr. Kuilman in his paper "Root Development and Fertility".

Dr. Kuilman mentions that the root system of the lowland rice-plant on the average reaches a depth of only 8 in. (max. 10 in.). A field, where rice is growing the year round, may be compared with a large basin, filled with mud, of which the hard layer of soil beneath the mud forms the bottom. In this basin the equation holds

$$I + M = O + B + A$$

wherein I, M, O and A are representing the mineral content of: incoming irrigation water (I), fertilizer (M), harvest (O) and outgoing drainage water (A), while B stands for the quantity of minerals absorbed by the soil.

Dr. Kuilman now points out that of the sum O + B, the factor O may represent a larger proportion than usual when varieties are used that are capable of assimilating more minerals from the soil than the average.

Quoting Kuilman:

"The investigation of many root systems of rice has led the author to the conclusion that the last-mentioned method by which the yield can be raised has a great significance in the case of rice.

"Lowland rice plants with many hair roots show a high degree of resistance to the 'mentek'-disease, while in the case of upland rice such plants show no symptoms of potassium deficiency, even when grown in a potash-deficient soil. It is highly probable that the 'mentek'-disease is caused by potash deficiency and hence the resistance to 'mentek'-disease may be caused by a better absorption of this mineral in consequence of the larger quantity of hair roots. In this connexion it is of interest to note that many of our newer high-producing varieties show a root system with a large mass of hair roots (variety Oentoeng).

"In Java there are many rice-fields, which depend entirely on rain for their water. In this case the term I of the foregoing equation is very small or approaches zero. Then the question arises whether there are factors, which under these circumstances work in the same way as the minerals in the irrigation water and therefore are able to prevent a steady decrease of fertility. In this connexion the root systems of crops and weeds, which grow on these fields after the rice has been harvested, merit close examination. It appeared that the roots of the principal crops in many cases quickly penetrate to great depth in the soil.[1]

"There seems to be reason for the supposition that these crops, under which the *Leguminosae* rank first, assimilate minerals in the deeper layers of the soil and that these minerals are transported by these plants to the upper layers, so increasing the fertility of the soil in which rice is grown."

The foregoing may furnish a supplementary explanation of the favourable influence of green manuring on marl soils and brings a new convincing argument for the growing of dry monsoon crops on these soils, and the building of the storage-reservoirs that are indispensable for this growth.

[1]Kuilman presents pictures of Leguminosae (groundnuts, soybeans, beans, crotalaria) with roots of 4 to 5 ft.

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Soils and Water Control

S. M. A. BUTT and P. B. A. SALIM

This short paper attempts to describe the relationship of soil characteristics to irrigation and drainage, and the effect of water control measures on soils.

By far the largest area under irrigation in Pakistan is in the West Punjab, and, quite appropriately, it is there that research has been carried on into the multifarious problems arising therefrom, for several years past. For the greater part of the material for this paper, we are indebted to the publications of the annual Waterlogging Conferences held during the years, 1933 to 1945. Allied problems are met with in East Bengal, where the rainfall is much heavier and natural waterways more numerous. Unfortunately, no official literature on them was available for this study. In the North-West Frontier Province and Baluchistan, on the other hand, rainfall is scanty and irrigation is so local and restricted that no evil results in the soil have been noticed.

SOILS AND IRRIGATION

Irrigation has been defined as the artificial application of water to lands whenever the rainfall is insufficient to meet the full requirements of crops. The soil acts as a storage reservoir for the moisture used by plants, and on its physical properties depends the availability of the moisture needed for plant growth. The moisture-holding capacities of different types of soil control the amount of water that can be retained from a single application of irrigation water, and this, with the rate at which moisture is used up by the crop, controls the frequency of irrigation required.

CLASSIFICATION OF SOILS

The usual classification of soils is based on the sizes of the soil particles. The U.S. Bureau of Plant Industry Soils and Agricultural Engineering has classified soils as below:

	Diameter in millimetres
Fine gravel or very coarse sand	2.0 to 1.0
Coarse sand	1.0 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.1
Very fine sand	0.1 to 0.05
Silt	0.05 to 0.005
Clay	Less than 0.005

PORE SPACE

All soils contain pore spaces between the soil grains. As these grains are neither spherical nor of uniform size, the pore space varies widely. The proportion of the pore space to the total soil volume varies with the texture of the soil, being larger in soils having a large percentage of silt and clay. Sandy soils have larger individual spaces between the soil grains but the total number of pore spaces and the percentage of the pore spaces to the total volume of the soil are smaller than for fine-textured soils. Under field conditions the pore space of most cultivated soils varies from 35 to 50 per cent of the soil volume. For sandy soils the pore space may be as low as 20 per cent; for some clay soils the pore space may exceed 50 per cent of the soil volume.

SOIL WEIGHTS

The weights of soils vary inversely with their pore spaces. The specific gravity of the mineral matter of the soil is usually from 2.50 to 2.70. With the usual percentage of pore space the apparent specific gravity varies from 1.25 to 1.75. Usual oven-dry weights per cubic foot are 75 to 80 lb. for clay soils, loams 85 to 90 lb., sandy loams 90 to 95 lb. and sands 95 to 105 lb.

VARIATIONS IN SOIL TEXTURE

Much variation occurs in soils both vertically and horizontally. Alluvial soils may vary widely in texture within the same field area. Vertical variations are frequent in arid soils. Such variations may be desirable or harmful depending on their effect on the moisture-holding capacity of the soil. The culturable land in the West Punjab generally consists of soil crust of varying thickness with sand underneath, which, if at sufficient depth, provides drainage for the heavy surface soil.

SOIL MOISTURE

The form in which moisture is distributed and held in soils varies with the amount of moisture present. The smaller amounts are held as a capillary film surrounding the soil grains. As the amount of moisture increases, the surface tension of the moisture film decreases and moisture moves more freely in the soil and is more easily obtained by the plant roots. Such moisture moves relatively freely in the soil under the influence of gravity. Below a certain level, soil layers are saturated with water. This level is the water-table and the sub-surface water which lies below it is ground-water. Soils free to drain will not retain sufficient water to cause saturation. Permanent saturation occurs in soils only where drainage is prevented by impervious soil strata, or by lack of outlet for water applied in excess of the ability of the soil to retain moisture in the form of films surrounding the soil grains.

EFFECT OF IRRIGATION ON SOILS

Although the benefits accruing from irrigation in the West Punjab have been manifold, it has not proved an unmixed blessing. In certain areas the water table has been rising at an alarming rate, ultimately bringing the ground-water so close to the surface permanently that large blocks of land have become unfit for cultivation. The extent of such waterlogged land was reported to be 30,000 acres in 1944 and 43,000 acres in 1945. In very large tracts, salts (locally called "thur") have been appearing on the surface rendering the soil unfit or uneconomical for cultivation. It is estimated that thur land has been increasing steadily at the alarming rate of 20,000 acres per annum. In 1945 the total for such areas covering 7,964 estates stood at the staggering figure of 1.4 million acres. This is 11 per cent of the area of the estates surveyed.

WATERLOGGING—ITS CAUSES AND REMEDIES BY WATER CONTROL

Deep percolation of water steadily over several years into the water table underground gradually brings it nearer and nearer to the surface. This increase in the ground-water is usually derived from the following sources:

1. Stagnant masses of water standing after rainfall because of bad surface drainage.

2. Seepage of water from canals, distributaries and minors. The remedial measures aim at lowering the water table to about 10 ft. below the ground surface. They are:

(*a*) A well-designed system of surface drains to carry off all the surplus water from above the ground and in some cases, from the waterlogged soil also, where the water table has risen very close to the surface. When this work has to be carried out in wet, saturated soil, it entails considerable practical difficulties and expense, but it is the first essential for the reclamation of waterlogged areas. This is being vigorously done in West Punjab, where 1,638 miles of drains were in action in the Chaj and Rachna doabs in 1945 and hundreds of miles of drains were either in hand or were projected.

(*b*) Staunching and lining of channels etc. to make them impervious. In canals which are in use, linings of cement are put in, but cement or lime plaster or bitumen is very expensive. It is comparatively easier to do this work when the channels are under construction. Lining the bed with soil treated with sodium carbonate has proved quite successful.

(*c*) Pumping of water by tube-wells. These are being installed gradually and have given satisfactory results on the whole. The West Punjab Government has lately acquired a factory for the manufacture of tubes, strainers and other appurtenances of tube-wells and are expanding it rapidly. The installation and working of tube-wells will be greatly facilitated by cheap electric power from several hydro-electric projects under construction and/or active investigation by the Pakistan Government. The Central Engineering Authority visualizes the sinking of 70,000 tube-wells in Pakistan within the next fifty years, for de-watering saturated soils, and for expansion of irrigation.

SOIL SALINITY

The appearance of salts at the surface has been under investigation for years. Its causes have been a subject of considerable controversy. Prior to 1934, it was the belief, not only in this country but also in the United States and Hungary, that the water table was the sole source of salts found to accumulate at the surface, and that the upward movement of salt-laden water was caused by evaporation, which concentrated and deposited the salts at the surface. Field observations in the Punjab, however, indicated that this did not explain their formation. It was noted that thur and non-thur soils occurred side by side over water tables similar in composition. This could be explained only by the difference in the salt content of adjacent soils dissolved and brought to the surface by water moving upwards. It was also noticed that thur always appeared in November, and that the characteristic efflorescence remained until about the end of March, when it tended to disappear. As the salts were not found to be present at the surface in greater quantity in winter than in summer, the conclusion drawn was that their visibility depended on hydration, which in turn depends upon temperature and humidity.

Further observations revealed that thur was appearing even on such tracts where the soil-crust was separated from the water table by some 30 ft. of sand, with no possibility of upward flow. In such cases all flow of surplus water would be downwards and should carry down the salts with it. The conclusion drawn was that the water table is not necessarily a factor in influencing the formation of thur. In its downward journey the irrigation water moves so rapidly as to be unable to take up its full charge of dissolved salts. Its subsequent upward movement is, on the other hand, so leisurely that ample opportunity is afforded for it to become fully saturated with salts. While the development of thur can take place independently of the depth of the water table, such development is very greatly accelerated when the water table rises to a level where the abrupt cessation of rise suggests that the water table is being depleted by losses upward to the surface.

RECLAMATION OF THUR-SOILS

The only remedy so far available is periodic leaching. Water flooding such lands dissolves the sodium salts and takes them down with it where they can do no harm. Attention was thus naturally diverted to a crop needing plenty of water, and this is rice. Rice cultivation has been very successful in the reclamation of thur-soils.

Reclamation, however, has its own attendant evils and problems. Obviously it cannot be successfully attempted unless the surplus water required for periodic leaching is available without affecting the normal demands elsewhere. Also very efficient drainage and/or pumping are essential to carry away what is not needed. Even then the danger is that such measures tend to raise the water table, so that increasingly heavy and general applications of leaching water would become necessary. The struggle to keep down the salts would end in failure by reason of the limit which would in practice be set upon the amount of water available for such measures. There is also the possibility that permanent reclamation may lead to accelerated deterioration of adjoining land.

Periodic leaching and rice cultivation impoverish the soil considerably. To restore fertility, it is found necessary to add gypsum to the soil and to follow rice with a leguminous crop. Rotations of crops, balancing various factors, have been worked out and tried successfully.

Soil Characteristics and Salinity in Relation to Irrigation and Drainage

H. M. STAFFORD and M. R. HUBERTY

ABSTRACT

Among the desirable requisites for an irrigated soil are: a deep, permeable profile; a soil structure which will permit good air exchange and a good water-infiltration rate; and a soil texture of sufficient fineness to be of fair water-holding and nutrient-holding capacity.

The nature and solution of the problems in irrigation agriculture associated with the occurrence of salinity in the streams, reservoirs, ground-waters, return water from irrigation, and irrigated soils are exemplified in the experience cited in a few outstanding situations in south-western United States, including Lake Mead and the upper Rio Grande and Pecos river-basins.

The solution of the dual problem of high salt concentrations in irrigation supplies and salt deposition in the irrigated soils requires the application of water in excess of crop requirements. The principles involved, and this and other remedial measures indicated in the case of the Pecos river-basin, are presented.

As another source of salinity, the invasion by sea-water of the half-million acre delta of the Sacramento and San Joaquin Rivers is cited. Two methods of salinity control—one by a physical salt-water barrier and the other by the repelling action of augmented stream-flow—are described; the river discharge required for the latter method (which has been adopted) is indicated; and comparison of the two methods as respecting supplemental water requirements and costs is made.

SOIL CHARACTERISTICS

The great regional soils developed under climatic conditions common to the major irrigated areas of the United States: namely, low total rainfall and warm, dry summers, are generally high in lime. These are the chernozem, brown, and desert soils. The soil profiles contain sufficient lime normally to ensure good structure. Local influences, such as topography and drainage conditions, can directly or indirectly modify the characteristics of a soil so that it does not conform to the great soil grouping (1)[1].

[1]Numbers within parentheses refer to items in the bibliography.

Primary soils (soils formed in place from parent material immediately below) are generally found on rolling to steep topography. They are normally shallow and are often difficult and expensive to irrigate. Specialty crops, such as early vegetables and subtropical fruit, are sometimes produced on these soils. The avocado orchards of southern California are to be found mainly on primary soil, the average depth of which probably does not exceed two feet. Application of water under pressure through sprinklers is a common method in these orchards.

Secondary soils (transported soils) constitute the great bulk of irrigated soils in the United States. Except possibly in the desert areas, the older, secondary soils have, as a result of leaching, a subsoil development normally referred to as the "B" horizon, which can restrict root development and water penetration (2). Measurement of infiltration rates made on some of the older soils showed the surface soil to be as high as 5,500 times more permeable than the "B" horizon. A soil with these characteristics should be excluded from the list of irrigable soils.

The most important irrigated soils are the deep, permeable, recent secondary soils found mainly on alluvial fans and flood plains. Their deep, permeable profile permits the growth of a wide range of crops, and the development of satisfactory irrigation practices.

Soil texture in relation to irrigation. Successful irrigation farming can be found on a range of soils varying from very coarse to extremely fine. Crops like peanuts and sweet potatoes have done well on the sandy soils of the San Joaquin Valley of California, while lemon orchards have been profitable on very gravelly loam soils on alluvial fans of southern California. Generally speaking, the great irrigated orchards are to be found on the medium-textured soils. Fibrous rooted crops do better on very heavy soils than do trees. Rice, where climate permits, is a crop well suited to the highly colloidal basin soils. The large acreage of rice in the Sacramento Valley, California, is on this type of soil. Water-holding capacity and potential soil fertility are largely functions of soil texture.

Moisture properties of soil. When water is applied to the surface of a soil, it moves downward through the action of gravity and capillarity. The rate of movement depends mainly upon the relative size of the pores in the soil (3). Water is retained on the surface of the soil particles and the smaller interstices between the soil particles. If sufficient water is applied to wet a deep, permeable soil to a depth of several feet, the water retained by the soil will be a rather definite quantity (4). The irrigation farmer has become accustomed to the term "field capacity", designating this soil-moisture condition. Under these conditions the moisture in the soil is being held at a tension equal to about 0.1 of an atmosphere (4 ft. of water). Not all this water in the soil is available to the plant, for when the force at which the water is held reaches about 15 atmospheres (500 ft.) the plant is unable to remove water from the soil at a rate sufficient for it to remain turgid (5) (6). These energy relations hold for all soils, but due mainly to differences in extent of root distribution and relation of root-absorbing surface to plant-transpiring conditions, differences in experimental results have been obtained. Although soil texture is a very important factor in determining the quantity of water available to plants which a soil will hold, it is not the only one. In some soils the amount of water available to plants is much greater than in other soils of equal water-holding capacity (5).

Soil structure in relation to irrigation. Soil structure refers to the arrangement of soil particles. Successful irrigation is largely dependent upon good soil structure. When a fine-textured soil is aggregated into groups the size of crumbs or nuts, a desirable structure exists. If, however, the soil particles are separate, the soil is said to be dispersed or puddled. In the former case water penetration and soil aeration are satisfactory; in the latter case conditions are unsatisfactory. Soil structure is largely dependent upon the character of the base ions that are associated with the colloidal fraction of the soil (7) (8) (9) (10) (11) (12). If the base ions are predominately calcium, or magnesium, or both, soil structure will be much better than if sodium or ammonium ions predominate. In fact, if as much as 10 per cent of the bases are sodium, water penetration can be greatly impaired. This is a very important factor when water of high salinity is used. Dispersed soils can result from poor cultural practices such as maintaining too low an organic-matter content in the soil, long continued use of large applications of ammonium sulphate and sodium nitrate fertilizers without occasionally adding gypsum, or the use of unsuitable irrigation water; they can result naturally from the rise of water by capillarity from groundwater close to the soil surface, causing high concentrations of sodium at or near the surface.

SALINITY PROBLEMS AND THEIR SOLUTION

In irrigation agriculture the problems of salinity are directly associated with the sources and occurrence of salinity which may be any one or all of the following: in reservoirs; in the irrigated soils; in the streams (13) (14) (15) as the result of erosion by solution of soluble rocks, soluble mineral matter brought in by sediment, and drainage return from irrigation; and invasion of sea-water. The nature and solution of the problems in various cases of these sources of salinity may be indicated by the experience in a few outstanding situations in south-western United States.

Salinity in Reservoirs—Lake Mead. In surface reservoirs the source of salinity is, of course, from the inflow, from solution of salts along the reservoir bottom and banks, and from water lost by evaporation and transpiration.

Records (of outflow, inflow, and reservoir water) for Lake Mead on the Colorado River behind Hoover Dam show an appreciable increase during storage in the dissolved-solid content of the reservoir water in the early years of storage in this reservoir (16). Some of this increase is the result of evaporation losses, but it is apparent that some of the increase is due to solution of soluble material from the reservoir site. It is likely that the rate of solution will decrease over a period of time because the more easily soluble salts will have been dissolved and some of the deposits will be covered with river sediments and, therefore, not available for the solution processes.

In many reservoirs the mixing process is slow and may be incomplete for long periods. Therefore, there will be stratification within the reservoir, with water of different concentrations at different elevations. In reservoirs which have fixed elevations from which water can be released, there may be a tendency to accumulate in the reservoir, water of increasing concentration. By operation of the outlet valves to withdraw water from the lower elevations, where the concentrations of dissolved solids are highest, and by avoiding excessive "spills" from the reservoir, it will be possible to prevent excessive accumulation of dissolved solids in the lake water.

Salinity in the streams, irrigated soils, and drainage return Upper Rio Grande Basin. In this basin, comprising some 34,000 square miles in the States of Colorado, New Mexico and Texas, drainage from the irrigation of upper lands returns to the river and is rediverted to lower lands, and this process is repeated many times in the length of river valleys from the upper to lower limits of the basin. Also, the major portion of the water-supply reaches the river in the upper portions of the basin with very little contribution from downstream tributaries. Under these conditions, the salt concentration of the downstream irrigation waters becomes increasingly higher.

As determined in connexion with the Rio Grande Joint Investigation (17), total yearly quantities and weighted mean concentrations of salts in the water of Rio Grande passing nine principal gauging stations from the upper to lower reaches of the river are given in Table 1. This table indicates clearly the progressive increase in total salt concentration of the river water from the upper to the lower limits of the basin.

In addition to the irrigation problem introduced by these higher concentrations in the lower reaches, there is the problem of deposition of salts in the soils of the lower lands implied in the condition that there was a decrease in the total tonnage of salts carried, from Elephant Butte Reservoir outlet to Fort Quitman, of 164,000 tons.

and leaching of soluble salts by means of a drain discharging into Rio Grande. It has been proposed that the State of Colorado be permitted to divert from Rio Grande, above the San Luis Valley, a volume of water in return for the drainage water from the Closed Basin. It is known that the shallow water in the Closed Basin is considerably more mineralized than the water of Rio Grande and that some of the waters have a high sodium percentage. Because of the probable poor quality of the water in the drain, there was concern over the possible pollution effect of this drainage on the water of Rio Grande. As a consequence, a quality-of-water provision was made in the Rio Grande Compact (18) which allocates the waters of Rio Grande among the States of Colorado, New Mexico and Texas. This provision states, "In the event any works are constructed after 1937 for the purpose of delivering water into Rio Grande from the Closed Basin, Colorado shall not be credited with the amount of such water delivered, unless the proportion of sodium ions shall be less than forty-five per cent of the total positive ions in that water, when the total dissolved solids in such water exceed 350 parts per million."

Table 1. Totals and Weighted Mean Concentrations of Salts in the Rio Grande in 1936 at Nine Control Stations

Item	*Gauging and sampling stations*								
	Del Norte	*Lobatos*	*Otowi Bridge*	*San Marcial*	*Elephant Butte outlet*	*Leasburg Dam*	*El Paso (Courchesne)*	*Fabens-Tornillo*	*Fort Quitman*
River discharge, in 1,000-acre-ft. units	472	281	1,072	867	747	693	474	224	150
Dissolved solids, in 1,000-ton units	52	74	352	653	590	596	560	433	426
Concentrations:									
Tons per acre-ft.	0.11	0.26	0.33	0.75	0.79	0.86	1.18	1.93	2.84
Conductance ($K \times 10^5$ at 25 degrees C)	8.5	26.5	30.5	79.4	86.3	91.5	129.9	245.2	332.0
Sum, milliequivalents	2.27	5.71	7.49	17.31	17.87	19.23	27.28	44.17	66.27
Constituents, iu 1,000-ton units:									
Calcium (Ca)	7.2	10.6	63.9	88.7	76.3	76.3	63.8	42.1	38.8
Magnesium (Mg)	2.1	2.7	12.2	18.2	15.9	15.5	13.3	10.2	9.3
Sodium (Na)	4.4	8.0	30.2	98.2	90.8	91.1	103.4	87.0	92.5
Bicarbonate (HCO_3)	13.7	18.0	94.1	106.7	82.3	81.0	69.8	38.1	24.8
Sulphate (SO_4)	9.7	18.3	89.8	232.7	232.2	220.7	187.8	121.0	99.3
Chloride (Cl)	2.8	3.9	15.5	66.0	55.4	64.5	91.1	105.3	136.9
Nitrate (NO_3)	.2	—	.9	.8	.1	1.5	2.1	.7	.8

As explained beyond in discussion of the Pecos River Basin, the solution of both of these problems involves the application of irrigation water in sufficient quantities to assure that a given concentration of the soil solution shall not be exceeded, and that a balance between input and output of salts shall be maintained.

A special problem of interest in the upper Rio Grande basin is that relating to drainage of the "Closed Basin", comprising 2,940 square miles to the northeast of Rio Grande in the San Luis Valley in the State of Colorado. There is no visible drainage from this basin and accumulated inflow has caused a raising of the water table; evaporation and transpiration have caused an increase in the concentration of dissolved solids in the water and deposition of salts in some sections of the area.

Consideration has been given to the recovery of land for agricultural use through lowering of the water table

Pecos River Basin. In the Pecos River Basin, comprising about 35,000 square miles in the States of New Mexico and Texas, the problems of salinity associated with irrigation water-supplies are probably more accentuated than in any other basin of comparable size in the United States. The primary source of salinity is directly related to the geology of the basin—to the erosion by solution of extensive underlying stratifications of soluble rock.

As determined in connexion with the Pecos River Joint Investigation (19), the total quantities and weighted mean concentrations of salts in the water of Pecos River passing 14 gauging stations from the upper to lower sub-basins are given in Table 2. As on the Rio Grande, the progressively increasing concentrations in downstream order resulting from drainage return from irrigation are indicated in this table. Not shown in the case of the Rio Grande, however, are the relatively large increases in total salts which, in

Table 2. Totals and Weighted Mean Concentrations of Salts in the Pecos River in the year ending 30 September 1940, at 14 Gauging Stations

Item	*Gauging and sampling station*													
	Santa Rosa	*Puerto de Luna*	*Guadalupe*	*Acme*	*Artesia*	*Avalon*	*Carlsbad*	*Malaga*	*Pierce Canyon crossing*	*Red Bluff*	*Orla*	*Pecos*	*Grandfalls*	*Girvin*
River discharge, in 1,000-acre-ft. units	64.4	115.5	178.6	126.9	181.1	126.3	52.2	89.8	94.4	98.3	110.2	63.1	38.4	51.8
Dissolved solids, in 1,000-ton units	48.3	258.0	344.0	335.0	716.0	596.0	214.4	493.0	647.0	687.0	840.0	511.0	476.0	779.0
Concentrations:														
Parts per million	542	1,642	1,416	1,933	2,910	3,440	3,020	4,030	5,030	5,120	5,640	5,950	9,110	11,050
Tons per acre-ft.	0.74	2.23	1.93	2.63	3.96	4.68	4.11	5.48	6.84	6.96	7.67	8.09	12.4	15.0
Conductance ($K \times 10^5$ at 25 degrees C.)	67.1	196	177	239	383	445	404	550	720	734	786	839	1,284	1,558
Constituent concentrations, in parts per million:														
Calcium (Ca)	118	366	309	391	436	533	420	488	497	496	592	618	725	737
Magnesium (Mg)	17	52	46	61	114	127	143	179	192	190	200	224	308	392
Sodium and potassium (Na-K)	—	64	61	122	362	408	363	610	965	1,004	1,066	1,134	2,051	2,629
Bicarbonate (HCO_3)	—	119	109	108	128	104	144	141	138	131	121	121	168	154
Sulphate (SO_4)	259	993	855	1,120	1,365	1,687	1,415	1,688	1,761	1,768	2,019	2,105	2,670	3,060
Chloride (Cl)	10	86	72	164	544	626	584	976	1,529	1,578	1,668	1,849	3,240	4,130
Nitrate (NO_3)	—	2	2	2	3	2	3	4	3	3	2	2	3	1
Per cent sodium	—	11	12	18	33	32	32	40	51	52	50	50	59	62

the Pecos River, represent the inflow of very highly concentrated ground waters resulting from erosion by solution. Thus, in the "Malaga Bend" section between the Malaga and Pierce Canyon Crossing gauges, the marked increase of 154,000 tons of dissolved solids with an increase of only 4,600 acre-ft. in river discharge is caused almost entirely by the inflow of very highly concentrated spring and seep waters. Test wells put down to depths of about 300 ft. in this section encountered highly concentrated waters overlying beds of salt. These brines are under sufficient head to flow into the river, and many analyses of the springs and seeps showed concentrations ranging up to 270 tons per acre-foot or more, predominantly sodium chloride.

With respect to the deposition of salts from the irrigation waters, the magnitude of the problem in the case of the lands of the Carlsbad Reclamation Project, for example, is indicated in Table 2 by the difference of 317,000 tons of salts between input, represented by the total load at Avalon, and output, represented by the increase in total load from Carlsbad to Malaga.

As information essential to any solution of the salinity problem in the Pecos River Basin, investigation was made to determine the concentration and composition of the soil solution in irrigated soils locally associated with the limits of tolerance (20) of the major agricultural crops of irrigation units in the middle and lower river valleys (21). In determining crop tolerances, the plant reactions were referred to the concentrations of saturated soil solution extracts as measured by specific electrical conductance. In relation to field conditions, therefore, the concentrations of the soil solution in the root zone would be from two to nearly four times higher than the concentrations of the saturated soil solution extracts, in accordance with the range in volume of the soil solution from field capacity to the wilting point.

The evidence of the field observations and soil analyses showed that in situations where the concentration of the saturated soil solution extracts, as measured by conductance, ranged below 400, there was little or no evidence of salt injury to any crop. In situations where the conductance ranged from 400 to 800, the less-tolerant crop plants did not thrive and the choice of crops was limited to those of the more salt-tolerant group, such as cotton, sugar-beets, alfalfa and some of the grasses, and to cereals including the sorghums. These salt-tolerant crops were grown, but seldom thrived or yielded well, in situations where the extract conductances ranged from 800 to 1500. Where the conductances ranged above 1500, plant growth was limited to a few species of salt-tolerant grasses, succulents, shrubs and trees.

Based on these findings with respect to the salt-tolerance of the irrigated crops as grown under the various conditions existing in the Texas districts from Red Bluff to Girvin, it was concluded that an average soil solution concentration of not to exceed 24 tons of salt per acre-foot would best represent the condition required to be maintained in these districts to assure a reasonable minimum of crop damage as the result of salinity. The determination, then, of the additional water requirements to assure that, under conditions of adequate subsoil drainage, this concentration would not be exceeded, was made by solving the simple equation which is developed from the following consideration of soil salinity—water input relations.

In the prevention of salt accumulation in the root zone of the soil, an essential other than good drainage is that enough irrigation water be applied, not only to supply the consumptive requirements of the crop and unavoidable losses from surface evaporation, but also to leach the root zone and remove the residual salt left from plant transpiration and evaporation. Since the plants absorb a negligible amount only of the salt contained in the soil solution, it follows that with increasing concentration of salts in the irrigation water, an increasing proportion of that water will be required to accomplish the root-zone leaching. The application of this principle may be illustrated by the following specific example: Let it be assumed that the consumptive requirement of the crop is 2 acre-ft. per acre; that the concentration of the irrigation water is 8 tons of salt per acre-ft.; and that it is desired that the average concentration of the root-zone soil solution shall not exceed 24 tons per acre-ft. Let X represent the additional amount of irrigation water required per acre. If there is to be no accumulation of salt in the root zone, the total amount of salt leached out must equal the total of the input. Hence, $8(2 + X) = 24X$, and $X = 1$ acre-ft. per acre. The total quantity of irrigation water to be applied is, therefore, 3 acre-ft. per acre.

Remedial Measures: Other than the application of irrigation water in quantities sufficient to maintain the salt balance and tolerable soil-solution concentrations, measures to remedy or ameliorate the conditions of salinity in the Pecos River Valley were indicated to include:

(1) Reduction of the river's salt load by

- (*a*) Watershed conservation to accomplish erosion control and a corresponding lessening of the salt-carrying silt load which enters the river;
- (*b*) Diversion and disposal of small volume inflows to the river of highly concentrated waters. In the case of the concentrated salt brine inflow in the Malaga Bend section, previously mentioned, the investigation indicated that an annual inflow of 120,000 tons of salt might feasibly be prevented by pumping the heavy saturated brine from the base of the alluvial fill or from the base of the Rustler formation to nearby depressions where the water would be evaporated and the salt precipitated.

(2) Changes in points of river diversion from lower to higher locations in order to utilize only the upper, less concentrated, water.

(3) Provision for adequate root-zone and subsoil drainage.

(4) Adjustments to utilize the best lands in situations where, because of salt accumulations and lack of drainage, irrigated lands have become unproductive or have never produced well, and there are adjacent good lands that have not been irrigated.

(5) Addition of gypsum to soil or water to improve structure of soils containing high percentage of sodium on the soil colloids.

Invasion of sea water

Sacramento-San Joaquin Delta. In the delta of the Sacramento and San Joaquin Rivers in California, the salinity problem is that engendered by invasion of saline waters from the ocean and San Francisco Bay in years when the stream-flow is insufficient to repel these waters. The delta, comprising an area of nearly half a million acres, is largely at or below sea-level, and is traversed by the multitude of deltaic channels through which the rivers discharge their waters to Suisun, San Pablo and San Francisco Bays. Water for the irrigation of some 350,000 acres of crops such as asparagus, corn, potatoes, sugar-beets, beans, celery, pears, peaches, alfalfa, wheat and barley is withdrawn from the many channels over or through the levees by countless numbers of culverts or flood-gates, syphons and pumps.

The extent of the salinity invasion has varied from year to year roughly in inverse relation to the summer inflow of the rivers. Thus, the extremely dry season of 1930-1931 resulted in an unprecedented invasion such that at the time of its maximum extent, about 70 per cent of the delta experienced salinity in excess of 100 parts of chloride per 100,000 parts of water, or greater than a concentration found to be toxic to the average plant and objectionable for human consumption.

Control of Salinity

As a means of controlling the salinity, two methods were investigated by the Division of Water Resources of the State of California. One method is to provide a physical barrier to obstruct the entrance of salt water into the upper bay and delta, and reports covering both the physical and economic aspects of such a salt water barrier have been published (22) (23). The other method, described in a separate report (24), is to control and prevent saline invasion into the delta by means of stream-flow.

As the basis for employment of the latter method, investigation was directed to determination of the basic factors governing the salinity invasion, to wit: stream-flow into the delta and its relation to salinity; consumptive use of water in the delta; tidal action and its relation to salinity.

From the relationships developed it was established that (*a*) the net stream-flow required to prevent the invasion of salinity depends upon the location at which control is sought and the degree of salinity desired to be controlled at the particular location; (*b*) in order to prevent advance of salinity, the basic essential of control is the provision of a net stream-flow downstream equal in magnitude to the amount of tidal diffusion; (*c*) if the net stream-flow downstream past any particular channel section is equal to the amount of tidal diffusion for any particular degree of salinity, its repelling action will counteract tidal diffusion and prevent any further advance of salinity; (*d*) the primary requirement for prevention of invasion into the delta is the furnishing of a sufficient water-supply into the delta to fully satisfy the consumptive demands for all purposes therein; and (*e*) after this primary requirement is met, an additional supply flowing into Suisun Bay is required to repel tidal action and the tidal diffusion of salinity resulting therefrom.

For the control of salinity at the lower extremity of the delta to a degree of not more than 100 parts of chloride per 100,000, it was established that the required flow in the combined channels of the Sacramento and San Joaquin rivers passing into Suisun Bay should be not less than 3,300 second-ft.

The consumptive use of water in the delta by crops, other vegetation, and evaporation was found to vary from a minimum in midwinter of 800 acre-ft. per day, or 400 second-ft., to a maximum in midsummer of 7,400 acre-ft. per day, or 3,700 second-ft. Hence, the total gross flow into the delta required to meet the combined demands of consumptive use and salinity control was indicated to vary from a minimum of 3,700 second-ft. in mid-winter to a maximum of 7,000 second-ft. in mid-summer.

After exhaustive analyses and comparison of the relative merits of these alternate methods of salinity control—the one by stream-flow and the other by a salt-water barrier located at any one of several sites in the upper bays which were investigated—the control by stream-flow was adopted and became an integral part of the Central Valley Project. As provided under that project, the supplemental water-supplies required for salinity control will be furnished from mountain storage reservoirs.

In the comparison of the two methods it is of interest to note:

(*a*) That because of the substantial quantities of fresh water required for barrier operation (navigation lockage, flushing and leakage losses) and for evaporation and transpiration from a barrier lake, the average annual supplemental water requirements for salinity control without a barrier were indicated to exceed those for control with a barrier by not more than 279,000 acre-ft. in the case of a barrier at the upper and of Suisun Bay, and 148,000 acre-ft. in the case of a barrier at the lower end of San Pablo Bay.

(*b*) That a plan of salinity control by stream-flow without a barrier and providing conduits from the delta to serve the fresh-water demands of the upper bay area, could be consummated for a capital and annual cost of less than half that required for a plan of equivalent scope and service with a barrier.

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Soils and Water Control Programmes

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ABSTRACT

Of the cultivated area in the Netherlands about 55 per cent (the polder districts) lies below the level of the sea or of adjacent rivers. This calls for control of the open water table in the polders. In ascertaining the proper water-marks it is possible to control soil-moisture conditions and to influence the yields of the crops. The height of the water-mark depends on soil conditions, the level of the land and the type of farming.

Arable land consisting of sea silt is provided with tile-drainage. Ditches and canals carry excessive water to the pumping stations. The climatic conditions of the Netherlands require a drainage capacity of ten to fourteen millimetres per twenty-four hours. Expenses for installing this capacity amount to \$ 375 to \$ 575 per hectare, including pumping-stations, canals, some bridges, tile-drainage etc. Working costs amount to four to seven dollars per hectare.

In some polders with sandy soils, infiltration is applied with three to five millimetres per twenty-four hours. Large areas are reclaimed from the sea. Reclamation starts with intensive draining. In two to three years the soil is fit for normal cultivation. The soils inundated during the war with salt water were restored by drainage and the application of gypsum (3,000 to 8,000 kg. per hectare).

1. Of the cultivated area of the Netherlands about 55 per cent or 1,300,000 hectares (3,200,000 acres) is below sea level or lower than the water-level of adjacent rivers or streams. Dykes are necessary to prevent inundation of this extremely flat country. An extensive system of ditches and larger canals carries the excess water to sluices or pumping-stations, which in large numbers discharge the water into the rivers or the sea. In addition about 300,000 to 400,000 hectares (750,000 to 1 million acres) are provided with tile-drainage. But for all these drainage works, the water table in less than a year would approach and rise above the surface of the lands, and agriculture would become impossible. The close relation between agricultural utilization of the land and the water in the soil and ditches calls for control of the level of the water table.

2. As the yields of crops depend mainly on ground-water conditions, the necessity of controlling the water table can be put to advantage. Some examples of the marked influence of the depth of the water table on the crops are shown in Table 1.

In coarse sandy soils the water table nearly equals the water-level in the ditches surrounding the fields owing to the high permeability of the sand. Both tables rise and fall simultaneously. As the water content above the capillary zone is low, the water-level has to be kept rather high to prevent wilting in periods of intensive transpiration.

In clay of good structure (the mutual arrangement of soil particles) the ground-water table is falling when transpiration of the crops intensifies. Supply from the ditches is impeded, or even does not take place, because the water-saturated, deeper layers of the soil, especially below the open water-level, are impervious to sufficient water-movement. Wilting of the crops does not occur since enough water is stored in the crumbs of a soil of good structure.

On arable land a proper structure is obtained to a sufficient depth by maintaining the open water-level at about 0.90 to 1.20 metres below the land-level. For pastures a higher water table is maintained, especially on peaty soils, because the root-systems of grasses are less developed. For these soils the water-level in the ditches during the growing season differs from the water-level in winter. During the growing season the water is kept at a high level to promote as far as possible the infiltration of more water from the ditches into the soil. In winter it is kept 0.10 to 0.20 metres lower to obtain good drainage, which means early growth in spring. Peaty soils are subject to shrinkage, oxydation and subsidence. Due to these factors the determination of the proper height of the water table is often very complicated.

In this low country on most soils ground-water and soil-water conditions are controlled successfully by ascertaining the proper height of the water-level in the ditches. Figure 1 shows the close relationship between the height and the prices of arable land in a sea-silt district. This

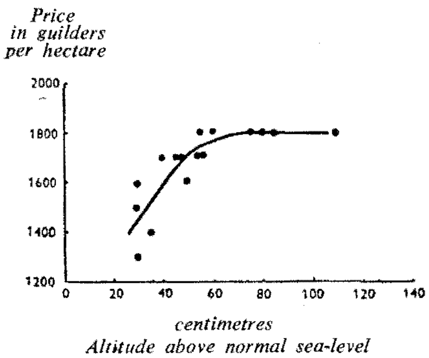
Table 1. Influence of the Depth of the Water Table on the Yield of Different Crops

Crop	*Barley*		*Wheat*		*Grass*		*Tulips*	
Soil	*Heavy sea-silt*		*Heavy sea-silt*		*dune sand*		*dune sand*	
	I	II	I	II	I	II	I	II
I: Depth of the water table in cm.	40	33.2	40	33.8	± 40	86	50	100
	60	39.5	60	41.9	± 55	70	60	92.5
II: Yield in kg.	90	42.1	90	43.7	± 70	57	70	81
per are (1 acre = 40.5 are)	120	43.0	120	43.7	>100	39	80	73.5
III: Ratio (max. = 100)	150	43.4	150	42.6				
Literature cited	(2)*		(2)		(6)		(1)	

*Numbers within parentheses refer to items in the bibliography.

relation depends for the greater part on those qualities, which become more favourable when the altitude above water-level increases.

Figure 1. Relation between Prices of Arable Land in a Sea-Silt District and the Altitude of the Land (5)



3. In districts where the country is very flat and the use of the land uniform (arable land or grassland or horticulture) it is possible to establish one water-mark for a large area. In districts or polders, where differences occur in soil types, in altitude or in use of the lands, the determination of the proper height of the water-mark is sometimes very difficult. In such a case the area has to be divided in a number of polders each with its own water-mark. Another method involves the separation of the low parts of a polder from the rest. These parts are given a lower water-mark, which is maintained by a small windmill or a pumping-station. In addition, higher parts are separated from the main area of the polder and their water is discharged over weirs.

Table 1 shows the importance of carrying through the division of a polder into a main part and lower parts if the desired water-levels differ by more than 0.20 to 0.50 metres. Polders are 100 to 5,000 hectares (250 to 12,500 acres) or more in size. In coastal areas their marks differ from 6 to 1 metres below normal sea-level, and in the districts further inland along the rivers, from 1 metre below this level to 8 metres above sea-level.

4. The optimum height of the water table with its favourable and decisive effect on plant growth is disturbed by rainfall, transpiration and evaporation.

With fluctuations from 600 to 1,000 mm. (24 to 40 in.) the annual rainfall amounts to 700 to 750 mm. (27.5 to 30 in.) with the following distribution over the different months of the year (in millimetres): January, 55; February, 40; March, 45; April, 45; May, 50; June, 60; July, 70; August, 75; September, 70; October, 75; November, 65; and December, 65.

Evaporation and transpiration total about 400 to 500 mm. (16 to 20 in.) per annum, with the following average distribution (in millimetres) for land with different crops: January, 4; February, 8; March, 16; April, 38; May, 67; June, 102; July, 106; August, 72; September, 40; October, 17; November, 7; and December, 4.

The intensity of rainfall is shown in Table 2.

Table 2. Intensity of Rainfall in Millimetres per 24 hours

In 25 years	1x		25x	
Periods of 10 days	13	(9)	7	(7)
Periods of 5 days	20	(14)	11	(11)
In one day	75	(38)	30	(30)

The data between brackets refer to the intensity during the months from October till March. In this period drainage plays its part. In spring and summer the rain-water is retained in the soil and fills up the pore spaces where water was lost by evaporation and transpiration. Unless an upward ground-water movement occurs, drainage during spring and summer is rare.

For short periods the intensity of rainfall amounts to ± 10 mm. (8) per 8 minutes, and ± 19 mm. (14) per 60 minutes (the intensity for October to March is in brackets). Transpiration varies under favourable conditions from 3 to 7 mm. per 24 hours.

5. Under ordinary conditions surface run-off is negligible and all the rain-water penetrates into the soil. When run-off occurs in the Netherlands, it is practically certain that the non-capillary pore space of the soil is too small or that impervious layers are present in the upper layers of the soil. Such soils are incapable of normal production not only because of their small infiltration capacity, but also for several other reasons, i.e., air deficiency for the roots and susceptibility to diseases.

After penetrating the soil the rain-water moves under the action of gravity through the non-capillary spaces, worm-tracks and so on, and joins the ground-water. The water table rises, which means less favourable conditions for plant growth. At the same time the water starts to flow from the water table to the open water, the level of which did not rise as much. The more effective this drainage is, the sooner conditions for plant growth again become normal. The time required for drainage depends upon the permeability of the soil, the thickness of the pervious layers and the distance between the water carriers (ditches or tile drains). According to W. C. Visser the yield of potatoes on sea-silt is reduced by 10 to 20 per cent if the yearly fluctuation of the water table is doubled owing to bad drainage conditions (5). In the North-East Polder (the second polder reclaimed in the former Zuyder Zee) a marked difference was experienced in the drainage of fine-textured sandy soils and loam. In fine sand the small proportion of non-capillary pores permits only a slow movement of excess water. Loam forms, after reclamation and drying up, however, a loose structure of crumbs with many cracks and other large pore spaces. Consequently this loam has a relatively high permeability, so that here larger intervals between the drains will suffice. The chosen intervals between the drains in the North-East Polder are considered to be right, when in periods of an average rainfall of 10 mm. (0.4 in.) a day the water table does not rise up to 0.40 metres (1.3 ft.) below the surface. Table 3 illustrates the effect of different intervals on two types of soil.

Table 3. Average Depth of Water Table on Two Types of Soil in the North-East Polder during a Period with an Average Rainfall of 9 mm. per 24 hours (4)

Light sandy soil		*Loam*	
Distance of open drains (in metres)	*Depth water table (in cm.)*	*Distance of drains (in metres)*	*Depth water table (in cm.)*
4	47	18	45
6	22	24	40
8	7		

In Table 4 the effect of drainage conditions on the crop is shown.

Table 4. Relation between Yield of Wheat and Drainage Conditions on a Trial Plot in the North-East Polder (4)

Intervals of open drains (in metres)	*Average depth water table in preceding February (in centimetres)*	*Yield of wheat grains (in kg. per hectare)*
8	33	2,988
10	25	2,586
12	19	1,818
16	14	1,417

In the North-East Polder drainage is started with small open drains (trenches). At a later stage of the reclamation when the soil has obtained a more permanent structure tile drainage is substituted for this open drainage.

6. Projects of draining work are carried out either by hand or by machinery. Tile drains are laid in trenches 0.60 to 1.00 metres deep. The drain pipes are laid down very carefully, in a straight line to permit in the future the use of tools for cleaning up silted drains without digging up. About 430 man-hours are required for 1,000 metres of drain pipes (131 man-hours per 1,000 ft.). At present pipes cost 170 to 255 guilders per 1,000 metres ($19.50 to $20.00 per 1,000 ft.). With draining machinery established methods are applied. Up to the present the use of a very big trench-plough has proved most efficient. The working cost of this plough is about 20 to 30 guilders per hectare ($3.00 to $4.50 per acre). In applying this method the number of man-hours is reduced by approximately 50 per cent.

A proper detail drainage of the fields is only possible if a proper general drainage of the polder-district is operative. Experience has shown that with a drainage capacity of 10 to 14 mm. per 24 hours (0.4 to 0.6 in. per 24 hours or 1.2 to 1.6 litres per second per hectare) excessive rain-water can be carried off without detrimental effect upon land utilization. In this flat country there is no need to take the run-off of surrounding districts into account. Owing to seepage for some low polders with pervious subsoil the drainage-capacity must be raised. The expenses incurred by the establishment of an adequate drainage-capacity amount to 1,000 to 1,500 guilders per hectare ($150 to $230 per acre) which include the cost of a pumping-station, canals and ditches, also the cost of some bridges and culverts, and tile-drainage. The working cost amounts to 10 to 20 guilders per hectare ($1.50 to $3 per acre) per annum. If the drainage-capacity is raised proportionally heavier expenses will be incurred, but only a slight increase of yields will be attained. If a lower capacity is chosen, the result will be a considerable decline in yields of crops.

7. Carrying through a too intensive drainage down to low water-marks can reverse the advantage of controlling excess water into desiccation. This happens when the land in the polder consists of sandy soils or soils with a thin (less than 70 cm.) upper layer of clay or loam on a sandy sub-soil. In these cases a well-chosen water-mark is required near the top of the sandy layer. Sometimes it is of great importance to infiltrate the soil to the extent of supplying the crop with 3 to 5 mm. of water per twenty-four hours (0.12 to 0.2 in. per twenty-four hours or 0.35 to 0.6 litres per sec./hectare) during periods of heavy transpiration. This can be done successfully when the sub-soil is provided with tile drains to conduct the water from the ditches into the fields and the permeability of this sandy sub-soil is adequate for the purpose. Under such conditions it is even possible to lay out rather good pastures on light soils.

8. Large parts of the Netherlands have been reclaimed from the sea (since 1500 about 350,000 hectares or nearly 900,000 acres). They were enclosed and when pumped dry produced saline soils. Climatic conditions in the Netherlands permit the reliance upon the leaching of the salt by water from rains in the autumn and winter months. For the purpose a low water-mark must be maintained in the canals and ditches, which have to be dug immediately after the water has been pumped out. The detail drainage of the fields is accomplished by small trenches. Crops (barley, alfalfa, clover etc.) can be grown as soon as the salt-content of the soil water has become less than 3 to 8 grammes of salt per litre.

A normal utilization of the land has to be postponed, however, until the harmful effect of the salt on the structure of the soil has been neutralized. This effect becomes apparent when the salt is leached from the soil. The sodium-clay is sticky and pasty under wet conditions and dries up like bricks in dry periods. Recently reclaimed marine soils contain sufficient lime to displace the sodium by calcium within a period of two to three years. A favourable effect is had by the growing of a crop, which protects the soil against the impact of the rainfall; the roots contribute to the attainment of a good structure. Tillage must be restricted to shallow ploughing or disking.

The malicious inundation with sea-water of nearly 70,000 hectares (170,000 acres) of land under cultivation by the enemy in 1944 and 1945 necessitated solving the same problems. Rehabilitation started with an intensive drainage. In most districts after the first winter the soil moisture was freed from salt. The deterioration of the structure, however, was disastrous. This effect means a heavy blow to farmers as they wanted to crop their land again. The reclamation of these soils was promoted by dressings of gypsum ($Ca\ SO_4$) in quantities varying from 3,000 to 8,000 kg. per hectare (1,200 to 3,200 kg. per acre).

On trial plots the ameliorating effect of gypsum was conspicuous as is shown in Tables 5 and 6.

Table 5. The Effect of 12 tons of Gypsum on the Yield of Oats on a Soil containing 30 per cent Particles $< 16\ \mu$, 1.6 per cent Organic Matter and 3.4 per cent $CaCO_3$ (9)

Yield (in kg.)	*0 ton gypsum*	*12 ton gypsum*
Grains	3,700	4,200
Straw	4,600	5,300

Table 6. Cations Adsorbed at 100 grammes Colloidal Complex of a Saline Soil with 19 per cent Particles $< 2\ \mu$, 1.7 per cent Organic Matter and 5.7 per cent $CaCO_3$ (7), (8)

Adsorbed at 100 grammes colloidal complex in mill. aeq.	*Ca*	*Mg*	*K*	*Na*
2 years without gypsum	44.8	13.6	2.9	4.2
2 years after a dressing of 3.6 ton gypsum per hectare	53.2	11.8	2.6	0.9
2 years after a dressing of 18 ton gypsum per hectare	56.2	9.9	2.6	1.0

The cost of applying gypsum amounts to about 30 guilders per ton.

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Soils and Water Control by Reclamation Management

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ABSTRACT

Among the fundamental natural resources are soil and water, both of particular importance in agriculture. These two resources must therefore be conserved by various well-considered and well-executed measures, which as a whole constitute reclamation management. In principle, two problems have to be solved: namely, the regulation of the entire water circulation on the one hand, and the regulation of the water regime of the soil on the other hand. The basis of regulating water circulation is provided by the underground and surface accumulations of the surplus of precipitations on which depends the regulation of water currents for various uses, especially for their use in agriculture. The water regime of the soil is regulated either by agricultural-biological means (the so-called dry farming methods), or by the reclamation of the soil itself according to the requirements of drainage, irrigation or cultivation. All these measures form the complicated entity of reclamation management, a problem which has to be solved in each country by an individual and systematic reclamation plan. The plan has to be based on detailed research work and experimentation in order to determine the requirements of the country with respect to its water economy and its agricultural production.

Reclamation management is one of the most important problems of every country, because it has a decisive influence upon the country's agricultural production and hence its food supply and agricultural exports. Reclamation management is therefore of international importance and requires the creation of an international organization for reclamation, which would unite all scientific workers and institutions in this branch of study, and would organize research work in reclamation on an international basis. The Economic and Social Council of the United Nations is the competent body to create this organization and thus to make possible a systematic conservation of the soil and waters in all civilized countries of the world.

Soils and water are the basic sources of life and energy. This is chiefly apparent in agricultural activity which through the intermediary of soil and water transforms the thermic energy of the sun into organic matter in the form of plants serving as food for man and animal. In the totality of natural resources, soil and water are therefore of outstanding importance, a fact which has been recognized by the most ancient of human cultures.

It is the task of agriculture to maintain a careful continuing relationship between the soil and the water so that one of these two elements does not interfere to the detriment of the other. It is necessary to supply arable soil with a sufficient quantity of rain-water and at the same time to avoid floods which could damage the soil. Similarly, water erosion must be guarded against as well as excessive moistening of the soil and its depreciation by drought. All these favourable conditions are rarely encountered in nature and it is therefore necessary to improve existing conditions by various measures. The most effective and hence the most important measures are those which protect both soil and water resources and improve them either permanently or at least for a long period of time. The method used is known as reclamation or amelioration and its systematic application is called reclamation management.

Reclamation management was already known in ancient times in Egypt, Babylon, India, China and other countries. Immense works were constructed for the purposes of river control and irrigation in these ancient states which could boast of a very high development of agriculture. During the Middle Ages this type of enterprise was in abeyance and many of the previously erected works disappeared. Then in the nineteenth century reclamation management revived and has been considerably developed in the present century. Today reclamation management is organized in every advanced State and is recognized as a concern of the international community.

Two principal hydrological conditions that are disadvantageous to the water economy in agriculture require organized reclamation management in difficult countries and States. These are the irregularity in the quantity and the occurrence of precipitation and, as a consequence, the sudden changes in water circulation, especially with respect to the flow of rivers. These irregularities are a result of the influence of regional and local climate, the geological structure of the area, the formation of the surface and hydrological and biological conditions which if uncontrolled can produce flooded and eroded soils, marshes or steppes, deserts and the like.

There are various kinds of controls which protect soil and water from the consequences of natural hydrological conditions. But if the controls are to be effective and advantageous, they must be planned and executed according to a given programme. Thus conceived, reclamation management has to solve the following two major problems:

...regulation of the entire water circulation so as to offset the irregularity of rainfall in incidence and in ...and to avoid the sudden changes in the occurrence ...off of water—changes that produce damage either ...d or erosion during periods of high water or by ...iency of water during periods of drought;

2. The regulation of the hydrological conditions of the soils in so far as these conditions lead to wet, dry or otherwise depreciated soils.

The regulation of water circulation is based upon the ac...ation of surplus precipitation so that the irregular ...ty of rains is balanced and the river-flow equalized ...ducing the high waters and increasing the water- ...during periods of drought. In principle there are two kinds of accumulation, namely underground accumulation and surface accumulation, referring to water retained in the soil and surface-water. Very favourable conditions for the creation of both kinds of accumulation are offered by mountainous regions which, as a rule, have a surplus of precipitation and thus can transfer most of the surplus to lowland regions which are much better adapted to agriculture but are often deficient in rain. However, the retention capacity of lowland regions, i.e., the amount of surface and underground water the soil is capable of retaining, may also be improved by various methods.

The underground accumulation is the supply of water in the soil that is created by the percolation of rain and ...w-water and retained in the soil. So important is this underground water for the nutrition of plants and other purposes that it is absolutely necessary to further its accumulation by all possible means, to facilitate percolation and at the same time to prevent surface run-off and erosion. Among the biological means of furthering underground accumulation, the most effective for sloping and mountainous terrain is reafforestation by continuous stands of forest or at least by zones of shelter forest. An equally effective method is the growing of grasses on properly-managed mountain meadows and pastures. On sloping fields percolation is induced and erosion resisted by contour cultivation and strip-cropping, and in lowlands, by ploughing the fields in the autumn, loosening the soil, manuring etc.

From the technical point of view, such different means as absorption ditches and coffer-dams, and terracing sloping fields, controlling torrents and preventing land-slips and gullies, serve either to retain the run-off of rain-water or to protect the soil from erosion. An advantageous combination of these relatively simple means is a considerable inducement to the accumulation of underground waters which, when rain is lacking, increase the flow of rivers and protect the soil of lowlands from aridity.

The question of surface accumulation must be considered in conjunction with the regulation of surface waters collected in torrents, brooks, rivers and standing waters. Lakes, ponds and river dams are natural water reservoirs. They should not be done away with without reason; on the contrary they should be kept in the best working order, renovated and if necessary, new ones should be built. Complementary to natural reservoirs are artificial water reservoirs such as weir dams and smaller reservoirs, and especially barrages which, if very deep, often retain immense quantities of water in a comparatively small space. All these means of retaining water are important not only for containing high water and regulating the flow of rivers, but also for stabilizing underground water in the neighbouring soils, for increasing the moisture in the air and promoting the formation of dew, and chiefly for producing a supply of water for a number of purposes, especially for irrigation, water-power, shipping and general water-supply.

The regulation of flowing water must be considered and carried out in accordance with the hydrological, biological and economic conditions of the region so that these conditions will not be unfavourably affected or even made worse; on the contrary they should become more advantageous and should be improved as far as possible. It is from this point of view that the system of regulation and its technical execution should be chosen and the over-all utilization of rivers and river systems should be considered. The general rule is that the upper course of a river should serve retention, supply and energy purposes, whereas the regulated lower course should effect a harmless removal of waters and at the same time use them for the purposes of agriculture, shipping, water-power, general water supply, fisheries etc. This useful connexion between mountain and lowland river-basins requires that the water-courses be regulated constantly and systematically along their entire length and even within the entire river-basin, for partial regulation can worsen the conditions of flow and at times assist rivers to become torrents.

Particular attention should be paid to the regulation of lowland rivers since the state of the river-bed may easily affect—sometimes unfavourably—the regime of surface and underground water and thus lead to the depreciation of even the most fertile soils. In particular, regulation by means of embankments is very dangerous because these constructions narrow the watercourse and may thus make the run-off of high waters very difficult, and the drainage of rain-water from the neighbouring regions impossible. Moreover, fixed weirs are often the reason for wet soils. Deep-cut river-beds and the beds of shipping canals and water-power channels may in light soils cause a dangerous sinking of underground waters and an excessive aridity of the soils. The unfavourable results of regulating rivers have therefore to be taken into account in advance and should be offset by supplementary reclamation measures, for instance, by draining wet areas with the use of pumps, by converting fixed weirs into movable weirs, by irrigating areas threatened by aridity etc.

It is also necessary to ensure that the water be pure and the watercourses be kept clean because water utilized for agriculture and for such other purposes as sanitation, production and supply must always be pure and free from harmful matter of every kind. Rivers into which sewage waters empty from town or industrial sewerages are polluted according to the sanitary and agricultural point of view, and may even be unfit for use. Rivers and standing waters should be analysed for purity, and sewage waters should likewise be analysed in order to determine the appropriate method for their clarification. The regional regulation of the entire water basin is the final link in a general sanitation programme.

A no less important problem with respect to the regulation of surface-waters is the regulation of the ground-water regime, if this regime appears to be a handicap to agriculture. Other less serious soil conditions with respect to water and moisture, and especially with respect to arid soils, may be improved by appropriate measures of cultivation or by agricultural-biological methods. In arid regions where the lack of moisture requires rather careful management, excellent results have been obtained from cultivating the soil by ploughing, loosening and manuring, and from an appropriate choice of crops and their rotation and the shading of fields and their protection from drying winds by wind-breaks. This method, called dry farming, has been used with success in the Soviet Union and the United States and is being introduced in other countries also.

More complicated types of disturbance in the regime of ground-waters—for instance, marshy regions, peat bogs or arid soils—may be improved only by appropriate technical methods of reclamation which will make possible the utilization of inferior or depreciated soils for agriculture. The methods of reclamation may be drainage or irrigation or even rebuilding the soil itself.

Drainage may be accomplished by means of open ditches or underground drains, depending on soil conditions. Irrigation may likewise be surface or underground; surface irrigation, again, may be based on distribution by gravitation (furrow-, basin- or flood-irrigation) or by pressure (spray irrigation). The rebuilding of soil is effected by silting up the ground with mud; adding soil-improving matter etc. The method chosen for reclamation must therefore be very carefully studied for its suitability to the given climatological, hydrological, pedological and biological conditions so that the undertaking will not result in only temporary improvement of the soil or in eventual deterioration thereof. Reclamation research, the study of the various problems and phenomena involved in any reclamation project, merits our particular attention.

Similarly, studies must be made of the relation between the constructions required by reclamation projects and the regulation of rivers and standing waters since these waters are the basis of reclamation, i.e., they serve as outlets for drained regions, water sources for irrigation etc. If the regulation of rivers and the building of weirs, canals and reservoirs alter unfavourably the regime of underground waters in the neighbouring soils, it is often necessary to undertake reclamation work.

The constructions necessary for reclamation must therefore be planned in relation to the regulation of rivers and their use, for in this working relationship certain installations for the purpose of reclamation may simultaneously be used effectively for other purposes. For instance, reclamation canals may also be used for drainage, irrigation, navigation and the production of water-power. This is especially true when the reclamation project involves extensive areas which include waste land, marshes, peat bogs etc., there, within the frame of the general scheme, rivers are regulated, soils are drained, irrigated and cultivated and work of a similar nature is carried out. If necessary, fields are redistributed by commassation in order to facilitate the planning of means of distributing water, the planning of roads and other common facilities, the cultivation of the soil and the mechanization of field work. Such a broad approach to the problem, which may be referred to as integrated reclamation, is the goal of reclamation work and has already been introduced in many countries.

The problems mentioned above show clearly that reclamation must today be conceived as a complex of many organically related methods which have as their aim the conservation of soil and water and their maximum utilization. In practice, reclamation must cope with the following tasks:

1. *Flood control* comprising the regulation of rivers and the accumulation of high waters in order to balance the run-off, and the creation of water reserves for various purposes of consumption;

2. *Errosion control* either by biological-agricultural methods such as appropriate lay-out and effective cultivation of fields, or by such technical means as regulation of the run-off of rain-water by means of ditches and dams, terracing and control of torrents, landslides and gullies;

3. *Control of the purity of water* for the purposes of protecting water-sources and underground waters including mineral and healing waters, clarifying sewage waters from town and industrial sewerages and providing for the self-purification of running and standing waters by efficient regulation;

4. *Control of the hydro-pedological regime of soils* by draining wet soils by means of canals, open ditches and underground drainage, by irrigating arid soils and introducing dry farming, and finally by reclaiming for agricultural purposes inferior soils such as peat bogs, alkali soils and the like;

5. *Control of soil utilization* by rearranging fields in a manner appropriate to local purposes, by commassating land owned by scattered proprietors and by facilitating cultivation of soil through the organization of transport, common agricultural installations, electrification and mechanization of agricultural work.

In every country such a large scale reclamation programme requires, for satisfactory execution, a systematically conceived and expert reclamation plan. Based on the water economy and the agricultural and industrial conditions of the given country, the plan specifies the kind, extent and technical execution of all the undertakings necessary for reclamation. Before the plan can be drawn up, there must be a preliminary study of the given climatological, hydro-pedological and biological conditions which affect water circulation and soil development and which are therefore closely related to the control and exploitation of these natural resources. It is necessary to determine the moisture conditions, precipitation and temperature of the various parts of a country, the regime of the natural circulation of water, the pedological character of the soils and the requirements of various localities since all these factors raise problems in reclamation.

The execution of a reclamation project requires preliminary research to ascertain the effects of the proposed works and to select appropriate technical methods. With respect to the complicated reactions that take place within the soil following the regulation of surface and underground waters, drainage or irrigation and the like, research work is an essential component of reclamation; in fact, it is the basis for the development of the modern science of reclamation, which makes use of experience gained in other scientific fields, especially climatology, hydrology, pedology and agrobiology. Hence, research in reclamation is undertaken in many countries; in Czechoslovakia, it dates from 1924.

Reclamation is one of the principal tasks of all countries for it has an enormous influence upon their agricultural production and their capacity to export agricultural products. For this reason, every country organizes its own reclamation service and promotes its development. But reclamation is equally important from the international point of view because it aims at the control and exploitation of soils and water, the two principal natural resources in the world. The international significance of reclamation has not yet been fully realized and there is so far no international programme for the solution of the problems and formulation of the tasks and techniques of reclamation. The congresses of the International Pedologic Society have alone dealt with the problems connected with the continuing improvement of reclaimed soils.

The problems of reclamation, which must be solved in each country, are as a rule quite complex, the more so because local experience, scientific research and construction models are often lacking. Of great assistance, therefore, are the results of experiments and research work from abroad into similar climatic, hydro-pedological and agrobiological conditions. The foundation of an international association of reclamation that would bring together scientific workers, specialists and institutes engaged in the study of reclamation methods would strengthen scientific co-operation by organizing conferences, by exchanging scientific literature, by studying local working methods etc. Another important task of such an association would be to organize reclamation research on an international scale so that the results obtained from various methods of research could be collected and studied, and the work of institutes of reclamation research, established in typical regions and under typical conditions, could be brought together and completed.

Reclamation management, the control of soils and water, is the main prerequisite for the preservation and continuous exploitation of these natural resources. For this reason the subject merits the greatest attention both internationally and in each country. History teaches that flourishing countries can become barren waste land and desert when control of the soil and water is neglected. On the other hand, various methods of reclamation—such as regulation of rivers, accumulation of waters, irrigation and drainage—that have been introduced in different countries especially in the present century, show the immense importance of reclamation management for the cultural development of mankind.

Recent Developments in Irrigation

MICHAEL W. STRAUS

ABSTRACT

Around this shrinking world, man is struggling intensely to see if he can produce food as fast as he reproduces himself. In many countries, he is turning to irrigation of arid lands as his road to survival. The wedding of the land and water produces food. Irrigated acres provide food for perhaps 10 to 15 per cent of the world's population.

Following the Second World War, the United States has inaugurated a programme to extend to all free countries financial and technical assistance in their reconstruction and resources development programme, a programme in which the Bureau of Reclamation is co-operating.

River control for irrigation is fundamentally a conservation activity. It conserves, in reservoirs, excess flood-waters for use at a later, more profitable time. Also, storage dams frequently provide a source of hydro-electric power which not only helps to carry the load of financing the project but also makes an additional contribution to the national welfare in the form of low-cost power.

The extension of irrigation practices into sub-humid and humid areas, the acceptance of national responsibility in irrigation development, the liberalization of repayment requirements, and international agreements for full utilization of international streams are, or could be, generally applicable throughout the world. In a great many instances they already have been applied. Guided by such precepts, the acreage under irrigation in the arid and semi-arid sections of the United States—and perhaps in the rest of the world as well, can be increased approximately twofold.

It is logical, in the light of world-wide food deficiencies, that irrigation development will command more and more attention. And it is logical to predict that the countries of the world will set as their goals, full development of irrigation potentialities. Reclamationists in the United States look forward to reaching that goal by sharing technical knowledge for the benefit of everyone.

Around this shrinking world, man is struggling intensely to see if he can produce food as fast as he reproduces himself. And in many countries on several continents he is turning with greater need to irrigation as his road to survival.

Every hour 2,500 persons are added to the world population of 2-1/3 thousand million—a rate of increase unparalleled in the population progression of man. Thus, as we live longer, there are over 20 million more people (8)[1] to eat more food each year. These are new mouths to share the inadequate fare of vast numbers of their predecessors.

"In the race between population and food, population is winning", Sir John Orr, first president of the United Nations Food and Agriculture Organization, said (9). Population growths cannot easily be stopped, but food

[1]Numbers within parentheses refer to items in the bibliography.

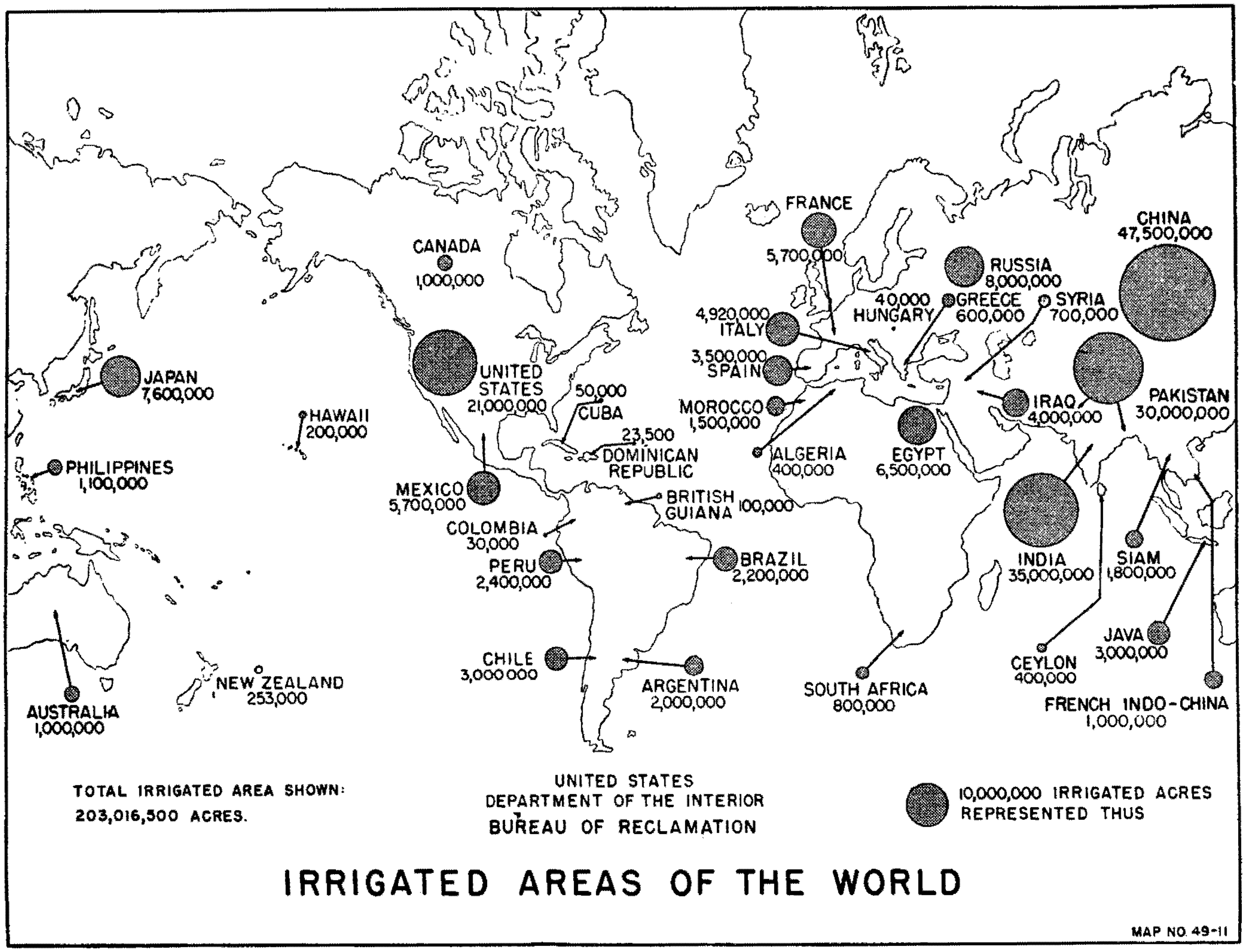

Figure 1

production can be increased. One sure way, still open, of feeding the world is by bringing water to the land, or irrigating. The most important recent development in irrigation is its rapid acceleration everywhere under the lash of hunger and necessity.

Irrigation is not new—it antedates recorded history of more than one country on more than one continent. Whole civilizations have flourished or fallen on the success or failure of their irrigation programmes. In the United States of America, just over half of the available irrigation water, under present standards, has been developed and put to work irrigating more than 21 million acres. In the world there are some 200 million acres under irrigation and there is possibly water remaining to irrigate a similar additional area.

It is the wedding of land and water that produces food. In the United States, and generally in the world, there is more land than water available for crops. That means sweet water is the first fixed limit that we encounter in food production. We have recently approached or encountered it already in this country and elsewhere in the world, with resultant violent political controversies. These produce no more water. Such political argument is merely the symptom showing the public that the area is bumping against its vital water-resource ceiling. An increasing number of areas are reaching the dry bottom of their water barrel.

China, India and Pakistan lead all nations, each with 30 to 50 million acres under irrigation. The United States, with more than 21 million acres, ranks fourth. The Soviet Union, Japan, France, Mexico, Italy, Iraq and a dozen or more other countries have substantial areas under irrigation. It has been estimated that these irrigated acres, either directly or indirectly, provide the livelihood for 10 per cent or more of the world's population (1). Figure 1 in the accompanying charts shows the distribution of irrigated acres throughout the world. Figure 2 shows the location of Federal Reclamation projects in the United States.

At the close of the Second World War, the Congress of the United States recognized the world importance and portending consequences of the destruction of great areas of the world's means of economic production. It recognized, also, the significance of the pre-war lag in increasing living standards in many lands. We, in the United States, have come to know that these problems in far-away places have reverberated to our own doorstep. Thus, the United States Government has inaugurated, as a major foreign relations policy, a programme (10) to extend to

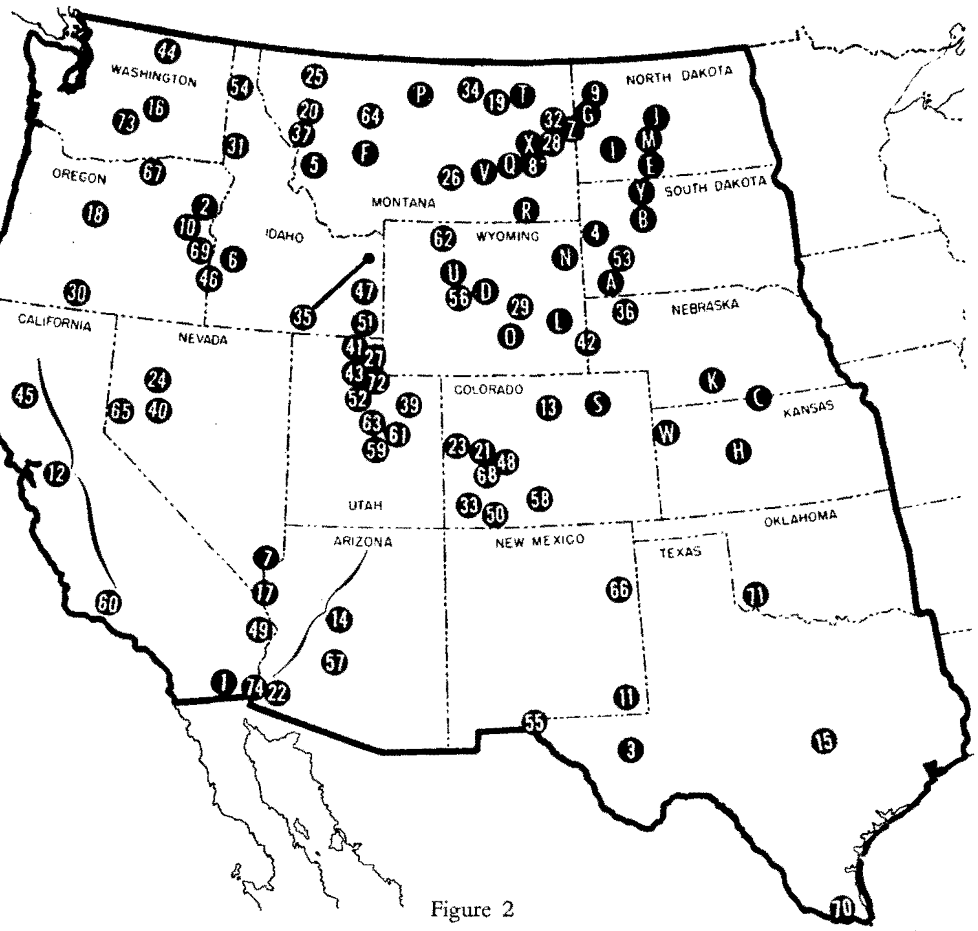

Figure 2

Project	State
1. All-American Canal System	California-Arizona
2. Baker	Oregon
3. Balmorhea	Texas
4. Belle Fourche	South Dakota
5. Bitter Root	Montana
6. Boise	Idaho
7. Boulder Canyon	Nevada-Arizona
8. Buffalo Rapids	Montana
9. Buford-Trenton	North Dakota
10. Burnt River	Oregon
11. Carlsbad	New Mexico
12. Central Valley	California
13. Colorado-Big Thompson	Colorado
14. Colorado River F. W. and L. S.	Arizona-Nevada-California
15. Colorado River	Texas
16. Columbia Basin	Washington
17. Davis Dam	Nevada-Arizona
18. Deschutes	Oregon
19. Fort Peck Power	Montana
20. Frenchtown	Montana
21. Fruitgrowers Dam	Colorado
22. Gila	Arizona
23. Grand Valley	Colorado
24. Humboldt	Nevada
25. Hungry Horse	Montana
26. Huntley	Montana
27. Hyrum	Utah
28. Intake	Montana
29. Kendrick	Wyoming
30. Klamath	Oregon-California
31. Lewiston Orchards	Idaho
32. Lower Yellowstone	Montana-North Dakota
33. Mancos	Colorado
34. Milk River	Montana
35. Minidoka (including Upper Snake River)	Idaho-Wyoming
36. Mirage Flats	Nebraska
37. Missoula Valley	Montana
38. Missouri River Basin:	
38a. Angostura Unit	South Dakota
b. Bixby Unit	South Dakota
c. Bostwick Division	Nebraska-Kansas
d. Boysen Unit	Wyoming
e. Cannonball Unit	North Dakota
f. Canyon Ferry Unit	Montana
g. Cartwright Unit	North Dakota
h. Cedar Bluff Unit	Kansas
i. Dickinson Unit	North Dakota
j. Fort Clark Unit	North Dakota
l. Frenchman-Cambridge Division	Nebraska
k. Glendo Unit	Wyoming
m. Heart Butte Unit	North Dakota
n. Keyhole Unit	Wyoming-South Dakota
o. Kortes Unit	Wyoming
p. Lower Marias Unit	Montana
q. Marsh Unit	Montana
r. Moorhead Unit	Montana-Wyoming
s. Narrows Unit	Colorado
t. N-Bar-N	Montana
u. Owl Creek Unit	Wyoming
v. Sadie Flat Unit	Montana
w. St. Francis Unit	Colorado-Kansas
x. Savage Unit	Montana
y. Shadehill Unit	South Dakota
z. Sidney Unit	Montana-South Dakota
39. Moon Lake	Utah
40. Newlands	Nevada
41. Newton	Utah
42. North Platte	Wyoming-Nebraska
43. Ogden River	Utah
44. Okanogan	Washington
45. Orland	California
46. Owyhee	Oregon-Idaho
47. Palisades	Idaho-Wyoming
48. Paonia	Colorado
49. Parker Dam Power	California-Arizona
50. Pine River	Colorado
51. Preston Bench	Idaho
52. Provo River	Utah
53. Rapid Valley	South Dakota
54. Rathdrum Prairie	Idaho
55. Rio Grande	New Mexico-Texas
56. Riverton	Wyoming
57. Salt River	Arizona
58. San Luis Valley	Colorado
59. Sanpete	Utah
60. Santa Barbara County	California
61. Scolfield Dam	Utah
62. Shoshone	Wyoming-Montana
63. Strawberry Valley	Utah
64. Sun River	Montana
65. Truckee River Storage	Nevada-California
66. Tucumcari	New Mexico
67. Umatilla	Oregon
68. Uncompahgre	Colorado
69. Vale	Oregon
70. Valley Gravity	Texas
71. W. C. Austin	Oklahoma
72. Weber River	Utah
73. Yakima	Washington
74. Yuma	Arizona-California

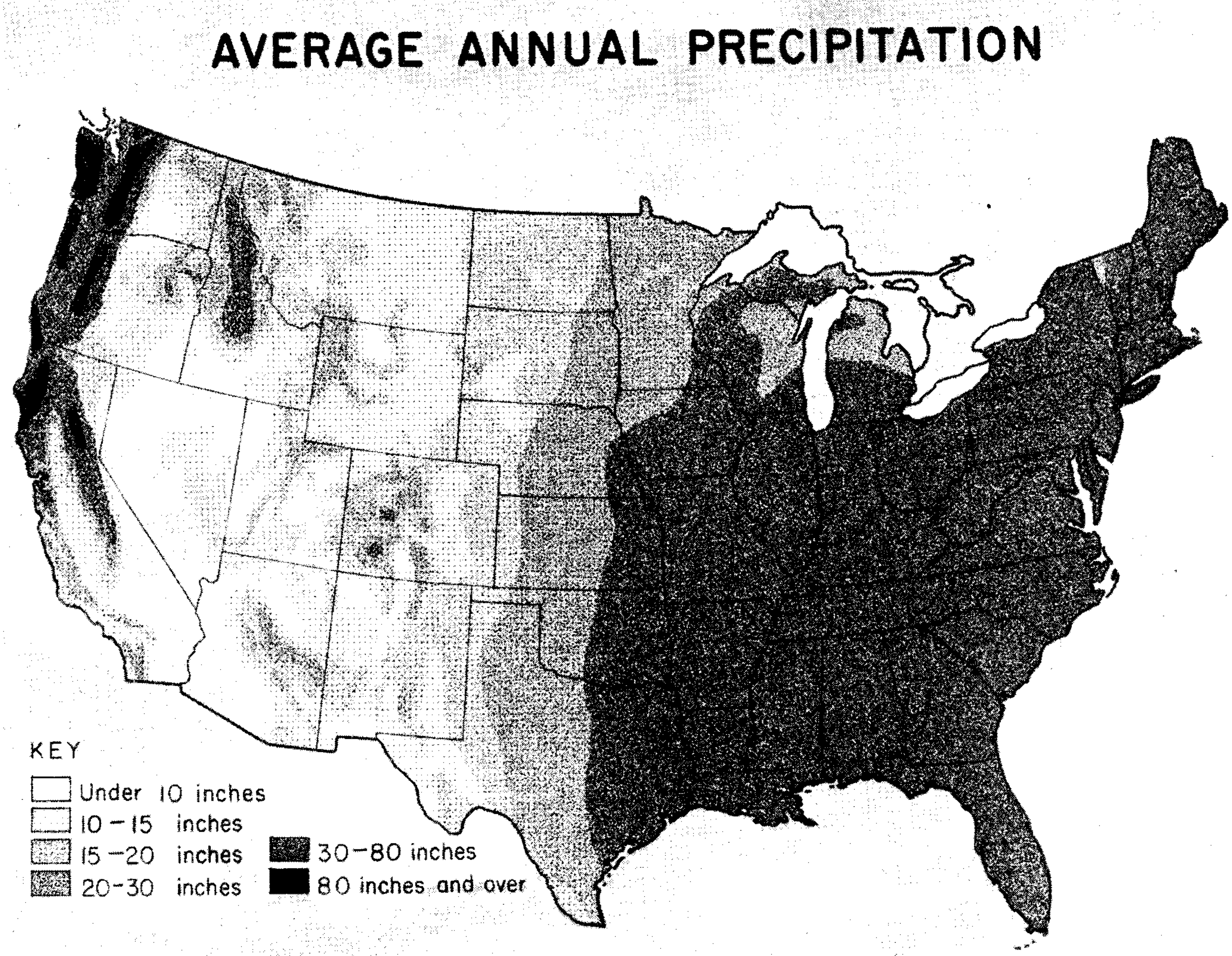

Figure 3

many free countries assistance in the reconstruction and resources development programmes. This plan puts forward an accelerated co-operative programme, under which the technical, administrative, financial and work efforts of many free people can work together to solve the basic problems of using and conserving natural resources. The Bureau of Reclamation is gladly co-operating in this programme to the fullest extent of its authority as limited by the burden of its domestic responsibilities.

The favourable reaction to this world-wide good-neighbour plan has exceeded all expectations. Each day the Bureau of Reclamation—among other agencies of the United States—receives many requests from abroad to share our experience and applied technical "know-how". The contributions of the United States in the field of irrigation development promise to be an important part of this world-wide resources development programme. American experience, particularly with vast water-control works, is shared with other nations as they have shared earlier water experience with the United States.

Although irrigation in the United States is young, by comparison with irrigation in many other countries, it has probably been more rapid and intensive here than in any other nation. Also, the engineering progress has frequently got ahead of the ecology, sociology and economy that has popular support. I would like to report upon some of the recent developments in irrigation in the hope that they might also be of value to other countries.

EXTENSION OF IRRIGATION INTO SUB-HUMID AND HUMID AREAS

River control for irrigation is fundamentally a conservation activity. It conserves, in reservoirs, excess or flood-waters for use at a later, more profitable time. We have traditionally considered irrigation to be of value only in arid or semi-arid climates such as the inland area in the western United States, as shown in Figure 3. In such climates it is a prerequisite to crops. But more and more we are realizing the value of irrigation for assuring and increasing crop production in semi-humid and even humid areas when warranted by the type of crops grown, or by the distribution of rainfall throughout the year. In the United States the frontier of irrigation development has been rolling eastward. It has now expanded into the area where rainfall is adequate for crops in some years but inadequate in other years, and it is moving towards the regions where rainfall heretofore has been considered ample for agricultural activity, but where irrigation can mean greater yields. Projects are now proposed well within semi-humid areas and some within humid areas. The world's greatest average yields per acre come from irrigated acres. Also, there are very few climates that do not suffer occasional droughts that cut crop production.

As the pressure on the land for more food production increases, it is entirely possible that irrigation in virtually all lands in virtually all climates may be a common sight. Therefore, it appears desirable, especially in countries that have limited agricultural land resources, to examine the possibilities of increasing food production through irrigation in all ranges of climates.

The farmer who can order his rainfall *via* the irrigation ditch at the precise time he needs it is the one who can be most certain of maximum yields from his fields. To pray for rain at a critical time is a human practice even older than irrigation. But the nation that can open reservoir gates to let the water on the land when droughts come is the one which will eat.

ACCEPTANCE OF NATIONAL RESPONSIBILITY IN IRRIGATION DEVELOPMENT

The responsibility of the national Government in the development of water and related resources has received widespread recognition in the United States only in recent years. This recognition has accompanied the growth of the basin-wide concept of multiple-purpose water-resource development. Only through such a concept can full conservation and utilization of these resources be accomplished. A reservoir in the great majority of cases must serve more than one purpose if it is to fulfil its potentialities. Irrigation, flood control, hydro-electric power generation, recreation, navigation and other functions can be served by a single reservoir, or by a group of reservoirs operated as a unit. And, in serving many purposes, a single reservoir can provide each benefit at less cost than would be possible if each purpose were served by a separate unrelated development. Further, because a reservoir placed in one part of a basin may affect the entire stream system, it is imperative that reservoirs and other structures throughout the basin complement and do not interfere with each other. This is attained when planning and development of the water resources of an entire basin are conceived of as a whole with a vision looking a century or more into the future.

It was natural and logical that the broad, national responsibility for water resource development would attain full recognition as a result of basin-wide, multiple-purpose concept. In the United States, only the Federal Government has broad enough powers, sufficient incentive and enough financial resources to carry out vast, complex and costly river-basin developments. Even to conceive them requires the driving force of the people as a whole, seeking to widen their frontier to provide the new raw resources required to accommodate their population growth. Within these basin-wide developments, a single large project, such as the Grand Coulee Dam on the Columbia River or the Central Valley Project in California, may cost 500 million dollars or more. A whole river-basin programme may cost several thousand millions of dollars. Such undertakings, though highly profitable to society on a long-term basis, require years to repay costs allocated to direct benefits. And they require that the cost of benefits accruing to the general public be paid for by the general public, and not made reimbursable by the local water-users. It is seldom that private or local financing established on an immediate increment and profit base could undertake such investment on a long-time basis. This is particularly true when part of the benefits is measured by lives and property saved from floods; in better, more stable living for the whole public, and when costs are amortized over extremely long periods.

For instance, a certain reservoir project may be infeasible for irrigation or for power production alone. But combined with needed flood control, the project may become economically feasible. As flood control generally produces no direct revenues to the reservoir, the project would still be infeasible from the viewpoint of private financing. The national Government, however, where its policy, as in the United States, is to provide flood protection and other general public benefits as a national service, could very well undertake the project. The Central Valley project in California is a good example of such a water conservation and use project. It serves the following principal purposes: irrigation, power, flood control, navigation, salinity control, domestic and industrial water-supply, recreation, and fish and wild-life conservation.

All these factors are important in promoting the rapid development of irrigation in the United States as one of the basic means of utilizing most efficiently the natural resources of this country.

The physical problems associated with sound irrigation development are too numerous to cover in detail here. Briefly, nothing better can be prescribed to perpetuate sound irrigation than to provide the means for keeping watersheds in balance by adjusting grazing, farming, forestry and other operations to the sustained productive capacity of the soil. If this balance is not secured and maintained, erosion is accelerated. Reservoirs and canals are filled with sediment. Operation and maintenance costs are increased. And, too often, the project decays to the point of uselessness through neglected maintenance. Proper upland watershed balance is essential; it is also necessary to keep the water-supply, land and drainage in balance in the agricultural area. This is one of the most difficult things to achieve in good irrigation practice. Although engineers and technicians can, after adequate study, define the limitations of water-supply and land, the temptation to let the essential watershed protection and control lag behind the more dramatic main-stream developments has led to the impairment or failure of many otherwise sound irrigation projects, as well as to the destruction of valleys.

LIBERALIZATION OF REPAYMENT REQUIREMENTS

Financing plays a vital role in irrigation development. It is only natural that in the United States, as in other countries, the more simple and least expensive projects were built first. Opportunities are exhausted to develop additional areas by building a simple diversion dam and irrigating nearby lands by inexpensive gravity methods. New developments are frequently very complex. Some projects in the United States require water to be transported over distances approaching 500 miles. Grand Coulee Dam must pump water into a second reservoir 280 ft. above the dam. We have one tunnel 13 miles long which diverts water through the Continental Divide from the Pacific into the Atlantic watershed. Construction of storage dams more than 700 ft. high, construction of other storage dams containing more than 10 million cub. yards of concrete, the construction of water channels like great man-made rivers with capacities in excess of 16,000 cub. feet a second, and pumps that will lift 720,000 gallons per minute are some of our more spectacular undertakings and achievements. Projects under investigation may require even larger and more complex features. For example, the possibility of diverting surplus water from the Columbia River, near the Canadian border, to thirsty lands adjoining Mexico a thousand miles away is now being given serious study. While such facilities may require the expenditure of substantial amounts of money, it must be remembered that, while money is a symbol value subject to many vicissitudes, an acre-ft. of controlled water is recognized world-wide as a real value.

Generally, most countries require the direct project beneficiary—the water-user—to repay some portion of the project costs which he passes on when he disposes of his irrigated crops. A recent examination of financial policies in twenty-two countries shows, however, that there is a definite trend towards liberalization of repayment requirements. The recognition that new national wealth is created by irrigation and that the nation is repaid many times over through the contribution of irrigation projects to the expansion and stabilization of national economies is, in large measure, responsible for this trend.

In addition to a growing policy of liberalizing project repayment, other recent developments in the financing of irrigation projects in the United States have tended to spread repayment of project costs over a wider base. That eases the burden on the water-user and enlarges the potential development that can be successfully carried out. Hydro-electric power has become a vital paying partner of irrigation. Through construction of storage projects involving irrigation, power, and other functions, the costs of such storage projects are allocated appropriately among two or more functions with savings to each function. As power is one of the beneficiaries of such allocation, low-cost power is in effect a by-product of irrigation development. It has been found equitable, therefore, to provide for reimbursement from power revenues of such part of the irrigation costs as exceed the water users' ability to repay, when this can be done without increasing power rates disproportionately. In many instances, the financial assistance so obtained from power equals or exceeds the amounts repaid by the irrigators. In many instances this irrigation subsidy from power revenues means the difference between feasibility and building and non-feasibility and not building of a project. This procedure has the effect of broadening the repayment base so that the many power-users who benefit indirectly from irrigation development contribute to its support.

Another relatively recent trend in financing reclamation projects provides for the non-agricultural people in the towns and counties near a project area, to participate directly in repayment of the reimbursable project costs. Such participation is made possible by the formation of conservancy districts. In such organizations, the people in the towns and counties in the general area of the project pay a portion of the costs through an *ad valorem* tax. Through this means, repayment of the costs are assessed against a broader base.

Other means of liberalization have involved making non-reimbursable the costs involved in providing for certain functions that serve broad general or national interests. Flood control is the foremost function now handled in this respect. Others include navigation and the conservation and propagation of fish and wild-life. The Congress is at present considering additional items such as pollution abatement, silt control, recreation, and several others which might properly, in the same manner, be made non-reimbursable.

INTERNATIONAL AGREEMENT ON INTERNATIONAL STREAMS

Parallel with trends in broadening the justification and in liberalizing the repayment of irrigation projects, has been the trend towards more co-operation, interchange of data, and consultation between individuals, cities, states and nations. Rights to the use of the valuable and scarce water-supplies and development of the resources have been the common interests in such activities. These trends are evidenced by the interstate compact agreements in the United States on such rivers as the Colorado, South Platte, Republican, Rio Grande, Belle Fourche and Arkansas. The international agreements between the Republic of Mexico and the United States on division of the waters of the Colorado, Rio Grande and Tia Juana Rivers have been negotiated and approved to the mutual satisfaction and benefit of both countries. Agreements with Canada on other international streams such as the Waterton-Belly-Milk, Souris, Columbia and St. Lawrence are under way. There is every good reason why free men and nations throughout the world should get together and resolve their claims to international streams as an aid to multiple-purpose resource development. Water is no respecter of political boundaries and it is getting scarce and valuable. Everywhere it flows downhill regardless of political lines and, unless free men and nations do resolve their claims, they encounter trouble.

The four major points I have discussed, namely, extension of irrigation practices into sub-humid and humid areas, acceptance of national responsibility in irrigation development, liberalization of repayment requirements, and international agreement on international streams, are or could be generally applicable in virtually all countries throughout the world. In a great many instances all or part of them already have been applied. Guided by such precepts the acreage under irrigation in the arid and semi-arid sections of the United States can be increased approximately two-fold, or more. Although little information is available on the undeveloped irrigation potentials for the world, I have no doubt that its irrigated acreage could be similarly increased. Should we include also the possibilities of irrigation in humid and sub-humid areas, the potential increase would be much, much greater.

INTERNATIONAL AID IN DEVELOPING IRRIGATION

It is logical, in light of world-wide food deficiencies, that irrigation development will command more and more attention, and, it is logical to predict that the countries of the world will set as their goals full development of irrigation potentialities. We, in the United States, look forward to reaching that goal. We believe it can be done by sharing technical knowledge for the benefit of everyone; by real and lasting friendship between good neighbours. Accordingly, if a nation's physical resources are to reach full growth, the Government itself must play a leading role in this development.

It is quite evident that the world is recognizing this responsibility for more and broader public works programmes, as the post-war nations turn from destruction to construction. Engineers and observers from foreign lands are visiting the United States in increasing numbers to study our great reclamation projects and to learn our methods and practices. Also, personnel of the Bureau of Reclamation are sent on missions all over the globe to assist in planning new developments for irrigation, power and related water uses. We also are gaining broader knowledge and the benefit of long experience from these international associations. Neighbourliness is a two-way street.

It is a great honour and privilege that we are able to share our experience with our international neighbours and that we are asked to do so. This is a mark of the progress of civilization. It is the road to our reaching full stature as men in a well-fed world.

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Development of Irrigation in a Semi - Humid Climate: The Ashburton - Lyndhurst Project, New Zealand

J. O. RIDDELL

ABSTRACT

The Ashburton-Lyndhurst Project, operated by the New Zealand Ministry of Works and covering 64,000 acres, is situated in Ashburton County, South Island, New Zealand.

Although rainfall is comparatively high (25 in. to 35 in.), hot dry winds, light soils and good drainage limit the amount of moisture available for plant growth, so that irrigation is necessary to permit full utilization of the resources of the soil.

The district was developed on a dry farming basis prior to irrigation and although this was an advantage in that all the social services necessary to a community were in existence, which is not generally the case where arid regions are developed, a serious disadvantage was the reluctance of farmers to change their established practices.

Compulsion is out of the question but the difficulty is being overcome by fixing attractive water rates and conditions of supply in addition to rendering assistance to irrigators in many ways, such as free surveys for land preparation, preparation of land at cost by efficient methods, advisory services, and a research station.

Although irrigation of semi-humid areas such as this does not show the over-all production increases associated with arid regions, there is not the same risk of failure either to the individual or to the project because farming them has already proved feasible without it.

The condition of the world food supply today demands closer investigation of the possibilities for increasing production from these so-called "twilight zones" of irrigation.

INTRODUCTION

The age old practice of irrigation is generally associated with the development of regions in which the rainfall is regularly inadequate to provide the moisture requirements of crops.

In these regions the results of irrigation are strikingly obvious in that production is increased from nothing at all to a plentitude, depending upon soil fertility. Where rainfall is sufficient to ensure that full use is made of the soil resources, no irrigation is necessary. In between these extremes there are many semi-humid regions in which rainfall is irregular and unpredictable, with the result that in some years the full capacity of the soils cannot be exploited.

In founding a farming economy in such a region, development must be based either on the limited production available during the dry years, or, if on maximum production, must be assured of the availability of sufficient moisture by the provision of irrigation.

As it will be obvious that the irrigation facilities in the latter instance will not be required to the same extent each year, and that perhaps in some years will not be required at all, it will be appreciated that the financing of irrigation projects under these conditions is difficult and inevitably raises doubts as to whether or not the service should be supplied.

This paper describes some aspects of the development in New Zealand of a project of this type, which after close investigation was considered economically justified and which so far is showing promise of success.

DESCRIPTION OF AREA

The project covers 64,000 acres in Ashburton County, South Island, New Zealand. Roughly rectangular in shape, it extends from an altitude of 800 ft. to 250 ft. above sea-level in gently sloping plains. The slope is fairly regular in the one direction and the terrain being particularly smooth, is suitable for border-dyke irrigation with comparatively little work. Homesteads, with plantations or shelter belts of exotic trees, form the only break from the normal plains topography.

Soils vary from light stony silt loams to heavy clay loams, with a preponderance of the former. Irrigation of the clay loams has rarely proved necessary, because of their lying in the heavier rainfall area and their ability to retain moisture. The stony silt loams, however, are not only light, but also thin (8 to 12 in.) and they are immediately underlaid by great depths of semi-permeable alluvial gravels. It is from these soils that the greatest response to irrigation is obtainable.

Rainfall varies from 25 in. average yearly at the lower altitudes to 35 in. at the higher, but is inconsistent and not only shows considerable annual variation but also in monthly totals follows no defined plan. The maximum fall for the year can occur in any one of the twelve months and the total for any individual month may be anything from nil to $9\frac{1}{2}$ in. At one particular station the maximum annual recording is 55 in., the minimum 15 in.

The effect of the somewhat high rainfall is offset by several important factors:

1. Hot dry winds in all but winter months induce high evaporation.

The average annual total is 46 in. and the maximum recorded for any one day is 65 in.

2. The thin cover of soil available for the retention of moisture, and

3. The efficient drainage afforded by the gravel subsoil.

Temperatures are moderate. The annual average is 51 degrees F with occasional maxima of 90 degrees F or a little more, and minima of the order of 16 degrees F.

The average duration of bright sunlight is 1,800 hours per year.

CONDITIONS PRIOR TO IRRIGATION

Over the 80-odd years preceding irrigation the area was developed on a dry farming basis—that is, the size of the holdings was automatically adjusted to provide for economic farming under the limiting conditions ruling in dry years. There were 147 holdings averaging 437 acres each.

Although some cereals were grown, the main crop was grass, supplemented by swedes and turnips for winter food.

The whole area was well provided with most modern amenities or social services.

WHY IRRIGATION?

Early experiments showed that under irrigation, grass pastures could carry up to six times the number of stock that could be risked without irrigation. No other type of crop could show anything like this proportionate increase. Wheat, for example, might harvest 25 bushels per acre under dry conditions but even with irrigation no more than 40 bushels per acre could be expected.

Irrigation in semi-humid climates starts off with a grave disadvantage in that the use of water is erratic and consequently its unit cost must be high. High proportionate gains in productivity are necessary to offset this and in the instance under review grass is the only crop which will give the returns.

Fortunately, pasture cultivation was already well understood by the farming community and the introduction of irrigation did not entail radical changes in farming practices.

This brings up a point well worth emphasizing. In semi-humid areas the types of crops already grown should be retained under irrigation. These crops will have demonstrated their suitability to the soils and climate so that no sweeping changes either in personnel or equipment will be necessary for farming them under irrigation.

Another factor which affected the decision to develop the project was that a full range of social services was already available. In arid areas, it is necessary not only to construct the irrigation project, to develop the farms and farmers from scratch, to build homesteads and other farm improvements but also to establish all of the social services so necessary to a modern community. This takes time and thus retards progress, but it also takes money and the money must come from the returns from the project. Consequently, where the provision of services has already been made, as in the case in point and in most semi-humid projects, the actual returns from the project do not require to show the same margins as for undeveloped arid projects.

In the area under discussion a paved main highway passes through the project from end to end, joining the towns of Ashburton (population 7,000) and Methven (population 1,000). The area is well covered by macadam surfaced secondary roads and is bounded on two sides by railway track. It is well endowed with schools, bus and mail services, recreation facilities, and it is reticulated for telephone and electric power. Every farmer on the project uses electricity.

OPERATION OF PROJECT

The project was constructed by the Ministry of Works of the New Zealand Government. No prior agreements were made with the landowners so that when the job was completed in 1945, the Ministry retained control and delivered water to irrigators on demand. Payment is required at the rate of 4 shillings per acre-ft. for water actually supplied, and no guaranteed minimum stipulated.

This method was adopted with the idea of popularizing the use of water and to remove any suggestion of compulsion from the minds of farmers.

At this stage it is opportune to point out that, from the inception of the work, there has been a strong body of opinion against the project. This opposition can be attributed mainly to an inherent objection to change in the established routine of farming.

Although, prior to irrigation, stock carrying capacity was not great, the farming of a sufficiently large holding—as most of them were—could be very profitable in most seasons and by no means onerous. It appeared to farmers that the adoption of irrigation would mean that they would have either to employ more labour or reduce the size of their holdings, but as labour is hard to obtain and no New Zealand farmer willingly reduces the area of his farm, the natural inclination was to oppose irrigation. No doubt something very much akin to this problem must be faced wherever irrigation in semi-humid regions is attempted.

The decision to supply water on demand, with no guaranteed payments, very early proved to be unwise. Immediately the project was opened there was a tendency for farmers to irrigate small portions of their farms only, so as to provide an insurance against loss in abnormally dry years and perhaps slightly increase their usual carrying capacity, without the necessity for either reducing the size of holdings or employing additional labour.

Limited irrigation of this kind would neither pay for the project directly nor produce sufficient indirect benefits to justify the capital expenditure.

A further defect of the "supply on demand" system was that irrigators would defer their demands for water as long as possible in the hope that a weather change might save the trouble and expense of irrigation. One result was that when water was required, everyone wanted it at once, which made the physical operation of the scheme difficult and, moreover, most expensive. Regular demands throughout the season can be handled by fewer operatives. In many cases, also, deferment of demand resulted in damage or complete loss of pastures that could have been retained by regular water applications. This is a detrimental advertisement.

The demand system proved unsatisfactory and, as any form of compulsion was undesirable for political reasons, a compromise system was introduced and put into operation in the current season. Demand supply will still be permissible but the price is increased 50 per cent to 6 shillings per acre-ft. But, an alternative is provided whereby the irrigator may contract to pay for one acre-ft. per annum for half the irrigable area of his farm, whether the water is used or not, and extra water may be obtained at the contract price, which, under contract, is 4 shillings per acre-ft. The term is 15 years, including a five-year development period in which contract payments are graduated.

Although the contract system was only introduced this season, 25 per cent of the regular irrigators are preparing for contracts, and the remainder, even if they do not contract, will make a greater return to the revenue account.

ECONOMICS

Unfortunately, experience on this project does not give an accurate picture of the economic possibilities in the region, the results being clouded by circumstances which would not be repeated. Much of the construction was done in war-time and hence was most expensive, but more important, part of the area has been shown as scarcely requiring irrigation and consequently the balance is required to shoulder more than its fair share of the costs. The use of the water for hydro-electric purposes during the winter also obscures the issue.

However, after three years' operation it seems safe to predict that when the lighter soils are fully developed, the present charges will cover operation and maintenance costs. This goal should be reached in about 15 years from now.

There is little prospect of revenue making any contribution to capital cost. This is not an unusual experience for State-owned projects and many Governments are well satisfied with the huge indirect returns which maximum output produces.

Some of the more important indirect returns are:

(*a*) Increased overseas exchange. New Zealand's economy is largely based on exports of primary produce and any increase must reflect to the benefit of the Dominion as a whole.

(*b*) Increased employment. Irrigation means more work for more hands, both on the project and on the farms. The value of this extra avenue for employment can assume gigantic proportions in times of depression, when unemployed must be supported entirely by the State.

(*c*) Increased taxation returns. Under full development it is estimated that the additional taxation returns from the project will pay for operation and maintenance costs three times over.

(*d*) Increased rail freights. New Zealand railways are government owned and the substantial new business from irrigated areas means a reduction in the general taxpayer's contribution to railways operating costs.

(*e*) Increased urban prosperity. More production in rural areas has a direct effect upon prosperity in the towns —more business, more population, and consequently cheaper services and a higher standard of living all round.

ASSISTANCE TO IRRIGATORS

As success of the project is judged in terms of production, special efforts have been made to encourage use of the water. Some practical measures adopted are:

1. Free preparation of 4 acres of border-dyke layout on each farm as a sample to encourage efficient methods.
2. Free surveying and advice for land preparation.
3. Preparation of land at cost for irrigators by a highly specialized team of operators with modern plant. Over 5,000 acres have been border-dyked to date.

4. The Department of Agriculture co-operates by providing advisory officers to assist in farm management.

5. A research station has been established by the Department of Agriculture for scientific investigation on the area of the problems associated with irrigation.

6. Practical support is given farmers' organizations by encouraging field days, pasture competitions, and similar activities.

CONCLUSION

Space does not permit of more than a brief summary of some of the important factors which experience on this project has shown should be considered when drawing up the pros and cons for the development of irrigation in semi-humid regions.

Generally, farming is already established. This is an advantage in that most services will be in operation already and pioneering will not be necessary. On the other hand farmers will not be enthusiastic about changing routines or techniques.

Because a progressive development of existing farming practice is generally possible, it is not necessary to train new settlers and the risk of failure, either for the individual or for the project, is remote.

Direct financial returns are not likely to be quite so spectacular as for arid regions but indirect returns are obtainable at less cost.

Finally, in many countries where arid land irrigation is being developed extensively, shortage of water limits further progress. In semi-humid areas as a general rule reasonable supplies of water are available and with the world demand for greater food production becoming more urgent year by year, more attention must be concentrated on the potentialities of these so-called "twilight" regions.

Some Aspects of Irrigation in Greece

A. KALINSKI

ABSTRACT

The efforts of Greece to increase food production under the European Recovery Programme depend to a large degree upon the development of irrigation projects. Better use of water would have a beneficial effect not only upon the domestic food supply but also upon the entire economy of the country. The diet of the population would be improved while at the same time the trade deficit, incurred by import of foodstuffs from abroad, would be reduced. With a rise in farm incomes there would be a larger internal market for goods manufactured by Greek industry, which is also undergoing expansion.

The topography of Greece has, however, given rise to traditional farming methods of which account must be taken in planning irrigation development. In the northern plains where the largest amount of arable land and surface water are available, the farmers have in the past grown only winter crops and have engaged in stock-raising. In this area irrigation projects must therefore be long-term and undertaken only at the rate that farmers acquire experience with irrigated crops.

The programme for the irrigation of 75,000 hectares by the end of four years should accordingly be introduced in the South where farmers already are experienced in the collection and adduction of water for agricultural purposes. The smallness of the land-holdings will increase the cost of distributing the water and regulating its flow but the higher costs will be justified by the expected improvement in food production and its related effect upon employment.

An appendix describes in some detail some characteristic features of the climate, topography and agricultural economy of Greece.

INTRODUCTION

Greece, like some other Members of the United Nations, is making a considerable effort under the European Recovery Programme to improve agricultural production, in order to meet the world demand for an increase in the production of foodstuffs and to establish the Greek economy on a more solid basis.

To a large degree this aim can be attained through a better use of water.

The development of irrigation presents various aspects—social, economic and technical, all of a more or less special nature according to the region. Actually, however, these aspects are common to all countries which have identical social or natural conditions. Consideration is given in the present statement to these common aspects as well as to those that are characteristic of Greece.

IMPORTANCE OF IRRIGATION

That the development of irrigation would have a beneficial influence on a region with the climatic, geographical, soil formation, social and financial conditions of Greece, is evident. The benefits, moreover, would be distributed throughout the economy.

Both the advantageous climatic conditions of Greece (abundant light and warmth) and the disadvantageous (uneven distribution of rainfall, long dry season during the period of growth of crops), call for an intensive use of water in farming.

In their turn, social and financial conditions would greatly benefit from a policy of irrigation. Increased production of crops, especially of those which Greece is obliged to import, would, on the one hand, insure a more satisfactory diet for the population, and on the other, would considerably reduce the trade deficit. At the same time the annual income of the rural families—now at a desperately low level—would be increased through better exploitation of their labour. Fully productive use cannot be made at present of the labour of the peasants and their families because of the small amount of land available to each family for cultivation and the impossibility of developing summer crops with satisfactory yields.

Improvement of the financial status of rural families and, consequently, of their capacity for consumption, will have an immediate and considerable effect on industry, because it will ensure a certain and ready market for manufactured goods.

Expansion of irrigation will, however, have a deleterious effect on stockbreeding as it is now practised in Greece. Since portions of the larger plains will be included within the scope of irrigation projects, fields will be eliminated that now lie fallow and nomadic flocks will thus be deprived of their winter grazing grounds. Simultaneously with the development of irrigation, therefore, there will have to be a change-over of stock-breeding from a nomadic to a sedentary industry, with the prospect, however, of improved financial returns.

These simple truths were perceived by Greek farmers many scores of years ago, in fact long before the Government had contemplated the initiation of irrigation development. The technical means at the farmer's disposal for irrigation were rudimentary, whether surface-water or ground-water was used. But, wherever it was possible for farmers to tap water resources with their own simple tools, either by digging wells and installing a bucket-bearing apparatus operated by animal power for raising the water, or by diverting the water of springs or streams, they carried out irrigation projects that in most cases achieved considerable results.

The discovery on a plain of the southern part of Greece, of a ground-water-bearing stratum at an average depth of 12 metres below the surface of the ground, has led to the digging of 1,700 wells to date, and has assured the irrigation of 3,000 hectares of land, with the result that the economy of the region has been radically altered. The population increased 60 per cent within thirty years, live-stock became sedentary and a special breed of sheep was developed. Vegetables took the place of tobacco and currant grapes.

In Greece, 3.7 per cent of the total tilled land used for crops is irrigated. In this connexion it is worth noting the ratio of irrigated land to the cultivated area in each of the larger regions of the country. The northern area, which is dominated by large plains covering 29 per cent of its total surface, contains 50.5 per cent of the total cultivated land, but only 28.5 per cent of the total irrigated area. The southern and western areas, where the plains occupy only 15 per cent of the total area, contain 39.5 per cent of the total arable land but 64.6 per cent of the total irrigated area.

This distribution must be attributed chiefly to reasons of ground configuration and to the traditional farming methods which have developed therefrom. In the southern and western areas the flat land is divided into relatively small portions surrounded by high mountains, and the streams crossing the fields have as a rule sufficient slope and are never at a great distance from each other. Their discharge, moreover, is small so that farmers with simple measures and elementary technical knowledge do not find it too difficult to collect and divert the waters to their fields.

Thus, in many regions, irrigation is practised not only during the summer from spring-water flowing in the streams, but during the winter as well with the object of diverting the surface run-off of the winter rainfalls towards the fields, thereby increasing the moisture in the soil. This technique has been applied traditionally and for a very long time to areas used for arboriculture (olive-trees and vineyards) with noteworthy results. The amount of water available per tree during the whole winter period varies between 5 and 20 cubic metres (180 to 700 cub. ft.).

In the northern area on the other hand, where the large plains are located and the rivers have a considerable discharge, the collection and adduction of the water require more important structures than could be devised by farmers, who are therefore obliged to restrict themselves to growing only winter crops, mainly cereals.

EXPANSION OF IRRIGATION PROJECTS

According to the detailed estimates of the Recovery Administration, another 400,000 hectares must be added to the already irrigated area in order to obtain sufficient quantities of agricultural and live-stock produce to cover the requirements of domestic consumption.

The distribution by region of the land to be irrigated can be made approximately as follows:

	Hectares
Northern area	250,000
Southern and western area	120,000
Islands	10,000
From ground-waters in various regions	20,000

Eighty per cent of the water required in the first three areas will be supplied by gravity-flowing surface-water, 10 per cent by pumping from lakes or natural reservoirs, and 10 per cent from artificial reservoirs, which may also serve for hydro-electric purposes.

Many problems will be encountered in carrying out such an extensive programme of irrigation, through which the economy of approximately one-fourth of the agricultural area of the country would be altered. Some of these problems are characteristic of all large-scale irrigation programmes, while others are related to, and depend upon, the natural features of the area and the prevailing economic condition of the inhabitants. A short description of these later problems, as detailed as the limited extent of this statement allows, will be given below.

The technical means and facilities at the disposal of Greece do not permit such an extensive programme of irrigation as the one mentioned above, to be put into effect simultaneously throughout the country. For this reason it is necessary first to select the areas in which the programme will be started.

As has already been stated, the northern areas present the greatest possibilities for an expansion of irrigation because of the quantity of available surface-water and the extensive flat lands. Furthermore, through large flood-control projects executed during the past twenty years, it has been possible to restrict the flow of most of the rivers to definite beds, and so protect the adjoining plains from the danger of floods. As against these advantages, however, the northern areas present the serious drawback that the farmers lack experience with irrigated crops. Since agricultural methods will have to be changed, the rate of exploitation of the irrigation projects will, of necessity, be very slow. The irrigation projects would, moreover, require the installation of sizeable structures for the diversion of water as well as other technical works.

In the southern and western regions the areas that could be irrigated are restricted, the ground is rougher and the farm holdings are very small. But structures needed to collect and adduct the water are less important, and the farmers have considerable experience in growing irrigated crops.

By comparing the conditions prevailing in these two areas, we come to the conclusion that our attention must be mainly drawn to the northern areas where irrigated crops, when they attain their full development, will yield the richest fruits to the national economy.

The farmers' lack of experience with irrigation makes it imperative, however, that the expenditure of funds for irrigation projects in these regions should constitute a long-term programme which should proceed only at the rate that the farmers adjust to the new methods that must be learned. The soundness of this policy is proved by the fact that an irrigation system covering an area of 13,000 hectares was constructed ten years ago in one district of the northern area, and yet no more than 10 per cent of the system has to date been usefully developed.

In order, therefore, to develop an irrigation programme on the 250,000 hectares of the northern areas, restricted irrigation systems will have to be provided at suitable points on the large plains, wherever both soil and hydrological conditions are favourable, and where at least a majority of the farmers show a willingness to co-operate in such a venture. The development of such a programme will, however, be extremely slow.

On the other hand, the Greek Recovery Programme being carried out within the scope of the European Economic Co-operation Programme, provides that 75,000 hectares at least are to be irrigated by the end of the four-year period including the following:

	Hectares
Alfalfa	10,000
Beet-roots	3,000
Corn and pulses	14,000
Cotton	20,000
Rice	10,500
Potatoes	4,000
Vegetables	4,000
Orchards	3,500
Soya beans	1,000

Attainment of these targets presupposes that in the meantime sufficient irrigation ditches will have been dug to cover at least twice the area under consideration, so that by applying a factor of exploitation of at most 0.5 of these projects, it will be possible to attain the objective proposed. It stands to reason, therefore, that the greater part of the 75,000 hectares must be found within the southern regions where there are greater facilities for the fullest exploitation of irrigation.

This is the more necessary with regard to the production of rice, for which it is intended to make use of salty soils to be found in the lower reaches of the river deltas. These salty soils will, in turn, be improved by the crops mentioned. Preliminary work is already under way, so that it should be possible to irrigate and grow crops on 200 to 300 hectares in two or three different regions of the country during the next summer. The necessary water will be obtained by pumping from the adjoining rivers. Depending on the results achieved by these tests, plans for the expansion of rice culture will be made. Emphasis must be here laid on the contribution to this work made by two American specialists, W. L. Packard of the ECA Mission to Greece, and C. T. Sturdivant of the FAO.

The installation of irrigation systems, especially in the southern areas, will encounter difficulties with regard to actual construction as well as to operation, because the farm holdings have been divided and subdivided to such an extent that there are plots of one-half and even of one-tenth of a hectare. In order to distribute the water for surface irrigation to each separate lot it will be necessary to multiply the length of the ditches and to have a much larger number of devices to regulate the distribution of the water, than would be commonly provided in areas where farms are of regular size (10 to 20 hectares).

This factor will increase the cost both of construction and operation of the irrigation system, and consequently the cost of the goods produced.

This drawback can to some extent be counterbalanced by the intervention of local organizations of farmers who can impose a uniform method of cultivation upon a number of neighbouring small plots. The proper solution to the problem of land fragmentation, however, will be the industrialization of the country. The demands of industry will absorb part of the rural population, thus decreasing to more acceptable figures the number of farmers per square kilometre of arable land. Industrial development is one of the aims of the ECA programme, the first step toward which is abundant and cheap production of hydro-electric power.

The higher cost of construction of such irrigation systems, together with their higher operating expenses, decrease the profit-cost relation to limits lower than are accepted in most cases, thus raising some doubt as to the advisability of the projects. Matters of social and financial expediency, which make it imperative that opportunities for work be given to as great a number of farmers as possible, and that food production be increased, render both acceptable and justifiable a higher than usual expenditure for irrigation projects in regions with conditions similar to those of Greece.

	Greece	*California*
Total population	7,500,000	6,907,387
Total area (sq. km.)	131,507	406,120
Crop land, including fallow, 1939 (hectares)	3,259,213	3,460,800
All farms	950,000	135,676
Population on farms, 1939 (per cent)	63.3	9.7
Crop land per farm (hectares)	3.4	25.5
Area irrigated (hectares)	192,000	2,027,827
Crop land irrigated (per cent)	5.8	70.1
Total value of farm production (in thousands of dollars)	250,000	1,062,515
Average income per farm (in dollars)	263	7,831
Installed hydro-electric capacity, 1945 (kw.)	8,000	1,989,000

Some idea of the results that can be achieved through a general exploitation of the water factor can be gained from the preceding table, giving a comparison of features typical both of Greece and California, a state where water is put to the best possible use.

APPENDIX

GENERAL FEATURES OF GREECE

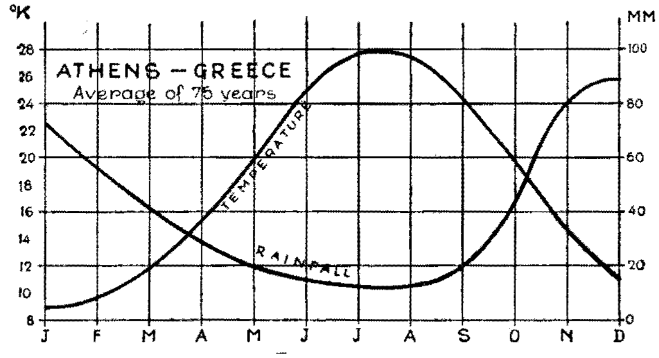
1. One of the main characteristics of the Greek economy throughout more than thirty centuries is its penury of natural resources susceptible of easy development, such as mineral ores and fuels—resources which usually furnish the capital by which the technical and financial development of a country is made possible. To this elemental handicap of the Greek economy must be added an acute shortage of land in comparison to the population. For these and other reasons Greece may unquestionably be classified among those countries which have a low level of technical and financial development.

2. *Climatic features*

Greece can be placed among the semi-arid countries, according to the classification adopted by Whidtsoe. Its climate is similar to that of other Mediterranean countries (i.e., central and southern Italy, Spain, Algeria, etc.) and to that of the Argentine and the western states of the United States. The Pindus mountains, whose long range extends from north to south, divide the country into two separate and totally different climatic areas; this difference is based on the amount of rainfall at an elevation not surpassing that of 100 metres above sea-level. In the western area the average annual rainfall in many parts exceeds 1,000 mm. (40 in.) while in the eastern areas it varies between 300 and 500 mm. (12 in. to 20 in.). The average number of rainy days—about 100—is approximately the same all over the country, but the rainfall is unequally divided between the various seasons of the year, i.e., 40 per cent during the winter quarter, 10 per cent during the summer quarter, and the other 50 per cent almost equally divided between the autumn and spring quarters.

Both the total amount and the distribution of the rainfall varies considerably between the eastern and western areas. In the eastern area, the distribution is as follows: 40 per cent of the rainfall occurs during the winter, 10 per cent during the summer, and 25 per cent during the autumn and spring respectively; while in the western area the distribution is 50 per cent during the winter, 5 per cent during the summer, 15 per cent during spring and 30 per cent during the autumn. From the above figures it can be deduced that during autumn and winter the rainfall in the western area is three times that of the eastern area, one and one-half times during spring and approximately the same during the summer.

The average annual temperature varies between 13 degrees C in the northern areas and 19 degrees C in the southern areas, the maximum during the year being 42 degrees C and the minimum —10 degrees C. It is interesting to note the distribution of average monthly temperatures in relation to the average monthly rainfalls, since this is a characteristic of the climate of importance to agricultural exploitation. The relationship is shown in the diagram below:



The average cloudy weather occurs in the ratio of 4 : 10, i.e., the sky is more sunny and clear than overcast, and more especially during the six-month summer season, the period of the growth and development of plants, when there are six sunny days to one cloudy day.

3. *Ground configuration and density of population*

Greece is typically mountainous. Eighty per cent of its total area is composed of rough uneven ground with steep inclines reaching a height of 2,500 metres above sea-level and more. Only 20 per cent is composed of relatively flat farming land at a height varying from 0 to 100 metres above sea-level.

The flat areas are divided into two categories: the relatively large plains, to be found chiefly within the eastern and north-eastern areas of the country, and the narrow coastal plains distributed along the 10,000-km. coastline of the mainland of Greece and that of the larger islands. There are also a few high plateaux. Owing to the configuration of the land in Greece only a small percentage of its area is suitable for agricultural purposes. Out of a total of 130,000 square kilometres only 32,600 square kilometres can be farmed.

4. *Characteristic features of the agricultural economy*

The land area of Greece is distributed as follows:

	Sq. km	*Per cent*
(*a*) Farm lands	32,592	25.1
(*b*) Pasture lands (low grade)	10,110	7.8
(*c*) Forests	31,374	24.1
(*d*) Lakes and marshlands	2,296	1.8
(*e*) Barren areas (bare rocky soil)	53,614	41.2
TOTAL	129,986	100.0

Here it must be noted that, owing to the ravages wrought on the forests during the enemy occupation, one-third of the area listed above as forest land must now be considered as pastures.

One-fifth of the agricultural area is not cultivated but is left lying fallow, under the system of crop rotation which in the larger plains is used for cereals and industrial crops as well as to assure enough grazing ground for the nomadic herds of sheep and goats during the winter.

The entire Greek population must live off this small expanse of land, and as was stressed by the special Commission of the FAO, "... The Greek farmer tries to make a livelihood out of agricultural lots which for each peasant family are smaller than any other country in Europe and the smallest of any in the world excepting India and China ...".

The density of population compared to other countries is shown in the following tabulations:

(*a*) Density of total population per square kilometre of arable land: Greece, 284; Yugoslavia, 169; Bulgaria, 142; and Romania, 135.

(*b*) Same as above, for rural population only: Greece, 157; Bulgaria, 118; Yugoslavia, 114; Romania, 97; Italy, 90; Germany, 52; France, 48; United States, 17; and Canada, 11.

(*c*) Distribution of farms according to size among the rural population:

Size of farms (in hectares)	0-1	1-3	3-10	10-100	100+
Farmers possessing such farms (per cent)	42.44	30.09	23.45	3.87	0.15

The small farms, furthermore, are seldom in one piece but are composed of many small, widely dispersed sections as a result of division of family holdings through sale and inheritance. One reason for the small size of these agricultural lots is that the Greek Government during the last thirty years expropriated large estates and divided them among the peasants who cultivated them. Being owner of his own land, the Greek farmer, although extremely poor, is conservative at heart.

The average annual income of the rural family does not exceed $250 in periods of peace. The Special Financial Mission of the United States Government (February 1947) states on this subject: "The standard of living of the 7,500,000 inhabitants of Greece was always dangerously low. And the national income as reckoned by our standards was always low, one of the lowest in Europe . . ."

Lastly, it is a characteristic of the agricultural economy of Greece that domestic production of foodstuffs does not cover more than 80 per cent of the requirements of its population, even though consumption is low. The daily pre-war average (1938-1939) was 2,060 calories *per capita*, decreasing to 1,300 to 1,400 calories during the war. The balance of requirements is ensured through the import of foodstuffs from abroad, especially wheat and live-stock products. This is, however, effected at the expense of the balance of payments of the country, a balance which has always been deficient. The average annual deficit during the period of 1936 to 1939 was approximately $40 million, and the average value of foodstuffs imported during this same period was $26 million annually.

There follows a tabulation of the various crops, showing for each crop the percentage of cultivated areas and the annual value of production.

	Cultivated area Per cent	*Value of production Per cent*
Cereals	70.44	42.91
Vineyards	7.73	9.34
Industrial crops	7.18	20.68
Crops for fodder	4.32	9.06
Pulses	3.57	2.26
Currants	3.46	9.74
Vegetables etc.	3.30	6.01
TOTAL	100.0	100.0

Recent Developments in Irrigation in Indonesia

W. F. EYSVOOGEL

ABSTRACT

To give an idea of the field of action from which the conclusions are drawn, a general outline of agricultural production and irrigation in Java and several other islands of the Indonesian Archipelago is given. After this several important problems of tropical irrigation are discussed.

The *method of irrigation* for rice-growing cannot be improved but the watering of the so-called second crops is still unsatisfactory. Too much labour is wasted in sprinkling by hand.

***Distribution* to the field is organized by forming units of 300 to 400 acres. In these units farmers are managing their water problems in co-operative activity.**

***Water requirements* in the plains depend in the first place not on plant transpiration or on percolation and evaporation but on the problem of soil cultivation. Where the monsoon rainfall is limited to four months it is necessary to cultivate at least part of the fields in dry weather. This takes large irrigation heads.**

The method of *repayment* in Indonesia is indirect, the profit of the Government being secured in the automatic rise of the land tax which follows the building of irrigation works.

IRRIGATED AREA AND PRODUCTION

In 1941, the total area of irrigated fields (terraced and dyked rice-fields, paddy-fields or *sawahs*) in Java was 3,350,000 hectares (8.4 million acres). Of this area, 1,200,000 hectares (3 million acres) are included in modern irrigation systems, for 300,000 hectares (0.75 million acres), dams and sluices are built as an improvement to older works constructed by the native Javanese and Sundanese population, 1,100,000 hectares (2.75 million acres) are irrigated by means of small canals and dams of boulders in bamboo-matting, and 750,000 hectares (1.9 million acres) finally get their water directly from rainfall. The big irrigation programme is nearing completion; along the flat north coast the irrigation districts range themselves one after another, getting their water by means of low masonry diversion dams from the rivers. Only for 200,000 hectares, partly under native irrigation, partly "rainfall-*sawahs*", are irrigation works still under consideration.

Moreover there are 4.5 million hectares (11.25 million acres), of dry fields, situated in the mountainous part of the island on slopes too steep for terracing and irrigation.

The irrigation works built by the population, for the greater part, are situated in the hills and on the slopes of the volcanoes. They give the well-known picturesque aspect to the country and are working satisfactorily.

The rice-fields depending on rainfall, are mostly small lots between the foothills, for which irrigation at reasonable cost is not possible.

Construction of modern irrigation works started at the end of the nineteenth century. The total expenditure on irrigation in Java till 1940 was 210 million guilders (80 million U.S. dollars). The construction costs of the projects vary widely; fl. 100 to fl. 125 per hectare (16 to 20 U.S. dollars per hectare), in the years 1938—1940, can be taken as a general average.

The staple product during the wet monsoon (December-April) is rice. Rice-production in 1940 equalled 4 million metric tons (1 metric ton = 1,000 kg. or 2,200 lb.). In the dry monsoon (June—October) a second rice-crop is harvested in nearly 15 per cent of the paddy-area; 50 per cent is planted with so-called *palawidja* crops (corn, cassava, sweet potatoes, peanuts, soy-beans) and 35 per cent is lying fallow. On 90,000 hectares (225,000 acres) sugar-cane was planted.

On the dry fields corn and cassava are the suitable crops; upland rice (a special variety, *padi-gogo*) is also planted.

The planted area and the average yield of the *palawidja* crops can be improved considerably by building storage reservoirs. In 1941, 10 reservoirs with a total storage capacity of 200 million cub. metres (160,000 acre-ft.) were in operation, 4 reservoirs with a total storage of 250 million cub. metres (200,000 acre-ft.) were under construction or planned. After the war a big storage reservoir was projected for Pasoendan (western part of Java). This will provide storage of 3,000 million cub. metres (2,400,000 acre-ft.). Many more are needed, but the geologic features of the Java hills generally are not favourable to dam-building.

During the war and the post-war difficulties, construction of irrigation works was suspended. Wilful damage to existing works was slight, everybody clearly appreciating their potential capacity for food production. Of course, extensive under-water repairs, due to scour and erosion during six years, will be necessary, and these are partly already in execution.

Of the other islands, the southern part of the Celebes and the island of Lombok are especially important for rice production. With Java, these islands are the only exporters to the islands where food is scarce (mining districts Bangka and Billiton, and rubber and oil districts in Borneo). As a general average, Java exports 50,000 tons, Celebes 50,000 tons and Lombok 25,000 tons of rice annually.

In the southern part of the Celebes and in Lombok modern irrigation works were under construction (Celebes 100,000 hectares, Lombok 30,000 hectares). They were nearly completed in 1941 and will soon be finished.

Bali is well-known for irrigation works built by the population. Nearly every hectare of the 94,000 hectares of paddy-area is irrigated in a most ingenious way, the yield being the highest in the Archipelago (average 1.8 ton shelled rice per hectare = 1,600 lb. per acre).

METHOD OF IRRIGATION

Rice is irrigated by the contour-check method. Water flows from check to check, sometimes as much as 8 to 10 checks getting water from one ditch-flow. Irrigation is continuous, from planting to ripening.

Where the fields depend on rainfall, the width of the levees is 3 to 4 feet; for the checks getting irrigation, widths 1½ to 2 ft. suffices. The population is expert in handling inflow and outflow. Regulation is done with the aid of a sod only but the water-level is kept within very close limits.

If sufficient irrigation water is available, corn, peanuts and soy-beans are flooded in rotation. Corn and peanuts get one irrigation in three weeks, soy-beans mostly only one irrigation during the growing period. In the last months of the dry monsoon (September-October) river flow in Java is not usually sufficient for flooding. Sprinkling by hand is the only feasible solution, the digging of furrows taking too much labour for the few irrigations that the ripening crop still needs. It is important to accustom the Javanese farmer to the use of corrugations, in the same manner as is done in the United States for row crops. Oxen may be used instead of tractors.

Sugar-cane is irrigated by sprinkling.

DISTRIBUTION TO THE FARM

As in most tropical countries irrigation water in Java is not delivered to the farm but to a group of farmers. The farms in these densely populated countries being extremely small (general average in Java 1.5 to 2 acres, in the other islands 2 to 3 acres), it is not possible to deliver irrigation water to owners.

In the hills, where dams and canals are constructed and operated by the population, the area of the rice-fields and the area of the village (*desa*) are usually parallel. In former times the villagers felled the trees, prepared the land and dug the canals in co-operation. Therefore, up till now, the operation of the system is supervised by the village board, one of the members (the *ulu-ulu-desa*) being specially assigned to look after water problems.

When the first modern irrigation systems in the plains were put into operation, difficulties arose. Here existed only sparsely populated villages, getting their food from a few rainfall-*sawahs*. The location of lateral canals and drainage channels in a modern irrigation system is determined by topographic conditions. Therefore, it is impossible to divide such an area into plots, for community distribution, which are even more or less conformable with the village boundaries. When distribution started, nearly every village had its paddy-fields in several distribution plots. Especially in the dry monsoon, when river flow is low, difficulties between the farmers were manifold.

It took a long time to get the population accustomed to the modern solution: the water-users' corporation. Even now the new idea has only partly penetrated and it will take some time to conquer the whole area.

The system works as follows. Each irrigation district is parcelled out into units of 300 to 400 acres. At the highest point of each lot, water is delivered by the Irrigation Service; there are found the delivery gate and measuring device (the most modern device is an adjustable broad crested weir, fit for checking and measuring). In the community unit irrigation ditches and drains are dug in co-operative effort; survey and location are done by the Irrigation Service.

The landowners choose their representative, who acts as water-master (*ulu-ulu-pembagaian*). He produces every five days (the Javanese reckon in a week of five days) the total acreage of planted and cultivated fields and receives the quantity of irrigation water which is proportionally due to his unit. For rice this quantity is distributed continuously, for corn etc. rotation between parts of the unit is practised. Distribution and rotation are the task of the *ulu-ulu,* who is paid by the owners, mostly in money, sometimes in rice, sometimes by the right to use some of the communal fields.

The most desirable acreage for the community unit is a continuing problem. The idea was advocated to take complete lateral systems as distribution units (the same idea as "lateral distribution" in the United States). It is evident that in Java this method will not work. The population are very simple people and to co-operate efficiently they have to know each other. Two villages are the utmost that can be grouped together. Other irrigation officials advocated very small units. They kept the idea that the unit was part of the Irrigation Service and that distribution in the unit had also to be supervised by them. This is the reverse of progress; the autonomy of the corporation has to be guarded carefully. The final conclusion was that, as a general average, 300 to 400 acres is the most desirable acreage.

WATER REQUIREMENTS

Water requirements in Java form a very intricate problem. In the young volcanic soils irrigation water is rich in soluble nutritious salts. The Javanese farmer who is not accustomed to the use of fertilizers, prefers an ample irrigation and many of the small canals in the hills have capacities of 3 to 4 litres per sec. per hectare (0.04 to 0.06 sec.-ft. per acre). In the plains the costs of such large capacities would be prohibitive, besides water is not so rich and drainage is more difficult. Thus the capacity of the canals in the first irrigation works was fixed on 1.4 litres per sec. per hectare (0.02 sec.-ft. per acre).

In later years the problem was studied extensively. The minimum water-supply is the balance of the water losses caused by plant transpiration and by evaporation of the flooded paddy-fields. Losses by soil percolation are negligible in the plains of Java, especially because wet-rice growing tends to form an impenetrable layer at a depth of 10 or 12 inches.

For rice being planted in the so-called wet monsoon (precipitation 8 to 10 in. monthly), the direct rainfall should be amply sufficient to evaluate these losses, if this precipitation was more or less regularly distributed. This is not the case; dry periods of 10 or 12 days are pretty frequent. Therefore the minimum capacity of the irrigation canals is the head which is needed for the compensation of these losses (5 mm. a day = 0.2 in. a day = 0.6 1/sec. per hectare = 0.008 sec.-ft. per acre).

Where water is bringing in fertilizing salts (the normal case in Java) it goes without saying that the maximum capacity is limited only by river-flow and costs. Yet there is another item to be considered: cultivation. Rice is seeded on small tracts (nurseries) and the seedlings are replanted when six weeks old. This means cultivating a hard-baked soil, which can be done only after an ample irrigation. But after the cultivation of the nurseries, which cover only one-tenth of the area, cultivation of the other nine-tenths of the area follows. Without rainfall this is only possible with large irrigation heads. This means that in irrigation-practice the capacity of the canals is often defined by the heads necessary for cultivation. Where the rains set in early, the canal capacity can be reduced. Rotation between the distribution units leads to a further reduction. Light soils take far less water for cultivation than the heavy clays along the sea coast.

This is the reason that canal capacities vary widely. The smallest irrigation head is given in a 20,000 hectares scheme in the Celebes where a light sandy loam and an early rainfall co-operate to make 0.01 sec.-ft. per acre sufficient. In the coastal plains of Java the capacity is mostly 1.5 times to twice as much.

METHODS OF REPAYMENT

In Indonesia irrigation water is delivered without charge. This is possible because repayment of construction and operation costs can be found in the land tax. This tax which is levied in Java, the Celebes, Bali and Lombok, is in reality a land-production tax, the productivity of the fields being the base. This productivity is calculated in two ways: taking a census of the harvest and classification of the soils by a committee of farmers. If second crops are harvested an additional percentage is added. The productivity is fixed for ten years.

After deduction of 1 ton per hectare for support of the family, the productivity is multiplied by the market price of paddy and a percentage is taken which gives the assessment. The percentage being based upon the classification, and irrigated fields being more highly classified than those depending on rainfall, it is easy to see that the costs of the irrigation works are automatically repaid.

The drawbacks of the system are: the difficult evaluation of the increase of production and classification when starting the project, and second the long time elapsing before the increase is effectuated, which means additional costs for the accrued interest on capital during so many years. In project evaluations it was usual to demand a 50 per cent fiscal rentability and in special cases, when the building of irrigation works took the character of relief work, the Government contented itself with less. In a very thorough study P. L. E. Happe, C. E., calculated that the return on construction and maintenance costs in the year 1936 was 4.5 per cent and that this percentage in the following years would be rising slowly. Where the interest on Government loans at that time was 4 per cent, this is a very satisfactory result.

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Development of Irrigation Farms with Special Reference to Irrigation and Crop Production under Desert Conditions as Observed in Saudi Arabia

JOE T. SMITH

ABSTRACT

Determining factors in selecting farm locations:

Land. Discussion of type and origin of some arid soils with reference to texture and value;
Presence of alkali salts in desert soils;
Desert sand and agriculture;
Economics of land reclamation with regard to availability of productive land.

Water. Discussion of water with regard to its application to land and with reference to the water-supply of Hofuf, Saudi Arabia;
Economics and means of water elevation.

Land Reclamation:

Alkali salts in soil; means of detection with reference to what salts may be expected;
Observed effects of high salt contamination in soil;
Means of alleviating toxic conditions resulting from salt contamination; mineral application;
Drainage of land;
Condition of excess clay in soils and its alleviation;
Wind-breaks; kind and purpose as observed in arid regions.

Irrigation:

Desirable time to apply water to growing plants; means of determining such time;
Danger of indiscriminate use of water;
Water requirements with regard to soil texture;
Methods of applying water to fields; transporting water;
Means of water application most widely used;
Application of water to land with regard to soil texture.

This paper is concerned with conditions under which little water is available from rainfall and none from diversion of surface-water such as that from rivers or other waterways; the only source is artesian wells and mechanical or hand-dug wells over which various types of pumping apparatus have been set.

Although this paper is an experience report resulting from several years' work and observation in agriculture within Saudi Arabia, it cannot be said that all practices advocated, such as those of a remedial nature, are being carried on at this time. On the other hand, this writer has not had an opportunity to observe agriculture in the western sections of the land.

DETERMINING FACTORS IN SELECTING FARM LOCATIONS

Land

Wadis located in arid localities and flowing at intervals of several years often fan out on flat plains at their extremities or along their course and form alluvial plains of various sizes. The soils of such plains are a result of untold years of water deposits, and more often than not they are found to be high in content of the elements needed for plant food. However, as the rainfall is not sufficient to sustain an appreciable amount of plant growth, such soils seldom contain an adequate amount of organic matter. Such alluvial soils are often found to contain a high content of clay matter, and may contain varying amounts of the alkali salts.

Other soils may be found which are a result, perhaps, of more than one soil-forming process, such as wind and water-deposits combined with the natural soil-forming process of creating soil from mother material lying under the upper layers.

In lands where the altitude is sea-level or slightly above and which are fed by artesian wells, the danger of a high water-table may arise to confront the agricultural worker. This danger may be present in other soils which are underlain by a heavy impervious clay strata at varying depths below the surface.

It may be found, particularly in the above-mentioned alluvial deposits, that the clay content of the soil is disproportionately high. In such cases the soil is apt to form upon drying after irrigation, a hard, near-impervious surface layer which may adversely affect seed germination and plant break-through.

As result of lack of rainfall, by which detrimental salts may be leached out from the root zone, many soils of arid regions contain toxic amounts of soluble salts in the upper portions of the soil. In severe cases of salt contamination, economics alone may deem the application of reclamation processes unprofitable.

Soils of desert lands may be overlain by layers of small pebbles or rocks of varying depths. When these layers are of too great a depth, all but the most primitive and unprofitable type of agriculture is impossible. This accumulation of small rocks on the surface is evidently the result of wind erosion by which the soil particles themselves have been swept away.

The great expanse of sand often found in desert localities offers little for the agricultural worker. Too often native vegetation consists only of sparse growths of desert shrubs and grass. The rolling sands of the desert have been found to contain little in the way of plant food.

When considering the economics of land reclamation projects in a region, the amount of land available for food production must be considered. Where this amount is small, the expending of exceptional effort and expense may be advisable where the feeding of a people is the goal.

Water[1]

If water of good quality is available at or near the surface of the ground, and land subject to crop production is available in the same general area, some means will always be found to apply one to the other. From the most primitive type of water extraction to the most modern, the principle remains the same.

The water feeding the city of Hofuf, Saudi Arabia, and immediate vicinity, is accumulated in underground rock reservoirs or cavities from the slight amount of rain falling in the area lying west of the city of Hofuf. In going from the higher to the lower area, the water builds head and consequently artesian wells are the result in the vicinity of this city. Not in all cases, however, does the water flow. When the water leaves the flowing wells and is directed into ditches it is often necessary to re-elevate the water to higher strips of ground. In the above two cases, therefore, some means must be had by which to elevate the water. Over a period of time economics will dictate the proper method to be used. If a sufficient amount of supplies are available, mechanical pumps both centrifugal and deep-well may be used economically on individual farms. As a farmer may adjust the size of his pump and consequently the cost to the land under cultivation, it is perhaps possible for farmers to elevate their water mechanically at a cost which would compare favourably to the expense incurred in its elevation by means of animals.

Although the irrigation water discussed in the paragraph above is relatively pure, areas have been observed which were fed by waters containing a high content of detrimental salts. The purification of such water in the amounts needed for irrigation entails so great an expense that the matter has not been considered. However, if the salt content of the water is not too great and proper drainage facilities are installed, crop production may be possible. In such cases it may be advisable to plant only those crops which are somewhat tolerant to saline conditions.

[1]The conditions under which this paper was written with regard to water-supply were explained in the first paragraph.

Where water is available, although at depths of several hundred feet, the advisability of bringing it to the surface will depend upon many matters, largely economic considerations.

LAND RECLAMATION

As stated before, the soils of arid lands are often prone to have a relatively high content of soluble salts in the root zone. Soils so affected may be observed to be supporting only those plants which are known to be salt-tolerant. Although the nature of such plants may vary with the area, it has been observed in the Al Kharj area south of Riyadh that where the plants are fed by a high water table, these salt-indicator plants take the form of high, stemmy and very tough grasses. In other areas the plants may be a salt-tolerant sage.

The presence of salt is often determined if its accumulation is relatively high by observation of the surface soil and examination of the soil texture. In extreme cases of contamination, the soil surface may become crusty to the foot and if the evaporation is great the area may become white to the eye. If the presence of alkali has resulted in the separation of soil particles within the soil granule, the soil may be somewhat plastic when wet or give a slight appearance of rubber.

If laboratory facilities or the equivalents of such are available, a more accurate determination may be made as to what salts are present and some indication derived as to their quantity. Chemical tests are sometimes made in the field to determine the degree of alkalinity. Numerous reports from studies made in this field seem to agree that the salts of sodium such as sodium hydroxide, carbonate and bicarbonate are the main offenders in creating a detrimental soil condition.

If the salt accumulation at the root zone is a result of a high water table, it follows that the first remedial action must be the lowering of the water table. If the land lies in a depression which is lower than any point of the surrounding area, the problem may become acute. In such a case it may be found that the water table is being supported by an impervious layer of material lying not too far below the surface. This being true, it might be possible to drain the soil adequately by penetrating this layer by various means over the field and directing the drainage-water down through more pervious material. If deemed economically wise, a pumping-station might be set by which the drainage water would be pumped up and out of the affected area.

If the land to be drained lies on a slope or has adjacent to it land on a lower level into which the drainage water may be directed, the problem, although involving a good deal of labour, is somewhat simplified.

The means of getting the excess water away from the land will vary according to the material available. Tile drains as a whole are considered to be the most efficient and give the longest service with the least amount of upkeep. However, in areas where tile of proper quality may not be available, other means such as open ditches are used. The depth and spacing of these ditches will depend upon the permeability of the soil itself and the amount of water which must be removed. An abundance of material is available with regard to the depth and spacing of tile drainage lines. If a large area is affected by a high water table, an interwoven system of drainage comprising the whole area may be established with the lateral drains from small plots emptying into large main lines.

In cases where the high content of sodium salts has deflocculated the soil particles and the soil mass has become rubbery to the touch, chemical means may be used in an attempt to alleviate the condition. This generally takes the form of applying basic elements to the soil to relieve the sodium with the idea of then leaching the sodium from the soil. These applied compounds may be the salts of calcium. Sulphur is often used. (In areas where such compounds are not available, the turning under of organic matter in the form of barnyard or green manure followed by periods of leaching has given good results).

In referring back to a condition which may exist—that of an abnormally high content of clay accompanied by a severe lack of organic matter—the growing conditions may be improved over a period of time by the application of organic matter in the form of barnyard or green manure. If the conditions are severe the tonnage needed per acre may eliminate the use of barnyard manure. As several tons per-acre may be grown in the form of a leguminous crop in a relatively short time, this method of applying organic matter is often more advisable. It has been observed that under conditions in which farmers own only fractions of acres, sand has been carried from adjacent areas and applied to the soil in attempting to make it more workable.

As high velocity winds, which often carry quantities of cutting sand, blow at intervals over most of the flat lands of Saudi Arabia, the question of wind-breaks and means of holding the soil continually arises. If the area to be considered is large, a correspondingly large number of shrubs or other plants will be needed. The area protected by a single wind-break is only several times the height of the wind-break itself. Therefore, in combating a high wind, rows of trees or growthy shrubs must be placed at not too great intervals. Because of its resistance to destruction, the tamerisk or athel is used almost exclusively here. This plant will in a short number of years reach heights of 30 ft. and more. If planted thick and only light pruning is practised, it will break the wind literally from the ground up. The athel is quick to grow from branch cuttings and is tolerant to a wide range of soil and water conditions. Practices such as strip cropping to hold the soil have as yet been used only slightly. Athel is sometimes grown along permanent ditches to divert the sand. The ditch banks may be planted to Bermuda grass.

IRRIGATION

If irrigation is to be defined as the artificial application of water to the soil, it cannot be separated and discussed as a whole to the exclusion of other farm practices such as land reclamation and tillage. However, the practice of applying water to growing crops may be discussed separately. The results obtained from using irrigation in an extremely arid locality fail to give any exact formula as to the time when water should be applied to growing crops. Periodic inspections of the crop and the soil are perhaps the only true methods.

As the plant derives most of its food from the soil solution or the water surrounding the soil particles, a sufficient amount of water must always be present in the root zone to bring the needed elements into solution from the colloids or particles of the soil. Although water in the root zone need not be present to the extent that it is observable to the eye, the soil below the surface in an ordinary loam should be wet to the extent that it will readily ball between the fingers. The use of soil-augers to determine the amount of available moisture both at and below the root zone may be advisable. Plants which have a shallow and limited root growth may be planted at various spots over the field and used as indicators, as such plants are usually the first to show moisture deficiency.

The above discussion has reference to those crops which are grown under average field conditions, and does not refer to crops such as rice where conditions for growth are not of the average.

The condition of the growing crop is, of course, a criterion in judging the time to apply water. However, this alone will often lead to diminished yields if water is not applied until after the crop has begun to suffer.

A great fallacy in irrigation farming is the idea that a certain amount of water must be used and that every plot of ground should take its turn on the schedule regardless of the need of the crop. Such a practice will lead to poor crop yields and may result in a deterioration of the land value from such factors as a rising water table with accompanying toxic salts.

Soils which are of a fine texture are in contrast to soils which have a coarse structure in that the fine soils retain moisture over a longer period of time and, therefore, produce corresponding crops with a lesser number of irrigations. Fields made up of a coarse sandy material cannot retain moisture for any great length of time. If a finer-textured material lies not too far below the surface, the action of capillarity may bring water from it up to the roots of the plant. If the plants are of a deep-rooted variety, the roots may penetrate down to this layer of finer material and draw sustenance there.

The methods by which water is applied to crops varies with the locality and the crop. Methods of applying irrigation water both from under the surface and from above the growing plants are in use. However, water supplied from underground pipe or tile and that supplied by overhead sprinkling systems usually entails the outlay of considerable expense and may be limited to special crops, the income from which is correspondingly high per acre.

The most common method of transporting water to and into fields is by the use of open ditches. Openings in ditches then allow the water to travel over the land either as sheet water or down plant furrows or furrows which have been constructed for the purpose of irrigation. Farmers of the same locality will differ as to their opinion concerning the most advantageous method to apply water from open ditches. However, it has been observed that the major methods are not many, although variations from these may differ slightly. Irrigation by the use of small confining borders is used widely. This method seems especially popular with hay crops and the cereal grains.

When crops are planted in rows or furrows it follows that such crops will be irrigated by turning water into the corrugations. This method is often used on open unplanted land and some saving of water may be gained. Another way in which water is applied from open ditches is by irrigating from lateral ditch to lateral ditch. By the use of this practice the necessity of borders or corrugations is eliminated. This is true sheet or flood irrigation.

In laying out an irrigation project the length of the borders and rows or the distance between the lateral ditches if this method is to be used, must be given consideration. In soils which are tight and therefore not able to absorb water readily, the distance which the water may be allowed to travel may be great, often reaching three or four hundred yards or more. This is possible because soils of a fine-textured material do not take water readily and, therefore, a considerable amount of time may be needed to allow the soil to be saturated to any appreciable depth. On the other hand, where the texture is coarse, a good head of water may be needed to get over the land. In coarse, sandy soils, the water is taken up readily by the land and less time is needed to apply the water. It has been observed that when irrigating sandy land, a good head of water is needed and should be applied over a short distance, often not more than 100 yards.

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Recent Developments in Irrigation in Mexico[1]

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The plan of the Mexican Government is in the main based on the conservation of renewable natural resources. As Mexico is one of the world's poorest countries in soil and water, it is quite natural that her great concern should be to make proper use and derive every advantage from these resources; consequently, being an arid country with an agricultural production insufficient to satisfy domestic needs, Mexico has planned its water policy along the following general lines:

1. The principal use to which the watercourses in the arid, semi-arid and semi-humid zones are to be put is the irrigation of the largest possible area; nevertheless, these waters, before being used for irrigation, must be harnessed for the generation of the largest possible amount of power.

2. In the humid zones the principal uses must be the generation of the largest amount of electric-power, and flood control.

As a result this policy has made it possible to develop irrigation schemes originally executed by the National Irrigation Commission and now being carried out by the Department of Water Resources for the purpose of improving the following areas:

Area improved by means of irrigation projects up to 1910 (before the present water resources policy was initiated) . . . . 700,000 hectares.

Area improved between 1926 (when the present water resources policy was initiated) and 1946, 816,224 hectares.

Area improved in 1947 . . . . 120,307 hectares.

Area improved in 1948 (preliminary figures), 135,542 hectares.

President Aleman's irrigation programme for his six-year term of office (1947 to 1952) provides for works covering an area of 1 million hectares at a cost of more than 1,500 million pesos.

It should be mentioned, however, that in spite of this vast effort, Mexico will never be a great agricultural country, since she lacks sufficient water resources and hence must look to industry for the future development of the country.

A study conducted by the Department of Water Resources shows that the areas irrigable in this country by means of storage dams, whereby 80 per cent of the mean volume carried by watercourses may be utilized, is 6,800,000 hectares in round figures; if to this we add the areas capable of being irrigated through use of subsoil water and the 2 million hectares of cultivable land in the humid zone, we reach a total of 10 million hectares of irrigable land. Since the area of arable land in Mexico is 23,300,000 hectares, the rest will be left for the cultivation of "rainy season" crops in which the element of chance enters. The irrigation area would be equivalent to 0.4 hectares per inhabitant for a population of 25 million. If the entire area of 23,300,000 hectares of arable land were cultivated, this would be equivalent to 0.93 hectares per inhabitant, which is still below the United States figure of 1.2 hectares per inhabitant.

Apart from the physical results of the water resources policy we shall have to consider within the scope of this experience paper the human aspects of this plan as it affects such matters as the system of land tenure and land distribution, the preparation of land and the methods used in Mexico for the recovery of investments in irrigation works.

In Mexico the irrigation plans have been held to be public-utility works on account of the physiographic,

[1]Original text: Spanish.

demographic, social and economic conditions of the country; they are indispensable for the well-being of our rural population and in most cases they cannot be carried out by private enterprise. Hence there is no prospect of any direct recovery of part of the moneys invested.

It is to the national advantage and in the interest of a better distribution of the rural population that many regions of our country should be settled. In the absence of irrigation this settlement was impossible, for to set up centres of rural population in areas which do not produce enough to sustain life is unthinkable.

It may be said that irrigation works are designed to improve agriculture and country life in Mexico and that, while these works represent the means to achieve that end, the correct handling of the physical and human aspects of the organization and operation of the resulting irrigation districts constitutes the real object of this magnificent effort.

From the moment when an irrigation scheme is conceived, careful thought should be given to the manner in which the project will influence the social structure for which it is to serve as foundation. From the very beginning all the stages in the study and execution of the problem of putting water on land should be linked with plans for building up the community which will use that land and for organizing that community.

The Mexican experiment in these matters may be considered in two stages: the initial stage during which the construction of hydro-works and the organization of irrigation districts were governed by the law promulgated in 1926, and the present stage in which the enterprise is governed by the present Irrigation Law (promulgated in December 1946).

In the planning and execution of the irrigation works account was taken so far as possible of the future needs of the users and accordingly not only were works designed and built for the irrigation of the land, but also all the installations necessary to prevent the waterlogging or excessive nitrification of the land; the necessary roads were built to enable the settlers or users to have access to their lots and to remove their products therefrom conveniently; the lands were divided in accordance with the relevant agrological surveys and, in addition, each lot has been laid out so that it can be easily irrigated and form units which are not split up by roads, canals or drains.

Even in cases where these general lines have been followed between 1926 and the present day, it was necessary in each case to take into account the system of land tenure prevalent in the irrigation zone. In the northern part of the country and in the others where agriculture was practically impossible without irrigation, the ownership of land was not very much subdivided and hence in these areas it was relatively easy to plan the division of land along the above-mentioned lines. In the central areas of Mexico where rural holdings were greatly subdivided, the work had to be adapted to the prevalent system of land tenure; this rendered the operation of the irrigation works more complicated and difficult. During the first stage, mentioned above, many irrigation works were built, including those in the districts of Don Martín (States of Coahuila and Nuevo Léon); Conchos River (State of Chihuahua); Santiago River (State of Aguascalientes); Tula River (State of Hidalgo), and, in addition, other great works which made it possible to control irrigation in areas which were then already using the water from torrential watercourses, such as the Angostura Dam on the Bavispe River (State of Sonora) and the Palmito Dam on the Nazas River (State of Durango). Many of the works built at the end of the first stage cannot really be regarded as forming part of that stage from the point of view of their settlement by human beings of which we spoke earlier, and hence should really be regarded as coming within the second stage. The criteria governing the settlement of those districts and the policy concerning the recovery of investments are now subject to the law in force, i.e., they are part of the second stage described above.

As a result of the progress achieved in irrigation works up to 1930 it was possible to have most of the improved areas ready for cultivation; this brought the National Irrigation Commission face to face with the problem of organizing the respective irrigation systems. This task, which is difficult enough by itself, was all the more difficult for us because we had no experience with settling land and hence we had to introduce untried measures or measures with special features; this involved rules and regulations which had to be experimentally applied on the spot and adapted to the social and economic fabric; we had to endeavour to obtain the best results from this legislative laboratory which, as was to be expected, had its ups and downs.

In the irrigation districts in the north of Mexico, such as the Don Martín (Coahuila) and Conchos River (Chihuahua) districts, the initial difficulty met with was to find sufficient prospective settlers because at first there was little demand for land, though in the course of the years this demand increased so much that now the applications for land in the irrigation areas cannot be satisfied.

At first a contract for sale was drawn up under which the settler had to pay 5 per cent of the value of the land and the balance in twenty-five annual instalments plus 4 per cent interest on the undischarged balance. Towards the end of 1930, as a result of the impression gained by the National Irrigation Commission from the settlement of the irrigation districts, a new form of contract was evolved, called a share-cropping-sale contract. Under this contract the settler received his parcel of land as a share-cropper for a term of three years and thereafter his contract was convertible into a contract for sale on conditions similar to those originally stipulated. It appeared at first that the results of this type of contract were excellent since a large number of rural settlers came into the irrigation districts of Pabellón (Aguascalientes) and Don Martín (Coahuila and Nuevo Léon).

In the districts of the central plateau, particularly in those which were densely populated already at the time when the irrigation projects were executed, the operation was simply one of preserving existing installations and distributing water, in conformity with the regulations issued to secure the better utilization of these resources.

Very soon experience showed that the rush for land and the lack of proper regulations were exploited and led to abuse on the part of applicants and settlers, and so, in 1932, stringent measures had to be enacted to prevent these abuses. These new settlement regulations prescribed the qualifications which settlers had to satisfy, together with their rights and duties, and contained such other provisions as were necessary to preserve discipline in the irrigation districts. An attempt was made in these regulations to enact all provisions necessary to correct the defects noticed during the first stage; an effort was made to obtain a more careful screening of the applicant settlers, and no allotment in excess of 25 or 100 hectares could be granted according to the type of settlement contract.

In the irrigation districts which were settled, land values were fixed at rates varying from 70 to 260 pesos per hectare, depending on the settler's means. These prices are lower than the cost per hectare of the works. They were fixed taking into account the fact that part of the investments were recovered indirectly by means of higher fiscal receipts, the economic well-being of the rural communities, the level of public trade and wealth which are of unknown value; and in addition, the settler's financial means.

As an example of the economic value of the areas developed in the irrigation districts during this first stage, we may mention that in twelve irrigation districts, involving an area of 189,330 hectares under cultivation in 1940, the value of the crops was 31,299,710 pesos; in 1945, over a cultivated area of 554,214 hectares in 22 irrigation districts, the value of the crops was 349,024,533 pesos.

The value of production per hectare can, of course, be doubled or even tripled as and when it becomes possible in each irrigation district to diversify agriculture, to grant financial assistance to the farming population, and to make a persistent effort towards the economic organization of the district.

The rates of contribution referred to above applied to the settlers who actually came to occupy the land. As regards the original owners of the irrigation areas, the Irrigation Law in force during the first stage (1926 to 1946) provided that there should be transferred to the National Irrigation Commission a part of each property involved, so that the owner would retain an area of land the value of which, assessed as irrigated land, would be equivalent to the value which the entire area of the said property possessed, before the execution of irrigation works, in the form of woodland or land cultivable during the rainy season. Owing to a large variety of circumstances but very specially because it was impossible to give full effect to the Irrigation Law of 1926, since that would have involved a serious retrogression in irrigation policy, this part of the law could only be applied in isolated cases; this in turn led to great difficulties from the legal point of view and to improper speculation on the part of some landowners. Hence, land in some cases had to be acquired by direct purchase and in others expropriation had to be resorted to.

Towards the end of 1946 there was enacted, with effect from 1 January 1947, the present Irrigation Law which now governs the construction of the works and the development and operation of irrigation districts.

Since this law came into force, the Mexican Government has stepped up its constructive efforts enormously and, as mentioned earlier in this paper, as it is planned, during President Aleman's term of office, to reclaim an area of 1 million hectares in a mere six years, but during the first stage (1926 to 1940) the completed works brought relief to an area of 816,224 hectares only. A radical change has now taken place in the procedures of colonizing land and of recovering investments.

The original owners of land exceeding 100 hectares in area are required to divide land in excess of that figure within the year following the date of the official organization of the district; if they fail to do so within the prescribed period the persons concerned are required to transfer their surplus land to the Federal Government at the market value of similar unirrigated land in that particular region.

Land so transferred to the Federal Government is used for settlement in accordance with the relevant regulations governing sale of land, admission of settlers and so forth.

On land retained by small landowners a compensation contribution is payable to the Federal Government to defray the cost of the irrigation works, for it is essential that those specially benefiting from the Mexican Government's water resources policy should contribute to the development of irrigation in the rest of the country. This contribution is to be determined on the basis of the following factors:

(*a*) The amount of the cost of the irrigation works as apportioned over the improved area;

(*b*) The increased production of the land as a result of irrigation;

(*c*) The market value of the land in the region or in regions similarly reclaimed;

(*d*) The rural population's financial means.

The compensation contribution may not exceed the amount of the cost of the irrigation works as apportioned over the total improved area.

The Department of Water Resources fixes this contribution after hearing the advice of a common representative of the users before submitting the rate of contribution applicable in each case to the consideration of the President of the Republic.

In conformity with these principles the law has been applied for recovering part of the building costs of the irrigation schemes since 1947. So far the compensation contributions have been fixed for the following irrigation districts: Conchos River (Chihuahua) (Second Unit), Lower San Juan, Lower Bravo River, (Tamaulipas), Culiacán River (Sinaloa); and is now being applied in some of the districts in the course of development, such as Valsequillo (Puebla), Mayo River (Sonora), Morelia and Queréndaro (Michoacán), Xicoténcatl (Tamaulipas) and others.

The contributions fixed on the above basis vary from 500 to 700 pesos per hectare. These figures are not exactly comparable with those fixed during the first stage since, owing to the fluctuation in the value of Mexican currency, the cost per hectare of land is much higher and hence the contribution now being fixed appears much higher, though, if the change in the value of money is remembered, it is not so.

At the present time and in view of the need for irrigation projects required by the agricultural interests, and also because the development of these projects is inevitably limited by our financial resources, the financing of many irrigation works has been executed with the direct co-operation of the persons concerned. Where this happens the persons concerned usually enter into commitments to pay within three or four years, and for the purpose of discharging these commitments they may apply to credit institutions for financial help.

As an example of the economic value of production in the irrigation districts we give the following particulars. In 1948, the value of production for 31 irrigation districts covering a cultivated area of 759,966 hectares was 637,936,634 pesos.

If the value per hectare resulting from the foregoing data is taken into account and is spread over the 1,072,000 hectares improved between 1926 and the end of last year, the value of the total production for 1948 would be in excess of 900 million pesos.

Within the limited scope of this paper we cannot go into further analysis or give more detailed statistics to illustrate these aspects. It was our object to present a general picture and we may conclude by saying that the Mexican Government's vast effort in developing the irrigation schemes which are so necessary for the economic development of the country may be regarded as successful both from the technical point of view of the construction of the works, and from the economic and social point of view, of the organization of the resulting irrigation districts

Irrigation in Pakistan

KHAN BAHADUR M. A. HAMID

NAMES OF PROJECTS RECENTLY CONSTRUCTED

Sutlej Valley Project (constructed 1921 to 1932): comprising 11 canals, with a full supply discharge of 48,231 cusecs and culturable commanded area of 6,193,754 acres.

Haveli Project (constructed 1937 to 1939): comprising 2 canals, with a full supply discharge of 11,964 cusecs and culturable commanded area of 1,166,989 acres.

Thal Project (started in 1940, still under construction): comprising one canal; full supply discharge 10,000 cusecs; culturable commanded area 1,800,000 acres.

WATER REQUIREMENTS

The information given in this paper relates to light and loamy soils as existing in West Punjab, Pakistan. Temperatures at Lahore range, approximately, from Jan.-Feb. lows of 35 degrees F and highs of 78 degrees F to June-July lows of 67 degrees F and highs of 115 degrees F. The maximum rainfall is during the summer months of July and August. The information can be of use in areas having similar conditions of soil, temperature and rainfall.

1. If rainfall exceeds 50 in. per annum and is well spread over the whole year there should be no need for providing any other means of irrigation for cultivation. But, as a rule, rainfall is concentrated in a few months of the monsoon season in summer and in some years it is deficient even in those months. So, in areas having rainfall mainly during the short monsoon season, means of irrigation have to be provided.

2. *Subsoil water-level:* Where the subsoil water-level is within 20 to 15 ft. from the natural surface and sweet water is available, well irrigation is sufficient and canal irrigation should not be provided, even though from the point of view of the cultivator canal irrigation would be more convenient and economical. Canal irrigation in such areas raises the subsoil water-level rapidly and causes water-logging unless the canals are lined with impervious material. However, canal irrigation may be considered necessary to get increased production of food and money crops. Only non-perennial irrigation should be provided, i.e., the canal should run from 15th April to 15th October providing for sowing and maturing of summer crops and sowing only of winter crops. Maturing of winter crops would be done with well irrigation.

3. *Drainage Conditions:* Where canal irrigation is to be provided surface and subsoil drainage are very important factors to be kept in view. Canals feed the subsoil reservoir. If canals are lined with brick in cement or cement concrete, absorption losses are reduced to about one-fifth of the losses in unlined channels. So, feeding of the subsoil reservoir continues even with lined channels, though at a much smaller rate. A stage may be reached when the reservoir level may rise even to the natural surface, unless proper drainage of the subsoil water exists, or the addition to the subsoil is taken out by well irrigation in the winter season.

Surface drainage is important so that addition to the subsoil from rainfall is minimized.

4. Under the conditions of rainfall and temperature prevailing in West Punjab certain crops can be grown during the summer season (called *Kharif*) and others in the winter season (called *Rabi*). The adjoining table shows the dates of sowing and maturing of various crops.

Some crops require heavy waterings, e.g., rice and sugar-cane, whereas others can do with a much smaller quantity of water.

Delta is the total quantity of water delivered in cubic feet during a crop season divided by the area in square feet over which the water has been spread.

Rice requires a delta of 4 ft.; Sugar-cane, 5 to 6 ft.; Cotton, 1.5 to 2 ft.; Wheat, 1.0 to 1.25 ft. and 0.5 to 0.7 ft. only in the case of open wells; Maize, 1.5 to 2 ft.; and Forest plantation, 4 ft.

Canal water-supply required for a certain area is calculated by taking into account certain factors, viz. —

(*a*) Intensity of irrigation required in the *Kharif* season —a percentage of the culturable commanded area; this varies from 25 per cent to 30 per cent on non-perennial canals.

(*b*) Full Supply factor. Acres which a cusec of full supply (a cubic foot of water flowing per second) can irrigate in the *Kharif* (summer) season, as known from experience on other canals. This varies from 50 to 70 acres on non-perennial canals.

(*c*) Duty means the area to be irrigated by a cusec in a year; this varies from 150 to 240 acres per cusec of full supply on perennial canals (flowing all the year round).

Non-perennial Canal

If q is the cusecs required for 1,000 acres of culturable area to be provided with canal irrigation, I is the intensity of irrigation required and F is the full supply factor, then:

$$q = 1000 \times \frac{I}{100} \times \frac{1}{F}$$

For example:

I = 30 per cent of the culturable commanded area,
F = 60 acres per cusec,

then $q = 1000 \times \frac{30}{100} \times \frac{1}{60} = 5$ cusecs per 1000 acres of culturable commanded area.

Period of Sowing and Harvesting of Principal Crops Grown on the Canals in the Punjab

(Adapted by editor from chart submitted by Mr. Hamid)

Crop	*Sowing*	*Harvesting*
Vetchfield	April -June	June -August
Cotton	April -July	September-January
Millets	May -July	August -October
Minor millets	May -June	October -November
Grass	May -August	May -September
Ragi or mandwa	May -June	October -November
Rice	June -July	September-October
Maize	June -September	September-November
Great millet	June -July	September-October
Moth	June -July	October -November
Pulses	June -July	October -November
Henna	June -August	October -November
Gingelly (til)	June -July	October -November
Water nuts	June -July	October -November
Cowpea	June -July	October -November
Spiked millet	July -August	October -November
False hemp	July	October
Hemp	July	October
Melons	July	October
Watermelons	July	October
Vegetables	August -November	October -April
Indian rape	September	January
Turnips	September-November	November-February
Potatoes	September	January
Vegetables	September-October	November-February
Mixed gram	September-November	April
Gram	September-October	April
Coriander	September-November	April -May
Carrots	September-November	November-February
Radish	September-November	November-February
Fodder	September-November	February -April
Egyptian Clover	September-October	November-May
Cumin	September-November	April -May
Chicory	September-November	April -May
Lucerne	October	December -June
Wheat	October -December	April
Barley	October -November	March -April
Oats	October -December	February -April
Lentil	October -November	April
Peas	October	November-April
Poppy	October	April
Aniseed	October -November	March -April
Safflower (Kasumba)	October -November	January -April
Rape	October -November	March
Linseed Flax	October -November	March -April
Linseed	October -November	March -April
Lucerne Grass	October	December -June
Maina	October -November	February -April
Millet	October	February -March
Persian Clover	October	February -May
Mustard	October -November	March
Garlic	October	April
Onions	January -February	May -June
Chillies	February -March	September-November
Vegetables	February -May	May -December
Tobacco	February March	June
Melons	February -March	May -June
Potatoes	February	May
Vegetables	February -March	May -August
Cucumber	February -March	May -June
Italian Millet	March -April	July -August
Indigo	March -June	August -December
Sugar-cane	March	October -February
Turmeric	March -April	November-December
Maize	March -April	May -June
Millet	March -April	May -July
Swank	March -April	July -August
Common millet	March -April	May -June

Perennial Canal

q = Cusecs required for 1,000 acres of culturable commanded area.
I = Intensity of irrigation for the year.
D = Duty

then $q = 1000 \times \frac{I}{100} \times \frac{1}{D}$

For example:

I = 75 per cent
D = 240.

$$q = 1000 \times \frac{75}{100} \times \frac{1}{240} = 3.12 \text{ cusecs.}$$

In West Punjab river water-supply is limited in the *Rabi* season. If a canal is designed for a certain discharge for the *Kharif* (summer) season then an adequate discharge in winter may be half (or even somewhat less) of the *Kharif* (summer) designed discharge.

Kharif-Rabi cropped area ratios are different for perennial (flowing all the year round) and non-perennial canals (flowing generally from 1st or 15th April to 15th October).

On perennial canals it may be 1 *Kharif* to 1-1/4 or 1-1/2 *Rabi*. On non-perennial canals it may be 1 *Kharif* to 1 *Rabi* or even 1 *Kharif* to 3/4 *Rabi*. These ratios give croppings in *Kharif* and *Rabi* which suit the agricultural economy in West Punjab. A small cultivator with the minimum economical holding would like to have:

In *Kharif*	In *Rabi*
1 acre of sugar-cane,	1 acre of fodder,
1 acre of rice,	2 acres of wheat,
2 acres of cotton,	1 acre of oil-seeds.
1 acre of fodder.	

It is considered generally that as a bare minimum the mean *Rabi* supply should be at least one-third of the designed *Kharif* (summer) supply for proper development of the area. If the available *Rabi* supply is less than this minimum then it would have to be supplemented by well irrigation or tube-well pumped supply.

An ordinary Persian well (open well in high subsoil area) gives a discharge of about 0.1 cusec and irrigates and can mature crops in about 20 acres per annum.

5. Some soils can grow all the important crops, viz., sugar-cane, rice, cotton and wheat. Others may grow all crops but rice. Some lands, which have been under rice for a long time, do not grow cotton well but can be adapted to grow cotton satisfactorily provided for three years at least rice is not grown on them and heavy green manuring is done.

At present chemical fertilizers are rarely used in West Punjab. Cow-dung manure is in common use. Green manure is provided by growing *jantar* (*sesbania acuteata*) and *guwara* (vetchfield) and ploughing them in when green. This improves the soil.

6. *Existing cropping and possibility of improvements:* The crops grown in West Punjab are named in annexure II. A large water-supply can increase the yield by a small percentage. Fertilizers can improve the yields to a very great extent, but are not within the means of the cultivator at the present market prices.

DEVELOPMENT OF IRRIGATION FARMS AND PREPARATION OF LAND

Farms in West Punjab fall under two categories, viz., (*a*) unmechanized, and (*b*) partially mechanized.

In the former ploughing is done with ordinary country ploughs worked by bullocks or camels (the latter in small zones where conditions admit of camels being kept in large numbers). The method of transport is the bullock-cart. Harvesting and threshing is done by hand labour.

In the latter category machinery is used for practically all operations. The latter are very few in West Punjab.

The distribution of the farms in the two categories depends at present on the area of land owned by each owner; labour rates; availability of bullocks; existence of metalled roads; and availability of cultivators.

The existing conditions favour the first category, and this leads to less productivity.

Improvement in existing conditions within the former category can be effected by:

(*a*) Conserving water-supply by lining watercourses with impervious material—(watercourse is a channel maintained by the cultivators and not by the Government).

(*b*) Use of manures and fertilizers—natural and chemical; cow-dung is the most common manure used, and goats' excreta is the best animal manure. Chemical fertilizers are used rarely, being very expensive at present.

(*c*) Farms in the first category are generally very small in size, an economical holding being of 12 acres. Pressure of population reduces them in size further, and particularly so since the partition of India owing to the large influx of refugees from India to Pakistan—and mostly to West Punjab.

Considerable improvement can be effected by co-operative farming. Partial mechanization would be possible under co-operative farming which would provide better ploughing, better levelling of land, use of better seed by all cultivators and better means of transport. This is the need of the day in West Punjab and is being introduced.

(*d*) By-products from farms at present are: milk, butter, wood and poultry. A market exists for these commodities.

(*e*) Fruit farming has been quite successful. Bottling of juices of citrus plants is done. Canning has not developed yet to any great extent.

(*f*) The existing farms are managed as explained below:

(i) Some farms are cultivated by labour employed by the owners.

(ii) Some are cultivated by the owners themselves; and

(iii) Others are cultivated by tenants who share expenses and taxes and produce with the owners.

The category (i) is run only by efficient owners who take keen personal interest in agriculture. Category (ii) is the best for efficient agriculture, but resources of such owners are limited and restrict development unless co-operative banks are available to advance loans to land-owners wherever required. Category (iii) is very common and not so efficient. The cultivators have to depend on loans from the owner in the absence of banking facilities.

The best size of a farm or group of farms is one getting a discharge of about 1.5 cusecs, comprising about 400 to 500 acres.

For canal irrigation one-acre fields are adequate. For well irrigation, whose discharge is only about 0.1 cusec, the field is much smaller—about 1/40th of an acre.

(*g*) *Reclamation farms:* Some areas in West Punjab are affected by *thur*—sodium salts—which reduce and finally destroy their productivity. Thur gradually rises to the natural surface under the action of evapo-transpiration and more rapidly with the rise of the water-table.

Sodium salts are soluble; it has not been possible so far to neutralize them by any chemical process. The present system of reclaiming such lands is to flush the land with an adequate quantity of water and wash the salts down deep below the natural surface and not allow them to come up to the zone of roots of crops. The crops required to be grown for reclamation are rice in summer and gram or berseem (Egyptian Clover) in winter.

Several farms for reclaiming *thur*-stricken lands are run by the Government with a view to carry out research in reclaiming such lands and to demonstrate to the cultivators the technique of reclamation. The extra quantity of water required for reclaiming lands is one cusec (cubic foot of water per second) for 45 acres in addition to the land's ordinary share of canal water. Light soils can be reclaimed in two to three years and heavy loamy soils in four to six years.

(*h*) For inferior lands basin irrigation helps in quicker development. Under this system only *Rabi* crops are grown for some years; when the land has improved the ordinary system of irrigation is resorted to and *Kharif* and *Rabi* crops are both grown. Basin irrigation has not been done on a large scale so far and is proposed to be resorted to on some parts of the Thal Project which is under construction.

EVALUATION OF PROJECTS

The cost of a project is worked out for administrative approval and sanction on the basis of the average rate of cost per acre of cultural area commanded by the projected canal for headworks, main canal and branches and distributaries. These rates per acre of culturable commanded area for the projects more recently constructed in West Punjab are:

Headworks, Rs. 12.36; Main canals and branches, Rs. 12.94; and Distributaries, Rs. 3.05.

A project is considered as productive if the return from the project covers the interest on the capital cost of the project and the annual working expenses; the present rate of interest is 4 per cent and the working expenses are Rs. 1.25 per acre irrigated or Rs. 1.0 per acre of culturable area commanded.

In working out the return from a project the main receipts taken into account are:

(*a*) Direct receipts. Water-rates on account of supply of canal water—approximately one-tenth of the price of crop yields, and

(*b*) Indirect receipts. Increase in land revenue on account of improvement of yield from land and in its price due to introduction of canal water-supply, less increase in cost of civil administration in the area. The average rate of land revenue receipt is about Rs. 3/8/- per acre irrigated.

(*c*) Interest on sale proceeds of land owned by the Government.

Indirect benefits from development of the area by canal water are not taken into account. This naturally restricts the consideration of projects as productive, but makes such projects sound and attractive financial propositions. If indirect benefits are also taken into account any canal project would be beneficial even though the direct returns might not cover the annual interest and working expenses. Obviously, the present system of evaluation is sounder when the capital at the disposal of a State is not unlimited.

METHOD OF REPAYMENTS

Repayment of the capital cost of a project depends on the method of financing of a project.

Financing of a project may be from: (*a*) surplus revenues, or (*b*) capital loans, or (*c*) contributions.

No repayment is required when a project is financed as per (*a*) and (*c*) supra. For (*b*) the receipts from the project are absorbed in the general revenues of the State and interest on the capital taken on loan is paid from the general annual revenues. Repayment of capital is made from surplus revenue when money market conditions are favourable.

Irrespective of the method of financing a project and whether repayment of capital is made or only annual interest charges on capital are paid, a *pro forma* account is kept showing for each canal system the annual direct and indirect receipts, interest and working expenses and the percentage of annual profit on the capital cost of the project.

Where the lands owned by the Government, commanded by a project, form a small proportion of the whole and the receipts do not cover the annual interest and working expenses, a land betterment tax is imposed on private lands, as in such undeveloped areas the price of land before introduction of canal irrigation is very low and rises suddenly to a very high level on the introduction of canal irrigation. This tax on the Thal Project is Rs. 60/- per acre.

An alternative method of financing small projects can be that the works be constructed by Government at the expense of the landowners, money being deposited by them in advance; the canals be maintained by the landowners and a royalty charged to them for the use of the water.

This system would be useful only where the landowners and cultivators work on a co-operative system and have a very high sense of discipline and civic responsibility. Experience so far shows that water is such a valuable commodity that if its distribution is left to the landowners, the weaker suffers at the hands of the stronger and, therefore, nationalization of this vital industry is much the best thing in the interest of the people as a whole.

Land Reclamation in the Federal People's Republic of Yugoslavia[1]

J. FILIPOVIC

ABSTRACT

The total area of Yugoslavia is 25 million hectares, of which 14-1/2 million hectares are cultivable. The area of partially-reclaimable land amounts to about 840,000 hectares, and about 590,000 hectares could be rendered fully productive. The Five-Year Plan provides for the drainage of 400,000 hectares of marshlands, and the irrigation of a similar area. This will involve the execution of twelve land-reclamation projects in Yugoslavia. The most important are those concerning the Danube-Tisa-Danube Canal in the Federal Republic of Serbia and Lake Skadar in the Federal Republic of Montenegro.

The *Danube-Tisa-Danube Canal* will be navigable throughout its length of 273 km. It traverses the Backa and the Banat, the "granary" of Yugoslavia. It will serve to drain a territory of 90,000 hectares, and will provide irrigation producing an annual revenue of 1,372 million dinars.

Lake Skadar. The environs of Lake Skadar are temporarily or permanently flooded. It is proposed to reclaim 44,272 hectares of this land, 31,231 hectares of which belong to Albania and 13,041 to Yugoslavia.

The first plan elaborated by the Federal Five-Year Plan Commission would have completely solved this problem. The plan was to change the course of the river Drim and regulate the flow of the river Bojana, thus lowering the level of the lake. For reasons unknown, Albania rejected this solution, and we were obliged to resort to another plan.

Under the new plan it is proposed to construct a system of successive embankments, accompanied by the gradual drainage of the lake. In order to avoid raising the water-level and causing damage in Albanian territory, a tunnel 9 km. long, with adequate capacity, will be constructed to take the excess water from the lake. In this way, 17,120 hectares of land will be reclaimed from the lake, and thanks to the warm climate it will be possible to cultivate subtropical plants such as cotton and rice on this land.

The yield obtained to date from the reclaimed regions amounts to about 67 million dinars, and will rise to 438 million dinars after completion of the works.

The Federal People's Republic of Yugoslavia covers an area of 250,000 sq. km., i.e., 25 million hectares. Of this area 14-1/2 million hectares are used for agriculture, as follows:

	Million hectares (Approx.)
Arable land	7.5
Flower and vegetable gardens	0.2
Grasslands	1.8
Pasturage	4.4
Vineyards	0.2
Orchards	0.3
Marshlands and reed lands	0.1

The Federal People's Republic of Yugoslavia is engaged in the reclamation of about 2 million hectares (2,031,260 hectares), including:

840,000 hectares (843,392 hectares) for partial reclamation;

590,000 hectares (592,719 hectares) for full reclamation (land liable to flooding and marshlands).

Full reclamation (anti-flood protection, irrigation and drainage) has not yet been completed. Only drainage and anti-flood protection works have been carried out, while irrigation has been organized only on a small scale.

The irrigation of the barren chalk-lands of the west and south-west, and the drainage of the south and south-west areas which suffer from a lack of moisture will permit of the development of intensive agriculture.

Agriculture in Yugoslavia was formerly extensive, most of the land belonging to great landowners who strove by all possible means to thwart agrarian reform. They were opposed to intensive agriculture because their estates were so large that they could make considerable profits even by extensive methods.

In present-day Yugoslavia the planned economy calls for a considerable effort from agriculture, including an appreciable quantitative and qualitative increase in the yields of cereal and industrial crops. If agriculture is to be enabled to fulfil this task, not only agro-technical, but also hydro-technical works will have to be undertaken. Thus agriculture requires two great contributions from land reclamation: firstly, the cultivation of hitherto barren lands, and secondly, the maximum improvement of lands already under cultivation.

It will be possible to complete the hydro-technical works referred to above within a period of five to ten years, depending on other economic needs, available man-power, the extent of mechanization and the reserves of trained workers.

Taking all these factors into consideration, article 12 of the first Five-Year Plan for the development of Yugoslavia's national economy covering the years 1947 to 1951, further recommends:

1. Draining 400,000 hectares of humid and marshy land;

2. Obtaining a higher and more regular yield of cereals and industrial and other crops by irrigating an area of 400,000 hectares, principally in the corn-growing and subtropical regions, and thus increasing tenfold the area of irrigated land as compared with 1939.

Pursuant to the provisions of the above-mentioned law, it was decided to carry out the first Five-Year Plan as follows:

In the People's Republic of Serbia: to construct the navigable Danube-Tisa-Danube Canal;

In the People's Republic of Croatia: to construct the navigable Zagreb-Sisak-Podsused Canal; to reclaim the

[1]Original text: French.

Lonjsko plain; to reclaim the Belje region; to reclaim the Neretva marshes (Vid and Luka sectors);

In the People's Republic of Slovenia: to reclaim the Prekomurje region;

In the People's Republic of Bosnia and Herzegovina: to reclaim the Bosanska Posavina region;

In the People's Republic of Macedonia: to reclaim the Pelagonija region (drainage of the Bitolj and Prilep plains) and the region of the river Bregalnica;

In the People's Republic of Montenegro: to reclaim the Lake Skadar basin (reclamation of the Donja Zeta and Ulcinj plains, construction of a hydro-electric station on the river Cievna and reclamation of the Belo-Pavlic plain).

The partial execution of the above works and the completion of other reclamation works of national and local importance will achieve the target figures set by the Five-Year Plan (drainage of 400,000 hectares and irrigation of 400,000 hectares).

The reclamation schemes mentioned above consist largely (to the extent of about 70 to 80 per cent) of embankment works, 60 to 70 per cent of these being on dry land and 30 to 40 per cent on flooded land. These works necessitate much technical equipment; but as this is not available and would for the most part have to be imported, two types of machines manufactured in Yugoslav factories will be utilized. The prototypes of these machines, which have been designed by Yugoslav technical experts, have already been made. The machines will be mass-produced in Yugoslavia and will be used for excavation in dry and flooded land.

The rotating "rotor"-equipped crane (a two-rotor prototype of which has already been constructed) was designed by Air-Commander Beshlin. On test, this machine has given better results per unit of time than the most powerful "caterpillar-track crane" which we possess in Yugoslavia. The hydro-monitor, constructed in Yugoslavia for work on flooded ground has given results per unit of time equal to those of caterpillar-track cranes and bulldozers of medium capacity (40 cub. metres per hour). In addition, a considerable proportion of the excavation works on dry land can be carried out by employing labour on a large scale.

The approximate volume of the clearance works undertaken under the first Five-Year Plan amounts to 180,000 million cub. metres.

We give below some significant details on the large-scale works referred to above.

Danube-Tisa-Danube Canal

This canal will serve for the drainage and irrigation of the Backa and Banat region, for river navigation and also for water-supplies for a number of industries.

The Backa, in the south, has an area of 400,000 hectares, and is damaged by surface and subsoil water. The surface-water comes from the High Backa (Telecka) and the subsoil water drains from the high to the middle ground.

The rate of flow of the existing canals in the Backa region is low (about 20 cub. metres per sec.). The rate of flow of the proposed canal is to be 100 cub. metres per sec.

The irrigation of the Backa can be effected by bringing the required water from the north. On arrival, the irrigation water will be distributed by canals. The necessary amount of water could be obtained from the Danube, since it has a fairly high rate of flow (more than 1,000 cub. metres per sec.) even in summer. The water could be diverted near Bezdan.

The main arm of the canal starts from Novi Vrbas in the direction of Novi Sad, where it will deliver most of its water, with the addition of that drained from the Backa.

The fall of the Danube between Bezdan and Novi Sad is about 9 metres.

The canal enters the Tisa near Becej. The high water level of the Danube near Bezdan is 8 metres above that of the Tisa at Becej.

The hydraulic power generated can be utilized near Bezdan, Novi Vrbas, Becej and Novi Sad.

It is proposed to construct a dam on the Tisa below Becej, with locks and hydro-electric stations.

The Banat Canal will begin below the Becej Dam, will pass through Zrenjanin, cross the Begej and Tamis, continue through Brzava and Karas and finally enter the Danube near Banatska Palanka.

The Banat section of the canal will supply water in summer to the Becej, the Tamis and the Nadel, and in spring will receive much of the surface water of the Banat.

The northern part of the Banat can be irrigated by the slower waters of the Tisa.

The canal will cross the Backa and the Banat in the form of a great navigable trunk-waterway about 275 km. long.

From Banatska Palanka to Bezdan the course of the Danube is about 90 km. longer than that of the canal.

The difference of high water level of the Danube between Bezdan and Banatska Palanka is nearly 15 metres.

The canal will also be useful as a drainage canal for the flood-waters of the Danube, the Tisa, the Begej and the Tamis.

The Danube-Tisa-Danube Canal will solve the Voyvodina's water problems and all related questions, not only for the present, but for the more distant future. It will facilitate the works projected and the development of all branches of the Voyvodina river system, of which it will be the backbone.

The economic importance of the Danube-Tisa-Danube Canal is therefore indisputable.

As mentioned above, the canal will perform various functions, e.g.:

(*a*) *Drainage* in the Backa, about 63,000 hectares; in the Banat, about 90,000 hectares.

The extensive works programme proposed under the first Five-Year Plan provides for the drainage of about 90,000 hectares. As the general canal system and the hydro-technical stations have already been constructed, the construction of the Danube-Tisa-Danube Canal will enable a more rational operation of the existing systems and make for more regular crop yields.

It is estimated that the increase in crop yields under the Five-Year Plan will amount (in terms of wheat) to: 90,000 hectares × 3 quintals × 400 dinars = 108,000,000 dinars per annum.

The economic gains obtainable from the water drainage system are beyond question; but it is difficult to give any figures, since no precise data exist. Furthermore, the land concerned produces not only cereals, but also industrial crops.

These regions will also feel the beneficial effects of irrigation, which will lead to the increases in crop yields outlined below.

(b) Irrigation

It is estimated that by the end of the first Five-Year Plan the following areas will have been irrigated:

	Millions of dinars per year
90,000 hectares of cereals: increase of crop yield, 6 c/hectare, i.e., 90,000 × 6 × 400 dinars	216
20,000 hectares of sugar beet: increase of crop yield, 80 q/hectare, i.e., 20,000 × 80 × 60 dinars	96
20,000 hectares sown with potatoes: increase of crop yield, 100 q/hectare, i.e., 20,000 × 100 × 300 dinars	600
20,000 hectares ......: increase of crop yield, 60 q/hectare, i.e., 20,000 × 60 × 100 dinars	120
15,000 hectares planted with vegetables: increase of crop yield, 80 a/hectare, i.e., 15,000 × 80 × 200 dinars	240
5,000 hectares of rice plantations: increase of crop yield, 20 q/hectare, i.e., 5,000 × 20 × 1,000 dinars	100
Total	1,372
Costs	
Amortization	260
Maintenance	250
Motive power	450
Total	960
Giving a net profit of	412

The amortization and maintenance costs have been computed for the entire irrigation programme, i.e., for an area of 400,000 hectares.

The climate of the Voyvodina is continental, with marked extremes of temperature; but for most crops irrigation is merely an added improvement, not, as in desert regions, an essential without which the land remains barren.

An analysis of the climate and crops for the period 1930 to 1940 shows, in the case of wheat for example, that 1938, the year of maximum yield, and 1932, the year of minimum yield, not only had the same rainfall but approximately the same monthly distribution of rainfall. About 35 per cent of the cultivated land in the Voyvodina is planted with wheat. This means that independently of the water available the factors of warmth, light, sun, frost etc., may have a serious influence on crops.

Cultivation on irrigated land is more intensive than on dry land. Irrigation requires the use of stronger fertilizers, for example animal manure. The level of subsoil water is fairly high. Analysis of subsoil water has shown that it is salt, and irrigation must therefore be carried out in such a way that reclaimed lands do not in the long run become salt. The presence of salt strata of soil shows that this is a slow but natural process. It may be arrested by applying agro-technical methods, but haphazard irrigation might accelerate it (*zaslanjivanje*).

(c) Water-supplies to industry

The various industries, particularly the hemp and sugar industries, are situated along the canal and will use large quantities of water.

(d) Communications and hydro-electric power

Generally speaking, canal transport will be used by agriculture and industry. Hydro-electric power will be of minor importance, and will be used to run the electrical equipment of the canal.

THE SKADAR BASIN

Lake Skadar

The Lake Skadar region, which is submerged, marshy or exposed to annual floods, covers a total area of 44,272 hectares.

The following areas are situated on Yugoslav territory:

	Hectares
Land below the surface of the lake to be reclaimed by lowering the level of the lake	3,600
Marshy lands bordering the lake	6,721
Land exposed to flooding; grasslands and pasturage	2,500
Cultivable land	200
Total	13,021

The following areas are situated on Albanian territory:

	Hectares
Land situated below the surface of the lake to be reclaimed by lowering the level of the lake	500
Marshy lands and grasslands bordering the lake	1,200
Land exposed to flooding in the Zabojna region	22,000
Lands damaged by floods in the Zadrilje region	7,531
Total	31,231

The Federal Plan Commission's project provided for the joint reclamation of the Skadar region, in accordance with the report drawn up at Skadar on 28 July 1947 by Yugoslav and Albanian technical experts. This project supplied a final solution for the problem of the Skadar basin water system by detaching the river Drim from the river Bojana and Lake Skadar. The new channel of the Drim was to drain into the sea near Ljes. The Drinjaca was to be completely closed, while the Kiri was to be led into Lake Skadar through a new channel.

Water was to be diverted from Lake Skadar through the Bojana, and the reclamation system also provided for anti-flood protection and the drainage and irrigation of the entire region.

The estimated cost of the project, covering reclamation works, the equipment of the Bojana for navigation and the construction of a preliminary barrage on the Drim, amounted to 2,820 million dinars.

This sum was distributed as follows:

	Dinars
Works carried out in the Federal People's Republic of Yugoslavia	1,014,354,000
Works carried out in the People's Republic of Albania	1,805,646,000

For reasons unknown Albania refused to take part in this project. The reclamation of Lake Skadar is a problem of primary importance not only to the People's Republic of Montenegro but to the entire country. The very favourable climatic conditions make it possible to cultivate the finest species of cotton, as well as rice and other subtropical plants. In these circumstances, it was decided to seek a solution permitting the reclamation of lands situated in the People's Republic of Montenegro independently of any works carried out in the People's Republic of Albania. For this solution of the problem it is essential that water conditions in Lake Skadar should not deteriorate, i.e., that the water should not rise above its present level. The greatest possible area of land must be reclaimed, particularly land bordering the lake, in preference to land below the surface. This is the solution which has been adopted; i.e., to construct embankments on the lake, without reducing the present low, medium and high water levels, in such a way as to recover the old cultivable land by degrees; and to bore a tunnel large enough to maintain the lake at its present levels.

In this process of reclaiming the land by degrees, the following areas will be recovered:

First stage

	Hectares	Hectares
1. The Donja Zeta Basin	7,850	
2. The Cetinjsko-Pucka Basin	4,760	
3. The Crnicka Basin	495	
Total		13,105

Second stage

1. The Jezersko-Podhumska Basin	8,920	8,920
Total		22,025
Excluding Pucko blato		20,045

Other improvements in the Lake Skadar Basin

	Hectares
1. Ockovo plain	600
2. Karabus	2,940
3. Land around Berislavac	1,560
4. Tolosko plains	1,000
	6,100
Brought forward	6,100
	Hectares
5. Momis plains	320
6. Ulcinj plain	4,000
7. Sasko plain	700
8. Bjelopavlicka plain	6,000
Total	17,120

This entire area of 17,120 hectares will be irrigated, and in addition, drainage works will be carried out in the Ulcinj plain over an area of 1,300 hectares and in the Sasko plain over an area of 300 hectares, thus providing further cultivable areas.

Economic benefits

The subtropical climate of the Skadar Basin region, it cannot be too strongly stressed, will provide favourable conditions for the growing of subtropical plants. The principal crops cultivated in this region will be cotton and rice, vegetables, cereals and fodder crops, roughly in that order of preference.

	Dinars
The total yield to be expected in the reclaimed regions amounts to approximately	438,320,000
The present yield in these regions is approximately	67,250,000
Gross increase of yield after improvement	371,070,000

Some details on the principal rivers of Yugoslavia

A list of our rivers shows that Yugoslavia possesses a total of 43,326 km. of waterways having a length of more than 10 km., including:

	Kilometres
Navigable rivers	1,693
Navigable canals	281
Rivers suitable for timber floating . .	2,787
Non-navigable rivers	38,565

We shall cite as examples some of the principal rivers crossing Yugoslavia. The largest is the Danube, which is 2,860 km. long, 582 km. of its course being in Yugoslavia. The maximum rate of flow is 13,618 cub. metres per second, near Pancevo. The largest river after the Danube is the Sava, 940 km. long, with a maximum flow of 5,769 cub. metres per second near Srem Mitrovica. Other rivers are the Drina, 461 km. long with a maximum flow of 5,391 cub. metres per second near Zvornik; the Tisa, 1,358 km. long, of which 167 km. are in Yugoslavia, with a maximum flow of 2,480 cub. metres per second near Santa; the Velika Morava, 245 km. long, with a maximum rate of flow of 2,480 cub. metres per second near Ljubicevski Most; the Drava, 406 km. long as far as the frontier, with a maximum flow of 2,935 cub. metres per second near Donji Milholjac; the Zapadna and Juzna Morava, the Vardar, the Ibar, the Kupa, the Una, the Bosna, the Vrbas, the Mura, the Savina, the Ljubljanica, the Nisava, the Neretva, the Drim etc. It will be seen that Yugoslavia is very rich in waterways.

Drainage of Land for Production

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ABSTRACT

In the following introductory paper on "Drainage of land for Production" special attention is drawn to the origin of the drainage-works in the Netherlands. The author shows how some qualities of the Dutch character were the consequence of the everlasting fight against the force of the waters. Without his great power of endurance the Dutchman could not have achieved what he has in fact achieved : a prosperous country of high repute, in which it is safe and comfortable to live.

The following sub-chapters deal with the coming into being of the so-called *Waterschappen*. These had their origins in the earlier co-operating teams of mud-workers and dyke-builders who were responsible for the creation of the Dutch delta.

After revealing some figures on upkeep-expenses, and the costs and the benefits of *Waterschaps*-works and some remarks about State-aid, assessments and land-classification, the paper turns to the increasing of the salinity of the "polderwater", giving some figures about the chlorine-content and the permissible limit.

A chapter is then devoted to the reclaiming of war-flooded areas, after which the paper concludes with some chapters on tile-drainage : cleaning tiledrains and ditching by means of tractor-driven plough-trenchers.

For a better understanding of the drainage problems in the Netherlands which are so closely intermingled with flood protection we start with a:

BRIEF HISTORICAL REVIEW

For about twenty-four centuries the delta at the mouth of the rivers Rhine, Maas and Scheldt, known as the Netherlands and popularly called Holland, has been inhabited by watermen and mud-workers. In particular we owe a great debt of gratitude to the Frisians or Coastal-Dutch, who in earliest times under most difficult circumstances started to open up this—now our—country.

As its name denotes, it means the Low Countries or Hollow-Land[1] or Land-on-Low-Level and of these twenty-four centuries, twenty or twenty-one have been spent in peril. Only in the last two or three hundred years has some reasonable security from flooding been achieved. It is therefore not far from the truth if we compare our delta with the areas wherein for ever and a day man and water fought and still fight each other.

In order to understand the character of the Dutch people you must know this fact, because as a result of our age-long struggle for existence in a country below sea-level, with an everlasting threat of ruin by inundation or even drowning by the flux of the sea, the rivers in flood or by the flush caused by the rains, or—the worst coming to the worst—a combination of these, the Dutchman became tenacious, persistent, stiff and obstinate. But besides this he acquired a great power of endurance and it is largely due to this endurance, that eventually he once more conquered the fierce force of the water and now is living in a prosperous country. But, as we already have mentioned, it took him a long time to get such a result.

In the dim long-ago one of the things he learned first was co-operation.

Without co-operation there was no chance to exist. What else can mere man do against the force of nature but to succumb and to perish? Only in combination with many others does he dare to stand his ground and even to attack the mighty powers which threaten him with death from drowning.

And so, about 2,000 or more years ago, the simple desire to live created the first teams of men, who used the sticky mud to build dwelling mounds high[2] enough not to be submerged by the highest waves in stormy weather[3].

Some 1,000 years later when the mounds became overcrowded, the teams grew bolder and they started to build the first small dykes to prevent their meadows from flooding and to protect their cattle from drowning. But Nature always seemed to be stronger than man and it went on destroying man's work until he had learned to discern the different properties of Nature and to deal with them.

THE TRANSGRESSION OF THE SEA

Not so long ago our research-workers found out that our country is subject to a constant, though very slow,[4] submerging into the sea.

More precisely during 750 years our country slowly sinks nearly 5 ft. and is submerged; then, after some period of rest, it again rises 1 foot out of the sea during about another 350 years. And thus it goes on every 1,100 years. The effect is an intermitting transgression and regression of the surface of the sea. Nowadays we have entered a new era of slow sinking, of which fact our dyke-makers are now aware. But it must have been strange and disheartening for those early dyke-makers, who lived at the beginning of the former transgression period, to observe in a single lifetime the high tides rising higher and higher and causing an ever-increasing number of inundations of their farmlands. Between 1250 and 1500 there were severe losses of land and lives. The "Zuider Zee" was already formed about 1300 and the Great "Hollandse Waard" near Dordrecht was destroyed in 1421. Out of it the Biesbosch came into being, which "wilderness of bullrushes" still exists. In the North the Lauwerszee and the Dollard-basin were formed, and some time later the extensive lands of Saaftinge and Reimerswaal in the province of Zeeland were lost.

[1]"Hol" can also be derived from "Holt", which means wood.

[2]Sometimes even to a height of 30 ft. above normal sea-level.

[3]It was estimated that in the early centuries, thanks to the invention of the iron-spade, some 75 million cub. metres or 100 million cub. yards of earth were carried to the artificial hills or mounds, which are called "wierden" or "terpen" (1,260 in all). They occur only in the provinces of Friesland and Groningen.

[4]Average about 1 mm. (0.04 in.) a year.

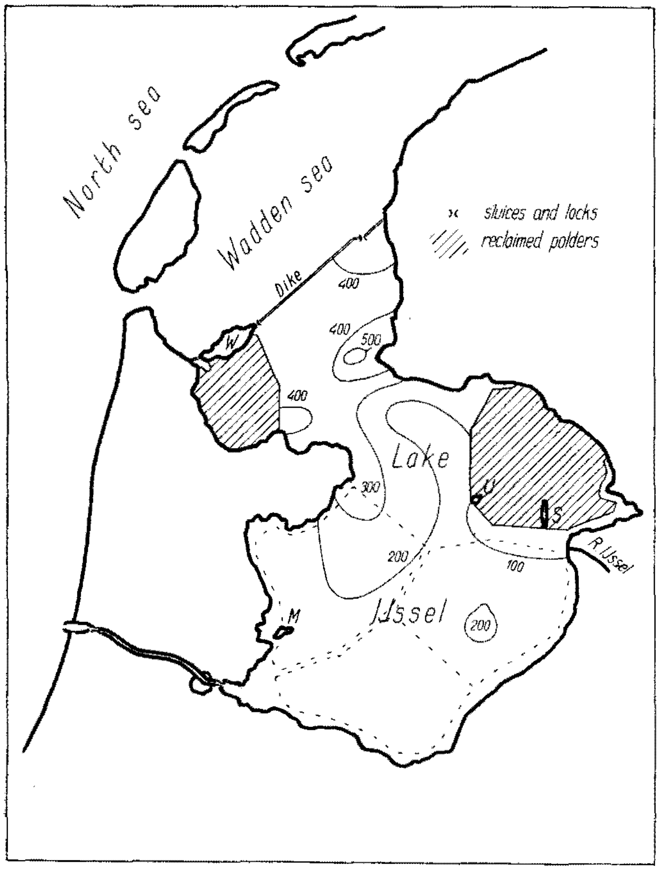

Figure 1. The former Zuider Zee after the enclosure. The original situation is denoted by thick lines. The isles of Marken, Schokland, Urk and Wieringen are shown by the letters "M", "S", "U" and "W". The three latter isles are now incorporated in the new land. The dotted lines indicate the projected dikes for the polders to be reclaimed. The salinity is marked by isohalines. The figures correspond to mg Cl' per litre of water, July 1948. (Mainly from *Driemaandelijkse Berichten betreffende de Zuiderzeewerken*).

It was a good thing for the Dutch in those times of stress that this dangerous transgression came to an end and changed into a regression. From that time on much land was regained.

We quote the figures given by Mr. Joh. van Veen, Chief Engineer of *Rijkswaterstaat*, in his remarkable book "Dredge, Drain, Reclaim; or The Art of a Nation", published by Trio Printers, The Hague, 1948.

Mr. van Veen reveals that since 1200 we have lost about 1,400,000 acres, but in the same time we have regained:

	Acres
On the seashores	940,000
By pumping lakes dry	345,000
By pumping the Zuider Zee dry	168,000
id. in the future	390,000
Total	1,843,000

which is more than we have lost.

Protecting against flood and gaining new land means building dykes, digging ditches and canals.

What this building and digging has meant for the people in our country is shown by the following figures: Mr. van Veen estimated that before the application of steam dredging—that is, before 1860—more than 250 million cub. yards of material had to be transported by hand-barrows, wheelbarrows and horse-drawn carts for the dyke-building, and that about 800 million cub. yards of earth had to be removed by hand in order to drain the land and separate the fields.

THE COMING INTO BEING OF THE "WATERSCHAPPEN"

This work was done in the course of a thousand years and experience was gained by those co-operating teams which—each in a different way, but all in a democratic spirit—drew up their own regulations, which still exist. Nowadays these teams are called *Waterschappen*, which are Districts or Polders in charge of Polder-boards or Catchment-boards and supervised by the engineers of *Waterstaat*, which organization has been for a hundred years the central water authority. Throughout the years the *Waterschappen* have maintained their self-government and the power to threaten trespassers with prosecution and to ordain by-laws. They also have autonomic functions, and the landholder in the polder who is chosen by his neighbours to serve as a dyke-master or a *Heemraad* (Homewarden) exercise power. Their regulations are all based more or less on the same principle, namely that in a democratic manner they are to bestow care on public dykes and ditches and, during the last hundred years, also on public roads, bridges and so on. But the main task of the greater part of the *Waterschappen* remains the

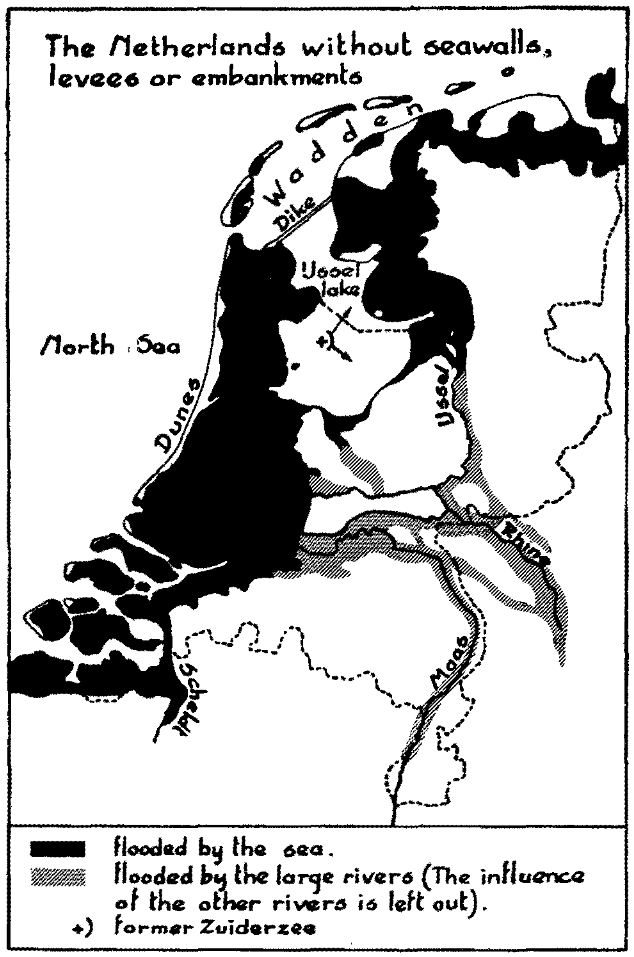

Figure 2

defence against the sea and the rivers and the control of the level of the local waters.

Of the whole surface of the Netherlands, almost 70 per cent or more than 2,300,000 hectares (5,700,000 acres) belong to the territory of one of these *Waterschappen* of which about 2,800 now exist.

Four hundred and twenty-two *Waterschappen* covering about 1,300,000 hectares (3,200,000 acres) attend especially to the protecting and securing against flooding.

The majority of the *Waterschappen*, namely more than 80 per cent, possess more or less extensive drainage statutes. This figure denotes that the drainage problem in the Netherlands is one of the most important.

Apart from the costs paid by the State for the drainage of the reclaimed parts of the endyked Zuider Zee, we will quote here some figures, which were published by Dr. D. R. Mansholt, advisory agricultural expert, in 1942 as to the upkeep-expenses paid by the *Waterschappen* during the pre-war years.

THE UPKEEP-EXPENSES OF DRAINAGE-WORKS EXECUTED BY "WATERSCHAPPEN"

It was calculated by Mr. Mansholt and his fellow-workers that the upkeep-expenses for the different kinds of works were apportioned as follows:

		Percentage of the total upkeep-expenses
Artificial draining by means of pumps . . .		24.2
Draining by means of watercourses (12,000 miles)	8.7	
Navigation canals (1,560 miles)	1.1	12.3
Brooklets and small rivers (1,400 miles) . .	2.5	
Seawalls, dunes, outer-dykes, river-dykes, embankments (4,600 miles)		14.5
Metalled and other roads, together with some contributions to the Government for the upkeep of roads (7,000 miles) . . .		25.8
Sluices, locks, bridges, dwelling-houses, etc.		6.0
Miscellaneous		17.2
Total		100

From the above figures one must conclude that about one-third of the total upkeep-expenses of all the *Waterschappen* are due to the drainage of land.

COSTS OF "WATERSCHAPSWORKS"

In pre-war years the sum spent on the above-mentioned works of the *Waterschappen* ran into about 10 million guilders[5] a year. As for the period during the war, we have much ground to make up. It is planned for the near future to invest some 14 million guilders a year on drainage-works, of which our government will subsidize 10 million guilders a year or about 70 per cent.

With this money, it is estimated, about 35,000 hectares a year (87,000 acres) can be better-drained. Our research-workers have found that the highest production is gained on lands in which the water table is kept as constant as possible. The water table must, of course, vary with the cultivation and the sort of soil. The specialized cultivation of tulips for instance requires a ground-water level of 55 cm. (1.8 ft.) below the land-surface. On arable land generally, the ground-water level should be between 4 ft. and 5 ft. below the land-surface. As these conditions do not yet exist in a great part of our country and the prospective increase in production due to these works is estimated as at least 10 per cent, we have framed an investment scheme for the "Long-term programme (ERP)", from which the above figures are quoted.

Tile-draining is not included in the above programme, being taken care of instead among the smaller ameliorations. In the next few years 8.4 million guilders have been put on the estimates of expenditure, of which the Government will provide 5 million guilders a year or about 60 per cent. Among these ameliorations not only tile drainage but smaller reclamations, landclearing, rebreaking-up of ground and other improvements of the soil are provided for. It is estimated that each year for the amount mentioned, about 20,000 acres can be improved, from which the increase in production is estimated at roughly 25 per cent.

In the last 3 years, more than 10,000 of such smaller schemes, costing in all about 25 million guilders, were finished. They covered about: 13,000 acres of tile drainage; rebreaking-up 13,000 acres of ground; 6,500 acres of reclamations; and 7,500 acres of other improvements.

On 1 October 1948, 6,800 other smaller schemes were carried out, the costs of which were estimated at 17 million guilders.

On the same date the costs of the 130 bigger drainage-schemes that were carried out, covering about 60,000 hectares (150,000 acres), were estimated at 27 million guilders.

THE BENEFITS OF "WATERSCHAPSWORKS"

The above-mentioned Mr. Mansholt calculated that about 1.5 million Dutchmen are benefited by the carrying into execution of *Waterschapsworks*.

He also calculated that the increase in value of our soil caused an extra yield in rents of tens of millions of guilders per annum during the pre-war years; besides which the increased return for man's labour in agriculture amounted to 50 million guilders per annum.

STATE-AID

In view of these figures you can easily understand that after the last war, in which our agriculture was heavily damaged, our Government considered agricultural reconstruction as a most urgent need. Drainage-works mainly in the inundated parts of our country, sometimes in combination with reallotments, were carried out; the subsidization and the superintendence being reserved to the *Cultuurtechnische Dienst*, the Netherlands Service for Agricultural Engineering, perhaps better described as the service for the execution of regional improvement schemes, established in Utrecht.

Because of the increased quantity of work to be done this service has expanded rapidly during the post-war years: on 31 December 1945 its staff numbered 124 and on 31 December 1948 this number had reached 209 and is still increasing.

[5] 1 guilder = about $ 0.38.

For the subsidization of the smaller ameliorations on behalf of private persons this service has to co-operate closely with the "Service for the provision of additional work" and with the provincial employment bureaux.

The total subsidy for ameliorations agreed on will not surpass 5,000 guilders per scheme within two years. Nevertheless it is possible for the *Cultuurtechnische Dienst*, within the frame of a reallotment, to subsidize the carrying out of some more extensive under-drainage-works and other sorts of ameliorations, as they are in such cases not only beneficial to the landowners concerned but also to the district or region as a whole.

ASSESSMENTS

So far we have seen that the Government (State and provinces) invests large sums, up to 70 per cent of the total amount, in our so-called *Waterschapswerken*, in behalf of increased food-production. Now if that is so, where does the rest of the money come from? This is paid normally by the assessable landowners and, in some cases, the proprietors of buildings also.

Due to the height-situation in regard to the outer water-level and to the historical development, there is a wide diversity among the *Waterschappen* as to methods of finance and administration; so much so that Dutch legislation does not give a definition of a *waterschap*, although it is an organization in accordance with public law and in that sense is mentioned in our constitution (articles 198 and 199). Since, however, it is built on sheer and good democracy, we may conclude that the taxes ought to be levied up to the measure of the interest that the assessable objects (the immovables) have in the *Waterschapsworks*. On addition there should be cohesion in assessability, which is justified on account of equity and social righteousness.

Therefore the landed proprietors and, in the case of the polders, also the house-proprietors should be levied proportionately to their interest in the projected improvements. A land-classification must therefore be carried out by independent assessors to establish the benefits and damages to be expected. This land classification, in America called the assessment-roll, should be laid on the table for the inspection of members of the *waterschap* concerned, who must be free to lodge an appeal to their board and, if there is no agreement, to the higher court in question, the county aldermen or the Crown.

In the Netherlands the average assessment during the pre-war years decreased from 3.5 guilders per acre in 1929 to 2.5 guilders per acre in 1939. In the post-war year 1945, this amount increased again by about 50 per cent. The polders most highly assessed occur in the province of Zeeland, one of them paying up to 26 guilders per acre, while the average for the province of Zeeland amounted to 6 guilders per acre in 1935. The *Waterschappen* with the lowest assessments were to be found in the province of Limburg. The average for this province amounted to ¾ guilder per acre. Rather a great difference between them! It is the provinces of Zeeland, North-Holland and South-Holland that in general have the highest assessments, as follows from their historical development.

The above-mentioned Mr. Mansholt calculated that of all the assessed land in the Netherlands some 73 per cent did not reach the amount of 4 guilders per acre in the period between 1933 and 1935, an amount which nowadays has risen to 5¾ to 6½ guilders per acre. In general the assessments follow the increases and decreases in the rentals. In 1935, the assessment amounted to about 10 per cent of the rental the landlord received from his tenants. In general it is estimated that this average percentage should not exceed 20 per cent, in view of the useful effect of the undertakings, although percentages of 35 do occur. In the latter case, however, the assessments have not adapted themselves quickly enough to the new rentals, or they are the consequence of the historical development of the *waterschap* concerned (e.g., the reclaimed lakes generally show the highest figures).

INCREASING SALINITY OF THE POLDER-WATER

Now we shall turn our attention to some other facets of the drainage problem. There is one facet in particular which causes great anxiety to the agricultural people in the western part of our country which lies below sea-level. In this country, surrounded by the sea and protected against it by sea-walls, with parts of it lying up to 20 ft. below sea-level, the only source of fresh water is rain-water. Due to its lower specific gravity this fresh water remains floating on the underlying salt-water. To a certain extent the fresh-water disk bulges into the sea-water, just as an ice-berg does, the lower side of this disk extending as much as 33 times as far below the salt-water level as its upper surface does above it. This fresh-water barrier, therefore, can only exist to some extent in the region of the dunes and here, it is estimated, it must be about 400 ft. deep. For years and years the water-companies used this fresh-water basin for their waterworks, but it has been found out that they pumped too fast and emptied the water basin, although slowly, with the result that the fresh-water barrier became less high and enabled the sea-water to increase its seepage from below into the polders. In The Haarlemmermeerpolder for instance, 43,000 acres in extent, the yearly ingression of salt runs into the amount of 73,000 metric tons! That is as much as 1.7 tons per acre per annum.

The brining of the soil in the polders was hastened by those farmers who, for want of electricity, drove a pump-barrel deep into the subsoil to allow the artesian water to raise the methane-gas for their cooking and lighting purposes. They also made Norton-tube wells in order to cool their milk in summertime in the cold subsoil-water. But in so doing, salt water was also entrained and brought into the watercourses. It was estimated that in the *waterschap* Rijnland (224,000 acres), especially in its low-lying polders, the gas-wells entrained some 23,000 metric tons of salt per annum! In the Haarlemmermeerpolder this amount runs up to 15,000 metric tons per annum! Nowadays these small but damaging gas-factories and deep wells are necessarily forbidden, but they have already done great damage to our horticulture.

In this respect also our locks do great harm. It was calculated that every time it was used, the lock at IJmuiden at the entrance of the canal to Amsterdam permitted the ingress of an amount not less than 1,000 to 1,500 tons of pure salt into the country. Nowadays the fresh-water reservoir of the Zuider Zee is of great value as it enables us to flush away this salt-water. But there are still other locks, used many times a day, which similarly introduce huge amounts of salt.

It has been the horticulturists who first sounded the alarm against this evil. They found out that the chlorine content of the pouring-water used in hot-houses should not exceed the amount of 150 milligrammes per litre (0.65 grain/10 oz.), otherwise the crops, especially tomatoes and strawberries, would decrease. Experiments with tomatoes showed that with chlorine-contents of 1.3 to 2.6 and 5.2 gr. per 10 oz. the yield decreased by 15 to 28 and 54 per cent. Our famous hothouse-grapes cannot tolerate more than 1.3 gr. per 10 oz. The same holds for the cultivation of flowers grown for cutting purposes. On the other hand the plants not cultivated in hot-houses, such as wheat, beets, peas, colza (rape-seed), cabbages and radishes, are less chlorine-sensitive. The first four can stand even up to 13 gr./10 oz. (3,000 mg./l.). But it has been stated that the water in our ditches contains already 2,000-3,000 mg./l. salt and in periods of drought, when the plants need a great deal of good water, the salinity becomes much higher, even up to 10,000 mg./l. (43.7 gr./10 oz.). In addition this brackish water makes a favourable environment for the malaria-mosquito-larvae which thrive in it.

What should be done against all these evils? The *waterschap* Rijnland has decided to do something by letting in fresh water from the River IJssel at Gouda. The average per annum will be 132 million cub. metres for the refreshing of the watercourses and 78 million cub. metres[6] for the water-supply of the polders, which water also should be drained off for the most part on the opposite side. The costs will run up to 160,000 guilders a year according to the amount of water let in. The aim is a salinity in the ditches not exceeding the maximum permissible limit of 500 mg. of salt per litre (2.2 gr. per 10 oz.).

In the future we shall have to include the water of the River Rhine in our efforts to ward off the danger of the increasing salinity of the soil. In view of the increasing salinity of the Rhine itself, we hope that this will be safeguarded by International Law.

RECLAIMING WAR-FLOODED AREAS

Another facet to be touched upon in this introductory paper, one caused by the last war, is the reclaiming and draining during 1945 and 1946 of the extensive inundations and flooded areas. As is generally known, most of the inundations were caused by the occupying forces, though some were caused by our Allied friends to drive the Germans out of their fortifications.

Among the latter the flooding of the largest part, 83 per cent of the isle of Walcheren (45,000 acres) got a world-wide reputation. Among the former the flooding of the Wieringermeerpolder (49,500 acres) became known.

Of the total Dutch agricultural area in 1943, 10.9 per cent or 630,000 acres had been flooded, of which 193,500 acres had been flooded with salt-water. Up to a milliard gallons of water had to be removed, and this was done in a relatively very short period, thanks to the 2,140[7] pumping

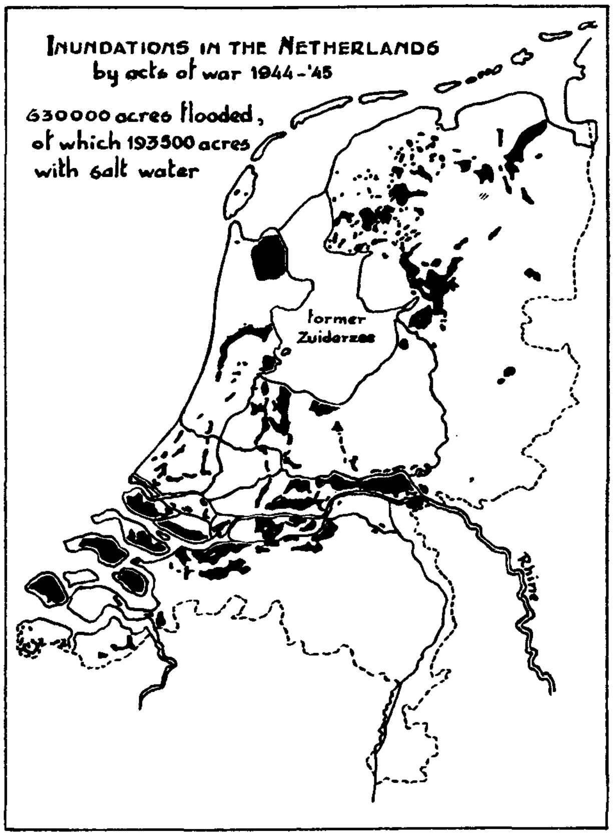

Figure 3

units of our own and the additional American pumps we could borrow and buy from our allies.

In Walcheren for instance, the work started with the closing of the three gaps in the main part of the island in June 1945 and by October of that year all were sealed. In three weeks the water was cleared.

This was partly the work of the only pumping-station Walcheren possessed at that time (of 80 cub. metres (2,820 cub. ft.) capacity), and partly the result of a gap made in the western canal-bank from the canal between Vlissingen (Flushing) and Veere. When at ebb-tide the sluices of this canal were opened, the water from Walcheren streamed from the canal into the sea.

The fourth and last gap at Rammekens in the polder South Watering (about 6,000 acres) was not closed until February 1946, and the pumping there was done by four American pumps of some 100 cub. metres (3,500 cub. ft.) capacity.

In the province of South Holland, where on 5 May 1945 47,000 hectares (115,000 acres) were flooded, the reclamation was already finished on 10 July 1945. Half of the total flood-water, which ran into about 110 million gallons, could be drained naturally, the other half had to be pumped out with the help of 160 pumping engines with a capacity of 10,000 cub. metres per minute (35,300 cub. ft. per minute) and 24 windmills and this was done within a period of 9 weeks.

The Wieringermeerpolder was flooded to a depth of 5 to 20 ft., averaging 12 ft. On 20 June 1945 they started to close the gap in the dyke and this was finished in the beginning of August 1945. After this the water, some

[6] 35 and 21 thousand million gallons.

[7] Of which 27 units were of more than 500 W.h.p; 58 units from 200 to 500 W.h.p; 550 units from 25 to 200 W.h.p; 922 units smaller than 25 W.h.p; and 583 windmills used for pumping: 2,140 in all. Almost all of these pumps are manufactured in the Netherlands.

155 million gallons, was cleared out in about 4 months, from 9 August till 11 December 1945. This is two months shorter than the first time the Wieringermeer was reclaimed (1930). For this purpose they used the existing pumps of the Wieringermeerpolder (with capacities of 1,200 and 550 cub. metres per minute or 42,100 and 19,400 cub. ft. per minute) and 11 auxiliary pumps, six Dutch and five from America.

After the water had been cleared out it took a long time to restore these overflooded areas and to return them to agricultural production. The lands flooded by fresh water came out all right, but those flooded by salt water were in a bad condition. In the latter case the calcium of the normal calcium-clay had been driven out by the sodium of the salt and the clay turned into sodium-clay, which in several respects has awkward properties. If sun-dried, it becomes a stone-hard impenetrable sheet and if wet, it looks like porridge and germination of plant life is practically impossible. To hasten the reversal of the sodium-clay back into calcium-clay in order to help the farmers who already had suffered such great losses in yields, only one thing could be done and it had to be done lavishly, namely the application of large quantities of calcium sulphate, which was imported from Belgium.

The dressing went up to three tons to the acre and applications were divided over a long period. Ploughing and rolling were prohibited. Ploughing would have turned up the salt subsoil; rolling would have enlarged the capillary action of the soil, which would again draw up brine to the surface. The soil was disturbed as little as possible so that the leaching action of rain and drainage could proceed unhampered. Due to this cautious process, after the second year the crops yielded fairly well. Without the application of gypsum it would have taken much longer—some seven years or more, as was learned after the first war.

A lot had to be done to clear out the ditches and the tile drains, which had been filled up, the former with sand and clay, the latter with that awkward sodium-clay.

CLEANING TILE DRAINS

A great many of the tile drains which did not have to be removed according to the reallotment scheme could be cleaned instead by digging out, by means of a specially devised apparatus and the help of three workmen. The leverage of this apparatus enables them to push into the drainpipe an iron rod as long as the drain is. As soon as the rod has reached the other end of the drain a chain is connected with it and rod and chain are pulled back under continuous adding of water. Then after having bladed some links of the chain with rubber-plugs, the chain is pulled backwards and forwards till the water comes out clearly. By pulling a stopper through the drain the work is finished.

Cleaning the drains in this way is much cheaper than digging them up. The ratio is as 20: 1 (lightly clogged drains) down to 4 : 1 (heavily clogged drains), but nevertheless "rod and chain-cleaning" is always much more economical.

In case the drain is clogged with sand instead of soft clay, the cleaning becomes more difficult and water should be injected, which is a more expensive method of cleaning.

DITCHING CARRIED OUT BY TRACTOR-DRIVEN PLOUGHS

Things were somewhat different in the newly reclaimed parts of the Zuider Zee. When this impervious seabottom became dry, it was not treated with gypsum, as this would have been too expensive, but we made the rain and time do the leaching work for us.

After the sea-water had been cleared out and the land-surface dried, the rain-water, which at first could not impenetrate the soil, had to be drained off by means of open ditches. The experience with these open ditches acquired in the vast areas of the "Wieringermeerpolder" (reclaimed in 1930) was used for the North-East Polder (reclaimed in 1942). In this last polder only one type of ditch was dug. It had the following dimensions: bottom width 25 cm. (7/8 ft.); depth 60 cm. (2 ft.) and side-slopes 1: 3/4. According to the several types of soil, the ditches were spaced at different distances. In light sandy clays the spacing was closest: 8 m. as the soil, after drying, does not fissure. The heavier the clay soil, the wider the spacing; 10, 12 and 16 metres are to be found. There is a still greater difference in the spacing in the pure sandy soils: the fine sands required 8 metres, the coarse sands up to 24 metres and more. During the war these ditches were dug mainly by unemployed, who could cover 2 hectares a year, which is much too little compared with the 5 hectares a year a skilled labourer can achieve. But after the war there were far too few labourers and therefore the use of tractor-driven-plough-trenchers became inevitable. In the second post-war year more than 5,000 hectares were trenched in this manner, which went four to five times quicker than gangs of skilled labourers could have achieved. Every year this acreage is increasing by thousands of hectares, and today the plough-trencher is still in action in the North-East Polder.

TILE DRAINAGE

As soon as the soil has been dried up sufficiently and, in the heavier soils, the cracks and fissures in the lower layers become evident so that rain-water can pass through, the under-drainage by means of tiles can start. Almost everywhere the tile drains were laid in the old ditches, which were deepened. Only in the heavy clays, which were fairly fissured, the distance of the laterals was made larger than the distance of the old ditches.

As much as possible of the deepening of the old ditches or the making of the first course in the undisturbed soil, was carried out with the tractor-driven plough-trencher. In that case the last course only was done with a tile-spade, as well as laying the tiles and blinding them (which means covering them with about 20 cm. loose topsoil). This method is much quicker than doing all the work by hand.

In regard to the man-hours needed for tile-draining, dug by hand or by machinery, the following figures can be issued. Manual labour in undisturbed soil needed 429 man-hours per km. (5/8 mile) drain; this was lessened to 233 hours by using the trenching-plough. Digging the trenches by hand in the former old ditches and tile-laying needed 219 man-hours per km. drain. Plough-trenching in the former old ditches and tile-laying by hand only required 174 man-hours per km. drain.

If we compare the costs per hectare of plough-trenching with the costs of trenching by hand, both in undisturbed soil, the former are much lower. The gain per hectare by the use of the trenching plough is at least 200 guilders. If the laterals are spaced at a distance of 10 metres the costs per hectare were about 450 guilders in 1946 when the trenching plough was used in undisturbed soil.

It is found that the yield on ditched land is 15 per cent less than on under-drained land.

CONCLUSION

We have recounted how the *Waterschappen* came into being and about their importance for our country; we have touched on the problems of the increasing salinity of our soil, and what we are doing against it; we took note of the damages done by flooding and how they have been dealt with, and lastly we have given some under-drainage results.

All the problems mentioned are vivid in the minds of large numbers of our people. The increase of food production by means of drainage of land and what is akin to it, is nearest to their hearts.

The motto that is written on the bronze monument marking the spot where the Zuider Zee was finally sealed off from the Wadden Zee still holds. It reads: "A People that Lives, Builds for its Future". Let this be a good example for others.

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Drainage of Land for Production

LEWIS A. JONES

ABSTRACT

The drainage of land for production in the United States is carried on by individuals, or under state laws that provide landowners with a means of co-operating in obtaining drainage improvements. The work is paid for by taxes levied against the land drained in accordance with the benefits received.

Approximately 40,000 drainage enterprises with a total area of about 87 million acres have been organized under state drainage laws. These enterprises have expended approximately 691 million dollars in obtaining outlet drainage. This expenditure does not include the cost of field drainage, clearing and other expenses involved in putting the land into cultivation.

Heavy equipment is used in constructing open ditches, tile drains and levees. Practically no work is done by hand or with teams and scrapers.

More than 100 million acres of fertile land have been added to the cultivable area or made more productive by drainage. While most drainage enterprises have been successful, there have been sufficient failures to indicate the desirability of assistance from state or federal sources in planning and developing such enterprises. Drainage should be a part of any national programme of improved land use and soil conservation.

The drainage of farm lands has played an important part in the development of American agriculture and in the improvement of public health. It is conservatively estimated that more than 100 million acres have been added to the cultivable area in the United States or have been made more productive by drainage. The benefits to health are difficult to measure, but it is known from early records that malaria was generally prevalent in the North Central States where drainage is most complete, and that it is practically unknown in that region today. Experience in the southern states also has been that after drainage the extent and seriousness of malaria have been generally diminished.

ORGANIZATION AND ADMINISTRATION OF DRAINAGE ENTERPRISES

There is no federal programme in the United States for the drainage of agricultural land. Such work is carried on by individuals or under state laws that confer special authority upon groups of landowners to obtain drainage. In general these laws provide the landowners with (1) a means of organizing to obtain drainage improvements; (2) a method of equitably apportioning the cost of the work; (3) the right to levy and collect taxes from all who receive benefits; (4) the right of condemnation against private property for public use; and (5) a method of financing by the sale of bonds to be repaid.

There are two major forms of organization provided under the drainage laws. In one, which may be called the "county form", management of the affairs of the enterprise is in the hands of county officials, who may or may not be personally interested in the enterprise. In the other, which may be called the "corporate form", management is in the hands of a board elected by the landowners in the enterprise. Both forms operate effectively when well administered. Under both forms the drainage work can be financed by the sale of bonds to be refunded over a period of years. These bonds are by law a first lien on the benefited land in the district, ranking immediately after state and county taxes, and ahead of land mortgages.

EXTENT OF DRAINAGE OPERATIONS

Approximately 40,000 drainage enterprises of one kind or another have been organized under the laws outlined above. These enterprises, which are located in 38 different states, contain within their boundaries about 87 million acres of land. This is more than the combined areas of the states of Illinois, Indiana and Ohio. The landowners have expended 691 million dollars, or an average of about $8.00 per acre, in constructing these improvements which, as a rule, provide only the main drainage outlets. Generally, before the land can be farmed to the best advantage it is necessary for the farmer to clear and prepare the land for cultivation and construct necessary farm drains.

The size of enterprises ranges from less than 100 acres to more than 500,000 acres with an average area of about 2,200 acres.

Prior to 1910 the organization of drainage districts requiring bond issues was confined primarily to the North Central states, with a comparatively few districts in the alluvial area of the lower Mississippi valley. The soil was fertile, the engineering problems were simple, the cost of drainage low and the expenses involved in putting the land into cultivation were small. The work proved very profitable and made possible the development of much of the most fertile and profitable agricultural areas in the country.

Drainage work continued, with but few exceptions, on a conservative basis until about 1915 when the agricultural prosperity resulting from the First World War led to the speculative development by drainage of cut-over lands and swamp areas during the period of high prices. A considerable number of these projects have, for one reason or another, encountered financial difficulties.

In many such districts the promoters failed to take into consideration such items as soil fertility, cost of developing farm units after drainage was completed, cost of maintaining drainage improvements, market for agricultural products to be grown, etc. In some areas, plans for drainage were incomplete or improvements were designed with insufficient capacity so that large areas remained poorly drained and could not be made to produce profitable crops without extensive additional work. Difficulties in most cases were due to poor planning and piecemeal methods of drainage. Few such districts employed competent engineers and many have no projects from their very beginning, because the soils were not of sufficient fertility to warrant development, or because the lack of control of erosion from surrounding hill lands makes it impractical to maintain the drainage improvement.

To avoid such difficulties in the future it is believed important that state or federal assistance be made available to the local people in determining the desirability of drainage enterprises from the land-use point of view, in developing sound engineering plans and in financing the work on a reimbursable basis.

The need for this type of assistance has been recognized by the state of Louisiana, which in 1940 inaugurated a programme of rehabilitating existing drainage enterprises and aiding in the development of new enterprises. Other states are contemplating similar programmes.

The national Congress in the Flood Control Act of 22 December 1944, authorized work on channels and major drainage improvements as part of the national flood-control programme. Under this Act, the outlet ditches of many existing enterprises can be rehabilitated at little cost to the local people.

During recent years several Bills providing for Federal guidance and aid to drainage enterprises have been introduced into the national Congress, but have failed of enactment. However, the importance of a sound programme of drainage in any national programme of land utilization and soil conservation is becoming recognized.

CONSTRUCTION OF OPEN DITCHES

In the early development of wet lands the outlet ditches were constructed by hand or with teams and scrapers. These methods limited the size of the ditch that could be economically constructed. Usually they were not more than five feet deep and the bottom width seldom exceeded four feet. As the projects increased in size, such ditches were found too small to provide the degree of drainage desired. There was need for an economical means of constructing large open ditches. In 1883 the first dipper dredge was developed and placed in operation and for a number of years was widely used. The dipper dredge was followed in 1906 by the dragline excavator which is the machine now in general use in the United States. The value of this machine is its flexibility. It is built in a wide variety of sizes, and with the proper size of machine, ditches ranging from 3 ft. to 150 ft. in bottom width and from 3 ft. to 20 ft. or more deep can be efficiently and economically constructed. At the present time the cost of constructing drainage ditches with draglines ranges from $.08 to $.20 to $.25 per cubic yard, depending on the size of the job and character of soil involved. With such a machine a clean wide berm can be left and the waste banks can be widely spread so that they can be readily levelled or smoothed with a bulldozer and planted to grass or cultivated. Such procedure simplifies maintenance problems. The latest model draglines are generally diesel-powered and mounted on caterpillar tracks. The bearing weight is generally such that the machine can be used in any area over which a man can walk. At the present time the half-yard dragline is selling for about $10,000 to $12,000. The larger sizes range in price up to $40,000.

MAINTENANCE OF DRAINAGE DITCHES

Maintenance of drainage ditches in the United States has been largely neglected, due mostly to the failure of landowners to recognize the importance of keeping their ditches in good shape. Investigations in many areas have shown that one year's growth of willows and other vegetation will reduce the capacity of a small ditch as much as 50 per cent and large ditches as much as 30 or 40 per cent. The rate of deposition of silt in the ditches is also materially increased by the vegetative growth. In recent years more attention has been paid to maintenance problems. In some areas controlled grazing of the ditches by live-stock has been found effective in controlling vegetative growth. In others planting the side slopes of the ditches to grass and keeping the grass mowed are common practices. In Florida and Louisiana, many drainage ditches have been completely choked with water hyacinths.

Spraying these ditches with the chemical 2,4-D has proved effective in controlling this growth, and during the last two or three years several hundred miles of ditches have been cleared in this manner. The use of this chemical in controlling the growth of willows and other broad leafed plants is now being experimented with.

TILE DRAINAGE

The use of tile for field drainage is widely practised in the United States, especially in the North Central states. In the early days tile was installed by hand, but at the present time practically all such work is done with trenching machines. The smaller machines can dig a trench up to 4½ ft. deep and about a foot wide. The larger machines dig trenches up to 6 ft. deep and 1½ ft. wide. At the present time the cost of such machines ranges from $5,000 to $12,000 depending upon the type and size. When operated efficiently under average conditions, a good trenching machine will excavate from 2,000 to 3,000 ft. of trench per day.

PUMPING FOR DRAINAGE

More than 2 million acres of land without satisfactory gravity outlets have been reclaimed by the installation of drainage pumping plants. Efficient low lift centrifugal and axial flow pumps have been developed for this work. The small installations are usually powered by electric motors or internal combustion engines, while most of the large installations are equipped with diesel engines. In the southern states the pumping plants are generally designed to pump from 1 to 3 inches of water, depending on the area drained. In the North Central states the capacities of modern plants range from ½ to 1 inch per 24 hours.

BENEFITS OF DRAINAGE

While many mistakes have been made in the development of wet lands for agricultural use, the practice of drainage has, as a whole, been of great importance in the development of the country. Millions of acres formerly too wet to be cultivated have been reclaimed and now rank among the most valuable agricultural areas of the country. Additional millions of acres, where crop losses were frequently due to inadequate drainage, now produce good crops every year.

Early records show that north-western Ohio, northern Indiana, central Illinois and north central Iowa were originally low, flat, swampy prairies that were flooded every spring and seldom became dry enough to grow a crop. Farming was restricted to the knolls or high prairie, and malaria was prevalent among the inhabitants.

Drainage has changed these conditions to such an extent that one travelling the same areas today and noting the well-cared-for productive fields, the substantial farm buildings, the good roads, the extensive urban development, does not, as a rule, recall that all of these developments have been made possible by drainage—that if this work had not been done, the areas would be in much the same state as when the first white settler arrived.

Profitable agriculture and drainage seem to be closely related. The states of Ohio, Indiana, Illinois and Iowa hold front rank in agricultural development in the United States. Notice also that they hold front rank in the amount of drainage improvements constructed. A comparison of the location of highly developed farm land and of community drainage enterprises shows that in a majority of the cases the two travel hand in hand.

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Summary Report on Greece's Water Economy

DEM. PAPANICOLAOU

Greece, for the most part, is a mountainous country. From its total area of 13 million hectares, only 25 per cent is cultivable land.

As a result of the above, the field lot per family in rural areas ranges between 1 to 3 hectares and in many cases it is limited to an even lower figure than one hectare (37 per cent of cultivator's field lots are less than that).

Land fertility is very low; the average yield per hectare in 1938 was 1,150 kg. per hectare, or about 17 bushels per acre of cereals.

Plain land is full of marshes, 504 in number, having a total surface of about 78,000 hectares. Besides the land thus wasted, the malaria frequent in marshes causes tremendous losses to the national economy. On the other hand, the population growth is very high and that creates a worse situation of scarcity of land.

An unusually great number of torrents crosses the country, due to the devastation of forests in the highlands, itself a result of the relatively dense settlement of population. Besides the geologic condition of the highlands and its climate (uneven distribution of heavy rains) create conditions favouring intense wearing of the highland soil and the creation of destructive torrents for lowlands.

Active primary torrents are up to 300. Their destructive consequences are felt by 900 villages with damages caused to their fields and houses, and in many cases to nearby highway and railway structures. About 40,000 hectares have been permanently destroyed due to the deposits of sand and gravel, and 250,000 hectares are subject to periodic damages from torrent floods.

The above situation created the necessity of executing flood-control works and highland-erosion control works and, on the other hand, plain reclamation and irrigation works, in order to create more available and more fertile land.

Unfavourable economic conditions resulting from the nation's constant struggle for its liberty which still goes on, have not permitted the development of the country's natural resources, as no chance has yet been offered for her economy to recover.

It was just before the war in a relatively calm period that Greece was given the chance to accomplish considerable work in the reclamation of the plains. 85,000 hectares of reclaimed land have been turned to agriculture, 200,000 hectares were protected from floods, 180,000 hectares have been irrigated. Most of the works were performed in the great north plains of Thessaloniki, Serres and Drama in Macedonia, and in the Thessaly Plains of Larissa and Trikkala.

For the construction of the above works in Macedonia, a sum of 30 million United States pre-war dollars only was spent. Modern methods and equipment were used. About 60 mechanical excavators of 3/4 to 6 cub. yards capacity and 5 suction dredges—one 16 in. and four 20 in.—were used in the Macedonia works alone.

During the enemy occupation periods the works were left without any maintenance and the Germans leaving the country systematically destroyed all major structures.

Just after liberation the country, with its own means and the aid of its allies—especially that of the United States of America—started the works again, primarily to restore damages. Work then began on a four-year programme called for by the Marshall Plan, by which 110,000 hectares will be reclaimed; 261,000 hectares will be protected from floods and 75,000 hectares will be irrigated.

This four-year programme of works does not complete the country's Water Economy Programme, for there will still remain for execution irrigation works of about one million hectares, flood protection works and works for protection from soil erosion. A long-term programme is expected to be terminated in a period of twenty-five to thirty years. On the other hand, at the end of the four-year period of American aid, the country will be in a position to pursue the integration of its long-term programme of water economy by its own means, for there will be quite a considerable increase in production with a consequent restoration of the country's economy.

Greece has also important water-power resources. It is again due to lack of economic possibilities that nothing important up to now has been accomplished in this field. Almost the total of the country's power production comes from thermal plants burning fuel mainly imported from abroad.

The main hydro-electric resources of the country, properly developed, may yield an average of 5,000 million kwh. against the 300 million kwh. present production of thermal installations corresponding to only 40 kwh. *per capita* per year.

The programme of American aid calls for hydro-electric power development which the American engineering firm "Ebasco" is now studying. By 1956, power production, both hydro-electric and thermal, using local lignites, will amount to 1,250 million kwh. distributed through a national transmission line net all over the country.

Finally, the four-year programme and the long-term programme include water-supply and sanitation works throughout the country to improve health conditions, for in many places the lack of such works creates dangerous conditions with a resulting decrease of production due to decreases in the number of working days.

Such is, in a few lines, the water-economy problem of Greece as to development of her natural water resources. The present programme, if carried through, will help to raise the very low standard of living of the Greek people, besides having a beneficial effect on the country's national economy and helping the nation to complete its long-term programme from its own resources.

The Enclosing of the Zuyder Zee and Its Effect on Fisheries

B. HAVINGA

ABSTRACT

The Zuyder Zee, formerly in open communication with the North Sea, has been enclosed by a dyke and within a few years was transformed into a fresh-water lake.

The herring and anchovy, once the most important fishes, were thus deprived of their habitual spawning places, and did not find a suitable equivalent in the adjacent Wadden Zee. The herring, a special race, is now nearly extinct, and the anchovy has been reduced to a fraction of its former numbers.

The eel, flounder and smelt were the only fish that could withstand the rapid decline in salinity in the enclosed area. The eel is now the most important fish, and special methods had to be worked out for the young to enter the lake.

Different fresh-water fish are present, and their numbers are still increasing.

A tabular presentation is given of the yield of the former Zuyder Zee as compared with present and future production.

Completion of the enclosing dyke of the Zuyder Zee on 28 May 1932 began a complete change in the hydrographical and biological conditions in this extensive area. Such a revolutionary change brought about by man over so great an area has—as far as I know—never before occurred in history: 3,000 sq. km. of an open arm of the North Sea, the Zuyder Zee, was converted into a fresh-water basin, Lake IJssel.[1]

At the moment that the general enclosing dyke was closed, a polder[2] of more than 200 sq. km. had already been reclaimed by the building of a separate dyke.

When the Zuyder Zee had been open, intensive and profitable fishing had been carried on, and in this paper a brief review will be given of the changes that have taken place in the different kinds of fish. A comparison will also be made between the amount of food produced in the former Zuyder Zee and in the same area now that it is enclosed, partly as to fishing and partly as to agricultural production in the reclaimed polders.

An extensive paper on this subject is being prepared, which will be issued as a publication of the Government Institute for Fishery Investigation.

THE ZUYDER ZEE BEFORE THE ENCLOSURE

Geologically the Zuyder Zee is a very recent formation, originating from inundations, especially in the fourteenth century. Up to that time the Zuyder Zee had been a swampy and peaty area in a lagoon separated from the North Sea by a narrow strip of sand dunes, which had been formed shortly after the glacial period. One small island in the Zuyder Zee, Schokland, has been left as a remnant of the old peat bottom; at present it is incorporated in a polder.

The Zuyder Zee can be divided into two parts: a central basin in the south, and a narrower northern part, the boundary of what is called the Wadden Zee. This is an area of channels and extensive shallows, running dry at low-tide, separated from the North Sea by a series of islands. Between these islands enormous quantities of water sweep with each tide into and out of the Wadden Zee, thus thoroughly mixing its water. So as a consequence, the salinity of the Wadden Zee is only slightly lower than that in the North Sea.

In the central basin of the Zuyder Zee the salinity was only about 10 per 1,000; in the boundary zone it increased from south to north, until it reached the salinity of the Wadden Zee. The low salinity in the central basin was caused by a slackening of the tidal currents on their way inwards through the boundary zone and they were hardly perceptible in the central basin. On the other side of the Zuyder Zee, the River IJssel and other smaller rivers carried large masses of fresh water into the central basin.

The depth in the central zone was quite uniform, being about 3.5 metres. Consequently, the water was easily stirred up at the bottom and, as this consisted of soft mud, the water was very turbid. Owing to this continuous mixing of the water with the superficial layers of the bottom, together with the great supply of nutrient salts from the River IJssel and the surrounding land, the fertility of the water was great.

The shallowness and the slight exchange of water with the North Sea resulted in a high temperature during the summer and this also had a favourable influence on the productivity of the water.

The great fertility, the high temperature and the lack of strong currents combined to make the Zuyder Zee an incomparable spawning and nursery area.

FISHING IN THE ZUYDER ZEE

Fishing in the Zuyder Zee depended almost exclusively on fishes who spent only part of their lives there: herring (*Clupea harengus*), anchovy (*Engraulis encrasicholus*), flounder (*Pleuronectes flesus*), eel (*Anguilla vulgaris*) and shrimp (*Crangon vulgaris*). The only stationary species of practical importance was the smelt (*Osmerus eperlanus*).

In Table 1 the quantities and total value of fish taken from the Zuyder Zee are given for the last ten years before it was enclosed.

From this table it is evident that the *herring* was by far the most important. This herring was a spring-spawning race characteristic of the Zuyder Zee. The shoals of nearly mature fish entered the Zuyder Zee in the beginning of March, and after spawning they returned to the North Sea. The larvae grew up rapidly; in the autumn the young fish disappeared and did not return before their third year, when they had attained maturity.

The *anchovy* was second in value to the herring; their annual catch shows however a most uneven course, fluctuating from practically nothing to millions of kilogrammes. Their price varied accordingly, but in an inverse ratio, and as the entire catch was cured by salting and could thus be kept for years (even improving in quality)

[1]The name is derived from the river IJssel (an effluent of the Rhine), which flows into the lake.

[2]The Dutch word "polder" means an area of land in which the water-level may be maintained at a desired height, independent of the level of the surrounding water. In many polders in the western part of Holland the level is below the level of high-tide in the sea. In the reclaimed Zuyder Zee polders, the surface is 4 to 5 metres below sea-level.

Table 1. Quantity and value of fish caught in the Zuyder Zee before the enclosure.

(*Quantity* in 1,000 kg.)

Year	*Total*	*Anchovy*	*Herring*	*Flounder*	*Eel*	*Smelt*	*Shrimp*	*Value in* 1,000 *guilders.*
1931	21,766	3,478	12,073	2,282	939	1,345	1,588	3,066
1930	24,669	5,338	11,172	3,631	834	1,285	2,313	4,753
1929	16,370	367	10,604	1,671	855	752	2,048	2,592
1928	17,602	75	12,285	990	692	1,273	2,117	2,435
1927	14,969	591	9,583	690	599	711	2,541	2,365
1926	12,716	2,376	6,247	676	713	802	1,588	3,099
1925	15,323	1,017	8,926	1,036	754	1,477	1,910	3,338
1924	17,950	167	12,173	1,271	754	1,909	1,612	2,432
1923	10,751	649	5,747	1,500	509	555	1,594	2,026
1922	11,129	1,007	5,785	1,118	646	789	1,621	2,347
Average	16,325	1,507	9,460	2,027	730	1,090	1,892	2,845

the trade was subject to heavy speculation. The anchovy was popularly called "the fish with the silver tail".

The fluctuations were due in large part to differences in temperature, eggs and larvae requiring a high temperature for their development. As by far the greatest part of the fish consisted of one year olds, the influence of the rate of development of one single year class on subsequent catches was very great.

In contrast to the herring and anchovy, which visited the Zuyder Zee for spawning and used its grounds as a nursery, the *flounder* and *eel* were born outside the Zuyder Zee. They entered as minute fish, grew up on the prolific feeding grounds and when ready for maturity they left for their spawning grounds outside.

Shrimp also utilized the Zuyder Zee merely as a feeding ground. Young shrimp that had not yet spawned entered in the spring and summer and left before laying eggs, for which they apparently needed a higher salinity. In autumn when the temperature fell considerably, they all disappeared.

The *smelt* spawned in the eastern part of the central basin where the salinity was lowest and in the IJssel River. They were the only fish of commercial importance that passed their entire lives in the Zuyder Zee.

THE AREA AFTER ENCLOSURE

At the western end of the dyke a set of fifteen sluices has been built together with a lock for navigation; at the eastern end a set of twelve sluices and two locks. The function of these sluices is to discharge the surplus water of IJssel Lake into the Wadden Zee. They are only opened when the tide level in the Wadden Zee is lower than the level in IJssel Lake. Therefore, the direction between the Zuyder Zee and the Wadden Zee is strictly one way. Fish that would enter IJssel Lake find it impossible to swim against the very strong currents in the sluices.

The large shoals of herring and anchovy that tried to visit their habitual spawning places in the spring of 1933, the first year after the closing, found their way barred by the dyke and had to spawn in the Wadden Zee. The herring deposited enormous masses of eggs at the foot of the dykes and other places. Young larvae were found in the plankton, but I never succeeded in finding any in the more advanced stages; evidently conditions were unfit for the development of the larvae. In the first year it was already rather certain that the herring fishing which had given an annual yield of 10 to 15 million kilogrammes, would soon come to an end. This proved to be true and in 1939 this fishing was discontinued. The species is now nearly extinct—only a few specimens being caught each spring.

The fate of the anchovy was slightly more favourable; the larvae proved to be somewhat better adapted to the changed conditions to which they were exposed, but nevertheless the catch fell off to about 10 per cent of what it was before the enclosure.

Within a short time after the enclosure had been completed, the salinity in Lake IJssel decreased rapidly. The supply of fresh water in a normal year is about the same as the volume of water in Lake IJssel.

In table 2 an analysis of the water balance is given.

Table 2. Water balance in Lake IJssel in a normal year (figures in cub. km.)

(Driemaandelijkse Berichten betreffende Zuiderzeewerken).

Discharged	*Supply*			
	Originating from		*Quantity discharged by*	
	River IJssel	*Adjacent land*	*Rain*	*Evaporation*
12.8	8.5	4.3	2.3	—2.3

At the time the dyke was completed, May 1932, the average salinity was about 10 per 1,000. In the early part of 1933 it had decreased to about 5 per 1,000 and in 1937 the figure of 0.25 per 1,000 was reached; this is about the average that can be obtained.

FISH IN LAKE IJSSEL

Of the fish that once populated the Zuyder Zee, only three species could stand the rapid decrease in salinity, viz., the smelt, eel and flounder.

Fresh water has an unfavourable influence on the growth of the *smelt* to such an extent that its small size makes it unfit for human consumption. In spite of this small size, they attain maturity in their second year and as propagation is not affected by the fresh water, they are still as numerous as before. They play a very important part in the metabolism of Lake IJssel; they feed on plankton and are themselves an important source of food for other fish, so that they form a direct link between the plankton and valuable food-fish.

The flounder and the eel have in common the fact they are born in the sea; the flounder in the North Sea, the eel in the Atlantic Ocean. The young of these species must find a way through the sluices and locks to enter Lake IJssel. The way, however, would have been very difficult for these tiny fish if man did not intervene.

It has been a gratifying task for the fishery research to find means for entrance for the migrating young fish, especially for the *eel*, which is by far the most important fresh water fish in Holland owing to the high price it fetches in the market.

As soon as the sluices came into regular operation, it was evident that the young eels (called elvers) would not have the slightest chance of swimming against the very rapid currents. In the first year after the enclosure a rather simple method was used which enabled the elvers to pass through the sluices. This was done by lifting the sluices for a few centimetres at the moment that the level of the tide in the Wadden Zee was equal to the level in Lake IJssel. At that moment there was only an insignificant current through the sluices, which was mostly directed inwards because the heavy salt water pushed itself under the light fresh water on the innerside. As the elvers concentrated in large numbers before the closed gates—apparently attracted by the fresh water leaking outwards along them—it was hoped that these concentrated masses of elvers would find their way in when the gates were opened slightly. By this operation, however, rather considerable quantities of salt water penetrated into Lake IJssel and as one of the purposes of the enclosure had been to have as fresh water as possible in the lake, this method could not be continued.

It was therefore necessary to seek another method that did not cause an influx of considerable quantities of salt water. The method finally evolved is based on the fact that the sluices have an inner and an outer gate, just like the locks for navigation. To begin with, the outer (seaside) door is opened and left open for about two hours. During this time large numbers of elvers accumulate before the inner gates, apparently trying to pass them in order to reach the fresh water. After two hours the outer gates are closed, and the inner ones are opened. The heavy salt water together with the elvers disperses rapidly under the lighter fresh water and within a few minutes all the elvers in the basin of the sluices have reached fresh water. After fifteen minutes the inner gates are closed again, the outer ones opened, and the whole process starts anew.

At each opening of the inner gate the entire volume of the salt water in the basin of the sluice enters Lake IJssel. In order to restrict this quantity as much as possible, the gates are opened only during the night as that is the time the elvers prefer to migrate. The quantity of salt water that enters by this method is tolerable, although its effect on salinity in the neighbourhood of the sluices is quite evident, especially when there is not a surplus of fresh water by which the salt water can be discharged.

Every two hours an experimental haul is made with a dip net and the numbers of elvers caught are counted. This has been continued since 1938, and the figures thus collected give many data on the relative frequency of elvers and on the factors influencing this frequency.

These figures cannot, however, give any indication of the absolute numbers that pass the sluices, nor can this figure be ascertained by other methods. We cannot, therefore, compare directly the numbers of elvers that enter Lake IJssel with those that entered when the Zuyder Zee was still in open communication with the North Sea. The statistics of the landings of eel provide the only means of ascertaining the practical results of the methods employed, results beyond every expectation, as will be seen from Table 3.

In the decennium preceding the enclosure, the mean annual catch was 730,000 kg. In the first year of the enclosure and immediately afterwards it increased to about a million kg. This increase must be attributed chiefly to more intensive fishing effort as a result of the discontinuance of fishing for herring, anchovy and shrimp. At the time the first year-classes of elvers that had been let in artificially had attained marketable size (beginning with 1937), and eel fishing became more and more dependent on these year-classes, the catches showed further increases attaining 4.5 and 5 million kg. in 1947 and 1948, respectively.

The high catches of recent years have given definite proof that the method of letting in the elvers artificially is quite efficient. It is, however, not justified to conclude that the numbers of elvers that now enter annually have increased to the same degree as the catch of eel has risen. For it is rather certain that a considerable part of the young eels of the former Zuyder Zee left the area in search of fresh water. On the contrary, in Lake IJssel with its fresh water this reason for further migration has been eliminated.

With regard to propagation, the *flounder* is in the same position as the eel, as its young also have to pass the barricade formed by the dyke. The young flounders, however, unlike the young eels, apparently lack the ability to pass the sluices so easily, and no method has been found to remedy this. The numbers that succeed in entering Lake IJssel must be small in relation to what came in before. This can be concluded from the catches, which are only a fraction of those in Zuyder Zee when it was open to the sea.

DEVELOPMENT OF FRESH WATER FISH STOCK

Owing to the rapid decline of salinity, fresh-water fish soon found favourable conditions for their development. In the freshest parts of the open Zuyder Zee there had always been a population of fresh-water fish: *Perca fluviatilis* (perch), *Acerina cernua* (ruff), *Leuciscus rutilis* (roach), *Abramis brama* (bream), and as an immigrant at the beginning of this century, *Lucioperca sandra* (pikeperch). All these species thrived well, but the rate at which they invaded the new grounds was quite different.

The ruff showed the greatest speed in adaptation. While the whole population at the time of the enclosure was presumably no more than a few tens of thousands of kg., five years later a catch of 3 million kg. was recorded and soon it increased to about 10 million kg. In the last few years the increase has levelled off, and the catches

Table 3. Quantity and Value of the Most Important Fishes Caught in Lake IJssel. Quantity in 1,000 kg., value in 1,000 guilders.*

The figures for fresh water species of 1930 and 1931 have been added for comparison.

Year	*Eel*	*Smelt*	*Flounder*	*Pikeperch*	*Perch*	*Bream*	*Roach*	*Carp*	*Total*	*Value*
1930	838	1,285	3,647	0	2	1	3	1	24,855	4,808
1931	941	1,349	2,321	0	2	0	5	1	21,967	3,094
1932	1,048	476	1,273	0	7	1	5	1	14,000	1,788
1933	2,125	337	1,265	0	5	1	4	1	4,220	1,470
1934	2,688	447	1,124	0	10	1	11	3	4,288	1,662
1935	1,907	317	232	2	18	2	8	2	2,558	1,068
1936	2,405	271	48	8	32	3	16	1	2,794	1,091
1937	3,595	130	43	71	32	18	21	2	3,919	1,315
1938	2,588	209	25	125	43	56	18	1	3,070	1,285
1939	2,108	24	27	2,662	84	147	23	4	5,081	1,479
1940	3,205	7	45	1,053	174	283	154	9	17,029	2,526
1941	4,563*	73	63	893	174	253	432	26	18,137	4,983
1946	3,402*	43	389	451	238	276	145	8	9.201	6,594
1947	4,488	122	526	1,194	243	415	201	8	11,050	17,119
1948	4,701	20	306	936	188	489	261	21	10,967	14,391

*In these years unknown quantities have been sold in the black market.

will now probably run less than 10 million kg. annually. Accurate figures, however, cannot be given, as the fish has only little value—as food for poultry—and is often not landed.

Next in speed of invasion came the pikeperch, as is shown in Table 3. This fish, which was scarce at the moment of the enclosure, increased so rapidly in numbers that seven years later—in 1939—a catch was made of 2.7 million kg. This is all the more remarkable when it is considered that the females do not spawn until they are three years old. Their further development was much hampered by the very intensive fishing of this valuable species, and thereafter the high figure of 1939 was never again reached.

The intensity of fishing also affected the rate of development of the other fresh water species, which show a tendency toward a slow but steady increase (Table 3). During the first years after the enclosure, however, their rate of development was far greater, as in that time the intensity of fishing was still low. It is regrettable that this could not be continued for a longer time, for in that case the stock of fresh water fish would now have been much larger and the annual yield would be much greater, because the fertility of the water is sufficient to support a much larger stock. There are, in fact, legal restrictions on the intensity of fishing in closed seasons, on the minimum sizes of both meshes and nets and a limit to the number of fishermen, but these are not sufficient to bring about a rapid increase in the stocks of fish.

Theoretically, Lake IJssel provides a superlative opportunity for making more efficient regulations for improving the stock of fresh water fish as there are reliable statistics of landing, and the life-history of the fish concerned is well known, as is the effect of different kinds of fishing on the stock. Existing regulations, however, cannot be more than a compromise between the biological requirements for the promotion of fish stocks and the immediate needs of the resident fishermen, who have to earn their livelihood and who know nothing else except fishing in the Zuyder Zee or in Lake IJssel.

Nevertheless in 1948 nearly 11 million kg. of fish were landed, 7 million kg. for human consumption and 4 million kg. for poultry feed. The value in 1948 was three times as high as in 1930. The high value in 1948 is the result especially of the large catches of eels and its high price.

BALANCE OF PRODUCTIVITY

It has been a frequent subject of debate whether the enclosing of the Zuyder Zee and the reclaiming of the land was economically justified.

I do not intend to raise this point again here, but it seems to me to be of some interest in our world of increasing demand for food to strike the balance between the productivity of the area before and after the enclosure.

In the last decade before the enclosure, the average annual production of fish in the Zuyder Zee, fit for human consumption, was 16 million kg.

In the enclosed Lake IJssel the corresponding amount is now about 7 million kg. and this figure is still increasing.

Up to now two polders have been reclaimed, one of 200 sq. km., which is in full agricultural production, and one of 440 sq. km., which is not yet cultivated in its whole extent. This is, however, a matter of a few years.

Presuming that the entire area, minus roads, canals, villages etc., produces grain and that the annual yield is 400,000 kg. per sq. km., the production of grain will be about 550 $\times$ 400,000 kg., or 220 million kg.

In relation to their food-value, however, fish, cannot be compared to grain directly, as fish is a highly valued food, rich in protein. For a rational comparison it seems to me better to convert the grain into pork; the quantity estimated above of 220 million kg. of grain will yield about 70 million kg. of pork.

At present the potential production, therefore, is 7 million kg. of fish + 70 million kg. of pork as compared with 16 million kg. of fish from the Zuyder Zee. The production, therefore, has increased nearly five times.

But at present we are only at the beginning of converting sea into land. Plans are already made for a new polder and two others will follow. One may expect that within a few decades more than 2,000 sq. km. of fertile soil will be added to our country.

Compared with the potential productivity of such an area, the production of fish in the original Zuyder Zee was quite insignificant.

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Summary of Discussion

The CHAIRMAN said that the question of irrigation and drainage, which was to be discussed at that meeting, could be divided into three parts.

Papers on each part would be read first, after which discussion would take place.

Mr. EYSVOOGEL presented his paper on the "Relationship of Soil Characteristics to Irrigation Programmes (Indonesia)", which dealt with a problem of considerable interest to most tropical countries. Irrigation water was the only source from which the soil could replenish its fertile constituents. It was therefore necessary to consider the influence of irrigation not only on the structure of the soil but also on its fertility.

The paper reviewed the three major types of soil, laterite, marl and limestone, in connexion with water of the same or other origin. Reference was made to experiences in the irrigation of marl soils and the principles of modern irrigation practices on marl soils in Java, as also to the use of water on adjoining rice-fields. It appeared that the favourable influence of irrigation water and silt on fertility was limited to the first and second rice-field irrigated.

The paper mentioned also the very important problem of the influence of root development on the fertility of the soil, and described the results of experiments carried out in that field at the General Agricultural Experiment Station. It was probable that the relatively great depth to which the roots of dry monsoon crops and plants penetrated had a favourable influence on the fertility of the soil.

Mr. HAMID presented the paper on "Soils and Water Control" prepared by Mr. Butt and Mr. Salim. He explained the general principles followed during the recent irrigation work in Pakistan. Irrigation works were carried out even in areas in which the total rainfalls were heavy, when the rainy season was short. There was no need, however, to irrigate areas in which the level of groundwater was not lower than 15 to 20 ft. below the surface of the ground, along rivers.

Mr. HUBERTY and Mr. STAFFORD presented their paper on "Soil Characteristics and Salinity in Relation to Irrigation and Drainage".

Mr. HUBERTY summarized the first part of the paper, which dealt principally with soil texture in relation to irrigation. The most important irrigated soils were the deep, permeable, recent secondary soils found mainly on alluvial fans and flood plains. Their deep permeable profile permitted the growth of a wide range of crops and the development of satisfactory irrigation practices.

Water-holding capacity and potential soil fertility were largely functions of soil texture.

Although soil texture was a very important factor in determining the quantity of water available to plants which a soil would hold, it was not the only one.

Mr. STAFFORD summarized the second part of the paper, which dealt with salinity problems and their solution. Records for Lake Mead, on the Colorado River, had shown an appreciable increase during storage in the dissolved-solid content of the water. Some of that increase was due to evaporation but some was due to the solution of soluble material from the reservoir site.

In the Rio Grande basin, drainage from the irrigation of upper lands returned to the river and was rediverted to lower lands. Under those conditions, the salt concentration of the downstream irrigation waters became increasingly higher.

The principal measures to reduce the salt content of irrigation waters included:

(1) Application of irrigation water in quantities sufficient to maintain the salt balance and tolerable soil-solution concentrations.

(2) Reduction of the river's salt load by:

(*a*) Watershed conservation to accomplish erosion control and a corresponding lessening of the salt-carrying silt load which entered the river;

(*b*) Diversion and disposal of small volume inflows to the river of highly concentrated waters.

(3) Changes in points of river diversion from lower to higher locations in order to utilize only the upper, less concentrated, water.

(4) Provision for adequate root-zone and subsoil drainage.

(5) Adjustments to utilize the best lands in situations where, because of salt accumulations and lack of drainage, irrigated lands had become unproductive.

(6) Addition of gypsum to soil or water to improve the structure of soils containing a high percentage of sodium on the soil colloids.

Mr. EYSVOOGEL gave a brief summary of Mr. Hellinga's paper on "Soils and Water Control Programmes". The paper recalled that of the cultivable area in the Netherlands about 55 per cent (the polder districts) lay below the level of the sea or of adjacent rivers. That called for control of the open water table in the polders. In ascertaining the proper water-level it was possible to control soil moisture conditions and to influence the yields of the crops. The height of the water-level depended on soil conditions, the level of the land and the type of farming.

The old system of ditching was still used for draining meadows. Arable land, however, was drained by means of tile drainage. Ditches and canals carried excessive water to the pumping-stations. The climatic conditions of the Netherlands required a drainage capacity of 10 to 14 mm. per 24 hours. The cost of that installation amounted to from 375 to 575 dollars per hectare, including pumping stations, canals, some bridges, tile drainage etc. Working costs amounted to from $4.50 to $7.50 per hectare.

In some polders with sandy soil, infiltration was applied with 3 to 5 mm. per 24 hours. Large areas were reclaimed from the sea. Reclamation started with intensive draining. In two or three years the soil was ready for normal cultivation. The soils inundated with salt water during the war had been restored by drainage and the application of gypsum (3,000 to 8,000 kg. per hectare).

Mr. RAUSHENBUSH, summarized, in the absence of its author, the paper prepared by Mr. Juva on "Soils and Water Control by Reclamation Management".

Mr. Juva indicated the major problems which had to be solved in reclamation management: flood control, erosion control, purification of water-supply, maintenance of satisfactory hydrological conditions of the soil and regulation of the use of the soil in the best interests of national economy.

He emphasized the importance of reclamation problems in every country and suggested that an international organization for soil reclamation might be created, to unite all scientific workers, technicians and specialized institutions in that branch of study. That would stimulate scientific co-operation and would make it possible to organize research on an international basis.

The CHAIRMAN said that the problem of reclamation had been dealt with from a wide variety of aspects in the papers which had been presented. He opened discussion on the first part of the subject before the meeting.

Mr. W. R. NELSON presented a few observations on

Mr. Huberty's paper. He explained in general terms the methods used to prevent the accumulation of saline deposits and excessive increase in the salinity of water. The competent hydrological services dealt with those difficulties by regulating the inflow to and outflow from the project, maintaining the salt balance and eliminating the excess salinity by the use of a volume of water in excess of that required for irrigation. The use of gypsum, which had been advocated for certain works in the Missouri basin, had been abandoned in one instance because its prime cost was too high. The inflow of salt water from the ocean into the deltas of the Californian rivers was counteracted by storage of water upstream and regulated release of the amount needed to maintain the flow of the stream in the required direction.

Mr. STORIE said that in the conservation of resources the permeability of the soil profile was the most important factor. It had been recognized only quite recently and had a particular bearing on salinity.

Mr. W. R. NELSON agreed with Mr. Storie. He stressed the importance of the permeability of the soil.

Mr. HAMID spoke about an experiment made in Pakistan, where extremely impermeable soil had been made permeable by specially selected crops. By the end of four years it had been possible to use the land for other crops.

The CHAIRMAN recalled that a few days previously a film had been shown concerning the leaching of saline soil near the Dead Sea by means of fresh water brought in from the river Jordan. That was a very economical method of reclaiming land, for the leaching water was spread in ponds used for fish breeding. He asked whether similar solutions had been applied to the problem in Indonesia, where such a method could be used for irrigated crops such as rice.

Mr. EYSVOOGEL replied that although many fishponds existed in Indonesia and especially in Java, that method of lixiviation was not used there.

Mr. STRAUS gave a summary of his paper on "Recent Developments in Irrigation". He pointed out that the increase in the population of the world necessitated an increase in food production and that in several countries and continents the food supply depended substantially on irrigation. The most important recent developments in irrigation had been due to new demands for food by the increased population. At the existing time irrigated lands were estimated to provide food for some 10 to 15 per cent of the world's population.

Although irrigation had been undertaken comparatively recently in the United States, about as rapid progress had been made there as in any other country. The extension of irrigation practices into sub-humid and humid areas, the acceptance by the Federal Government of national responsibility for the financing, development, and liberalization of repayment requirements for those benefiting from irrigation, and finally the conclusion of international agreements for utilization of international streams had been the outstanding factors in the development of irrigation in the United States. Such factors could be equally applicable in the rest of the world; they had, in fact, already been applied to a certain extent. The acreage under irrigation in the arid and semi-arid sections of the United States, and probably in the rest of the world, could be increased approximately twofold by the application of those principles.

In the light of world-wide food deficiencies it was logical that the extension of irrigation would command more and more attention. It was also logical to predict that the countries of the world would set as their goals full development of irrigation potentialities. The reclamationists in the United States looked forward to helping them by sharing their technical knowledge.

In the absence of Mr. Riddell, the CHAIRMAN summarized his paper on the "Development of Irrigation in a Semi-Humid Climate: the Ashburton-Lyndhurst Project".

The Ashburton-Lyndhurst Project, described in Mr. Riddell's paper, covered 64,000 acres and was situated in Ashburton County, South Island, New Zealand.

Although the rainfall was comparatively high (25 to 35 in.), hot dry winds, light soils and good drainage limited the amount of moisture available for plant growth, and irrigation was necessary to permit full utilization of the resources of the soil.

The district had already been cultivated on a dry farming basis, before the introduction of irrigation. Although that had been an advantage, in that all the services necessary to a community had been in existence, which was not usually the case where arid regions were developed, the reluctance of the farmers to change their established practices had been a serious disadvantage.

Compulsion being out of the question, the difficulty was being overcome by fixing attractive water rates and conditions of supply and by rendering assistance to irrigators in many ways, such as free surveys for land preparation, preparation of land at cost by efficient methods, providing advisory services for the farmers and putting a research station at their disposal.

Although irrigation of semi-humid areas did not show an over-all production increase comparable to that in arid regions, there was not the same risk of failure either for the individual or for the project itself, since farming had already proved feasible in that area.

The state of world food production at the present time demanded a closer investigation of the possibilities for increasing production in the semi-humid regions.

Mr. KALINSKI presented his paper entitled "Some Aspects of Irrigation in Greece".

The object of the paper was to examine the economic aspect of irrigation development in Greece, which was an under-developed country. The principal problem of the Greek economy was the deficiency in the balance of payments caused by the necessity to import foodstuffs. The development of irrigation should permit an increase in food production.

Mr. Kalinski pointed out that the development of irrigation was confronted with difficulties of a social nature which arose whenever there was a question of changing the mode of living and working of the rural population, which had a natural tendency to be conservative. The most important factors in the successful development of irrigation had been correctly listed in the following order: the peasant, the peasant's family, political factors, economic and financial factors, and, last of all, technical factors.

In view of those difficulties the Greek technicians, whose goal was to put under irrigation in the course of the four-year period of the Marshall Plan, 75,000 hectares of land, had not undertaken that project in an area of individual holdings, where technical conditions would have been most favourable. The population of that area was not inclined to change its accustomed methods of farming. The land to be irrigated had therefore been divided and the chief efforts had been concentrated where social conditions were the most favourable.

Mr. EYSVOOGEL, presenting his paper on "Recent Developments in Irrigation in Indonesia", began by giving a general description of the problem of agricultural production and irrigation in Java and several islands of the Indonesian Archipelago. He then discussed several important problems of irrigation in tropical countries.

The method of irrigation for rice growing could not be improved, but the watering of so-called secondary crops was not always satisfactory. Sprinkling by hand entailed too great a waste of labour.

The distribution of the water was organized by forming units of 300 to 400 acres. In those units irrigation was handled by the farmers on a co-operative basis.

Water requirements in the plains depended in the first place not on plant transpiration, percolation or evaporation but on the problem of soil cultivation. Where the monsoon rainfall was limited to four months, it was necessary to cultivate at least part of the fields in dry weather, which necessitated large irrigation heads.

The method of repayment in Indonesia was indirect, the profit of the Government being the automatic rise of the land tax which followed the construction of irrigation works.

Mr. SMITH outlined his paper on the "Development of Irrigation Farms with Special Reference to Irrigation and Crop Production under Desert Conditions as Observed in Saudi Arabia".

He pointed out that the determining factors in the selection of farm locations were: land, water, means of development (drainage, wind-breaks, etc.), and the possibilities of irrigation.

Mr. GARCÍA QUINTERO summarized the paper submitted by Mr. Rodríquez on "Recent Developments in Irrigation in Mexico". The plan adopted by the Mexican Government was chiefly based on the conservation of the country's natural resources.

Mexico being one of the world's poorest countries in arable soil and water, the problem was of prime importance for it.

In the arid, semi-arid and semi-humid zones, the water courses would be used chiefly for irrigation. First, however, they were to be used to generate the largest possible amount of power.

In the humid zones, they would be used chiefly to generate electric-power and for flood control.

Two million three hundred thousand hectares of land had been improved as a result of irrigation projects undertaken since the initiation of the plan in 1926. Before that date, the irrigated area had been 700,000 hectares.

By using 80 per cent of the mean volume carried by watercourses, it would be possible to irrigate nearly 7 million hectares, after storage dams had been constructed.

Counting the land which could be irrigated by the use of subsoil water and the 2 million hectares of cultivable land in the humid zone of Mexico, 10 million hectares could be irrigated. There would still be 13,300,000 hectares of cultivable land which could not be irrigated and consequently could be used only during the rainy season. Even if all the arable land in Mexico could be irrigated, there would still be only .93 hectare of irrigated land per inhabitant as against the United States figure of 1.2 hectares. With an irrigated area of 10 million hectares, there would be only .4 hectare of irrigated land per inhabitant; those figures were calculated on the basis of a Mexican population of 25 million.

In Mexico, irrigation plans were considered as public utility works; their realization was essential to the well-being of the rural population. Moreover, they could not be carried out by private enterprise. Hence, there was no prospect of recovering even a part of the capital invested in irrigation projects. It was to the national advantage that large areas of Mexico should be settled, so that the rural population could be better distributed. Irrigation would make it possible to settle hitherto uninhabitable areas.

Mexico had therefore to take into account the effects of its irrigation policy on the system of land tenure and the distribution of land.

Mr. HAMID gave a summary of his paper on "Irrigation in Pakistan". Pakistan possessed the third largest area of irrigated land in the world, only China and India surpassing it. If the proportion of irrigated land to the total area of the country were considered, however, Pakistan took first place, with the best irrigation canals in the world. Despite the fact that heavy taxes were collected for the water, there were still 1 million hectares in the Punjab alone which remained arid for lack of water and in western Pakistan there were 500,000 hectares which could not be cultivated until irrigation was available.

Where water could be obtained, it was distributed at a rate of 3 cub. ft. a second per 400 hectares of cultivated land. Standing water did not represent a problem but soil salinity raised many difficulties.

About 15,000 hectares had to be abandoned each year because of the salt content of the soil. The only known remedy was to leach the soil by flooding.

An annual flow of water of 8,000 cub. ft. a second would be needed for the recovery of land lost through salinity.

Most of the farmers had only small fields, but it was those small farmers who succeeded in cultivating the land most efficiently. All irrigation projects were undertaken at State expense and the State was also responsible for the cost of maintenance; the farmers were responsible for the upkeep of the irrigation channels only.

Before a project was undertaken, an estimate was made of the additional revenue which could be obtained as a result. If that revenue over a period of ten years was sufficient to cover the capital invested, at the normal rate of interest, together with the cost of maintenance, the project was considered to be productive.

The Government gave full approval to projects of that kind.

When a project was unproductive according to the foregoing criterion and public interest made its adoption necessary, the Government had recourse to a soil improvement tax affecting the persons profiting directly from the irrigation.

The experience gained in Pakistan showed that irrigation projects and water resources should be controlled by the Government, or in other words that irrigation was an activity which should remain nationalized.

Mr. PAVLOVIC introduced the paper by Mr. Filipovic on the irrigation and drainage projects envisaged in the Yugoslav Five-Year Plan for the period ending in 1951.

Out of 14 million hectares of cultivated land in Yugoslavia, 840,000 hectares were to be irrigated by 1951. Part of that area would also be drained. The plans included 12 projects, two of which were of particular importance. One was the construction of a canal 272 km. long, linking the Danube and the Tisa, with a flow of 100 cub. metres a second. 180,000 million cub. metres of earth would have to be removed in order to construct the canal. It would not be used only for irrigation but would also be navigable. It would make it possible to irrigate the best land in Yugoslavia, in the Banat province. The cost would be 950 million dinars a year, including maintenance and amortization. The net annual income was estimated at 412 million dinars.

The second major project was the draining of Lake Scutari, which straddled the Albanian-Yugoslav frontier, 13,000 hectares lying in Yugoslavia and 31,000 hectares in Albania. A joint plan had been prepared by both countries at first, but Albania had since refused to take part. Yugoslavia had decided to drain that part of the lake and marshland which lay on its side of the frontier and in order to protect the water-level, had decided to build an embankment and a tunnel 12 kilometres long for the disposal of surplus water.

In that way, 22,000 hectares of land would be improved, 17,000 hectares of which would be irrigated.

The profit which would accrue from the improvement of the area was estimated at 438 million dinars a year.

The CHAIRMAN opened the discussion on the papers which had just been introduced.

Mr. SAIN made the following comments on the papers read by Mr. Straus and Mr. Hamid.

It was true that the world's population was growing at a faster rate than the area of cultivable land, and hence the shortage of food. In 1941, the population of India had been 389 million; by the end of 1948, it had risen to 420 million inhabitants. In 1948, India had had to import food from the United States at a cost of $66 million. In future it would prefer to buy American "know-how" regarding construction of high dams rather than the food the United States was able to produce through that "know-how".

In the past, India had undertaken a vast irrigation programme bringing waters rising in the Himalayas on to the arable lands by means of works and channels that had been constructed simply with the available man-power without machinery and with the ass and the bullock as the only beasts of burden. In that way India had put to beneficial use about 76 million acre-feet of water for cultivation, making it possible to irrigate 48 million acres of land. This is almost twice as much as the irrigated area in the United States, and is larger than that irrigated in any other single country in the world. When all the projects now under contemplation had been executed, say in ten years hence, about 75 million acres of area would be brought under irrigation, and India would be able to produce enough food to be self-supporting.

He thought that Mr. Straus had been rather categorical in stating that it was water resources which limited the area of land that could be made cultivable through irrigation. In India there was no shortage of water. So far India had used only 6 per cent of its total resources; the remaining water flowed out to the sea. If the total quantity of water which flowed annually through the rivers of India were spread over the cultivable area of the country, it will cover it to a depth of 3.56 ft. It must be admitted however that the irrigation projects which could be undertaken to utilize the normal flow of the rivers had already been exhausted. It would therefore be necessary to build high storage dams for storing the flood-waters. The technique of building high dams had been developed to a great extent in the United States. It was gratifying to mention that the engineers of the United States Bureau of Reclamation welcomed the opportunity of imparting this knowledge to engineers from other countries.

Nevertheless, after reading the papers presented to the Conference on the irrigation techniques adopted in various parts of the world, he realized that the knowledge and experience acquired in India about canal irrigation in the last few centuries could be of use to other countries.

The need to make one central authority responsible for initiating irrigation works and establishing projects had been decisively proved. With regard to repayment of cost on projects, India had proceeded empirically but after long experience it had succeeded in establishing a very equitable system. The farmer using the water paid for the water in accordance with the kind of crop matured. If the farmer did not succeed in raising a crop due to reasons beyond his control, he did not pay any water charges. This did not mean that he wasted water. He tried to spread it on the maximum area.

Capital investment on some of the older irrigation projects produced an annual return of more than 20 per cent; that was enough to show the success of these undertakings.

The future projects would require much greater outlay which would be difficult for the farmers to repay. Greatest economy in the design and construction of works was therefore imperative. India possessed six efficient experimental stations and a lot of valuable information has been collected. In 1945, the Government of India established a Central Commission to look after water-power, irrigation and navigation projects all over the country.

Experience in India had shown that it would be of advantage to irrigate even those areas where annual precipitation exceeded 120 centimetres, as such precipitation took place only during two or three months of the year.

The possibility of artificial rainfall deserved serious and careful consideration. If artificial precipitation did succeed as a practical proposition, it might bring about a technical revolution. So far, however, this had not assumed a practical shape.

Speaking on the paper submitted by Mr. Butt and Mr. Salim of Pakistan, introduced by Mr. Hamid, Mr. Sain who had for twenty-five years been a member of the Service of Engineers responsible for irrigation in the Punjab, stated that the annual average precipitation in West Pakistan did not exceed 50 centimetres a year.

The greatest difficulty in the Punjab was to preserve fertility of the soil which had deteriorated considerably as a result of water-logging. The only effective remedy against water-logging was extensive pumping. It was admitted by him that pumping was a long and laborious process, but he considered it better to resort to this method, since the accumulation of stagnant water was even more harmful than saline deposits. He considered that it would be worth while imposing some sort of tax on the land and other property in order to finance the works which were necessary to prevent deterioration of soil.

Mr. TIMMONS observed that Mr. Straus had emphasized in his summary that the world's population was increasing more rapidly than food production. Nevertheless, the United States was enacting legislation to control the area of land in certain crops. There was an undoubted contradiction there.

The population-land resource problem must be envisaged on a world basis and it seemed that the best course would be the following: each country should decide on the type and quantity of foodstuffs it needed. It would then be necessary to decide what regions could best produce those products based on comparative advantage. Once that analysis had been made, it would be a matter of determining the best means of utilizing the land, either through irrigation, including the irrigation of semi-humid or humid areas, or through the use of fertilizers or other methods of agriculture.

In establishing those data, an important factor would have to be taken into account; it could, for example, be physically possible to irrigate the entire United States territory; the expense of irrigating certain areas, however, would be extremely high. It would therefore be necessary to make a careful analysis of the time and place most suitable for the capital investment which was to finance the work. It would be necessary to analyse various alternative methods of achieving the production to satisfy human wants under least cost conditions in terms of labour and capital used in the production process.

To sum up, it was necessary to analyse world food needs and the means of satisfying them, while at the same time making sure that the measures employed were as rational and economical as possible.

The CHAIRMAN recalled that he had had a paper distributed to the members of the section, asking them to estimate the cost of irrigation per acre in their countries.

Mr. S. F. KELLY stated that solving some of the problems of irrigation could be aided by the use of scientific methods for the discovery of new sources and for the conservation and exploitation of existing water resources.

The science of geophysics had furnished man with new techniques such as the electrical and seismic methods which had been used successfully to discover new water-supplies in Palestine, as reported by Mr. Loehnberg and Mr. Lowenstein in 1936. They had also been widely used in Spain, Uganda, the United States, Hawaii, Peru, and elsewhere, with considerable success in the task of augmenting available water for domestic, agricultural and industrial uses.

The science of geophysics was also of value for water conservation and flood control and was particularly useful in studying proposed dam sites.

Governments and private enterprise concerned with such work should be recommended to give careful consideration to the possibility of using geophysical methods to increase the water-supply available for municipal use, for irrigation and for the production of hydro-electric power.

Mr. AULL drew attention to two statements in Mr. Straus's paper which seemed to him to be contradictory.

Mr. Straus said first of all that the necessity for the world-wide development of water resources was fully recognized; he then proceeded to state that the science of hydraulics had outstripped sociological and economic thought.

Mr. Aull questioned the first statement but agreed with the second.

It would have to be decided whether to apply the science of hydraulics in the exploitation of water resources without reference to social and economic need or whether to make social and economic need the motivating force in the development of water resources. Mr. Aull thought it fortunate that economists were not agreeable to all developments of which science has knowledge.

Mr. MACKENZIE was especially interested in that part of Mr. Straus's paper which dealt with projects of interest to both Canada and the United States.

The principle of national and international responsibility for the solution of drought problems was generally recognized in Canada. Since 1935 the question of irrigation in western Canada had been considered of primary importance and justified the assistance of the Canadian Government. The plans put into operation had already brought about remarkable results.

It would be seen from the map on Figure 1, annexed to Mr. Straus's paper, that a million acres had been put under irrigation in Canada alone. It should be noted that in actual fact the irrigated area under cultivation annually rarely exceeded 750,000 acres.

There were, however, projects in the planning stage which would triple the irrigated area in western Canada and would add, to the total area, 300,000 acres of irrigated land in the valleys of British Columbia.

Contrary to the situation in some other countries, where water resources were practically inexhaustible, Canadian irrigation projects were limited by the supply available.

Mr. Straus referred in his paper to international agreements for the full utilization of international streams. The agreements on that subject between the United States and Canada had proved so satisfactory that the Canadian

Government had considered reports on the utilization of Canada's share of three international rivers, although the International Commission for the United States and Canada had up to that time allocated the waters of only one of those rivers.

Mr. STRAUS was impressed by the fact that the many papers that had been presented and the comments of the different speakers laid stress on the relationship between technical progress and the social aspects of irrigation.

The paper by Mr. Kalinski, Director of the Engineering Division of the Greek Ministry of Agriculture, which laid particular emphasis on the social and human aspect of the question, was outstanding.

Mr. Straus said he would be very grateful to Mr. Kalinski if he could complete his work by submitting a report on the measures taken in Greece, showing the significance of social factors in the development of irrigation and, in particular, whether the system of land management had been changed and whether a uniform method for the administration of irrigated land had been adopted, as had been done, for example, in the United States.

Mr. EYSVOOGEL explained that the paper presented by the Technical Agricultural Service of the Netherlands on the "Drainage of Land for Production" should be considered as a more detailed description of some of the points raised by Professor Hellinga in his paper on soils and water-control programmes.

After an interesting historical description of the growth of civilization in the muddy deltas of the Rhine and the Meuse during the course of two thousand years, the paper gave a detailed account of the work undertaken by the *Waterschappen*, a kind of conservation board working on a co-operative basis, which constituted the principal weapon in the constant battle waged by the Netherlands against the sea. The paper gave the costs of upkeep, as also the considerable sums spent annually on the improvement of drainage along modern lines.

The paper next gave a detailed description of the salinity problems which had arisen during the last fifty years.

By drawing on their water reserves for public health purposes, the big cities in the west of Holland had apparently exhausted the ground-water resources, while at the same time the primitive methods used by the farmers to obtain methane-gas had seriously damaged the natural underground cover which kept out the salt water. Figures on the percentage of the chlorine-content of the ditches during the summer were also furnished. In examining those figures account should be taken of the fact that the salt only partly penetrated the soil.

The paper concluded with a description of the measures taken for the reclamation of war damaged polders. 435,000 acres had been flooded with fresh water during the war and 190,000 with salt water. When the dykes had been repaired and the salt water pumped out, it had been seen that the latter area had suffered most. An abundant use of gypsum had given very good results and in a few years the whole area would recover its former prosperity.

In presenting his paper on "Drainage of Land for Production", Mr. L. A. JONES pointed out that drainage was one of the most important factors in the development of agriculture in the humid areas of the United States. As a result of drainage, at least 100 million acres of fertile land had been added to the cultivable area or been made more productive.

To give some idea of the important part drainage had played in the development of the United States, Mr. Jones recalled that in 1826 an expedition under Major Lang had proceeded on horseback and by flat-bottomed boats from Pittsburgh to Chicago and as far as the banks of the Mississippi. Describing that voyage he stressed the abundance of marshland, the dearth of dry areas and the prevalence of malaria. While modern travellers might realize the difference, few of them would attribute it, as they should, to drainage works. Without drainage Chicago would probably still be a swamp.

The drainage of land in the United States for production was carried on by individuals in accordance with State laws which provided landowners with a means of co-operating so as to profit from drainage works. The works were paid for by taxes levied on the land drained, in accordance with the benefits received. Land of public use was expropriated with compensation. In general, drainage was financed by the sale of bonds.

Approximately 40,000 drainage enterprises covering a total area of 87 million acres (approximately 34 million hectares) had been organized under State drainage laws. Those enterprises had spent approximately 691 million dollars on outlet drainage. That figure did not include the cost of field drainage, clearing or other expenses involved in putting the land under cultivation.

The needs which the First World War produced brought about speculation. Drainage projects were then undertaken by companies or by individuals, with no over-all planning. Most unfortunate results ensued; for example, in draining land where it was difficult to maintain drainage owing to the lack of control of erosion from the surrounding hills, the project improvements as well as the quality of the cultivable soil was jeopardized by the soil washed from the hills. Mr. Jones believed that either the state Governments or the Federal Government itself should assume the responsibility for undertaking or sanctioning drainage works on a reimbursable basis.

There appeared to be a close relationship between an abundant agricultural yield and drainage. Ohio, Indiana, Illinois and Iowa were foremost in agricultural development in the United States; it should be noted that they also possessed the greatest number of drainage works. It would be seen that those places where agricultural land was highly developed coincided with the location of drainage works.

In presenting his paper entitled "Summary Report on Greece's Water Economy", Mr. PAPANICOLAOU stated that of the mountainous country of Greece only 25 per cent of the total area was cultivable land. For that reason the land was cut up into very small lots. The land was not very fertile and the plains included approximately 78,000 hectares of marshland.

The torrential rivers of the country, the discharge of which varied from 10 cub. metres per second in summer to 4,000 cub. metres per second in winter, flooded the cultivable land. The devastation of the forests in the highlands, which was the result of the relatively dense settlement of population, of geological conditions and of the climate (uneven distribution of heavy rains), made conditions favourable for intense erosion and the creation of highly destructive torrents, numbers of which crossed the country.

Those conditions made reclamation by means of flood and erosion control and irrigation projects essential in order to increase the cultivable areas and their yield.

Unfavourable economic conditions had not permitted the full development of the country's natural water resources. It was not until just before the war that Greece had had the opportunity to carry out important reclamation works, chiefly in Macedonia, Thessaly and the Epirus plains. 85,000 hectares of reclaimed land had been turned over to agriculture, 200,000 hectares had been protected from floods and 180,000 hectares had been prepared for irrigation.

During the enemy occupation the works had not been maintained and when leaving the country the Germans had systematically destroyed all the chief installations. Immediately after the liberation the country had had to start on the work again and repair the damages. The four-year programme of American aid provided for the following projects in Greece: 110,000 hectares of land to be reclaimed, 261,000 hectares to be protected against floods and 75,000 hectares to be irrigated.

The programme also provided for the development of hydro-electric power. By 1956 power production, by both hydro-electric and thermal plants using local lignites, would amount to 1,250 million kwh. distributed through a national transmission line all over the country.

Finally, the programme provided for water-supply and sanitation works in many towns throughout the country.

In the absence of Mr. Havinga, Mr. EYSVOOGEL read the abstract of his paper on "The Enclosing of the Zuyder Zee and its Effects on Fisheries".

The Zuyder Zee, formerly in direct communication with the North Sea, had been enclosed by a dyke and thus transformed within a few years into a fresh-water lake. The herring and anchovy, once abundant, were thus deprived of their habitual spawning ground and did not find a suitable equivalent in the adjacent Wadden Zee. The herring had become almost extinct and the anchovy had been reduced to a fraction of its former numbers.

The eel, the flounder and the smelt were the only fish that could withstand the rapid decline in salinity in the enclosed area. The eel had now become the most abundant fish and special methods had had to be used to allow the young fish to enter the lake.

Various fresh-water fish were now to be found in the waters and their numbers were constantly increasing.

The paper contained a table showing the yield of the former Zuyder Zee as compared with present and future production.

Hydro Power and Other Water Uses

1 September 1949

Chairman:

Mr. Thorndike SAVILLE, Dean, College of Engineering, New York University, New York City

Contributed Papers:

Hydro Power in Sweden
Åke RUSCK, President of the Swedish State Power Board, Stockholm, Sweden

Hydro Power and Conservation—A New Engineering Technique
Leland OLDS, Federal Power Commission, Washington, D.C. U.S.A.

Hydro Power and Conservation of Power Resources
P. MASSÉ, *Directeur Général Adjoint*, and M. ROUSSELIER, *Chef du Service des Projets hydrauliques Electricité de France*, Paris, France

Considerations for General Planning of Water-Power Stations
Georg BEURLE, Construction Consultant, Stadlerstrasse 9, Linz, Austria

Recreational Use of Water
C. L. WIRTH, Assistant Director, National Park Service, United States Department of the Interior

Protection of Fish in Sweden
Gunnar ALM, Chief, Freshwater Fisheries Bureau, Swedish Board of Fisheries; Chairman, Migratory Fish Committee, Stockholm

Protection of Wildlife in Sweden
Harry HAMILTON, National Consultant to the Swedish Hunter's Association, Stocksund, Sweden

Protection of Wildlife and Fish in India
B. PRASHAD, Fishery Development Adviser to the Government of India, New Delhi, and
T. J. JOB, Chief Research Officer, Central Inland Fisheries, Barrackpore, via Calcutta

The Protection of Fish and Wildlife in Water Use Projects
J. D. DETWILER, Head, Department of Zoology and Applied Biology, University of Western Ontario, London, Ontario, Canada

Hydro Power and Other Water Uses: Protection of Fish and Wildlife
Ira N. GABRIELSON, President, Wildlife Management Institute, Washington, D.C., U.S.A.

Summary of Discussion:

Discussants:

Messrs: DAHLGREN, OLDS, KAMPMEIER, RODRÍGUEZ, ANGUS, JONY, SAIN, HATHAWAY, KARPOV, WING, AUBERT, DE LUCCIA, RAUSHENBUSH, HANNUM, PAPANICOLAOU, GONZÁLEZ MOLINA, WIRTH, DAHLBECK, HORA, DETWILER, GABRIELSON, DE LA TORRE, BOWMAN

Programme Officer:

Mr. S. RAUSHENBUSH

Hydro-Power in Sweden

ÅKE RUSCK

ABSTRACT

Sweden is practically without its own resources of coal, oil and natural gas. On the other hand there are fairly large resources of wood and water-power. The main part of the wood must normally be reserved for the paper and pulp industry. To save fuel, electricity is therefore used to a great extent where this is economically possible, for instance for industry, transport, and household use.

The power supply in Sweden is administered by the State, by municipal authorities and by a number of private companies. Each group takes care of the power supply within its respective areas. Co-ordination of development takes place jointly between the State Power Board and the other power enterprises.

The main part of the power resources of Sweden is situated in the northern part of the country, while the load is chiefly concentrated in the southern part. This fact makes power more expensive and at the same time imposes heavy demands on power transmission technique, the development of which in Sweden has been an important part of economic utilization of its water-power.

In 1948 the total output of electric energy amounted to about 2,060 kwh. per head of the population. Shortages of material and labour and an unexpectedly quick increase of the load during the years after the war have resulted in insufficiency of power. An extensive development programme is going on which will increase production to about 3,000 kwh. per head of the population in five years. More than 40 per cent of Sweden's water-power resources will then be utilized. The water-power resources should be sufficient for the reasonably near future but are not great and must be reserved for the country's own needs.

WATER-POWER IN RELATION TO COAL AND OTHER FUEL

Sweden has practically no coal resources, though in the south of Sweden there is a minor deposit of low-grade coal. The mining of this coal amounts, however, only to some few per cent of the total demand for coal in Sweden. There are big resources of peat. But, although study of the problem of the economic utilization of peat on a large scale has advanced of later years, it must be considered unsolved so far. Sweden has no resources of oil or natural gas. A small quantity of oil is, however, obtained from shale. The resources of wood are comparatively great, but only a small part of the wood may normally be used as fuel. The main part must be reserved for the manufacture of paper, pulp, wooden-ware etc.

Water-power resources in Sweden are large. The water-power that may be economically developed amounts to about 50,000 million kwh. a year, which corresponds to a little more than 7,000 kwh. per head of the population. Because of the lack of natural fuel and the fairly great resources of water-power, Sweden has long been trying to utilize this water-power to save fuel. Electricity is, at present, practically the only source of stationary driving-power. The greater part of the railway system is also electrified and 85 per cent of transport is handled by electrified railways. Trolley-bus lines have also come more into use during the last decade. To a great extent, also, electricity is used for the industrial heat processes of higher quality; for instance, the production of pig-iron in electric blast-furnaces and the refining of pig-iron to steel in electro-furnaces. In recent years, electric high-frequency furnaces have been extensively employed for smelting iron in foundries etc. Certain advantages are gained by the use of electricity as fuel in these cases, such as a higher quality of finished product, lower proportion of rejects and a more rational and economic production.

The power resources of Sweden are situated chiefly in the northern part of the country, with not less than 85 per cent of the total power resources but only about 17 per cent of the population. The population and the big industries are mostly concentrated in the southern part of the country, necessitating power transmission over distances of 400 to 1,000 km., involving heavy cost. As the Swedish waterfalls are characterized by comparatively low hydraulic heads, the developed water-power is in itself more expensive than in countries with high hydraulic heads. Because of this, water-power can only be economically utilized as a substitute for heat requirements of high quality. Thus it seems impossible to base house heating on electric-power to any great extent in Sweden. Complete electric house heating is installed only in certain municipalities farthest north in the vicinity of big power-plants. Nevertheless part of the water-power is used by industry as a direct substitute for imported fuel. This is only applicable when an otherwise unutilizable surplus of water-power happens to be available. Big industries usually have both fuel-heated and electric boilers.

WATER-POWER HITHERTO DEVELOPED AND THE PRESENT DEVELOPMENT PROGRAMME

At the turn of the year 1948/49, the developed water-power amounted to about 14,000 million kwh. a year. A quarter of the water-power potential is thus used. During times of water shortage and at full load, some steam power is utilized both in condenser steam-power plants operated on imported fuel, and in back-pressure installations where waste fuel from the cellulose and wood industry is often used as an auxiliary to water-power. By burning lye in the cellulose industries, not only are the heat requirements of the industries themselves covered but in many cases additional back pressure power is also effected. This is available all the year round. With normal water conditions, the necessary addition of steam power produced from imported fuel is only a few per cent. The purely water-power production may therefore be considered normally to compose about 95 per cent of the necessary power production.

In 1948 the total output of electric energy amounted to about 2,060 kwh. per head of the population. In the year 1946, which is the last year for which statistics are available, Sweden held fourth place among the countries of the world, after Norway, Canada and Switzerland. Extensive water-power developments are at present in progress in Sweden. On the assumption that power plants now under construction and projected are finished according to plan, the developed water power may be estimated to have increased by 7,500 million kwh., or by an average of 1,500 million kwh. per year by the end of 1953 (i.e., in five years). By then, more than 21,000 million kwh., or somewhat more than 40 per cent of the potential water-power resources of the country, should thus be utilized. The total output of electric energy per head of the population will then be about 3,000 kwh.

According to present estimates, the water-power resources of Sweden should be sufficient for the reasonably near future. On the other hand, the resources are not great, and must be reserved for the country's own needs.

SOME CHARACTERISTICS OF SWEDISH WATER-POWER

The water-power stations

A fairly low head is generally utilized at Swedish power-stations. This head is frequently less than 50 metres and exceeds 100 metres only in rare cases. The natural falls are often very extended in length, so a gathering of the head must be brought about. This is done by damming the top surface of the water and by blasting space for the power-stations totally in the rock, with a discharge into tunnels and canals. The discharge tunnels, nowadays usually only one in each station, are thus rather long, often as long as 5 km. There are generally good reasons for this form of construction. The foundation consists of rock usually on the surface or not far down, and is of such quality as to provide a good foundation for the construction of dams and machine stations. As a result of recent improvements in blasting methods, this form of construction is now adopted wherever it is found economic. In fixing dimensions for the discharge tunnel and in placing the dam, the aim is to attain a balance between the amount of rock filling needed for the dam, and the amount blasted for the machine house and the waterways.

Because of the low heads, Francis or Kaplan turbines are now used almost exclusively. The latter type, to the development of which Swedish engineers have made valuable contributions, and which is now used in Sweden for heads up to 35 metres, is coming more and more into favour. The turbines, generators and other equipment for the Swedish power-stations have been manufactured almost entirely by Swedish firms.

The mean annual flow of water in the bigger rivers amounts to some 100 cub. metres per second at the mouth of the river. The volume of water to be developed at the power-plants amounts to an average of 1.5 or 1.6 times the average water-flow per year at the plant. The amount of water to be developed, which is thus relatively high, is nowadays spread over only a few (2 to 4) units. Experience has shown that the greatest economy is almost always reached in this way. The whole power-station and the equipment will be cheaper and the operation simpler. At the new power-station at Harspranget, the units will have a capacity of about 100,000 kw.

Water-flow control

In the southern and central Swedish rivers the flow is fairly uniformly distributed over the winter and summer half-years. The northern rivers, where the main part of the power resources is situated, exhibit strongly marked variations with water shortage during the winters and copious water-flow during the summer months due to the melting of accumulated snow. In order to utilize water power economically, it is of vital importance to be able to compensate for the appreciable variations in the quantity of water available. Fortunately, Swedish watercourses abound in lakes and thus offer excellent means of regulation. These lakes are as a rule situated in the upper reaches of the rivers at considerable distances from the power-plants. The necessary volume of the reservoir is created by appropriate adjustment by damming and lowering of the lake by means of clearing the outflow. In the northern watercourses, where dwellings are few and where at the same time the need for regulation is great, regulating heads of up to 10 to 20 metres are sometimes utilized.

The purpose of regulating the available water is not only to obtain a uniform flow, that is to say, the economizing of the water during a period of abundance for use in a period of shortage, but also to adjust the flow at the power-stations to meet the varying demand for energy throughout the year, week or day. For this latter form of regulation, which frequently necessitates local reservoirs situated immediately above the power-stations, conditions in the Swedish watercourses are likewise favourable.

Owing to the fact that regulation systems are used by a number of power-stations located in sequence, the question of regulation is of common interest to many power-plant owners. As a forum for the necessary co-operation, it has thus become a practice to establish water regulation societies, which carry out the necessary construction work and regulate the flow from the reservoirs. This kind of co-operation has proved to be very flexible and there are at present some twenty of these societies, each of which regulates the flow in its specific watercourse.

This regulation has been continuously extended, particularly during the Second World War. The existing storage reservoirs have a total capacity of 24,000 million cub. metres. With the heads at present available, they make possible the storing of an annual quantity of energy of 4,300 million kwh., that is to say, 30 per cent of the country's total water-power production for the year 1948. Extensive new lake storages are under construction.

Irrigation and inland navigation

Irrigation in a true sense is not used. Apart from the Gotä älv between Lake Vänern and the sea, hardly any inland navigation occurs in Swedish water-power rivers. There are thus no multiple-purpose developments apart from co-ordinated water-power and timber-floating.

Co-ordination of floating and power production

Large quantities of timber are transported to the coast each year in the northern rivers from the forest territories in the interior of the country. This must be taken into consideration in constructing the power-stations and carrying out lake regulation. Floating is affected by these measures both at the power-station itself and along the river.

It is of interest to the power undertakings that the floating past the stations and along the river shall be done with the smallest possible amount of water. The power interest has for this reason carried out model tests in co-operation with the floating societies to devise methods enabling this condition to be fulfilled. New designs have been devised for chutes and above all for chute inlets. Effective direction of the floating timber into a chute may be obtained by these inlets, making its capacity great with small water-consumption. Efforts are made to reduce the duration of the floating season by constructing timber stores with the object of saving water. One field where the effect of water control has become current, is banking up of timber along the rivers during the winter to await the floating season in the spring. Extensive investigations are at present going on in this field in co-operation with interested parties.

Organization of power supply

Power supply in Sweden is administered by the State through an independent commercial enterprise, the Swedish State Power Board, by the municipal authorities and by a number of private companies. The three parties concerned co-operate to a great extent and are responsible for power supply within their respective areas. Normally, the State does not regulate co-ordination of development. In practice, however, such co-ordination takes place jointly between the State Power Board and the other power enterprises.

The State is responsible for 40 per cent of the total energy production and distributes power over an extensive network, both directly to the railways and large industrial concerns and to the municipal electricity works and distributing associations, which undertake the retail distribution within their particular districts. Hitherto, the State has only undertaken retail distribution on a small scale. The municipal authorities are responsible for 6 per cent of the total power production. The private companies provide for the remaining 54 per cent, of which 20 per cent falls to industrial concerns which generate power mainly for their own requirements, the remaining 34 per cent being supplied by power distributing companies. The majority of the municipal undertakings are chiefly concerned with retail distribution. Some of the private power companies have concentrated on the production and transmission of power as the State has done, and have left the retail distribution to the local undertakings.

Power transmission systems and joint operation

As stated above, the relation between developed and total potential water-power is very different in different parts of the country. The water-power is almost completely utilized in the southern, populous parts of the country where the main load is concentrated. Developments now have to be made in the northern parts of the country, which will mean the transportation of the power over long distances. The development of power-transmission technique has therefore become an important problem for Sweden for economic utilization of its water-power.

For power transmission from north to south there are six 200 kv. lines with a transmission distance of a maximum of 900 km. The constantly growing demand for power and increased transmission distances has, however, given rise to a need for a transmission system with a higher capacity than the 200 kv. system. For some years past, therefore, intensive research and design work has been in progress in the field of power transmission with high-voltage direct current or with alternating current at higher voltages than 200 kv. Research work has been going on for a couple of years at an experimental installation working on 90 kv. d.c. As the research work on the direct-current transmission line is likely to take a number of years, the State Power Board has decided to construct the new long-distance transmission lines required in the near future for alternating current at 380 kv. The 380 kv. line will be completed in 1951 and will have a length of 970 km. A second 380 kv. line with a length of about 500 km. is planned for 1953.

The extensive power-line system is necessary for the wide-spread grid operations, taking place between the power enterprises. Practically all power stations in the country are run in parallel continuously and an exchange of power takes place on a large scale in accordance with schedules drawn up each week under close contact between the managements of the different undertakings. The grid operation is voluntarily organized in the Central Operating Management (*Centrala Driftledningen*, CDL). This organization comprises all the bigger power undertakings and has its executive body located in the State Power Board.

From the above it may be seen that the absence of oil and fossil fuel in Sweden is to some extent compensated for by fairly good resources of water-power. The lack of material and labour during recent years and the unexpectedly quick increase in the load since the war have, however, led to the developed water-power being insufficient at present. Even with an ample supply of water, a considerable contribution from steam-power stations is needed to cover the demand for electricity in the country. However, with present load forecasts and the extensive programme of development, the balance between water-power production and load is expected to be restored in the middle of the 1950's.

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Hydro Power and Conservation—A New Engineering Technique

LELAND OLDS

ABSTRACT

Development of water-power provides a key to comprehensive river-basin development. It is vital to the conservation of exhaustible energy resources. Full utilization is possible only through river-basin plans involving the balanced use of all water resources for multiple purposes. This approach has led to a new technique combining all branches of engineering. Applied to development of hydro-electric power this requires full knowledge of the flow characteristics of the river and the power market viewed in terms of an expanding regional economy.

Hydro possibilities are generally maximized by design of projects for peak use with steam electric plants carrying the base load. Individual units in a river system are designed to complement each other. River systems are approached as economic as well as physical units, justifying construction of certain individual projects with unfavourable economic ratios when they offer important contributions to the entire programme. Gains in power, conservation storage and flood control can be obtained by seasonal variation in the use of reservoir storage where large volume floods are seasonal in character.

The author outlines basic elements in the new river-basin-planning technique. He gives practical illustrations of its application to river-basins with varying characteristics and requirements, showing ways of maximizing hydro-development in harmony with the best utilization of basin resources for all beneficial purposes.

The development of the water-power resources of a river provides an important key to the realization of the full benefits from the water resources of the river-basin, because the production and distribution of electricity, more than most other factors, requires valley-wide co-ordination. This paper reflects the experience of the Federal Power Commission in developing the techniques of hydro-electric power planning from this point of view.

In the United States of America we are dealing with water-power resources of great magnitude. Estimates made by the staff of the Federal Power Commission indicate that plants with capacity aggregating about 77 million kw., capable of generating on the average some 400,000 million kwh. per year, remain to be developed in the United States. These figures are about five times the present installed hydro-electric capacity and energy generation in this country, but their full realization will depend upon the adoption of comprehensive multi-purpose reservoir programmes for most of the country's river-basins.

The vital importance to this country of this great, inexhaustible resource must be measured in terms of its tremendous contribution to the conservation of exhaustible energy resources. Coal, oil and natural gas have been the principal sources from which we have obtained the mechanical energy required by our modern civilization. They are also important sources of raw materials for the modern chemical industry. But they are definitely exhaustible. The welfare of millions of people, therefore, is tied up in the fullest utilization of the energy resources, like water power, which are practically inexhaustible.

To make this hydro-electric power fully available requires that we approach the development of our water resources from a long-range point of view in terms of co-ordinated river-basin programmes providing for the full use of water resources through economically sound, comprehensive, and integrated multiple-purpose developments. The achievement of this objective involves more than just a better use of individual resources of a particular site—it involves the balanced use of all the water resources in a basin-wide plan of development for all beneficial public purposes.

To meet this challenge the various Federal agencies, including the Federal Power Commission, have been developing a technique which might be described as a new branch of engineering, combining hydraulic, civil and electrical engineering into "river-basin engineering". The objective, so far as hydro-electric development is concerned, is to approach the utilization of the water power resources as interrelated with other resources of a given river basin on a comprehensive basis, reflecting all the knowledge of the flow characteristics of the river isteIf throughout its annual and longer cycles, as well as all the knowledge of the characteristics of the regional power market, projected far ahead in terms of general regional economic development.

What are the essential elements of this technique, and what do they involve? They may be summarized briefly as follows:

1. The entire river is looked at as the physical unit to be developed rather than limiting the planning to individual projects.

2. The needs within the entire river-basin for the various water uses are appraised in terms of their relation to and effect upon the development of power.

3. Various alternative plans for dams, reservoirs, waterways and power plants are laid out upon a multiple-purpose water-use basis, and analysed physically and economically to determine the best plan for power consistent with the other water uses.

4. The various plans are weighed in terms of the effect of the construction and operation of the river system upon existing improvements, and particularly upon the inundation of agricultural lands.

Cardinal to all plans studied is the adequate control of the stream through storage reservoirs. Because of the impact of inundations due to storage in the more highly developed areas, large storages are more generally found practicable in the headwater and tributary streams, with developments only for pondage and power head on the main stem of the river.

Analysis of the economic feasibility of hydro-electric developments is based on the most economic alternative source of power which is generally steam-electric. These two sources of power, however, are no longer looked upon as competitive, but as having their own peculiar characteristics and values, with their greatest values achieved through their complementary use.

So approached, steam-electric power is generally best and most economically used at high load factors in the base of the power load, with hydro-electric power serving the shorter duration peak loads, a service for which it is peculiarly well adapted. This approach leads to the sharp distinction between the capacity and energy components of hydro-electric values, a distinction which has a marked effect upon considerations of the economics of water power.

The design of the individual projects and the power installations to be provided for at each project are predicated upon their operation as units in the river-basin system of projects, with the system contributing to the regional power loads according to its best use in combination with other sources of power. The individual units in the river-basin system are designed to complement and support each other to the end that the system will make its greatest contribution to the regional power supply.

The long-range view of the future use of the hydro-electric power is kept to the forefront. This is reflected in the provisions which may be made at the projects for installation of additional generating units. In turn, these provisions for the future reflect the possibility that the need for other water uses that may be restrictive on power today may change in the future with a resulting improvement in the power potentialities.

More and more the river with its tributaries is being looked upon as both the physical and the economic unit of development. Under this concept individual projects, which considered alone show unfavourable economic ratios, may be included in a river-basin programme because their over-all contribution to the system will provide significant additional power supply and render the entire programme's benefit-cost-ratio feasible.

In several regions of the United States it has been found that the incidence of floods of large volume of flows is decidedly seasonal in character. This has made possible seasonal variations in the use of storage for power, thereby securing improvement in the other water uses as well as substantial increases in the power available from many rivers.

In a real sense this technique treats the system of potential water power sites in a given basin as if they were notes and stops on an organ, or instruments in an orchestra, to be played in complete harmony in terms of the hydraulic and electric characteristics of the region. Let me cite specific examples of typical plans for water control projects and their co-ordinated use for the service of a given region, to illustrate the application of this technique by the Federal Power Commission and associated Federal agencies.

ALABAMA-COOSA RIVER

The Alabama-Coosa River, in Georgia and Alabama, is susceptible of basin-wide development for a large block of power and also for navigation, flood control, water-supply, pollution abatement, recreation and improved land use. Congress has authorized the whole development to obtain the maximum beneficial use of the river, with emphasis on hydro-electric power, and the work is now under way. For the purpose of summarizing the basin-wide plan, the Alabama-Coosa watershed may be considered as being divided into three parts: the headwater and tributary streams in the hills; the Coosa River between the cities of Rome, Georgia, and Montgomery, Alabama; and the lower trunk river called the Alabama (formed by the confluence of the Coosa and Tallapoosa) until it meets the Tombigbee above Mobile harbour.

The basin plan includes multiple-purpose reservoirs on the headwater tributaries, to provide flood protection for Rome and the agricultural lands along the Coosa and large storages for stream flow regulation for the benefit of power plants located at the reservoir sites and at points downstream. Proposed dams along the Coosa itself will provide supplemental storage or pondage for flow regulation and serve to concentrate the fall of the river for power development. Proposed dams on the Alabama River will provide a series of power and slack-water navigation pools extending from Montgomery, Alabama, to the mouth of the river.

Because of the favourable topography and the lack of valuable farm land or major improvements in the valley of the Tallapoosa River, the plan for its development includes especially large reservoirs with so-called "holdover" storage capacities. This means that more storage capacity is available than is required for the regulation of the annual cycle of flows so that water may be collected during years of abundant run-off for use during periods of deficient run-off.

The general plan calls for the filling of the reservoirs during the high-flow periods of the winter and spring months for subsequent release of water during the summer and fall dry periods. While reservoirs are being filled, the main river power plants will supply a major part of the power load by utilizing the run-off from uncontrolled portions of the watershed. The subsequent release of stored water at comparatively high rates during dry months through the high heads at the reservoir plants for re-use at downstream plants will provide a sustained rate of generation throughout the year. In exceptionally dry periods the holdover storage in reservoirs on the Tallapoosa will be released for use by plants on that river and on the Alabama to firm up the output of the group of plants.

Thus, the hydraulic integration of the plants provides a large amount of dependable power from the group considered as a unit; and the electric interconnexion of these plants makes it possible to utilize the resulting output

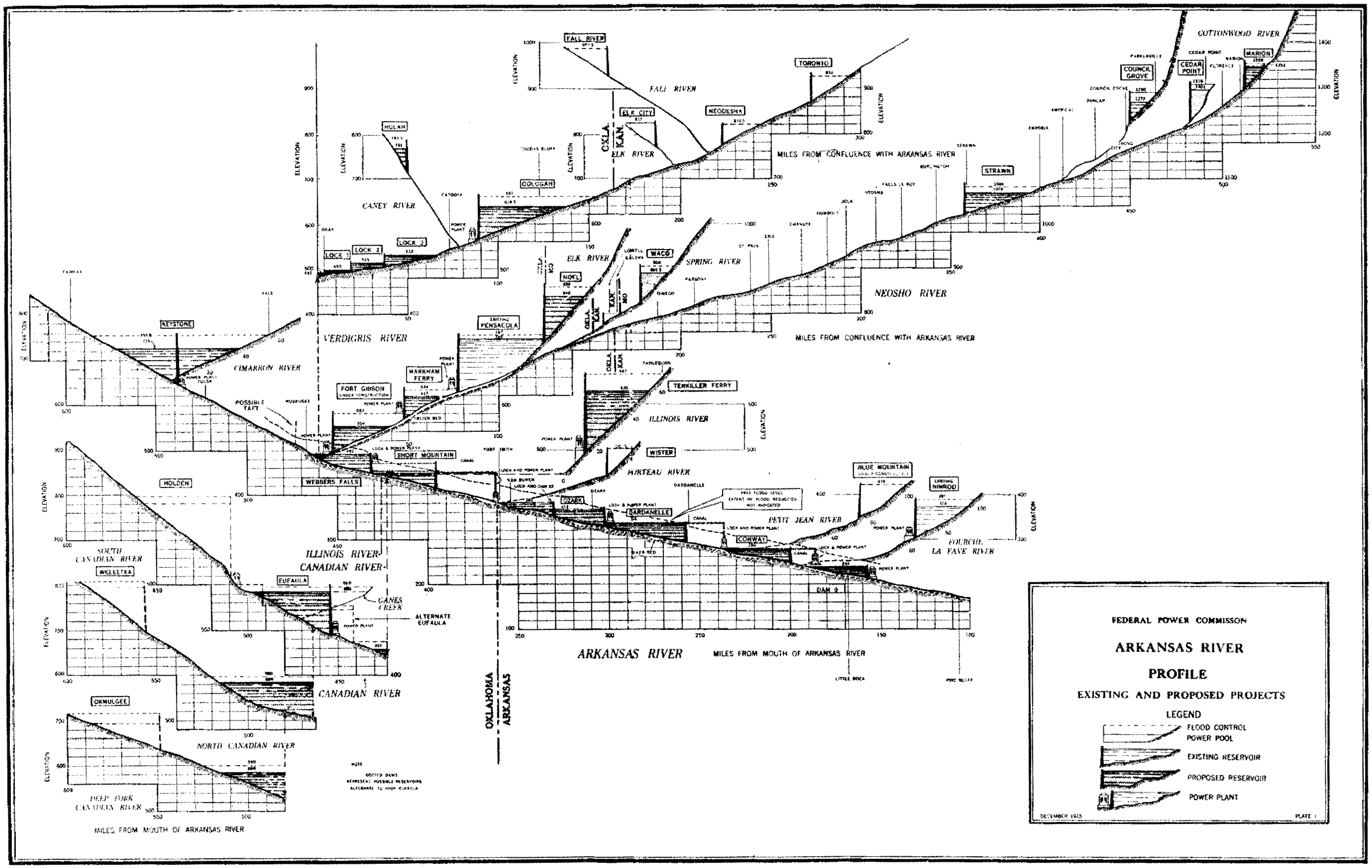

FEDERAL POWER COMMISSION
ARKANSAS RIVER
PROFILE
EXISTING AND PROPOSED PROJECTS
LEGEND
FLOOD CONTROL
POWER POOL
EXISTING RESERVOIR
PROPOSED RESERVOIR
POWER PLANT
ARKANSAS RIVER
MILES FROM MOUTH OF ARKANSAS RIVER
OKLAHOMA
ARKANSAS
COTTONWOOD RIVER
FALL RIVER
ELK RIVER
CANEY RIVER
VERDIGRIS RIVER
SPRING RIVER
NEOSHO RIVER
CIMARRON RIVER
ILLINOIS RIVER
POTEAU RIVER
PETIT JEAN RIVER
FOURCHE LA FAVE RIVER
SOUTH CANADIAN RIVER
CANADIAN RIVER
NORTH CANADIAN RIVER
DEEP FORK CANADIAN RIVER
MILES FROM CONFLUENCE WITH ARKANSAS RIVER
FALL RIVER
TORONTO
ELK CITY
NEODESHA
HULAH
OOLOGAH
COUNCIL GROVE
CEDAR POINT
MARION
STRAWN
LOCK 1
LOCK 2
LOCK 3
NOEL
WACO
PENSACOLA
KEYSTONE
MARKHAM FERRY
FORT GIBSON
TENKILLER FERRY
SHORT MOUNTAIN
WEBBERS FALLS
WISTER
OZARK
DARDANELLE
BLUE MOUNTAIN
NIMROD
CONWAY
DAM 9
HOLDEN
WELEETKA
EUFAULA
OKMULGEE
ALTERNATE EUFAULA
CANES CREEK
POSSIBLE TAFT
ELEVATION

Figure 1

effectively on the regional load. Operation of the regulatory storage capacities in the manner described above, combined with the use of storage space reserved specifically for flood control, assures the maximum degree of flood protection for portions of the basin subject to flood damage.

This application of the modern technique of river-basin engineering has resulted in plans which will make possible the generation of 45,000 million kwh. per year in contrast with 1,000 million kwh. expected under the original plans for this river. These figures are additional to the 2,000 million kwh. now being generated each year at constructed plants. The development of this power will make possible the securing of the navigation and flood control improvements which considered separately would not be feasible.

THE LOWER ARKANSAS AND THE WHITE RIVER BASINS

Application of the technique of development to the easterly or lower half of the Arkansas River basin is quite different from that in the Alabama-Coosa basin, principally because of the fact that some of the most valuable agricultural lands in the State of Arkansas lie in the flat flood plains along the Arkansas main stem. Multiple-purpose storage reservoirs are under construction on major tributaries and on the main river above Fort Smith, Arkansas, to provide flood protection for the extensive agricultural lands and important municipal centres along the Arkansas River, to reduce flood heights along the lower Mississippi River, and to augment low stream-flow for water-supply and power development.

The plan provides for a navigable waterway extending from the confluence of the Arkansas and Mississippi Rivers to Tulsa, Oklahoma. In this case navigation dams of sufficient height to permit full power development are impracticable along the lower Arkansas River because of the broad flat nature of the valley. Therefore, to preserve the power values, a different type of development is required from that employed on the Alabama River. As a solution to the problem, the Federal Power Commission has suggested a system of low diversion dams combined with power-navigation canals with locks and power-houses located where the canals return to the river. By this means fewer navigation locks are required, while the concentration of power at the fewer sites permits the development of power through higher heads, less affected by rises in tail-water. These advantages are obtained without the inundation of the valuable farm lands which would be covered by high-head main-stream dams.

With this type of navigation and power development, and with certain other modifications to increase the capacity of multiple-purpose storage reservoirs on the tributaries, it will be possible to increase the average annual generation from 15,000 million kwh. to about 35,000 million. Under this plan the installations at the tributary reservoirs will be made for operation as low-load factor peaking plants; and the installations at the power drops in the navigation canal system will be at high-load factors to conform with navigation needs. The control of the river will not be complete and some reductions in head will take place at the main stem plants during high flows. At these times the tributary power-plants will have their maximum capacity and will make up any deficiencies at the lower plants.[1]

The plan of development of the White River basin, which adjoins the lower Arkansas basin, will provide a high degree of river control for power, flood control and open-river navigation in the alluvial plains. Although the run-off in the two basins is somewhat similar, it has been possible, on the assumption of electrical interconnexion and co-ordination, to set up plans for their development which take advantage of the different flow characteristics of the two rivers in order to permit the fullest use of the power potential of each. The result will be that each river system will complement and support the other and will permit each to contribute more to the regional power supply than if developed and operated as a separate programme.

BULL SHOALS PROJECT

The Bull Shoals flood control and power project in the White River basin offers an example of the sound application of river-basin engineering to obtain the maximum of usable conservation storage and power development at a specific site. This project now under construction by the United States, is a key project in the development of the river and the control of floods on the Mississippi River.

In selecting the height of the Bull Shoals dam it was decided to place the maximum power pool at the tail-water of the existing privately-owned Ozark Beach hydro-electric plant located directly above Bull Shoals. This will mean that during floods the Bull Shoals flood control pool, as it fills, will raise the Ozark Beach tail-water and, in times of maximum flood, reduce the Ozark Beach head to zero. During these periods of high flow, however, the maximum head will be maintained at the Bull Shoals power-plant and replacement power will be available to make up the loss at Ozark Beach.

This decision to build a 42-ft. higher dam at Bull Shoals will increase the maximum static head at the project by about 84 ft. The usable power storage will be increased about ten times, the maximum regulated flow nearly doubled, the primary or continuous power nearly trebled, and the average annual generation increased from about 300 million kwh. to about 600 million kwh. This plan will also mean very substantial benefits to proposed downstream development.

KINGS RIVER, CALIFORNIA

An example of the technique involved when irrigation is a primary function is provided by the Kings River project in California. The Kings River is a part of the Sacramento-San Joaquin River system in the Central Valley area, and is a very important stream for both irrigation and power. A plan which will harmonize the requirements of both these purposes will provide about one million kw. of power, with average annual generation of about 5,000 million kwh.

The proposed plan includes storage reservoirs and power projects in the mountainous headwater areas to utilize the flows through high power heads. In order to develop the

[1]Figure 1 shows the relationship of existing and proposed Arkansas Basin projects on a profile of the river. Figure 2 shows the location of projects in the multiple-purpose plans for development of the Arkansas and White Rivers.

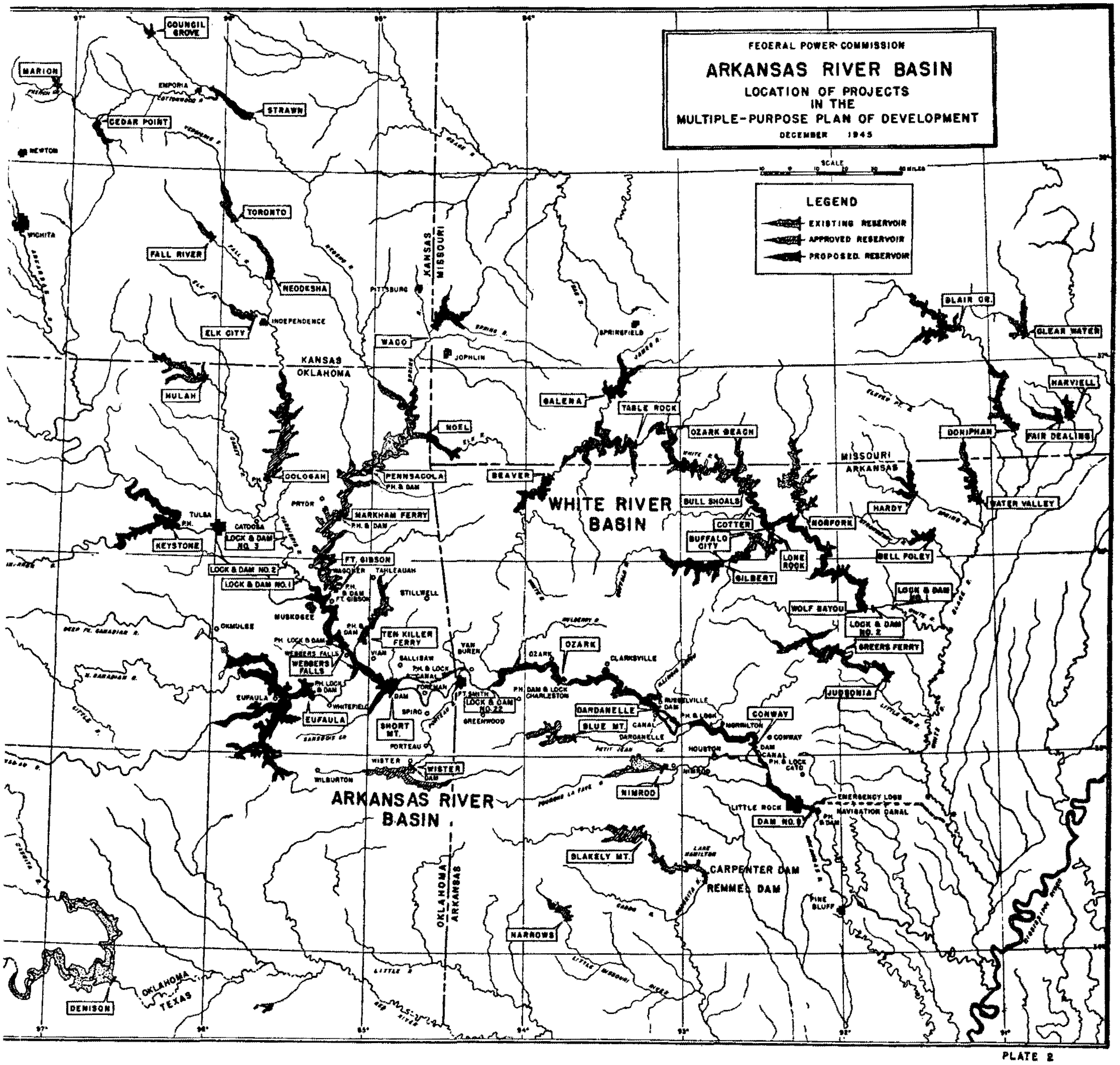


Figure 2

best power from the upper watershed, re-regulation of the resulting variable discharges for power must be provided so as to make the flow suitable for downstream irrigation use. A reservoir site was found for this purpose where the river debouches from the mountains into the flat plain region. The Pine Flat project, now under construction at this site, will accomplish these purposes and also provide necessary flood control storage.

The headwater power development, providing as it does in this case for holdover storage, will make available twice as much water for irrigation during years of extreme drought as would be available without the power development.

CONCLUDING COMMENTS

In the brief compass of this paper I have attempted to suggest some of the broader characteristics and problems of what I have described as a new engineering technique for the optimum utilization of water-power resources as a part of comprehensive basin-wide, river-basin development. It is only through the perfection of such techniques that regions can obtain the full contribution which their rivers can make to their energy economies while at the same time realizing the other values offered by river-basin reservoirs. Whatever the future may offer in the way of energy resources, other than the exhaustible coal, oil and gas reserves of some parts of the world, the efforts to establish balanced regional economies are going to require that the perpetual supplies of energy available in falling water be fully utilized.

This leads naturally to my final suggestion that, in the application of improved techniques to the planning of water-power development, the part which the power will play in the social economy of the region must never be absent from the planner's mind. In the words of the epoch-making report of October 1934, by the Mississippi Valley Committee of this country's Federal Emergency Administration of Public Works:

"Engineering does not exist for its own sake. It is of little use to control rivers if we cannot thereby improve the quality of human living. Therefore, the final and most significant element which the Committee has considered is neither land nor water, but the people who live on the land and are dependent upon the water."

Hydro Power and Conservation of Power Resources[1]

P. MASSÉ and M. ROUSSELIER

ABSTRACT

The prospect of the exhaustion of mineral resources cannot be disregarded and, consequently, rational and orderly methods for the utilization of the inexhaustible resources provided by water must be studied in relation to geographical units of sufficient size.

The study of a problem of this kind is impossible unless founded on primary data, namely a physical and economic inventory, which must be as accurate as possible, of the water resources of the various countries of the world.

It is proposed in this paper to draw up simple and uniform rules for the determination and easier calculation of these data. This paper while setting out those rules which appear most suitable for the French inventory also emphasizes the advantage of each country giving an account of the methods arrived at as a result of its experience.

The physical inventory leads to two elementary conceptions : the gross natural potential, or gross annual power from water-flow and the net natural potential or annual power which can be harnessed in practice.

The economic inventory is founded on rules which call for greater skill. It would seem useful to consider : (1) the resources the cost of which is less than or equal to the ceiling capital costs now regarded as permissible ; (2) the resources limited by ceiling costs 50 per cent or 100 per cent above those in (1) above.

The mineral power resources (coal, oil etc.) are available to man only in the form of limited stocks progressively decreasing to the point of exhaustion. This prospect of exhaustion is barely perceptible in one generation and is balanced over a century or a millennium by the discovery of new deposits and inventions which are liable to upset existing information on the problem. Nevertheless, the need for the conservation of power resources cannot be disregarded. The sources of hydro-power are in the nature of an inexhaustible flow constantly maintained by the water cycle and their utilization, although involving large initial investment, subsequently calls only for a moderate effort for maintenance and renewals.

Consequently hydro-power would appear likely to become a considerable factor in the conservation of the non-renewable power resources. As such it should therefore be given priority in the supply of equipment in all cases where its unmeasurable flow can be substituted for the consumable stocks and at the same or a moderately higher cost.

Several nations are already faced with this problem. The search for an optimum plan of development and utilization of the various sources of power is an acute and precise question in most countries owing to the limited resources available and the large requirements.

A fully rational solution to this problem of the optimum cannot be found within the boundaries of one country alone. As a result of technical progress, particularly in transport, and of the economic and political development of trade, it can be foreseen that the application of this idea of the optimum to ever larger geographical units will become a reality tomorrow.

It appears to us that the most direct and positive means of solving this problem is to work out methods for an accurate appraisal of national and international water resources and their economic value, and to define international rules guaranteeing their uniformity.

Our knowledge of these matters is very vague. In the few Western European countries which appear to be among the most advanced in the appraisal of their resources, it is by no means rare to find divergencies of appraisal in the proportion of 1 to 2 or 3, according to the authors, and none of them is able to give an exact definition of "possible" resources or "economically interesting" resources.

In what follows below we suggest definitions of some simple conceptions.

(*a*) *Gross natural potential*

The above term may be taken to mean the *aggregate of all the gross power from water-flow* which could, in theory, be obtained by totalling the product Qh (flow × head) of the whole of the visible flow. In other words, it is the product of flow by altitude for the water resources the appraisal of which is dealt with in the papers which were presented at the first meeting of this Section of the Conference.

In practice, and on a national or continental scale, one can reckon the summation of the potentials of hypsometric sections whose total run-off is calculated. In most cases this calculation is made by means of specific precipitations, thanks to the remarkable invariability of the loss in flow-off

[1]Original text: French.

of areas which have the same climatic, geological and plant characteristics.

The summation completed along the water courses of the product Qh would appear to be more applicable to large rivers or to flat countries where the hypsometric method would be deceptive. The two methods will have to be used to supplement and check each other in areas where they are both applicable.

One of the difficulties which affects the determination of the natural potential, and which we shall constantly encounter later on, is the fact that the flow of hydro-power is a contingent variable depending on the unpredictable irregularities of the climate.

It is natural to consider first of all the average value or mathematical probability of the contingent variable since this is the normal method of expressing the productive capacity of a waterfall.

Consequently, the gross natural potential will be the average of the total productibilities computed by the methods of summation indicated above. It is an indication of average abundance.

Apart from quantity, there is also the question of quality which is bound up with fitness for consumption. For instance, the inter-annual regularity may be measured by the inverse of the mean quadratic deviation of the dependent variable. However, this index may seem too theoretical and does not cover all the aspects of quality. A better index would be the total productibility guaranteed with a given probability (e.g., 0.95) during the period of the year regarded as "critical". The critical period varies in accordance with the proportion of hydraulic and thermic factors and consequently in accordance with the size of the geographical unit in question and the development policy of the countries concerned. Hence, it would seem that this conception should merely be borne in mind for future clarification.

(*b*) *Net natural potential*

The gross natural potential provides an ideal ceiling figure for hydro-power resources. But this ceiling figure is too far beyond practical possibility to be of other than theoretical interest.

An approximation to the actual potential can be obtained by using suitable reduction coefficients to correct the gross natural potential. This correction would appear to be the most practical and rapid method of making preliminary estimates of the actual possibilities in new countries where thorough exploration of the sites would involve expense and delay for which it would be impossible to obtain consent.

The reduction coefficients take the following into account:

Water losses due to the limited capacity of the diversion works;

Losses in height of falls due to the nature of the terrain;

Volume of water left in rivers for the other uses of water (irrigation, sanitation etc.);

Losses of energy in diversion works, machines etc.

For instance, Mr. Albert Caquot has made an estimate of hydro-power resources in metropolitan France.

Taking as a basis the modules of 65 selected measurement stations, he has drawn up a series of laws giving the average capacity of each elementary surface of 1 sq. km. depending upon its altitude, geographical co-ordinates and orientation of the slope. The integration of the product of these functions by the altitude extended to the whole country gives a gross natural potential of 314,000 million kwh.

The net natural potential has been estimated by him at 138,000 million kwh. This figure was obtained after a reduction of 6 per cent, representing energy available at heights above 2,000 metres, and an average reduction of approximately 50 per cent for the losses and physical impossibilities mentioned above.

ECONOMIC INVENTORY OF THE RESOURCES

The physical appraisal of hydro-power resources is only a first stage, the second stage being their economic appraisal.

This problem is far more difficult than that of physical appraisal, as the value of a waterfall depends not only on the power potential in an average year but also on the quality, which is itself dependent on complex factors which vary from one country to another (hydrological conditions, consumption cycle, cost of thermic production).

It may be said in general terms that man is logically led to classify the sites of falls and reservoirs in the order of increasing costs and constantly to select those which are most economical, that is, to observe the law of diminishing returns. However, practical considerations, the development of techniques and ideas, doubts regarding certain geological and hydrological data, the impossibility of carrying on all the studies at the same time and the desire to avoid "skimming the cream off" resources, prevent a strict observance of the law of diminishing returns and in the most carefully considered development schemes a certain dissipation of the specific costs of the waterfalls concerned cannot be avoided.

Nevertheless, certain reasonable limits to the capital costs of power-stations and reservoirs are generally accepted in each country. In order to avoid going into all the complex nature of matters as they are in reality, we propose to deal specially with two ceiling figures for capital costs, p_h for the kwh. producible on the stream as it flows and p_r for the kwh. storable.

It would be of great value if each country were to give an account of the intuitive, empirical or reasoned principles governing the choice of these ceiling costs which are usually costs which balance the indigenous or foreign thermic production. In France, for instance, the ceiling costs have so far been estimated in continuity with before the war, taking into account the rise in the price of coal which is slightly greater than the rise in the cost of the works. Other methods are now being studied for a synthetic determination of the equilibrium but figures have not yet been arrived at.

If it is assumed that the present p_h and p_r ceiling costs are known and accepted as valid, it would be necessary to determine the p'_h and p'_r ceiling costs (higher than p_h and p_r owing to the diminishing returns) which must be taken into account in the following stages of development, and from them to deduce the developable resources between p_h and p'_h and p_r and p'_r.

The upward margin must be broadly computed owing to a number of factors whose long-term tendency is to shift the equilibrium in favour of water-power:

(*a*) The persistent trend towards lower interest rates;

(*b*) Reduction of the cost of civil engineering works owing to mechanization and of the prime cost of machines owing to standardization;

(*c*) Progressive exhaustion of certain coal deposits;

(*d*) Increasing use of coal in the chemical industry;

(*e*) Persistent trend towards higher wages.

In view of the above, one might be tempted to accept a value of 2 for the ratios $\frac{p'_h}{p_h}$ and $\frac{p'_r}{p_r}$.

We consider, however, that it would be advisable not to go so far, as in a number of countries the classified costs curve now shows not a levelling-off but a semi-levelling-off (that is, it is slightly rising).

This is particularly the case in France where a new programme equal in scope to the present programme (approximately 10,000 million kwh.) appears possible at an average cost approximately 10 per cent in excess of the present cost. The fact that this semi-levelling-off exists is explained by reasons which are probably valid in other countries. One of the reasons is that, generally speaking, the period of development of exceptionally remunerative sites has passed and that the adaptation of the marginal characteristics of the projects to the p_h and p_r ceiling costs leads to a certain equalization of the overall economic characteristics of sites of extremely unequal value. The other reason is that technical progress and the increasing size of the schemes carried out make it possible to embark on projects which were formerly abandoned not because they were too costly but because they were too venturesome or too large. Lastly, there are additional possibilities arising from new ideas which make greater use of geographical features such as the diversion of water from one valley to another and the intricate supply of water to seasonal reservoirs by a combination of diversion and storage pumping.

The probable existence of such a semi-levelling-off in the costs curve means that the adoption of the ratio 2 to 1 would lead to the inclusion, in the economic inventory of the following stages, of a large number of projects considered to be of too little interest to permit of serious appraisal. For this reason, we believe that the economic inventory proposed by us could be limited to the ratio 1.5 to 1, the p'_h and p'_r costs being, of course, assessed in accordance with existing conditions, in the same way as the p_h and p_r costs.

A preliminary estimate of the economic resources in metropolitan France based on an intuitive rather than calculated application of the above principles gives a probable figure of 80,000 million kwh.

On the other hand, Mr. Albert Caquot arrives at a figure of 100,000 million kwh. by extending to the whole of France the correlations, based on experience, between the net natural and economically producible potentials per square kilometre. The discrepancy between the two figures, which have been arrived at independently, is more or less made up of the available small (micro-central) hydraulic power resources. The check provided by these figures is of great interest and confirms the practical value of the physical data proposed in this paper.

The annexed diagram shows the various conceptions connected with the appraisal of water resources.

Considerations for General Planning of Water-Power Stations[1]

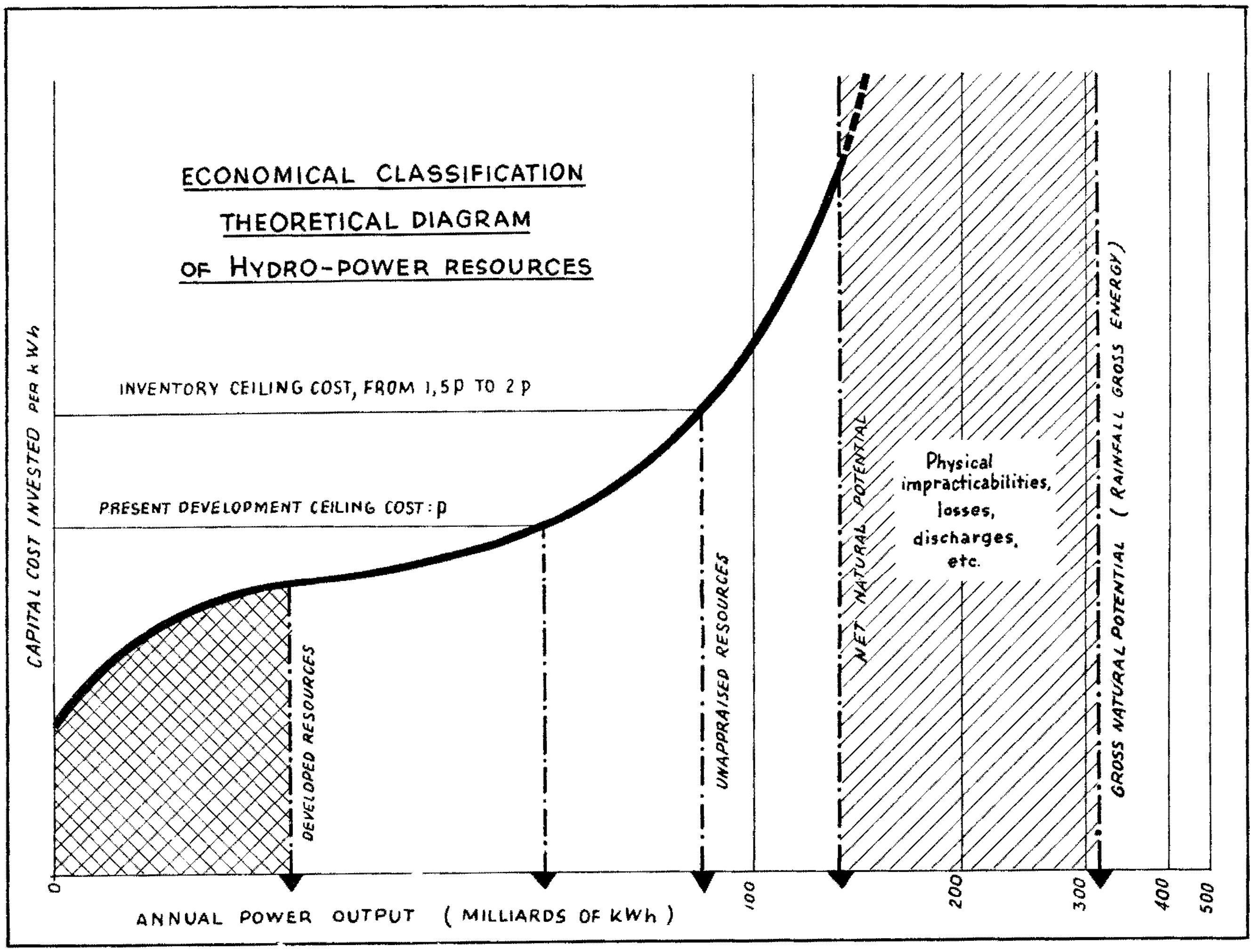
GEORG BEURLE

ABSTRACT

The purpose of every form of water management should be the full and most suitable use of the water resources. In the development of water-power it is possible to observe progress from single installations at particularly favourable points towards the construction of chains or groups of installations, towards conservation of power constancy in the waterflow, towards deliberate straddling of heights of fall in the longitudinal profile, towards systems of reservoirs which involve entire areas, and towards an expansion beyond natural catchment areas into adjacent watercourses outside the area. Water-management plans are expanding not only territorially but also in scope : all possibilities of utilizing water are to be taken into account even if thereby a particular form of utilization is constricted. By means of broad development plans these possibilities are investigated on the basis of all technical and economic data ; such preliminary work may result in framework plans which in turn may be followed by comprehensive legislation provisions based on them which, though not *per se* projects, lay down the legal conditions governing the development and utilization of water in particular areas or on particular sections of watercourses. Provisions of this kind should remain operative for a long period but must be capable of being adapted to technical and economic progress. A material condition preliminary to the enactment of such provisions is a sound knowledge of all the data.

The thought which runs through the development of the water system as a whole is that of the fullest and most profitable utilization of the water resources of nature. As long as a country's water economy is flourishing, this consideration is given due heed. *Pari passu* with a decline in the culture and civilization of a region accompanied by a decline in its water management, this overriding purpose tends to recede into the background and instead the utilization of water assumes more primitive, imperfect and less creative forms. While it is surely correct that the nature and form of a country's water management are a criterion of that country's material development, it is equally true that as part of a far-reaching utilization of this common asset priority should undoubtedly be given

[1]Original text : German.



to those forms of use which both legally and technically give precedence to the notion of systematic over individual use of water. We in Austria are heading in that direction, but even here the final goal has not yet by any means been achieved.

WATER: A NATIONAL ASSET

The concept that water is a national asset and a public resource which may and should be used by the individual (though not as absolute master of the property), and that this utilization must be regulated technically, legally and economically becomes quite naturally more predominant as interests in water become more complicated. In this paper we shall not deal with the important topics of water-supply, prevention of pollution, agricultural irrigation and drainage, and the use of watercourses for the purpose of floating, rafting and navigation. These are matters in which the utilization of water has for long been governed by the general public interest. Nor shall we deal with the regulations governing mills, and other enactments dating back to the early nineteenth century, which reflect the conditions when the installations using water were numerous but very small. We shall deal here only with measures taken or proposed in recent years to integrate large modern power installations (nearly all of which are hydro-power stations) into a general rational water management within the meaning of our subject. For this purpose general plans for the utilization of water are drawn up, indicating on very general lines what points or reaches of a watercourse are suitable for the construction of hydro-power plants, where reservoirs may be constructed and so forth. If planning does not go so far but merely provides for what in town-planning is called zoning, the result is a framework plan which demarcates the limits within which the more detailed planning is to take place. It is possible to trace the stages of development leading to this point.

THE SINGLE INSTALLATION

Single installations were usually created at points where particularly suitable local conditions made the construction of a power plant advisable. Until twenty-five years ago a material part of the activity of the technicians concerned was to look for the best possibilities of utilizing water-power. In many countries this is still the case; but in the countries which are more progressive in water management this type of planning has to a large extent been abandoned. Yet important cases may still occur in which it is proper or even necessary, and hence plainly correct, to take the planning of a single installation as the point of departure for comprehensive planning. This will occur whenever local conditions clearly suggest not only that at that particular point the construction of a single plant is suitable, but also that in respect of the utilization of the other parts of the catchment area or river system that place necessarily presents a breach of continuity, a section. It may, for example, be a spot where the construction of a plant or of a dam is practically compulsory. In former times the places regarded as naturally the most favourable points for utilizing water-power were very often the waterfalls. Indeed in many cases they still are, particularly where diversion is costly and must be kept as short as possible. To some extent the steep reaches of streams and small rivers correspond to the waterfalls or rapids of large rivers. Whilst in the former case it is immediately obvious at what points and within which limits utilization is most favourable under optimum conditions, in doubtful cases planners came to rely on the plotted longitudinal profile to show them more or less clearly which initial or end points had to be considered if the maximum results were to be achieved with the most economical means—that is, if the supreme principle of strictly and purely economic planning was to be observed. Numerous installations have been created, or at least planned, in this way.

THE CHAIN OF INSTALLATIONS

Thence one proceeds to one of the best-known forms of planned development of a river for power production, viz. the chain of installations in which plants form a co-ordinated series along a river or canal. The tail-water of the upper proprietor is the upper water of the lower proprietor. This form is not new; we find it on small watercourses which owing to their fall or their proximity to favourable sources of supply or markets justified the installation of several plants. The determining factor in all these old examples was that in those days it was impossible to use great heights of fall in a single gradient section, and hence plants were necessarily built in rows with the greatest possible height of fall between any two. In many cases adjacent plants were operated by a single proprietor; in many others different proprietors shared the water-power of one and the same river. This easily led, and still leads, to disputes about water rights, and the records of our administrative authorities are full of complaints about unjustified damming, irregular yield, improper retention of water and similar complaints between neighbours. Conditions are better if the series of such plants is properly planned from the very beginning—for example, where the river is entirely undeveloped and hence offers ample opportunity, or where plants exist only at a few points which then either become the fixed points in the planning or else are sacrificed for the sake of the larger plan. In this way the technical concept of a chain of installations on watercourses of the most diverse types can be translated into fact. Indeed, this concept was really the *fons et origo* of ideas on the systematic utilization of water-power. Nothing so well illustrates the interdependence of different possibilities of use as the transmission of water from one plant to another; and nothing is so disruptive as an irregular or unjustified water supply from the upper to the lower proprietor, or, looking upstream, an attempt by the lower proprietor to encroach on the demarcation line of the proprietor immediately upstream.

CONSERVATION OF POWER CONSTANCY IN THE WATER-FLOW

It has, however, long been recognized that in cases where water-power can only be extracted if a river is developed in gradient sections the fullest and best utilization does not always occur if all contact between the upper and the lower proprietor is scrupulously avoided. Quite on the contrary, the objective to be aimed at is partial damming at seasons of low water throughout the year and throughout the chain of installations. The conservation of power constancy in the water-flow represents a further advance in this direction. It results in a sort of synchronization which means that the differential all the way down from the member of the chain of installations highest upstream to the lowest downstream is regulated in such a way that all installations may be operated during a given period with vastly-improved performance, provided that the installation furthest upstream has sufficient water at its disposal and the installation furthest downstream can still supply water to the main stream or to a counter-basin.

Since river dams can store only a small volume of water, it is evident from this example of storage by means of an arrangement of installations that there is a great deal to be said for jointly planned storage. This is all the more true of high-pressure installations, in which there can be no economic development at all unless there is an upper storage reservoir, though its efficiency, of course, decreases from the point of view of the utilization of energy both relatively and absolutely as one goes downstream. Special conditions occur: thus, for example, Sweden has its vast lakes, Lake Geneva acts as reservoir for the Rhône, Lake Constance is the reservoir of the Upper Rhine, the lakes of the Salzkammergut act as reservoirs for the Traun. Where such favourable natural reservoirs occur it is possible to plan the storage of water, with or without application—or with partial application—of the principle of conservation of power constancy, according to requirements. We are now at a stage of general planning at which these considerations are paramount and supersede all those considerations which were formerly relevant to the discovery of favourable but isolated possibilities of utilization.

But we are not stopping at this stage. Development is tending much farther: planning is expanding territorially, for not merely are isolated stretches of watercourses being integrated but whole river systems with all their tributary valleys are being taken in. Indeed, at times plans provide for the participation of neighbouring territories in development, so that the system will far exceed the limits of natural watersheds. Planning is also expanding in scope: water management is no longer pursuing any one single object but is concerned with several—for example flood protection, irrigation, navigation and hydro power—even though this may affect the scope of one particular manner of utilization.

UNFORESEEN EFFECTS

There is only an apparent increase in the number of possible solutions to keep pace with these possibilities of expansion in space and in scope. First and foremost, the more comprehensively one draws the plan for the utilization of the water-power in any one territory, the sooner one must realize and consider the limits set to the possibilities by the fact that the total turn-over of water in the particular watercourse cannot be increased. So long as the problem of the direct conversion of sea-water into river-water is technically and economically unsolved, we shall have to rely for the natural and basic supply of water in our large river systems on precipitation in all its forms. Hence human effort can effect only a few isolated points in this circuit where it includes the surface of the earth or the subsoil water. Furthermore, the problem of modifying weather has hardly been touched and certainly has not been solved. As the potential scope of modern technique expands, so the conflict grows between the various interests within the framework of our water system. As the external forces which we are capable of applying increase, the risk of misguided efforts and the danger of unfavourable unforeseen effects increase also. We would mention only two cases in this connexion: the lowering of the level of the subsoil water in broad alluvial river valleys as a result of river control measures which lead to a depression of the water level; and the silting in the reservoir areas of weirs and dams which in turn leads to a rise of the water-level above the main dam. Phenomena of this kind teach us to be moderate in our attempts to change the natural or gradually formed conditions of an area.

The planning of water projects of a general kind frequently suffers from the fact that the person or body commissioning the work is aiming at a particular kind of water management the achievement of which appears to him more important than other possibilities. The result is a specialization in the purpose to be achieved exactly opposite to what must be desirable on general grounds. This specialization reflects an inevitable development from which all professions suffer, at least all scientific professions: our factual knowledge is increasing to such an extent that any person who wants to keep up with modern times is forced to specialize in a narrow field. Hence it is not entirely surprising that in water management also the main impetus towards synthesis, towards rational comprehensiveness, comes not so much from the specialists who are trained to pursue a particular technical or economic line, but rather from outside. It comes from the Government, which is largely concerned with the law. The Government suffers from, but is not responsible for, departmentalization; it recognizes specialization but cannot put it to use. This process may, particularly for technicians, be unpleasant, painful or even mortifying; but it is perfectly understandable and natural.

FRAMEWORK PLANS FOR WATER MANAGEMENT

Accordingly, in the most recent legislation on water rights we find a general tendency or, rather more than that, guiding lines and mandatory rules leading to the water management of the future with a view to a universal water system which promises the greatest success not in its separate components but in its total sum. The State stands above individual interests, and the means it uses to win recognition for the concept of the best possible utilization of water for the economy as a whole consists of general guiding lines calculated to achieve that object. But since in practice and in individual cases it may be very difficult to decide whether one or the other solution is preferable, and since in particular it is always questionable if a particular new water project fits into the concept of maximum total utilization (a question which in most cases cannot be answered affirmatively *a priori*), concrete guiding lines must be established to prescribe the way in which new plans and projects have to fit in. That is the meaning and object of framework planning for water management.

In other words, a plan of this nature is to define the limits within which all planning must move. For example, it may have to stipulate that certain stretches of water or certain valleys must not be touched for such reasons as the protection of nature, the landscape or the sources. The plan must state whether on a given reach of the river rafting and navigation should continue, or whether such utilization is to be taken into account in the future. It will have to define the upper and lower limits of the hydraulic development so as to avoid any possibility of disputes when and if arrangements are made later for conserving the power constancy of the water-flow. In some circumstances an existing division into sections will have to be maintained, or alternatively, provision will have to be made for its alteration. A plan of this kind may also prescribe a specific kind of utilization such as industrial self-supply, or the supply of remoter works, railways etc., whenever special reasons make this advisable or necessary. Special attention will have to be paid to the possibilities of storage; this may take the form of reserving certain suitable valleys for reservoirs. Or the plan may have to provide that gradient sections (if any) situated below points where good possibilities of storage have been proved to exist, must make allowance for a possible development even though the contingency may be remote.

On the other hand, the framework plan and the relevant legislative provisions must not act as a strait-jacket or a brake on actual development, nor should it tend to supersede expert planning on single installations. For this reason provision will have to be made for possible modification, to become operative whenever, subsequently, compelling reasons emerge which make it inappropriate to adhere to an existing framework plan.

Finally, distinction will have to be made between a total plan for water management and a framework plan as described in this paper. A total plan is the concrete solution proposed for the fullest possible utilization of a certain catchment area or watercourse—in other words, a plan or a rational co-ordination of a number of plans for the formation of an organic whole which takes into consideration all forms of water utilization. A framework plan only indicates what should—not what may—be done at a given point. If regarded in this way it ceases to have the frightening aspect of a further attempt by the State to order and prescribe by force or compulsion matters which are still in the development stage. Intervention by the authorities will be confined to certain fundamental commands and prohibitions which every person affected and every worker should and must know. It is a condition precedent to such provisions that the area concerned should first be studied generally with a view to the possible utilization of its water resources. Hence countries where this condition of comprehensive and thorough preparatory work has not yet been satisfied must be particularly careful in enacting such legislative provisions.

Recreational Use of Water

C. L. WIRTH

ABSTRACT

The paper summarizes the experience of the National Park Service in the recreational planning and development of reservoir recreational areas and states the importance of recreation in the life of the United States citizen. The paper outlines the work of the National Park Service in making preliminary recreational reconnaissance studies for Corps of Engineers and Bureau of Reclamation projects in the initial planning stages, discusses the kinds and types of recreational activities that take place on reservoir areas, and the recreational facilities necessary for maximum utilization of recreational resources. One section of the paper deals with the planning of recreational developments on reservoir areas, both in the preliminary and later stages of development ; one section discusses the construction of recreational facilities ; and one section is given over to the administration and management of reservoir recreational areas. The experience of the National Park Service in the evaluation of costs and benefits is briefly touched upon, and the final section epitomizes the work of the Service and the Smithsonian Institution in their joint historical, archaeological and paleontological studies.

INTRODUCTION

The water recreation values inherent in reservoirs and waterways have long been recognized in the United States, and in the past decade the Federal Government has become increasingly concerned with the full utilization of the recreational resources that its vast programmes of reclamation, irrigation, hydro-power, navigation and flood control have created. No acceptable over-all yardstick has been evolved for comparing the many benefits resulting from water impoundments; however, it is now generally recognized that the recreational assets which they create constitute one of the important benefits. In the United States we have learned that recreation is an important component of everyday living, an absolute essential to a full and enjoyable life. We have seen our leisure time double in the past half century in spite of the enormous increase in our productivity. We have read the pages of past civilizations and learned that leisure time, ill-spent, can contribute to social, moral and political degeneration. We hold that recreation is not a perquisite of living, but a basic ingredient to life itself, and we place a high value on the outdoor recreational activities offered by reservoirs and waterways and know that full utilization of such areas must be predicated upon ample provision of requisite recreational facilities and due regard for the health and safety of the recreationists.

Planning Recreational Development of Reservoirs

Planning for the recreational development of reservoir areas must be carried out from the earliest inception of the project to its final completion. In the United States, preliminary planning reports with regard to the recreational aspects of all reservoir development projects are prepared by the National Park Service for the two main governmental agencies constructing such projects, the Corps of Engineers of the Department of the Army, and the Bureau of Reclamation of the Department of the Interior. Studies of potential reservoir and water control projects are authorized by the Congress, and in the early stages the National Park Service is requested by both agencies to make preliminary reconnaissance appraisals of the recreational values of the proposed projects.

In the initial study phases of the project the National Park Service makes only preliminary reconnaissance surveys designed to ascertain the suitability of the project area for recreational development, the probable use that the reservoir may receive, whether or not the project will have any adverse effect on the existing recreational potentialities of the area, the extent of recreational development that may be warranted by the use that the area may receive, and a general appraisal of the character of the country in which the proposed project will be located. This preliminary reconnaissance report is submitted to the agency concerned and is taken into consideration in the submission of their report to the Congress. If the project is authorized for construction by the Congress, further recreational study and reports are required. The Corps of Engineers usually make studies of the recreation development with their own staff. Similar studies for the Bureau of Reclamation, however, are made by the National Park Service. Recreational facilities to be constructed with Federal money, in the case of Corps of Engineer projects, are supervised by that agency, while recreational facilities for Bureau of Reclamation projects are designed and developed under the supervision of the National Park Service.

The creation of large bodies of water, particularly in semi-arid regions where natural lakes are rare, profoundly affects the recreational habits of the people in the vicinity. These new types of areas must be integrated into a plan which includes existing and proposed recreational areas of other Federal, State and local agencies. This integration requires a knowledge on the part of the planning agency of the recreational plans of all agencies in the vicinity and, in the final analysis, cannot be effected until the planning agency has inventoried completely the existing and proposed recreational developments, not only in the immediate vicinity of the proposed project, but in the state, region, or basin in which it is to be located.

The National Park Service was authorized by the Congress in 1936 (1)[1] to make a nation-wide inventory, in co-operation with the several states, of the outdoor recreational areas in the United States and to plan for future recreational development on a nation-wide scale. Under the programme so authorized the National Park Service has co-operated with the states in state-wide recreational studies and published an over-all report of the recreational problem of the county in 1941, (2). This report has become the basis for subsequent recreational planning work of the Service.

[1]Numbers within parentheses refer to items in the bibliography.

The Service is currently making recreation studies, on a basin-wide basis, evaluating and inventorying the recreational potentialities of such large areas as the Missouri River Basin and the Columbia River Basin. Comprehensive plans for the development of the recreational resources of large basins of this type necessitate careful and detailed studies if the maximum value of the potential recreational facilities is to be secured. Such over-all basin studies should be completed prior to the completion of individual studies of any given reservoir area within the basin. Basin studies, however, take a long time, and in the interim, we are called upon to evaluate individual reservoir sites without the benefit of the over-all basin pattern. Nevertheless, by careful consideration of the various controlling factors, such as probable use, scenic desirability, vegetative cover, adequacy of size, recreational water use, fishing, hunting, climatic suitability, accessibility, method of operation of reservoir, adaptability for recreational development, proximity to other recreational areas, near-by population distribution and the known recreational habits of the potential reservoir users, we are able to predict with some degree of accuracy the probable use that the area may receive and furnish estimates of the probable cost of recreation facilities necessary to the full utilization of the recreational potentialities of the area.

DEVELOPMENT

The development of recreational facilities at reservoir areas may be divided into two phases: (1) The construction of facilities that may be accomplished during the period of the construction of the dam itself, and (2) the construction of recreational facilities which must be planned for completion subsequent to the completion of the dam construction. Close co-operative planning between the dam construction agency and the recreational planning agency is imperative from the initiation of the project to its final completion. Many of the facilities that may be necessary to the construction of the dam and appurtenant works, through joint planning may be so located as to be of maximum service in the recreational development of the project subsequent to the completion of the actual dam construction. Project construction roads may be planned to serve recreational areas; water and sanitation systems incident to the dam construction may be so located as to serve later recreation facilities; burrow pits may be located to insure a minimum of unsightliness and interference with the later recreational development; buildings designed for the project construction programme may be so designed as to serve later in the recreational development programme, whether in place or by moving them to other suitable locations. The National Park Service and the Bureau of Reclamation of the Department of the Interior work closely together in this respect to ensure that the maximum utilization of the project construction facilities will be secured.

The recreational activities offered by reservoirs and waterways are of the outdoor type and may vary from area to area, but our experience indicates that fishing, picnicking, boating, swimming, hunting, camping, winter sports and nature study (in the approximate order named) are the principal activities that can be anticipated, and necessary recreational facilities for these uses should be given priority in both planning and development. Minimum basic recreational facilities for reservoir recreational areas would include boat-launching ramps, a potable water-supply, sanitary facilities and some form of shelter. Such minimum facilities are supplemental to the provision of an adequate access road and the requisite space for automobile parking. In areas where more recreational use is anticipated, other facilities which have to be planned and constructed include: boat docks, picnic tables, fireplaces, picnic shelters, a concession facility for picnickers' and fishermen's supplies, boathouses and facilities for a boat-rental concessioner, bath-houses and related utility and sanitary facilities. The development of recreational areas of this latter type also entails the construction of administration buildings and facilities for the maintenance and operation of the area.

In planning the development of reservoir recreational areas, priority of (3) development is always given to facilities to serve public use, but when sufficient areas are available for this purpose, other areas may be set aside for the construction of organized camp facilities. Where the needs for public areas and organized camping facilities have been met, with additional lands available, consideration is given to areas that may be subdivided into summer home sites with appropriate sized lots for leasing to individuals who may wish to construct vacation cabins on them.

On reservoir sites under the control of the Bureau of Reclamation, the National Park Service prepares the plans for the general recreational development of the area, and tentative cost estimates. When funds for the recreational development programme are received, the Service prepares construction and working drawings and supervises the construction of the facilities. Priority in recreational development is given to the areas that have been set aside for public use, with organized group camp sites and summer home site areas having second and third priority respectively.

ADMINISTRATION AND MANAGEMENT OF RESERVOIR AREAS

Reservoir recreational areas, resulting from the reclamation projects of the Bureau of Reclamation, have been divided into (1) areas of national significance, and (2) areas of less than national significance. Areas of national significance (examples: Coulee Dam Recreational Area, Lake Franklin D. Roosevelt, State of Washington; and the Lake Mead Recreational Area, Hoover Dam, Arizona and Nevada) are developed and administered by the National Park Service through its regional offices. Funds for these areas are granted by the Congress as a part of the regular National Park Service appropriations.

Areas that are classified as "of less than national significance" constitute the vast majority of the reservoir recreational areas created by the Bureau of Reclamation activities. The Department of the Interior believes that since the primary benefits of such areas will accrue to the local, county, state or regional users the responsibility for the permanent management and administration of the areas should fall to these agencies. The development of recreational facilities therefore is predicated upon the prior agreement of such agencies that they will accept the permanent management and operation of the areas and that the necessary funds for this purpose will be forth-

According to the statistics of 1947, fishing on the west coast produced a yield of 114 million kg. and fishing on the east coast and the Sound, 42 million kg., the total being valued at $26 million. For fresh-water fishing the annual catch figures are estimated at 15 to 20 million kg. with a value of $8,400,000 to $11,200,000.

The relatively low value of the sea fishery is due to the fact that the catches, though large in quantity, consist of the cheaper kinds of fish, such as herring, Baltic herring, haddock, cod, whiting etc., whereas the more important fresh-water fish are pike, pike-perch, whitefish, burbot and char, which always fetch considerably higher prices. Owing to the rather low percentage of salt in the water along the whole Baltic coast (approximately 2 per cent in the southern Baltic Sea, 1 per cent north of Gotland and 0.5 per cent in the Gulf of Bothnia) the majority of fresh-water fish also are to be found here. Many of these, such as sea-trout, whitefish, grayling, pike-perch and ide often ascend the coast rivers for spawning. To these must be added the really anadromous species like salmon and eel as well as lamprey.

Most important of the fresh-water fish is the pike (*Esox lucius L*). It occurs in many parts of the country and gives an estimated annual yield of 3 million kg. valued at $1,650,000. Next come the perch (*Perca fluviatilis L*), also generally distributed, with a yield of some 2 million kg. valued at $550,000, and various forms of whitefish (*Coregonus*) with a total annual catch of approximately 2 million kg., valued at $1,100,000. Pike-perch (*Lucioperca sandra L*), which is valuable with respect to price, is mostly confined to the large lakes of the clayey plains of middle Sweden, and trout and char appear predominantly in Norrland.

The two kinds of fish most valuable in respect of price in Sweden are salmon and eel. They are caught chiefly along the coasts and in the open sea. The value of the catch in 1947 amounted to about $1,600,000 and $1,400,000 respectively, or 6.2 and 5.4 per cent of the total value of sea fishing. Nevertheless these fish are entirely (salmon) or in large measure (eel) dependent on fresh water. Salmon has to ascend the rivers for breeding and the greater part of the eel stock grows up to migratory size in the lakes. As far as fresh-water yield is concerned, catches in 1947 amounted for salmon to approximately 0.6 million kg. and for eel to roughly 0.3 million kg., valued at $670,000 and $280,000 respectively, or about 7 per cent and 3 per cent respectively of the total value of fresh-water fishing. Salmon varies greatly in abundance and has reached a very high level in recent years.

In the absence of reliable statistics, nothing definite can be said about the development of fishing during the present century. The transition to larger and also more effective fishing gear than was previously used, and greater interest in fishing and fish management, as well as an increased number of fishermen, especially non-professionals (anglers) who have been more and more active in recent years, have most certainly resulted in a considerable increase in the catches of fresh-water and sea fish. At the same time the stocks of fish have sometimes, though rarely, been decimated by overfishing or, more often, by water-utilization projects (dams, pollution, timber-floating).

The number engaged in the fresh-water fisheries can be estimated at about 1,500 commercial fishermen, some 70,000 fishing for their own requirements and about 200,000 anglers. The latter category of fishers is, as already mentioned, constantly growing. Angling undertaken for sport and recreation is also of great importance from a social point of view and has lately received attention from the authorities. Thus there are proposals to open to anglers a large part of the State fishing-waters which often contain trout and char, both by leasing the waters to anglers or their associations, and by selling fishing cards according to the American custom. In fact, this is already being done on quite a large scale.

FISHERY LAWS AND REGULATIONS

Fishing rights in Sweden belong to the landowners around or adjacent to lakes and rivers. Thus the fishing rights are mostly in private hands. In many cases also, the State as owner of large stretches of land is owner of the fishing. In the sea and the outer parts of archipelagoes as well as in open parts of Lakes Vänern, Vättern, Hjälmaren and Storsjön (Jämtland), every Swedish citizen has the right to fish with certain restrictions regarding tackle.

With a view to conserving the fisheries as a general resource of the country, fishery regulations have been introduced. These prohibit fishing with noxious or unsuitable methods (poisonous matter, fish-spear, gaff), fishing during the spawning season and the use at this time of certain gear liable to result in large catches (fyke-nets, seines), catching fish under a certain size (salmon, 50 cm., salmon-trout, 35 cm., pike, 40 cm., pike-perch 38 cm.), using nets and traps with meshes below a certain size etc. Unfortunately fishing is not so well controlled as is desirable, and poaching is done in many places as well as fishing in violation of the fishery regulations in force.

In order to conserve the fishery resources and to compensate damage thereto from man's interference in waterways, a special Water Act makes it a duty to take conservation measures or to pay for such measures.

WATER UTILIZATION PROJECTS AND FISHERY RESOURCES

Dams

Dams for the utilization of water-power (hydro-electric power dams in running water and regulating dams at the outlet of lakes) seriously interfere with the fish supply. This is partly because these dams cause great changes in the natural properties of the water and partly because the most valuable species of fish are chiefly affected. A hydro-electric power dam may obstruct the migration of fish (especially salmon and eel at their spawning and breeding places). Upstream of the dam a larger or smaller stretch of still water is formed which has entirely different hydrographical and biological conditions than prevailed previously in the current. Downstream of the dam the river-bed becomes more or less dry, at times for stretches of some kilometres. In addition, very rapid and extreme variations in water-level are produced by short-time-storage regulation at most of the power stations. Above the dams increasing numbers of pike, perch, burbot and other voracious fish of prey dangerous to the growing young salmon gradually mature. Furthermore, a large part of the most important food for young salmon will disappear both above and below the dam, so that spawn and young fish are eventually threatened with being left on dry ground. The possibilities for the spawning of salmon and the growth of the young both upstream and downstream of power dams are therefore greatly curtailed or entirely eliminated. Salmon have, indeed, nearly disappeared from some Swedish rivers which have many dams. Since the stock of salmon in the sea entirely depends on the opportunity to spawn in the rivers, the presence of many power dams frequently has serious and extensive consequences. At the same time it should be observed that in the damned-up parts of the rivers, which sometimes form real lakes, it becomes possible to catch newly-planted species, and in many cases to catch whitefish also.

Many fish passing through the turbines of hydro-electric power-stations are injured and killed. This happens most often with the Francis turbines where, according to researches made, more than 50 per cent of the descending eel are destroyed and where a great many small fish, such as young salmon, are also killed. The descending fish have a better chance in turbines of the Kaplan type, which today are to be found in the majority of power stations where the head of water is not too high.

Regulating dams erected in lakes to retain the spring and early summer floods and to store the waters for use during future low-water periods, above all during the last part of the winter, also obstruct the migration of fish. This applies especially to trout which are common in the upper parts of the large rivers where most of the regulation works are installed. In many cases the regulation heights are considerable, up to 12 metres (Torrön) and 18 metres (the Suorva lakes). In such cases wide stretches of the banks are flooded at times, then when the stored water is discharged, considerable parts of the lake become dry. These great variations of water-level cause considerable alterations in the flora and fauna of the lakes, entailing in certain cases the destruction of spawning places and a reduction in the supply of food for the fish. By the lowering of the water-level during the winter, the eggs and fry of char and whitefish, which spawn in autumn, remain on dry ground where they are either compressed by the ice or frozen in, being killed in both cases.

Thorough investigations of several regulated lakes have shown, however, that damage to fish stock is not so great as was earlier assumed. Sometimes the spawn has been hatched so early that the fry succeed in following the run-off, sometimes spawning occurs in water so deep that the spawn is not left on dry ground. In years when the water-level is raised at the time of the spawning of pike, the regulation may even involve certain advantages, since the water will be high until rather late in the summer, whereas it usually falls rather rapidly with the attendant risk that spawn and newly-hatched pike fry may remain on dry ground. With regard to fish food it has been found that in the years after a regulation on submerged ground there is a very abundant development of different small animals, primarily *Eurycercus*. The cause is that feeding stuff is extracted from the ground. After some years, however, this high production diminishes and the fauna become scarcer than before. In the case of lake regulation, *Gammarus*, particularly important as trout food, always disappears.

At the beginning of the 20th century, when water began to be utilized for hydro-electric purposes, the few power- and lake-regulation dams did not do much damage to the fish stock. The hydro-electric policy of later years, in conjunction with Sweden's constantly increasing need for electric power, has resulted in the drawing up of comprehensive water-utilization projects for the more important rivers. Many of the larger salmon rivers will soon be almost completely utilized by a number of hydro-electric power dams, while several of the more important lakes in the upper parts of the rivers have already been regulated. In other river systems such works are being undertaken.

The conservation measures adopted vary greatly in rivers where there are still important spawning and breeding places for salmon. Such places are kept in use by giving salmon access to them. Thus at many dams salmon ladders, mostly of the Landmark type, in some cases of the Denil type, have been provided. The following table furnishes data on some installed salmon ladders:

River	*Plant*	*Material*	*Length (metres)*	*Head (metres)*	*Water consumption (cub. metres)*	*Cost (dollars)*	*Year of erection*
Ume älv	Norrfors	Concrete	83	8.8	3.0	8300	1935
Dalälven	Älvkarleby	Wood	43	4.5	8.5	6400	1914
Mörrumsån	Svängsta	Concrete	37	4.5	0.8	7000	1944
Ätran	Herting	Denil type concrete wood	50	6.0	1.5	8300	1944

By means of an apparatus designed by the Royal Swedish Board of Waterfalls, consisting of a photo-electrit cell built into the top-most ladder-mouth, the number of fish ascending the salmon ladder can be counted. At Norrfors, where such a salmon-counter has been operating since 1935, the number of ascending salmon in 1948 amounted to 1,216 and at Älvkarleby, where it was fitted in 1946, to 3,733. Such an apparatus costs at present about $550. Drawings and descriptions of it have been sent to the American fishery authorities.

In cases where a number of hydro-electric power dams are installed in a river which still has good spawning facilities in its upper reaches, transportation of salmon has been carried out. In the Klarälven River flowing into Lake Vänern, with its stock of landlocked salmon, transportation has been carried out for about ten years. The salmon are caught in a salmon trap (a built-in part of the river that can be drained), transferred to a basin and from there to a container of about 1.7 cub. metres. In the first years oxygen was injected into the water; at present air is used. For a transport of two hours (about 60 km.) about 30 salmon of an approximate total weight of 60 kg. are taken. The cost of one transportation is about $30 and during a season these costs are much lower than would be the total amortization and operating costs for salmon ladders in a number of dams.

A similar method is used in the Ångermanälven River. Because of two large power-stations the main part of the salmon's spawning and breeding places has disappeared. In the upper reaches previously inaccessible to salmon there are suitable spawning places to which a large number of salmon are transferred (643 salmon in 1948). A large number (in 1948 approximately 1,500 salmon) are transported only past the lowest power-station, this transportation being designed to replace ascent through a salmon ladder. The salmon are here caught in a salmon trap, put into a basin and transferred to a large container (2.7 cub. metres), into which air is injected but which lacks cooling arrangements. The container is lifted to the top of the dam by a special crane. For a transport of some two hours (longest distance 100 km.) 15 to 20 salmon are taken, i.e., a total weight of 150 kg. (the average weight of salmon is considerably higher here than in the Klarälven River, 9 to 10 against 2 kg. respectively). Transportation is carried out in the night. The cost of catching and transportation amounted to about $7,200 in 1948, when it was begun on a large scale, but it should be lower in the future. Transportation of salmon was also started in 1948 in the Ljusnan River. Experiments are now being carried out to test the most suitable transportation and airing arrangements. In this field the best and cheapest solution has not yet been reached.

At Höljebro in the Ljusnan River, salmon have for some years been carried directly over a power dam. The fish are caught downstream of the dam with a large hoop-net fitted to a small hoisting crane, immediately put into wet sacks and transferred through a staircase in the dam body to a large basin directly by the top dam wall. It can then be observed when the salmon leave the basin and continue upstream.

In rivers where both the main stream and the affluent streams are changed by dam works or where for other reasons such as timber-floating, pollution etc., places otherwise not unsuitable for spawning cannot be used advantageously, the hatching of salmon is the most common conservation procedure, undertaken mainly with a view to maintaining salmon fishing in the sea. With regard to salmon hatching see below under "Research Activities".

To ensure the ascent of eel in the rivers eel-ladders are usually installed. These consist of wooden drums with the internal dimensions of 0.25 × 0.25 metres with numerous perforated transverse walls to reduce the velocity of the water and to offer the eel gripping facilities. The incline of the ladders is in the ratio of 1: 5, they are frequently arranged in zigzag fashion, and they require only a small quantity of water. The cost of such eel-ladders with accessories varies between $30 and $100 per metre-head of water. In many rivers, particularly in the southern parts of the country, large quantities of elvers or somewhat larger young eel ascend. They ascend also to small watercourses where a relatively large lake area furnishes suitable feeding-places. Numerous dams are often installed in these streams rendering difficult the ascent of the eel or constituting real obstructions. Instead of providing eel-ladders at all these dams another system is being adopted more and more, viz., the eels are caught at the lowest dam, then transported and distributed to different parts of the waters upstream. The lowermost eel-ladder opens in this instance into a catching container, whence the eel are collected at definite times. A plan for the distribution of the eel, drawn up with regard to the lake area and the location of the dam installations, is also provided.

In certain cases there are obstructions to the descent of salmon and eel past the power dams. Sometimes special fish-ways are provided, and in addition the keeping of racks in front of the turbine inlet (with a maximum distance of 2 cm. between the rack rods) is required. In the case of power stations fitted with Kaplan turbines this obligation has usually been dispensed with, for reasons stated earlier.

All the measures enumerated above to prevent or compensate damage to salmon and eel, trout, whitefish and char and other species, have to be taken by the owners of the dams in conformity with the provisions of chapter 2, paragraphs 8 and 10 of the Water Act mentioned above.

Pollution

In connexion with the increase in the population and its concentration in certain places and districts on the one hand, and the great development of industry during the past decades on the other hand, the question of removing the waste produced has become more and more acute. The waste from sewage and a large number of industries (cellulose factories, dairies, sugar factories, tanneries etc.) frequently contains large quantities of organic matter, the disintegration of which consumes all the oxygen in the water. The fish and the majority of water animals and plants are thus killed unless they escape from the contaminated water. At the same time a vegetation of polysaprobes is produced, such as *Sphaerotilus*, *Leptomitus*, *Fusarium* and a number of infusorias. Water pollution of this kind arises especially in small watercourses during times of the year when droughts reduce stream-flow, and the fish may then be destroyed entirely. New recruiting from adjacent rivers and lakes is, as a rule, effected rather quickly. Such pollution is sometimes also produced in towns situated on the coast.

Moreover, many factories discharge waste that even in very slight concentration is a heavy poison for the fish (particularly phenol matter from sulphate factories and gas and oil works) or which gives a disagreeable flavour to any fish that can exist in the infected waters. This kind of pollution has in some cases had extensive effect both because of the large amount of dead fish and the difficulty in selling the ill-flavoured fish. At times a single factory or a single town is not exposed to any tangible noxious effect, although waste matter can be proved both chemically and biologically. Through accumulation of waste carried to several points, however, a state is gradually reached where the self-purifying capacity of the water is no longer sufficient.

The discharge of large quantities of waste also implies heavy losses to the corresponding factories. Thus in Sweden about 1.3 million tons of wood matter is annually discharged by the sulphite factories. By the evaporation process a part of the wood matter is recovered and utilized. This also applies to certain waste products in the sewage water, which by a special process are extracted and used as fertilizers. Intensive research work is also being pursued in the fields of technology, limnology and bacteriology to discover rational and economic methods to utilize different kinds of waste products, and at the same time to purify waste water and to improve conditions in the lakes and rivers and sometimes in the sea—the bodies of water that must serve as recipients.

Chapter 8 of the Water Act makes it obligatory for the persons concerned to avoid polluting water and to take all necessary measures, such as providing sedimentation basins, septic tanks and bacteriological filters, installing irrigation fields, introducing chemical purification methods etc. The costs of many of these measures are, however, so heavy that in some cases they can scarcely be borne by the industries concerned. Owing to lack of material and difficulty with building permits, it has often not been possible in recent years to install the purification plants prescribed. The question of water pollution is thus for Sweden still a very pressing problem, primarily as it affects the fish stock, but also as regards general water hygiene and protection of the countryside.

Timber-floating

Since olden times the floating of timber products has been practised in Sweden. Timber to the amount of 3.67 million cub. metres as well as 8.56 million cub. metres of small timber, pulp wood etc. was floated in 1947 in the large rivers and in many small watercourses. These so-called general waterways for timber-floating had a length of 38,400 km. The floated timber is frequently not barked and by impact against rocks and stones and through biological processes large flakes of bark come loose and are deposited in still water and in eddies. From here small pieces of bark containing fungi and bacteria noxious to fish are carried down into the spawning places of salmon and whitefish, which to some extent become contaminated. To facilitate floating, many lakes are regulated and many small brooks are cleared up and canalized. By these regulations the water is dammed only for a short period in spring, whereafter it is rapidly drawn off. Since these operations most frequently coincide with the spawning time of the pike, large quantities of pike spawn and fry are left dry and die when the flooded areas are hastily drained. In the brooks trout are common in many places, sometimes also grayling, but these species disappear when large stones, tree roots and other objects protecting the fish but constituting impediments to floating are removed. Floating thus causes considerable damage to the fish stock. Frequently, however, this damage can be compensated by various fish-hatching measures which are, in particular, directed at the output of young pike. Chapter 6 of the Water Act lays down stipulations for such measures and the fees to be paid (paragraph 9).

Lowering of lake levels

On the flat plains it is quite common to lower lake levels in order to drain the surrounding marshy grounds or parts of the shore for purposes of cultivation. More extensive lowerings of lake-levels entail damage to fish partly because fewer fish are produced in the reduced area, and also because of the destruction of spawning places especially for pike, and the decimation of shore fauna that are important as food. Frequently also the conditions are less favourable for crayfish. Since lake-levels are as a rule lowered by the very persons who own the fishing rights, the view has been taken that such a lowering is the private matter of the persons concerned. From the public, therefore, there has not been the same demand for compensation measures for damage caused to fish as in the cases of interference enumerated earlier.

RESEARCH ACTIVITIES

To determine the most rational methods (i.e., the most efficient and the cheapest) of compensating damage to fish stock, extensive investigation and research activities are being carried out.

Research institutions and associations

Fishery Board: The State Institute of Fresh-Water Fishery Research, situated at Drottningholm, near Stockholm, is under the Fishery Board of Sweden set up in 1948 (it had previously been a fishery bureau in the Board of Agriculture). The Institute started its activities in 1932. Research work is carried out at the Institute, in part on a number of questions regarding the growth of different species of fish and the connexion between growth and heredity and environment, on the nature of food and its abundance, as well as on biological factors relating to production etc.; the research work is also concerned in part with the effects upon fish life of lake regulations in particular. Rather comprehensive investigations on salmon trout are thus carried out directly by the Research Institute, which also has at its disposal a field station at Kälarne in the north of Sweden (Jämtland) and some fish-hatcheries. The Fishery Board also has jurisdiction over a special water-pollution branch with its own laboratories, likewise located at Drottningholm. Here intensive research work is being carried out specially concerning the injuriousness of different types of waste water to fish and the effect of various purification methods.

The Fishery Board has made proposals respecting the reservation of certain rivers for the undisturbed existence of fish life.

Regulation Associations. That part of the research work which is directly concerned with the influence of lake regulations on fishing is carried out at the State Institute mentioned above, but it is entirely financed by the great water-regulation associations. Here very extensive work is being carried out to collect statistical data on the fisheries before and after the regulations, and to make investigations into the biology of existing species of fish, especially the spawning conditions (spawning places, depth, time etc.) as well as the influence of the regulations upon the shore flora and fauna. The Regulation Association of the River Indälsalven has on its own initiative set up two large fish-hatcheries, both in Jämtland, with a view to obtaining fish for stocking the regulated lakes and for direct research work. Here the object is to supply enough fish of their own breeding to cover the requirements of fry, which are estimated at about 6 million trout and 3 million char.

Migratory Fish Committee. Upon the initiative of the Swedish State Power Board a special committee, called the Migratory Fish Committee, was formed in 1946 to carry out investigations regarding the possibility of maintaining the stocks of salmon and eel especially in the rivers utilized for hydro-electric works. The Committee consists of representatives for both industry and fishing, and a special biologist is employed. Here a number of extensive investigations are carried out on such subjects as the abundance of the year classes of salmon, the migration of salmon, the hatching of salmon, the influence on the stock of enemies of the fry, the creation of new stocks of salmon in very small rivers, the capacity of young salmon to pass through turbines and stand alterations of pressure etc. All expenses for these activities (some $17,000 annually) are paid by the Swedish State Power Board and the industrial enterprises concerned. Collaboration in this field with representatives of interested parties from industry and fishing in the other Scandinavian countries has been started.

Swedish Salmon and Trout Association. In 1944 a private person at Malmö, Mr. Ph. Wolf, director, began certain researches on the stocking with salmon and sea-trout of a small watercourse nearby, the Kävlingeån River. The object was primarily to utilize the small brooks flowing down from the surrounding ridges as breeding places for planted fry. By electrical catching methods the previous stock of coarse fish, such as stickleback, minnow, small perch, are removed and thereafter salmon and trout fry are set out. As these brooks have a quite even water temperature and are rich in food, a good growth is obtained. If favourable results are achieved in the Kävlingeån River, it is intended to extend the activities to other small watercourses. For this purpose a special association has been formed with the name given above. The meritorious initiative and the untiring work of Mr. Wolf have resulted in the Association's receiving large grants both from the State and from private persons.

Rearing of fish fry

The different types of interference in rivers, referred to above under "Water Utilization Projects and Fishery Resources", mostly affect spawning and breeding places. Since planting of fry is not worth while in such cases, recourse must be had to the planting of fingerlings and young salmon ready to migrate (smolts) in rivers where dams have entirely destroyed the fishery. The institutions concerned with research work in the fisheries pay considerable attention to these problems. The principal question is how to procure sufficient quantities of large young salmon at a reasonable cost. Apart from the research carried out in brooks mentioned immediately above, we have proceeded along two lines in Sweden, either rearing fry in troughs and small ponds of different types and feeding them, or putting out fry in large ponds where they can feed themselves on the food produced in the pond. The problems arising in this connexion are the following: Does it pay to accelerate the development of spawn and fry by heating the hatching water? How is feeding to be undertaken and what foodstuffs are most suitable? What types of troughs and ponds are the best for feeding? Under the working programme, such problems as the most suitable number of fry in different cases are being studied as well as additional problems which are acute even in other countries and particularly in the United States.

Regarding experiments with feeding, these have in part been based on results achieved at research stations in the United States. Definite answers to the questions put forward have not yet been obtained. It has, however, been ascertained that with careful attention (suitable food, feeding several times a day, the greatest cleanliness) considerable quantities of one-summer young salmon can be produced with relatively small losses (20 to 30 per cent). Sometimes circular ponds, sometimes rectangular ponds or wooden troughs have proved to be best. The average cost for the production of such young salmon is $11 to $14 per thousand.

Rearing in what we call "natural ponds" is likely to become a special characteristic of the Swedish fishery. The reason why this method has been employed is partly the difficulty of procuring food and labour, partly the assumption that the young salmon reared under these more natural conditions will be stronger and have better chances when finally set out. A large number of ponds ranging in size from a few hectares up to 45 hectares are provided in different places, mostly, however, in Norrland. As a rule no more than two fry per square metre of pond surface are set out. The losses are larger than in feeding ponds, generally about 50 per cent and the cost is high, on an average $30 per thousand of one-summer young, including amortization of the cost of erection, which amounts to about $3,000 per hectare. The young fish from these ponds are, however, generally considerably larger, their average weight being 3 to 4 grammes as opposed to about 2 grammes in case of feeding. The short summer in these latitudes does not permit of any large growth.

The rearing of young salmon ready to migrate has hitherto been carried out only on a small scale and mostly in ponds with feeding. As food, coarse fish have frequently been used. Experiments regarding this are, however, being carried out on a large scale. At the hatcheries in Jämtland experiments are going on to procure stocks especially of trout and char, but also of salmon. There is already a small stock of large trout, whereas the experiments with salmon have not turned out well so far. The male fish become mature at an age of two to three years and then give milt for several years in succession. The female fish on the other hand have matured in only a few cases and then at the age of five to six years. The spawn has, however, not been capable of fertilization. Experiments with char have recently been started.

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Protection of Wildlife in Sweden

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As a branch of industry hunting is nowadays of little importance in Sweden. But inasmuch as the right to hunt in Sweden still belongs to the landowner, it can be said that the fauna subject to chase is in this country considered to be a valuable agricultural property. The importance of hunting lies, however, not so much in the kronor and öre represented by the game shot but in the opportunities for sport and outdoor life that hunting gives to its devotees.

Hunting in Sweden is regulated by the Act on the Right to Hunt of 3 June 1938, as well as the pertinent statutes. These modern hunting laws contain the stipulation that the person who wishes to hunt on land other than he owns or on which he has a certain right of usufruct shall pay an annual hunting-promotion fee. During the last hunting year (July 1947 to June 1948) about 200,000 hunters in Sweden paid almost one million kronor into the fund for the promotion of hunting, from which annual state contributions are paid to the authorized, voluntary organization for the promotion of hunting, the Swedish Hunters' Association, which has at present 111,000 members and 1,500 local branches over the whole country. Twenty-five consultants employed by the association are working as leaders of the campaign for good manners in hunting and as organizers.

According to the game statistics for the hunting year 1947, published on 7 January 1948, by the Swedish Hunters' Association, hunting in Sweden yielded a total commercial revenue of $3,100,000 during this period, of which $1,500,000 represented the value of elk, deer and roedeer shot, $1,100,000 that of small game and $500,000 that of fur-bearing animals. Regarding the yield of hunting on the Swedish lakes and watercourses the statistics show that during the hunting year mentioned 94,000 wild ducks, 16,000 teal and summer teal, 23,000 other ducks and 4,000 snipe were shot. To these figures are added a smaller number of pochard. The total annual commercial value of the ducks etc., thus shot on Swedish lakes and watercourses might be estimated at about $100,000. The fauna of the Swedish lakes and watercourses also include otters, of which some 1,000, worth $35,000, have been shot in the country. Expressed in cold figures, hunting on Swedish lakes and watercourses should thus yield annually about $135,000. As pointed out above the greatest value lies, however, not in the yield expressed in figures but in the recreation and sport that hunting affords to its devotees; for this reason hunting along with other sports ought to have a certain importance for the health of the nation.

To obtain a larger area of land for agricultural purposes in Sweden many shallow lakes in the plains have been lowered, and in order to increase the country's supply of electric energy by means of water-power, the levels of lakes and watercourses are regulated. Both these measures may exercise an unfavourable influence on the well-being of the wild fauna and the stock thereof in and around these waters.

The lowering of lake levels may have a very different influence on the life of lake fowl. Some examples may be mentioned. By the lowering of the water-level of Lake Tåkern, the most remarkable lake for birds in Sweden, a more favourable depth for vegetation has been achieved, thus improving the living conditions of lake fowl. The opposite is true of Lake Hornborga in Västergötland, where repeated lowerings of the water-level have made conditions more and more barren for wild-fowl. These examples can be multiplied.

The important lake regulations are carried out to the greatest extent in the north of Sweden. The water-level is in some cases raised and lowered by many metres, and in addition certain areas that formerly were dry land throughout the year are transformed during certain periods of the year into shallow lakes. The natural vegetation both on the shores and the bottom of the lakes is considerably altered, and often in a way unfavourable to the life of lake fowl. If the fowl do not find hatching protection on the shores and the food they require on the bottom of the lakes, they move and the fauna is thus impoverished.

Otters thrive in direct relation to the supply of fish in the water. As the lowering or the regulation of lakes and watercourses have often greatly reduced the supply of fish, the conditions for the survival of the otter have worsened, causing it to emigrate.

In Sweden there are no stipulations respecting any disturbances in wild-life caused by the lowering of lake-levels and regulations. The right to hunt on lakes and watercourses belongs as a rule to the landowners whose land is adjacent to water. Occasionally compensation for impaired hunting conditions has been claimed from the enterprises responsible for the water regulations, and in exceptional cases such compensation is said to have been paid.

Finally reference may be made to the damage to the fauna that is caused by the power transmission lines through the forests connecting water-power resources. Every year thousands of woodland birds of all kinds fly against the lines and perish. The resultant loss to the stock of Swedish woodland birds which is at present very weak, is considerable. The owners of forest areas obtain reasonable compensation both for land ceded and for production lost on such land, but compensation for deteriorated hunting facilities has probably not been obtained.

Protection of Wild Life and Fish in India

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ABSTRACT

In India, conservation of wild-life and fish had until recently received comparatively little attention. This paper gives details of the legislative measures in force for the conservation of wild-life in various parts of the country and briefly discusses the inadequacy of the machinery for the enforcement of these measures. It is hoped that in the new Constitution for the Dominion adequate provision will be made for the preservation of its wild-life resources.

The fishing industry of India is of the nature of a cottage industry, and the protective measures hitherto adopted for the conservation of the fishery resources have, in general, been ineffective. The paper lists the legislative measures in force and discusses the problems of controlled fishing, stream pollution, effects of dams etc. on the inland fishery resources. Brief mention is made of the proposed programme of investigations connected with the construction of effective fishways in connexion with various dam projects. As all this work has been initiated only recently, it is not possible to give detailed statements of the costs connected with these programmes.

INTRODUCTION

The need for adopting concerted and practical measures to counteract the forces of destruction, which have been responsible for a great reduction in the natural resources of wild-life in almost all parts of the world, began to receive serious recognition by the authorities of even the most advanced countries only at the beginning of the twentieth century. In the earlier era of man's dominance on the face of the earth, extensive areas of undisturbed forests and uninhabited parts in almost all countries provided extensive safe sanctuaries where wild-life was able to survive and even flourish. Conditions changed as a result of the rapid advance of civilization, the gradual conversion of forests and grasslands for habitation by the ever-increasing population and for meeting the needs of agriculture, opening up of new roads and waterways, reclamation of marshy and swamp lands and greatly improved methods of transport. Today very few areas are left where wild-life can continue to live undisturbed by man.

Most of these factors continue to have a devastating effect on wild-life, but concurrently Man's outlook towards Nature has been undergoing a significant change and his dependence on natural resources is being increasingly realized. Apart from humanitarian considerations, authorities are gradually becoming alive to the dangers inherent in the uncontrolled destruction of wild-life. To undo even a small amount of the damage to organic resources, which has resulted from the rapid spread of civilization, necessitates carefully planned long-term programmes of reconstruction and the development of social concepts in regard to colonization, agriculture, forestry and other allied activities of man.

The principles in respect of such conservation measures would generally be the same everywhere though the methods to be employed would vary from country to country and even in different parts of one country. This is one of the reasons why legislative and other measures which have to be adopted for the protection of wild-life resources in the case of a large country like the Indian Dominion become very complex and not easy of implementation. In this paper is presented a brief outline of the measures which have been taken with reference to the preservation of wild-life and the fishery resources of the Dominion. As the methods to be employed in reference to these two divisions are materially different, they will be dealt with in two separate sections.

TRADITIONAL AND LEGISLATIVE SAFEGUARDS

No detailed information is available regarding any legislative measures for protecting wild-life in prehistoric India or during the periods of Hindu, Buddhist and Moslem dominations over the country, but such information as is available indicates that the authorities and the public in general were conscious of the importance of conserving and maintaining the wild-life resources.

The ancient Hindus prescribed certain seasons during which eating of fish or meat was prohibited, while the strict vegetarian habits of the majority of the population served as a very effective measure against indiscriminate destruction of wild-life. In so far as fish is concerned, eating of fish was proscribed during certain months in spring and autumn. During spring there is the greatest contraction of the water-surface in various parts of the country and consequently most of the fish congregate in large numbers in the few pools and depressions which still hold sufficient water. Autumn coincides with the subsidence of floods following the heavy rainy season, and it is at this time that the spent fish and the young fry migrate back from the shallow channels to the main streams and rivers. The Hindu sages apparently thought that if during spring and autumn the eating of fish was prohibited, there would be little inducement for the fishermen to catch fish during these months. These periods would thus serve automatically as closed seasons without any legislative measures having to be enforced for the protection of fish.

While there are no records of any specific legislative measures during the long period of Moslem domination in India, there is historic evidence to show that several of the Mogul Emperors of India were eminent naturalists who in various parts of the country declared large areas as reserved areas for hunting and other similar pursuits by the rulers and their retinues. Such areas served as sanctuaries and provided a fair amount of protection to the wild-life of the country.

Wild-Life

With the advent of the British rule in India and the rapid colonization of large areas of lands, wild-life was gradually exterminated. It is to the credit of vigorous propaganda and intensive agitation on the part of the Bombay Natural History Society for over thirty years that an Act for the Preservation of Wild Birds and Game (Act XX of 1887) was passed. This was replaced by the

Wild Birds and Animal Protection Act (Act VIII of 1912), which together with the Indian Forest Act (Act XIV of 1927) is the basis of rules in force at the present time for the conservation and preservation of wild-life in the country. The Indian Arms Act, 1878, under which the purchase and possession of arms is restricted to licensed holders only, has also rendered useful service in connexion with such protective measures. To sum up, the legislative measures consist of: (1) the Wild Birds and Animals Protection Act, 1912 ; (2) the Indian Arms Act, 1878,—both of which are applicable to the whole of British India; (3) the Indian Forest Act, 1927; (4) the Provincial Game Rules made by various Provinces under the Wild Birds and Animal Protection Act, 1912; (5) Provincial Forest Acts and Rules thereunder; and (6) some special Provincial Acts dealing with protection of special types of wild-life.

The Provincial Game Rules and Forest Acts were unfortunately drawn up rather haphazardly and are often contradictory. In addition, no definite machinery was set up for enforcing these legislative measures particularly in regard to poaching and the indiscriminate destruction of game etc. These enactments did not include control of trade in meat, hides, skins and trophies, nor were any restrictions laid down against shooting of animals from motor cars etc.

The most comprehensive measure enacted by the provincial legislature was in the Punjab in 1933 under the name of the Punjab Wild Birds and Wild Animals Protection Act. The rules under this Act provided for the better protection and preservation of certain animals including birds and fish. Following the passing of this Act, a Game Warden for the province was appointed for ensuring that the rules under the Act were properly enforced. District Fauna Committees were established for performing functions assigned to them under the rules and for advising generally about the protection of fauna in their respective districts.

Acts on similar lines were passed in the Central Provinces in 1934 and in the United Provinces in 1935. In 1932, a special Act known as the Bengal Rhinoceros Preservation Act, which prohibited the killing, injuring or capturing of rhinoceros in Bengal, was passed, and a small sanctuary for the preservation of this animal was established in Jalpaiguri district. In 1934, a National Parks Act was passed by the United Provinces legislature and, as a result, a national park in the famous Patli Doon of an area of about 100 square miles was set apart. About the same time, certain areas were designated as game sanctuaries in Assam and in the States of Mysore, Travancore etc.

In 1935, the Government of India convened an All-India Conference for the Preservation of Wild Life at Delhi, in which it was agreed that the duty of preserving the fauna should be assigned to the Forest Department in the areas under their charge. The Conference adopted a set of resolutions and prepared two lists of species, first of animals that were to be protected as completely as possible, and second of those which "while not requiring such rigorous protection" shall not be hunted, killed or captured except under licence granted by competent authorities. The Conference laid special stress on the establishment of wild-life sanctuaries. Resolutions were also passed for the closest co-operation between the forest departments, police, magistracy and game associations for the preservation of game and wild-life. It also laid stress on the introduction of nature study in the educational institutions and for carrying out such propaganda as would popularize with the general public the urgent necessity of preserving wild-life. As a result of the deliberations of this Conference, an All-India Convention for the preservation of fauna in India was drafted. It was hoped that the convention would be adhered to by all Provincial Governments and the States, and that the signatories of the convention would adopt all possible measures for the protection of the wild-life in the areas under their jurisdiction. Unfortunately, owing to the war and changes in the administrative machinery of the country, these hopes were not realized.

Present position. The present situation with regard to the protection of wild-life in India may briefly be summed up as follows:

A number of legislative measures have been enacted from time to time for the protection and conservation of wild-life, but no comprehensive legislation has so far been passed for the Dominion as a whole. In some of the Provinces, legislation has been enacted on more up-to-date lines and some special staff has also been appointed for this purpose, but the enforcement is left to the police and judiciary in general, and in the reserved forest areas to the forest staff. In some areas, a few sanctuaries and national parks have also been set up, but these measures have not contributed to any material extent towards the preservation of wild-life of the Dominion as a whole.

The subject has again been revived through the efforts of the Bombay Natural History Society. A pamphlet entitled "Wild Life Preservation—India's Vanishing Asset" prepared by Lt. Col. R. W. Burton has been published and widely circulated by the society. This pamphlet strongly advocates that in addition to the setting up of national parks and sanctuaries, a special Wild-Life Department should be set up at the centre for the management and conservation of wild-life of the country. This Wild-Life Department under the Central Ministry of Agriculture should be linked with the provincial Agricultural and Forest Departments and each Province should have a Provincial Warden and as many Deputy Wardens as are found advisable or necessary. Since August 1947 when India became a free Dominion, and some parts of the country were separated as the Dominion of Pakistan, the Constitution for the country as a whole and its constituent parts is still under consideration and has not been finally adopted. It has not, therefore, been possible for the Administration to adopt comprehensive measures for the conservation of wild-life. It is, however, hoped that as soon as the administrative changes are completed, the question of the preservation of wild-life will also receive due consideration at the hands of the authorities.

Fish

Introduction. The fishing industry of India is mostly of the nature of a cottage industry and until recently has received very little attention either at the hands of the Government or the public. As the conservation, control and development of fisheries had so far been a direct responsibility of the Provincial Governments concerned, Central Government until very recently had not taken any active share in their development. Due chiefly to the conditions resulting from the last war and the prevailing food scarcity in the country, both the Central and the Provincial and State Governments are now taking vigorous steps for the conservation and development of their vast fishery resources.

Historical. In 1867, as a result of general complaints that anicuts constructed across the big rivers in the Madras Presidency were injuring the fisheries in the province, Dr. F. Day (a Medical Officer) was placed on special duty to inquire into the subject. In his report submitted in 1868, he suggested certain remedial measures and recommended a general survey of the Madras fisheries, both fresh-water and marine. Later, the scope of Dr. Day's investigations was extended to the whole of India and Burma. His report in two volumes dealing with the fresh-water and marine fish and fisheries of India was published in 1873. This report confirmed the view that the construction of anicuts, weirs etc., and uncontrolled fishing were resulting in a general and widespread destruction of brood fish and fry, and the valuable inland fishery resources consequently were being gradually impoverished. Dr. Day, therefore, strongly urged the necessity of undertaking protective measures.

After prolonged consultations with the Provincial Governments, the Indian Fisheries Act (Act No. IV of 1897) was passed. This Act is only a summary legislation consisting of seven sections containing general provisions for prohibiting dynamiting and poisoning of waters for killing fish, and enabling Provincial Governments under certain conditions to make rules for regulating (*a*) the erection and use of fixed equipment (*b*) the construction of weirs; and (*c*) the dimension and kinds of nets to be used and the modes of using them and finally for prohibiting fishing in any specified waters for a period not exceeding two years. This Act in the absence of a special machinery for enforcement is, more or less, a dead letter.

The first advance was made in 1914 when the Punjab Fisheries Act (Act II of 1914) was passed; this was amended by Act II of 1923 and further revised in 1941. The Fish Committee of the Indian Council of Agricultural Research, which reviewed the situation in 1942, came to the conclusion that the available legislative provisions were quite inadequate for protecting the fishery resources of the country. While the available data were found inadequate for comprehensive All-India legislation, it was decided to draft a Model Act which may be enacted by all Provinces and States with necessary modifications to suit their local needs. As a result, the United Provinces Fisheries Bill of 1948 and the Central Provinces and Berar Fisheries Act VIII of 1948 have already been passed and many other Provinces are proposing to undertake similar legislation in the near future. From amongst the maritime States, Cochin and Travancore have had Fisheries Acts since 1917 and 1921 respectively. All these enactments have, in general, proved of little value, as the necessary machinery for enforcing the legislation is not available. The Punjab Act, however, proved useful in view of the provisions for the licensing of the fishermen and the control of fishing operations.

Protective measures. While the lack of statistical, biological and bionomical data and the inadequacy of the existing legislative measures and machinery to enforce these have stood in the way of rational conservation of the fishery resources of the Dominion, the measures adopted so far have, to a limited extent, helped in their protection. The capture of potential breeders of carps, catfishes, hilsa (*Hilsa ilisha*) and other food fishes which congregate in large numbers during and after the breeding season below high dams and steep waterfalls has been stopped by declaring such areas to be sanctuaries. As examples may be mentioned the Hoganikal Falls and Stanley Dam on the Cauvery, various anicuts in the Cauvery, the Kistna, the Godavari and certain specified regions in the Punjab. The observance of a closed season enforced at the peak of the breeding period, as in the case of the hilsa in the Godavari and certain other waters, has also provided some protection for this valuable food fish. Use of poisons, explosives, fixing of traps and other destructive types of fixed equipment is prohibited by legislation in most parts of the country, but it is known that destruction to a large extent is still going on in out-of-the-way places. Giving of rewards for exterminating otters, crocodiles and other natural enemies of fish has also begun to show beneficial results in some Provinces.

Stream pollution. In view of the rapid industrialization that is taking place in the country, the discharge of factory effluents and of municipal sewage into waterways has raised a serious problem in connexion with the conservation of the riverine fisheries. Though various aspects of the problem are still being studied and no comprehensive remedial measures have yet been devised, recent experience in the case of the Cauvery River in Madras has proved the value of neutralizing discharges and thus rendering them innocuous before liberation into the streams.

Effects of dams. Another very serious problem facing us at present is in connexion with the construction of dams across many of our larger rivers. The construction of these dams for irrigational, hydro-electrical and navigational purposes is of paramount importance, but such dams seriously affect the valuable fisheries of the rivers unless suitable measures are simultaneously adopted for the conservation of the fisheries of these waters. Many of our fishes of major food importance, such as carps, large catfishes and some of the estuarine fishes like the *Hilsa polynemus* and others are migratory in habit. These fishes ascend upstream during the rainy season for feeding and breeding. The dams that have been or are being constructed are likely to present insurmountable barriers against the upstream migration of these fishes and unless proper steps are taken to enable these fishes to negotiate the barriers, fisheries of the entire river systems in connexion with which these dams are constructed are likely to be severely affected. In several of our dams, fish passes and fish ladders have been provided, more or less, on the models of similar devices in America and Europe, without adequate knowledge of the biology, bionomics and leaping capacity of the fishes concerned or of their ability to negotiate the gradients. As such, these passes and ladders have, for the most part, proved ineffective. At the Mettur Dam across the Cauvery River, close co-operation between engineers and fishery biologists, however, resulted in an effective arrangement for the opening and closing of sluices and surplus outlets. Full details of the successful working of this arrangement are not yet available, but it is believed to have provided a solution for the migratory fishes in that river. The problem of devising suitable fishways in connexion with our numerous dam projects is, however, engaging the serious attention of the Government of India. It is proposed to associate experienced fishery biologists with every major project. These fishery workers, in close co-operation with hydraulic engineers, will study the migratory habits of the fishes concerned, their ability to negotiate various gradients and falls, and on the basis of the information collected devise the most suitable passes for the upward movement of the migratory fishes. Steps on these lines are already being taken in connexion with the Hirakud Dam and the Kosi Dam projects.

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The Protection of Fish and Wildlife in Water Use Projects

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ABSTRACT

The protection of fish and wild-life in water-use projects is a complicated problem of improvisations. All such improvisations represent efforts to readjust, or to compensate for, environments made artificial in the development of electric power, navigation, flood control and other water uses. In the fish category outstanding examples are: fish-ways and hydraulic and mechanical lifts to overcome dam obstructions; hatchery and rearing operations to stock, annually, streams and lakes made inaccessible to anadromous fishes, and the resort to the re-routing of ancestral fish-runs.

The demands for protection come from two sources, commercial and recreational; the former vocal in localized areas and the latter rapidly becoming the voice of the people. The recreational demand stems from the realization that man must not "live by bread alone", and it becomes the more insistent as labour is integrated with leisure.

The improvisations must not, as too often in the past, be after-thoughts. Big dams, for example, make permanent changes in the environment, and post-project improvisations may be costly, perhaps impossible; whereas pre-project provision is often possible with little additional cost.

These improvisations are wise provisions and they should be provided for by experts and incorporated in the Official Plan.

To illustrate wise provision the Muskingum Watershed Conservation District is taken as an example.

INTRODUCTION

The more we plan for the full use of our resources the more we realize that our rivers are the life blood and the soil the nourishment of the people. In nothing has this realization become more apparent than in the many river-basin projects under development or under advisement in America today.

The role of water-use projects. Since all modern river-basin, or water-use projects have for their objective the integration and perpetuation of the resources within the watershed, and since human welfare is the impelling motive, it is essential that the welfare of the people receive priority consideration in contra-distinction to exploitation for wealth. It follows further that, as the surest satisfactions for the people are those at hand, it is just and proper that all such planning should give primary consideration to the people of the watershed as far as this is consistent with the general good.

The impact of community interests. The earliest and most effective opposition to the abandonment of river-resource development to commercial enterprises was that offered by the fishing industry on coastal rivers. This was a defence of community interests and the fight, in so far as it has been successful, was won almost entirely by way of improvisation. However, it was the fishermen's opposition and the fact that man, because of his biosocial history, cannot realize himself completely except as a part of a living environment, that power development, navigation, industry, irrigation and even flood control interests have ceased to be the absolute considerations in river resource development.

THE PRINCIPLE OF THE PROTECTION OF FISH AND WILD-LIFE

As just stated, the appeasement of the coastal-river fishing interests came by way of improvisations. These were in principle protective devices in the form of fishways, and hydraulic and mechanical lifts over dam obstructions; hatchery and rearing operations to stock, annually, streams rendered inaccessible to anadromous fishes, and the re-routing of ancestral fish-runs.

Fortunately the substitutionary devices, from which there was no escape, have been moderately successful, and from the nature of the case one would be safe in predicting that what has happened in the past is prophetic of the future: that is, that the protection of fish in water-use projects will continue to come by way of improvisations. One can also assume, further, that the twin resource of fish, that is, the wild-life resource which enters the picture more and more as watersheds are developed, will be realized in the same manner.

Protection by way of improvisation bespeaks a grudging compromise. This holds for fish and wild-life. With the growing realization, however, that the community environment must provide the essentials of a full life, the finality of the engineers' blueprints for commercial and industrial development of a river is slowly breaking down. It is giving way to a new evaluation of resources—an evaluation of the aesthetic possibilities, as well as those strictly economic. It is the realization that "Man cannot live by bread alone", but that he must also satisfy the appeal which comes from out of his biosocial past—that homing call—which becomes the more insistent as labour is integrated with leisure.

The problem then confronting fish and wild-life protection is one of improvisation; the claims involved are those of providing a livelihood in localized areas, and those of making secure for the people the aesthetic resources inherent in their environment. The demand, which essentially is that of a watershed community, is rapidly becoming the voice of the people. This cannot be otherwise as community horizons fade in the light of the democratic concept, and as powerful organizations, pooling a common interest, espouse the cause.

The biologic basis of protection. Generally speaking, life in the wild is jealous of its environment. It has made its adjustments by slow processes. As a consequence provision for fish and wild-life should be included in the Official Plan, and by those who understand the requirements.

The principle applied to fish and wild-life. It follows then that the protection of fish and wild-life begins with wise provision, albeit by improvisations: Indeed, the accepted thesis here is that protection of fish and wild-life in water-use projects consists in wise provision.

THE RECOGNITION OF THE PRINCIPLE IN THE UNITED STATES

In the United States of America the necessity of wise provision has been recognized by Public Law 732. This was provided for by the 79th Congress and approved by the President in 1946. This "New Co-ordination Act", as it is sometimes called, requires that biological resources be given proper consideration in Federal construction and provides the authority, presently vested in the Fish and Wildlife Service, Department of the Interior, for making studies and recommendations pertaining to such water-development projects. Federal construction agencies are now required to consult with state conservation departments, as well as with the Fish and Wildlife Service, prior to the construction of water-utilization projects. The writer maintains that such initial provision should be required of all water-utilization projects.

Big dams as factors of the environment. In the past impoundment programmes have generally ignored the fish and wild-life habitats on which they encroached. It cannot be too strongly emphasized that big dams bring about permanent changes in the environment, that adequate post-project reconstruction may be very difficult, if not impossible, and, as a consequence, that such resource values may be lost for good.

The Office of River Basin Studies. As evidence of the import of the authority vested in it by Congress, the Fish and Wildlife Service delegated the function of river-basin studies to the Office of River Basin Studies. This Office, appreciative of the skills required, employs three types of technicians. These may be best described as: terrestrial, or wild-life biologists; aquatic, or fishery biologists and engineers with a biological background. The Office is headed by a Co-ordinator.

River development projects as business propositions. In principle river-development projects are business enterprises though not necessarily business ventures with financial profits as the directive force. Numerous river-development projects are launched as a matter of necessity, particularly those having to do with flood control and the conservation of natural resources.

Business ventures and fish and wild-life evaluation. Where such projects are business ventures and where the resources involved must of necessity submit to a cost-benefit ratio, the fish and wild-life resource component can scarcely be an exception. The evaluation in this category, however, presents some very real difficulties. These arise from the circumstance that a very considerable part of the resource has to do with aesthetic values—with the currency of another realm.

In an effort to solve this problem, the Fish and Wildlife Service currently accepts the principle that at least a part of these aesthetic values, those accruing to the sportsman and representing his "harvest", can be equated in monetary terms. These values, the so-called primary unit values, are arrived at by computing, on a national basis, the sportsman's average costs, per pound for fish and per unit of game, in bringing such fish and game to creel or bag.

Obviously these unit values leave out of consideration many of the satisfactions experienced by the sportsmen in the realization of their individual satisfactions, or perchance vagaries. They also leave out of account the satisfactions provided by the numerous non-game species that enter into the recreational complex.

Besides providing a basis for the comparison of the cost-benefit ratios, these values, taken in conjunction with the more readily determined commercial values of fish and wild-life, also facilitate the proper allocation of the share of joint-project construction costs; and further, they indicate the economic advantage of additional project expenditures involved to mitigate the losses or increase the benefits to fish and wild-life. The recent fish and wild-life survey in connexion with the proposed Manitoba Central Basin Project (Canada) provides an instructive study of the advantages and application of cost-benefit determination. In this basin fish and wild-life have very considerable commercial significance.

Commercially "harnessed" rivers and protection to fish and wild-life. Many of the larger streams of the United States, particularly those in the Western States, are "harnessed" for navigation, irrigation and power development. Many more have such developments pending. With such the writer has had no experience. This much however, can be said of such projects: generally speaking, protection (sometimes elaborate) for fish and wild-life has been attempted, either as an after-thought or in drawing up the initial plans.

The extent to which the streams are marked for commercialization is, nevertheless, causing some apprehension, particularly in regions where mountain streams, still unspoiled through exploitation, afford "solitude", recreation and retreat.

River-basin projects as necessities

As previously stated, river development projects are not always prompted by the profit-making motive. Many are undertaken as necessities, with a protective, redemptive and, subordinately, recreational *quid pro quo*. The economic redemption of the region and the protection of life and property must of necessity be of sufficient importance to justify the undertaking.

THE MUSKINGUM WATERSHED CONSERVANCY DISTRICT

The most outstanding example of such an undertaking on this continent is on the Muskingum River and its tributaries in the State of Ohio. It is known as the Muskingum Watershed Conservancy District, and merits priority reference, not only for its engineering accomplishments but also, and perhaps with equal credit, for the vision and wise decision manifested.

The Muskingum Watershed Conservancy District is a public corporation and was created by residents of the Muskingum Valley in June 1933. It was established for the purposes of flood control, water and soil conservation, river regulation, purification of streams, afforestation and recreational development.[1] The project is the first of its kind to be undertaken as a co-operative enterprise of local people, the State and the Federal Government. It is also, apparently, the first of its kind and extent in America where recreation, including fish and wild-life, received initial consideration in the Official Plan.

Although the organization of the Conservancy District had its genesis in the flood disasters that ravaged the valley, the adoption of the Official Plan by the Board of Directors, and its approval by the Conservancy Court, was made upon the assurance that the recreational needs (of which fish and wild-life are an integral part) had been given proper consideration. Some parts of the District were primarily interested in the project because of the protection afforded against floods; others had need of the benefits arising from the conservation of water; all had a common interest in the creation of opportunities for wholesome, outdoor recreation.

As a matter of record it is interesting to note that as the engineering studies proceeded it became apparent that, with proper planning, recreational use could and should be one of the beneficial uses of the water conserved in the reservoirs. As a consequence, ways and means were found to design the artificial lakes, including the adjoining lands, to recreational and park uses and at the same time meet the other objectives with little additional cost. It should be added, too, that as the development of the general plan progresses from year to year the requirements for the fuller use of the recreational possibilities grow apace.

Basic to the Muskingum project is the provision for flood control and water conservation. To this end 14 reservoirs were constructed. Ten are dual-purpose, in that they provide for flood control and water storage. These are, in effect, lakes. They have a total water-surface area of some 16,000 acres and provide a lake shore-line of about 365 miles. The more important ones, from a recreational point of view, range from 850 to 3,550 acres. These reservoir lakes constitute no small asset in an area of 8,038 square miles of watershed (almost wholly devoid of lakes) of great natural beauty owing to a much dissected topography.

Protection favouring fish and wild-life

Each of these "lakes" is encircled by at least a 100-foot strip of land reserved perpetually for the public. Indeed the entire shore-line and much of the adjacent land is owned or under the control of the District. This makes it possible for the areas to be developed by and for the use of the public, and thus prevent private exploitation—the common curse of so-called public projects.

A further protection for fish and wild-life was the provision in the Official Plan that there should be no draw-down below the permanent pool-level as established in the plan, except in emergencies. This protection was insisted upon because of the fear that excessive impoundings and releases would be inimicable to the growth of aquatic life, and thus render impracticable the fish and wild-life programme.

In order to develop and perpetuate the fish and wild-life resource in the District, and before all the reservoirs were filled, the Board on 1 July, 1940 leased to the Division of Conservation of the State of Ohio, for a term of fourteen years, the water maintained in the storage reservoirs, including the surface rights therein, for the following purposes: the propagation of birds, ducks, geese, fish, wild animals and other wild-life; the establishment of sanctuaries; controlled or public fishing, hunting or trapping; the right to erect and maintain the necessary fishing, boating and other docks, breakwaters or retaining walls—all in the best interests of conservation, subject as always, however, to the operation of the dams, reservoirs and pools in accordance with the Official Plan.

By so doing the fish and wild-life future of the District was placed under the immediate supervision and direction of a Department staffed with specialists, and matured by experience.

To bring the newly impounded reservoirs to production certain aids such as the establishment of shore-line vegetation, stocking, the placement of gravel for spawning areas and brush shelters, were introduced. These are some of the common methods used in the protection of fish in newly impounded areas. Just how much they contribute is still problematical. Of the Muskingum "lakes", only one supports much marginal growth, yet all are very productive of fish.

It is also noteworthy that no provision was made for the migration of fish upstream over the dams, that is, no fish-ways were installed. The same obtains in the TVA project. Indeed, there appears to be a general consensus both in the United States and in Canada that such protection of warm-water fishes is unnecessary, and may indeed be prejudicial to the maintenance of sport fish.

Fish and wild-life benefits. With respect to the "lakes" they have, as stated before, developed and generally maintained good fishing. During the 1948 season the Muskingum "lakes" continued to rate near the top as

[1]Recreation in the Official Plan includes the fish and wild-life resource. The Muskingum Valley does not provide commercial fishing and hunting. As a consequence fish and wild-life fall into the more comprehensive category of recreation. This classification is retained in this discussion.

compared with other fishing areas in the State. They have attracted water fowl in very considerable numbers, particularly during the migrating season; also many are nesting in the sanctuaries.

The "quid pro quo". Based on the tables supplied by the National Park Service the annual value of the Muskingum "lakes" for recreation is $807,000. This represents a fair interest return on the $46 million investment in the entire project, of which the cost of the dams and contingent undertakings was somewhat over $45 million. Furthermore, during the 1948 season an estimated 2.5 million visits were paid to the "lake" area—now among the most popular fishing grounds in the State. Two and one-half million recreational satisfactions, provided in one season, through an almost total environmental improvisation, is indeed indicative of vision and wise decision, and is proof of the efficacy of wise provision. The primary objectives, too, it should be added, are being met as anticipated.

CONCLUSION

Since the fish and wild-life resource is not a primary consideration in the development of river-basin projects for the generation of electrical power, and for other water uses, its protection must be achieved by way of suitable improvisations, that is, by wise provision. And further, since wise provision may often be made at little extra expense, if anticipated, it is essential that in every river development project the protection of fish and wild-life receive expert attention in drawing up the Official Plan.

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Hydro Power and Other Water Uses: Protection of Fish and Wildlife

IRA N. GABRIELSON

ABSTRACT

This paper outlines the major effects of water-use developments upon fish and wild-life resources and points out some of the methods used to remove or modify any adverse effects.

Drainage, water impoundments for purposes of providing irrigation, hydro-electric power, flood control or navigation, stream canalization, including inland waterways and the use of streams to carry away human and industrial wastes are listed among the major uses of water that may have marked effect upon fish or wild-life.

Definite efforts are being made to minimize the adverse effects (1) by correlating efforts by technicians of all groups in the planning stages of impoundments and other water developments. This co-ordinated effort extends to the development of operational as well as construction plans. Controlled water-levels, by limiting time and extent of fluctuations, conservation pools, which establish minimum water-levels for impoundments, sub-impoundments to provide fish-spawning areas and water-fowl feeding areas, dewatered areas that can be reflooded at will, fish-ladders for migrating fish, transfer of migratory-fish runs to other streams and replacement of habitat unavoidably destroyed are the more important techniques being used to accomplish this purpose.

It is obvious that every water-development project has some effect on fish or wild-life. The effect may be local and insignificant, or it may be widespread and of major importance depending upon the character and the extent of the development project and the character of the life affected.

Water management programmes, including drainage, impoundment and subsequent operations for flood control, irrigation, navigation and hydro-electric power, and the dumping of human and industrial wastes into streams and lakes, all affect wild-life and fish. At times such projects have been destructive of these and other natural resources, often needlessly so.

In speaking of the effects of either necessary and wise or unnecessary and unwise developments, it might be well to outline first the major adverse effects of these operations.

MAJOR ADVERSE EFFECTS OF WATER-MANAGEMENT PROGRAMMES

Drainage projects

Drainage, either by ditching or by diversion of water from basins, has a major effect upon wild-life populations. The radical alteration in the vegetation and character of the area has profound effects upon fish and wild-life resources. Some drainage projects justified themselves by providing rich agricultural lands which yielded greater values than might have been produced by marsh lands.

Others have failed to produce results either because of poor soil or inadequate drainage after the projects have been completed.

One of the major adverse effects of drainage is the elimination of breeding, feeding or wintering grounds for migratory waterfowl. It also destroys habitats suitable for aquatic and semi-aquatic fur-bearing mammals and reduces the production of fur. Wherever drainage eliminates permanent waters, it also eliminates fish.

Drainage also lowers water tables which sometimes has adverse economic effects by reducing domestic water supplies, particularly when rainfall is below normal.

There are engineers and others who hold the opinion that any marsh land is wasteland. Some feel that any land not in farm crops is also wasteland. Until these opinions can be modified, there is little hope that drainage projects will be developed on a sound basis.

Water-impoundment projects

Water-impoundment projects also have direct effects upon fish and wild-life populations. Major impoundments are usually made to provide irrigation water, hydro-electric power, flood control or navigation. In some cases two or more of these purposes are combined in one project. Minor impoundments may be small ponds built by individuals to provide stock water on grazing lands or to prevent excessive soil erosion.

All of the effects of impoundment are not necessarily bad. In fact, there are projects in which the total benefit of impoundments has tended to increase certain of these resources. They can, however, be very destructive. Impoundments, primarily for irrigation, sometimes destroy valuable mountain lakes or mountain streams without providing equivalent fish or wild-life values. The nature and season of draw-down of irrigation projects often makes it difficult to maintain stable fish or wild-life populations in or adjacent to irrigation reservoirs.

Impoundments, when first flooded, usually have periods of high fish productivity, but as oxidation breaks down the flooded vegetation, the food production slumps and fishing is down with it. Reservoirs that fluctuate widely, particularly during spawning periods for valuable fish and the growing season for aquatic plants, are not normally permanently productive of fish, waterfowl or aquatic mammal food.

Impoundments, primarily for the production of hydro-electric power, often do harm to fish and wild-life. Often they provide only minimum values of wild-life habitat to replace those destroyed by the impoundment. Such reservoirs are, of necessity, filled at flood times and drawn down at the period of greatest power demand. Their widely fluctuating water-levels make it difficult and sometimes almost impossible to provide biological management on such impoundments.

Impoundments for any purpose may have numerous other harmful effects. Among those that occur most regularly are the loss of fish, waterfowl and fur-animal habitat as well as vital winter habitat for widely dispersed wild-life forms by inundation of stream beds and bottom lands. Dams may interfere with the movement of migratory fish. If channels are dewatered permanently or intermittently, the habitat for many forms of life is destroyed. Rapid fluctuation of volume of water released can be harmful to fish by scouring stream bottoms and destroying vital habitat. Improperly controlled diversions result in loss of fish in canals and on fields. Hydro-electric turbines and rapid pressure changes cause further losses.

Under ideal conditions reservoirs may increase fish production, provide temporary refuge for fishes of intermittent tributary streams and create waterfowl resting, feeding and nesting grounds. Muskrats and other fur-animals may be benefited. Better environment for many forms of wild-life can be provided about the shores of reservoirs. Under ideal operating conditions, more uniform stream flow below dams can benefit fish, shellfish and fur-animal populations; may dilute pollutants and benefit some forms of wild-life by flood abatement. Some types of irrigated crop lands and canal banks usually benefit upland wild-life.

Large impoundments and levees for flood control have provoked much controversy. An increasing number of soil scientists, biologists and limnologists believe that flood control programmes should not rely on huge dams and levees on the lower reaches of the streams. Such structures are, in the opinion of this group, at best of temporary value and logically the effort to reduce flood crests should begin by utilizing natural mechanisms for storing and distributing water. To this group proper flood control should start with the installation of proper land management which should control water so far as possible from the moment it falls to the ground. This group believes that small ponds, proper terracing, contour plowing, strip cropping and revegetation to store and distribute water are the natural and local beginning of flood control.

To emphasize this idea, it is pointed out that reservoirs built without such prior effort silt up within a comparatively short time and become progressively more useless for flood control or other purposes. Proper revegetation and proper management of agricultural lands would benefit fish by reducing silt in streams and lakes. Small impoundments properly constructed can easily be managed to maintain fish production. These ponds and proper land management as well as revegetation of sharply sloping lands and inferior soil also provide improved general conditions for wild-life. Therefore, wild-life technicians will generally give first priority to this type of management.

Stream canalization

Stream canalization also affects biological production and fish and wild-life values. Straightening slow, sluggish, meandering streams may cause little interference. In fact, by creating additional ox-bow lakes or sloughs, such operations sometimes produce additional values. Canalization of streams with relatively steep gradients almost invariably damages fish and wild-life habitat and its inhabitants. Straightening of such streams often produces scouring, which quickly destroys fish spawning beds and aquatic growths. It may also cause lowering of the water table. Under such circumstances, stream straightening usually produces adverse values which are difficult to offset.

Development of waterways for navigation

The development of inland waterways for navigation also affects fish and wild-life values. A series of dams on the upper Mississippi, operated for the sole purpose of maintaining a nine-foot channel, has had disastrous effects in some seasons upon fish and fur-bearers. In this case it was not the presence of the nine-foot channel but the method of operation and the season of draw-downs that produced the adverse effects.

Construction of an inland waterway along the Atlantic Coast has also had adverse effects upon wild-life populations. Salt water followed the waterway into marshes that had previously been fresh. Under the conditions which prevail, changing of the marsh from fresh- to a salt-water type may reduce the production of fish and waterfowl food by as much as two-thirds. The development of this waterway also impaired or totally destroyed important local spawning grounds for shrimp, crab and commercial species of food fish.

Effect of water pollution on wild-life

Pollution of streams and lakes has become a major factor in reducing water values not only for fish and wild-life but for industrial and human use. Control of new pollution and the reduction of the old sources of pollution has become a major problem. The adverse effects now in operation upon fish and wild-life, serious as they may be, are overshadowed by effects on human health and human affairs.

Pollution has been a major factor in decreasing the shad crop on the Atlantic Coast. It has likewise been a factor in the decreasing productivity of the Illinois River and other major inland fishing streams. It has had an adverse effect upon oyster and clam production in many waters on the Atlantic Coast. It is only in comparatively recent years that the general public began to understand the biological effect of such pollution. Public health standards of water purity established to reduce health hazards and the quality of water necessary to maintain biological activity of water are not always identical. Human or animal wastes if unmixed with oil or chemicals are not particularly harmful to biological production until they accumulate to a degree sufficient to utilize nearly all of the oxygen in the water. In fact, in moderate quantities, human and animal wastes may act as a fertilizer.

Conversely, human and animal wastes are particularly objectionable from a public health standpoint. On the other hand, many industrial wastes that may be present in quantities so small as to be unimportant from a public health standpoint may easily be destructive to aquatic biological production. Industrial pollutants of this type do not need to be present in sufficient volume to kill fish directly to destroy biological values. They can do this as effectively if somewhat more slowly by preventing the growth of the small aquatic creatures which provide the basic food supply in the water.

This discussion has attempted to outline the major adverse effects which present water management and proposed water-management projects may have upon fish and wild-life values. It is time now to consider the methods that may be utilized to offset these adverse effects.

CO-ORDINATED PLANNING OF WATER-MANAGEMENT PROGRAMMES TO OVERCOME ADVERSE EFFECTS

In recent years definite efforts have been made to correlate the work and viewpoint of engineers, biologists, soil physicists, soil conservation technicians, foresters and all other needed technicians from the beginning of project planning. In preparing plans for any area which includes both water and land management, it is highly improbable that any single group of technicians is entirely satisfied with the results attained, and perhaps the efforts to correlate their various activities have been somewhat clumsy. However, there is a growing consciousness of progress that comes partly from a better understanding by each technical group of the problem confronting other groups and from the development of better techniques and methods of integrating programmes to get the highest possible value from all sources.

Perhaps the major progress in the field of co-operation is between the great United States Government engineering organizations and technicians concerned with forestry, fish and wild-life and recreational values. This co-operation has developed not only between federal organizations but with state organizations as well. It can safely be said that organized teamwork involving all of these organizations is gradually developing.

Before proceeding further with this discussion, it might be well to state that under our laws, fish and game is declared to be the property of the state for the benefit of the people. This concept is the basis for public administration of the resource, for public concern regarding its maintenance and for public interest in the effect upon fish and game resources of any water or land management programme that may be installed, particularly when developed at public expense.

Drainage projects

There have been no outstanding examples of collaboration of technicians in drainage programmes. The reason is simple. Drainage has largely been accomplished by local drainage districts using local tax funds. Many projects were completed before the development of the present public understanding of the close relationship of all resources. Much land was drained on the theory that any land covered by water must necessarily be good agricultural land. The failures of such projects were due to the character of the soil or to poor engineering that failed to provide drainage to keep the land in condition for farming in average years.

Many of these drainage units became bankrupt and the land remained idle and useless for years. The Fish and Wildlife Service has spent millions of dollars buying these lands and reflooding them so that they can again produce breeding, feeding and resting places for migratory waterfowl, fish and other aquatic life, and help restore and maintain water tables. There is no obvious remedy for these past mistakes except further expenditure of public funds. Up to the present time, no federal agency has engaged in extensive drainage operations with the exception of certain operations carried on for mosquito-control purposes and which have now been reduced in volume.

Drainage enthusiasms and drainage promotions have abated somewhat, partly because the land that could be economically and profitably drained has already been so treated and partially because some individual landowners and some officials have learned that marsh lands are not necessarily always unproductive. Salt marshes sometimes provide spawning grounds for major food fish. Both salt-water and fresh-water marshes are of importance as wintering grounds for waterfowl populations and some fresh-water marshes annually produce a greater net return per acre than adjoining farm lands under intensive cultivation. Many hundreds of thousands of acres of land are now being managed for fur-animal, largely muskrat, production. Management cost per acre is low and the net return relatively high for the effort and expense involved. Much of the land is managed for fur production but other resources add to the returns from such land.

Water-impoundment projects

The planning of construction and management of impounded water offers visible evidence of progress in co-ordinating techniques to secure the greatest value from all resources. It is obvious that this cannot be easily accomplished by planning for single impoundments and isolated projects. Therefore, the thinking has tended toward planning by drainage basins so that an integrated programme of the management of land, water, forests, wild-life and fish may be obtained at a minimum expenditure.

At present the Fish and Wildlife Service and state conservation organizations are working actively with the engineers from the time the first engineering studies begin. Federal and state park authorities are making similar studies for recreational and scenic values and forest and soil conservation organizations are also drawn into the integrated programmes.

This co-ordinated planning is still too new to have completed projects on which to base judgment of its efficiency in all phases. Some of the potential values can be measured by more or less accidental results of past construction and development programmes. A specific example can be cited in Boulder Dam, built as a hydro-electric and irrigation project on the lower Colorado River. The huge lake settles out the silt before the water reaches the dam and the water spilled through the turbines is cool and clear. As a result, many miles of the river below Boulder Dam have become a fine trout stream. This was an entirely accidental by-product of the construction and operation plan but one that can be used to advantage in planning similar projects.

The impounded waters have also become fishing and recreational areas, again largely by accident. It was not by planning either of the structure or the operation that such results came about but a fortunate combination of breeding seasons and operating schedules has resulted in providing a good bass population. It is probable that the fish production will eventually decrease as in most artificial impoundments, but valuable lessons have been learned from the results achieved.

You have heard much of the Tennessee Valley Authority. It is not proposed either to critize or defend its concept and programme since that is not within the scope of the paper. However, the series of impoundments on the Tennessee have unquestionably increased the fishery values many-fold above that of the stream in its original condition. Originally, the river was a fluctuating stream that produced comparatively small fishery values. The series of impoundments that now form a chain of lakes extending from the mountains to the junction with the Ohio River have up to the present had beneficial effects upon fish. TVA, originally, was not the co-ordinated planning programme that it is sometimes represented to be. It was largely a hydro-electric, flood-control and navigation project. Forestry, fish and wild-life values were largely an afterthought added after the projects were well under way and the Authority has not yet developed an adequate soil-conservation programme for the lands it controls.

However, because of a favourable combination of conditions, the operation of these dams largely to produce hydro-electric power has so far maintained good fish-production and extended the period beyond the normal expectation of production that usually follows impoundment. The draw-down in these lakes does not come until after the spawning season of the important fish. In recent years the system of management has tended to hold fluctuations of water-levels within narrower limits than at first planned and it now appears possible to preserve high fish-production. If that proves to be the case, again some valuable lessons have been learned that can be applied to other water-development projects in similar river-basins.

Bonneville Dam was the first great structure to interfere with the Columbia River salmon, a major run of migratory fish. In this dam, fish ladders costing $7,236,000 were built to permit the chinook and red salmon to pass to their upriver spawning grounds. These ladders operate successfully in getting adult fish upstream but there is some question as to the ultimate success of the operation due to the loss of young fry in the downstream migrations.

Grand Coulee Dam, much further up the river, started at the same time but completed somewhat later, completely blocked access to the upper spawning grounds for approximately 5 per cent of the upper river run of both chinook and blueback salmon. This run was successfully trapped at a dam farther down the river and re-established in various tributary streams entering the Columbia below Grand Coulee. These streams had not been used previously by salmon for spawning purposes because of falls or other obstructions which were either removed or eliminated as obstructions by placing fish-ladders around them. The salmon were trapped over an entire cycle of runs and either spawned in hatcheries and the fry planted, or the adults were transplanted into the streams and held there by weirs until after spawning. This programme has been successful and the runs that formerly travelled to the head waters of the Columbia are now spawning in these new grounds. This operation, including the construction cost of the hatcheries, cost approximately $3,643,400. This expense has been included as a part of the cost of the project. Since fish is a natural resource reserved for the public, this seems to be only fair.

The only questionable part of the long-time programme for the Columbia River is that raised by the many additional dams planned for this stream. It is known, that, with present knowledge and methods, there is some loss of downstream migrants at each dam. Multiplication of dams would seem to make it almost certain that salmon runs of the upper river will eventually be destroyed unless new techniques of handling this problem can be devised.

As a corollary to this work, plans have been made for building up the salmon runs in tributaries entering the Columbia nearer its mouth, using the methods that have been successfully applied previously. This work is not completed and the total cost is still unknown. The fish-ladders at Bonneville are lifting fish approximately 65 ft. which is one of the highest ladders over which fish have been successfully carried.

Co-ordinated planning is the greatest safeguard yet developed for wild-life resources in connexion with water development. It is now started and all future federal water-development projects will be based on co-ordinated planning designed to secure the greatest possible value from all resources.

There is one apparent weakness in the established machinery. The engineering agency, which is the promoting, proposing and construction agency, is still the final judge of relative values. Conservation interests are urging the establishment of a Board of Review not directly connected with any of the official agencies, composed of distinguished citizens known for their interest in public welfare who will review these proposals before they are submitted to the Congress, to determine whether or not they are really co-ordinating the development to secure the most value from all resources. Conservation organizations believe that this final bit of administrative machinery is necessary before the admittedly fine work now being developed in co-ordinated planning can become fully effective.

It is not possible to present much information about the final results or costs of these co-ordinated activities. The land to be irrigated from Grand Coulee Dam has been considered by this co-ordinated planning group. It is already obvious that when water is actually placed on the land, there will be in effect better provisions for the protection, utilization and maximum development of all possible resources than there has been on previous unplanned units.

There are many projects in many units in the co-ordinate planning stage—some have reached the construction phase and some are nearing completion, but in most cases, it is too early to evaluate the results.

Among the things being planned are replacement of habitat destroyed by the flooding by impoundment, particularly for deer and other big game in the West, but to some extent for minor upland species; the replacement of waterfowl habitat, particularly on state-owned or federally-owned refuges which may be flooded by the development of comparable areas outside of the impoundment area; maintenance of conservation pools to protect and preserve the fish-life that can be developed; the re-establishment of refuges on or adjoining these areas to further protect wild-life populations. Fish-ways have been planned and included in dams that interfere with runs of migratory fish; isolated potholes resulting from dredging and other development work will be connected with the main stream to prevent the trapping of fish with reservoir fluctuations. Food and cover plantings are being developed in various places to replace destroyed habitat or to improve habitat conditions. Various other wild-life protective and improvement measures are being included in plans for the development of future areas. In the past, dredging projects have sometimes used the spoil to construct dykes on national wild-life refuges. The operation thus served a double purpose of providing navigation channels and providing dykes along the boundaries of proposed or existing national wild-life refuges.

Sub-impoundments on shallow arms of larger units have provided stabilized water-levels to the advantage of fish and wild-life. Shallow bays cut off by dykes and pumped dry during the summer in areas of high malaria hazard have been used to grow food crops for waterfowl. This food is made available by slow reflooding after the malaria season.

There are enough actual units of these practices in existence to serve as guides in developing future projects. Sub-impoundments in larger impoundments have been used successfully. On the Santee Cooper project in South Carolina, an area of 3,003 acres of shallow water cut off by a dyke, impounded water which provides both spawning grounds for warm-water fish and excellent waterfowl habitat. It has been developed to replace habitat destroyed downstream by the diversion of water and has been accepted readily by the waterfowl whose usage of the area is constantly increasing. Total cost of this development was $176,370.

A similar unit was installed many years ago at the Minnedoka irrigation reservoir in Idaho. This reservoir is a refuge but shallow arms cut off by small dykes have automatic valves which permit the units to fill as the water of the reservoir rises. This stabilizes the water-levels and provides areas heavily utilized for both breeding and feeding by waterfowl.

The Fish and Wildlife Service has found it advantageous to cut large marsh areas into smaller units that can be held at various levels in order to increase the area of shallow water. This practice has been applied successfully also in some reservoirs. Plans for similar developments can be included in proposed future reservoirs.

Dewatered areas have been provided in TVA reservoirs by dyking off shallow bays which have been emptied either by gravity or by pumping. On dewatered areas, plants suitable for winter food for waterfowl have been planted and the areas are gradually reflooded in the fall when migrating waterfowl and wintering birds can get maximum use from them. It should be pointed out that this type of development would be useless as breeding grounds but does provide an abundant supply of winter food where it can be practiced.

Conservation pools, which means primarily the maintenance of a level of water in a reservoir below which there will be no draw-down, have been included in a number of areas particularly for the preservation of fish populations. Flood-control reservoirs and irrigation reservoirs are sometimes completely emptied. These conservation pools, when provided, leave water to afford protection to breeding stocks of fish but do not provide values other than protection for fish and resting grounds for waterfowl. It should be pointed out that such conservation pools are of a somewhat temporary nature unless excessive erosion, which will result in silting up the pool, is controlled on the drainage basin above.

MODIFICATION OF OPERATING PROGRAMMES FOR WILD-LIFE CONSERVATION

Perhaps the greatest value that can be provided for fish and wild-life is in the modification of operating programmes so far as it is possible to meet the needs of the fish and wild-life populations. Ideal operations would maintain stable water-levels through the breeding period with a relatively limited amount of fluctuation permissible thereafter. It has been noted that declining water-levels in the late summer following the breeding season of waterfowl, the spawning of the fish and the production of major food supplies, does not do a great deal of harm to those resources. Whenever the operating conditions make it possible to avoid draw-down until after 15 July, it is possible to provide certain types of waterfowl food and also to maintain good fish populations at a level somewhat above that usually occurring in impounded waters.

Where operations do not require sudden and drastic winter draw-downs, fish and fur-animal populations can be maintained with less loss than where sudden and drastic draw-downs occur in the fall or winter. The fact that such fluctuations do not normally occur on the TVA reservoirs has been one of the factors contributing to the production of fish in those waters. The use of chains of reservoirs on a sound basic plan also offers possibilities which cost little or nothing but which meet the basic biological needs of fish and wild-life.

Replacement of destroyed areas has been one of the major problems, particularly where impoundments flood fish hatcheries, major fish-spawning areas, highly developed state or federal wild-life refuges or other wild-life units. At the present time the Reclamation Service has agreed to replace such units where there is no other alternative in the development of a water programme. So far as it is possible, such drastic action should be avoided—both to conserve public funds and to maintain existing habitat. However, when development plans make it imperative to flood such areas, the constructing agency should purchase, provide water for and develop areas of equal value. The areas selected must be agreed upon between the agencies concerned and development plans worked out co-operatively.

This paper is merely a report of progress. Much of the work projected and many of the results of unified planning are still in the future. However, those interested in fish and wild-life are gratified at the progress already made and at the prospects that future developments will be planned more carefully. With such planning it is possible to avoid much impairment of fish and wild-life values, to replace values that have been lost, and, perhaps most important of all, to add to existing resources whenever it proves feasible and possible to do so.

The increasing co-operation between technicians can, if it continues to develop, bring about a new and revolutionary concept of the importance of proper management and proper care of all basic natural resources.

Summary of Discussion

The Chairman reminded members that there was a very heavy agenda and asked them to make the summaries of their papers and their statements as brief as possible.

Mr. Dahlgren presented Mr. Rusck's paper on "Hydro Power in Sweden".

Sweden had practically no resources in coal and oil but had large water-power resources. The water-power that could be economically developed amounted to approximately 50,000 million kwh. per annum. Electricity was practically the only source of stationary driving power and the greater part of the railway system was also electrified. Sweden's water-power resources had the disadvantage, however, of being situated in the northern part of the country, while the consumption was concentrated in the southern parts. This necessitated power transmission over distances of as much as 1,000 km. To get a system with sufficient transmitting capacity it was therefore necessary to complete the 220 kv. network with 380 kv. lines.

In 1948 water-power production had amounted to approximately 14,000 million kwh. Thus, about a quarter of the water-power potential had been used.

The head in the Swedish water-power stations was frequently less than 150 ft. and only in rare cases exceeded 300 ft.

The Swedish watercourses abounded in lakes and thus offered excellent means of regulation.

Power supply in Sweden was administered by the State through an independent commercial enterprise, the Swedish State Power Board, and further, by the municipal authorities and by a number of private companies. The State was responsible for 40 per cent of the total energy production, the municipal authorities for 6 per cent and private companies for the remaining 54 per cent.

Mr. Olds, presenting his paper entitled "Hydro Power and Conservation—a New Engineering Technique", gave a brief summary of it.

The development of water-power provided a key to comprehensive river-basin development, which was vital to the conservation of exhaustible energy resources.

To make hydro-electric power fully available the development of water resources should be approached from a long-range point of view, in terms of co-ordinated river-basin programmes which would ensure the utilization of water resources through economically sound, comprehensive and integrated multi-purpose projects. To meet that need the various federal agencies of the United States, including the Federal Power Commission, had developed a technique which might be described as a new scientific branch and could be called "river-basin engineering".

The following were the essential elements of that technique:

(1) The entire river was looked upon as the physical unit to be developed rather than limiting the planning to individual projects.

(2) The needs within the entire river basin for the

various water uses were appraised in terms of their relation to and effect upon the development of power.

(3) Various alternative plans for dams, reservoirs, waterways and power plants were laid out upon a multiple-purpose water use basis, and analysed physically and economically to determine the best plan for power consistent with the other water uses.

(4) The various plans were weighed in terms of the effect of the construction and operation of the river system upon existing improvements, and particularly upon the inundation of agricultural lands.

The individual units in the river-basin system were designed to complement and support each other, so that the system could make the greatest possible contribution to the regional power supply.

Mr. Olds proceeded to cite several examples of how the technique he had just described had been applied in certain specific cases, such as the Alabama-Coosa River and the Lower Arkansas and White River basins. Each of those areas had had its own special characteristics, and the solutions adopted had therefore shown a wide variety.

Mr. Kampmeier said that the experience of the Tennessee Valley Authority confirmed Mr. Olds' statement in many respects. The complementary use of steam and hydro power is emphasized in TVA power operations. The long-range viewpoint is important. When a dam is being constructed, it is well to provide space for generating capacity large enough to make additional resources of energy available for later use in the event of the economic development creating fresh needs. The designers of the Wilson Dam had made such provision and the experiment had been fully justified.

Mr. Rodríguez observed that in certain countries, particularly in the Philippines, attempts to develop the use of hydro-electric power to a maximum came up against various difficulties. There might not be sufficient figures on the hydrographical regime, or there might be a lack of funds. Moreover, it was difficult to draw up programmes in countries which were still economically under-developed.

Mr. Olds agreed that there was a close connexion between any programme for the development of hydro-electric power and the general economic progress of the country in question. That question arose in the United States, particularly in relatively less developed areas.

Mr. Angus wished to hear the views of the members of the Conference on the two following points: whether the attainment of the maximum volume of hydro-electric power was the only aim to be considered in drawing up programmes, and whether it was not a first essential to obtain hydrological data.

In connexion with the second point, he raised the question of the length of any hydrological "cycle" to be taken into consideration prior to dam construction.

Mr. Olds thought that the production of hydro-electric power was only one factor to be considered in a programme in which account should be taken also of such factors as irrigation, navigation and flood control.

Mr. Jony said that, generally speaking, the examination of hydrological data gathered in various countries, often over very long periods, did not appear to make it possible to establish any precise theory of cycles.

He agreed with earlier speakers that among the various factors which had been mentioned there was no single one that should govern the drawing up of a comprehensive river-basin programme. Moreover, it should be possible, in the light of experience, to change the rules of development as operations proceeded. Finally, he pointed out that every basin had its own characteristics and there was no formula which would apply to every case.

Mr. Sain spoke of some of the difficulties met with in India. Owing to the high cost of coal in certain regions it was advantageous to give higher importance to hydro-electric power. In such cases subsidiary reservoirs could be constructed below the main dams, to meet the needs of irrigation and navigation.

Mr. Hathaway confirmed that with any degree of certainty, the hydrological data in his possession did not allow cycles to be established.

Mr. Karpov said that statistics brought to light two types of overlapping cycles: a short-term type with a fairly clear outline, and a long-term type which could not be defined.

Mr. Wing said that observations made over the centuries in the basin of the Nile had shown the existence of long-term cycles.

An international body should be set up to collect all existing hydrological data from the various countries.

Mr. Aubert recalled that Mr. Frolow had written a report on cycles. Certain cycles had been observed in the past, but there was no law whereby they were bound to reappear in the future. He compared those observations with the statistical data which could be gathered from observation of a simple game of chance, such as "heads or tails": it could be studied mathematically, but it provided no means of forecasting for a sure win.

All too often in Europe the mistake had been made of planning hydro-electric plants on the basis of data for years when the rainfall had been plentiful; as a result many plants were paralysed during droughts. There existed, therefore, a surplus of idle machinery.

Mr. Olds said that in the United States programmes for hydro-electric installations had been based on average years.

Mr. de Luccia pointed out that in drawing up programmes in the United States, account had been taken of general economic studies over a period of twenty-five years, so as to ensure a rational distribution of the various hydro-electric plants.

Mr. Aubert gave a general outline of the paper by Mr. Massé and Mr. Rousselier on "Hydro-Power and Conservation of Power Resources".

The authors emphasized the need for a physical and economic inventory, which should be as accurate as possible, of the water resources of the various countries with a view to their rational development. The physical inventory led to two basic conceptions: the gross natural potential or gross annual power from water-flow and the net natural potential or annual power which could in practice be harnessed. The gross natural potential was of theoretical interest only, and should be corrected by the use of reduction coefficients, of which the numerical value could be established only approximately.

The economic inventory was founded on rules which called for greater skill. It would seem useful to consider, on the one hand, the resources, the cost of which was less than or equal to the ceiling capital costs currently regarded as permissible, and, on the other hand, the resources limited by ceiling costs 50 or 100 per cent higher than the former.

Mr. RAUSHENBUSH gave a brief summary of the paper prepared by Mr. Beurle on "Considerations for General Planning of Water-Power Stations". Hydro-electric plants were becoming progressively larger. Programmes should therefore be based on well-founded technical and economic data. Legislative provisions should permit full development and complete utilization of water resources.

Mr. HANNUM pointed out that when scheduling the development of comprehensive programmes, consideration should be given to the relations between the existing dams and the projected dams in an area to provide for the addition of the most needed benefits in sequence. Also, such considerations should take into account the relative costs of building transmission lines from the dams to load centres, as compared with needs for upstream flood control storage and downstream fish resources.

Mr. RAUSHENBUSH announced that the Conference had received a paper, which had not yet been circulated, on hydro-electric installations at Jablanitza and Mavrovo, submitted by the Yugoslav delegation. Thirty-seven hydro-electric plants, which were to produce one million cv, were under construction in Yugoslavia. The Jablanitza dam provided 758 to 980 million kwh. and the Mavrovo dam 343 million kwh. annually.

Mr. PAPANICOLAOU spoke about the programme for the general development of hydro-electric resources in Greece. The realization of that programme was essential for the economic progress of the country. The production of the existing plants was low, but the possibilities of hydro-electric power production might rise to 5,000 million kwh. The actual programme prepared by the Greek technical services provided for an annual production of 1,800 million kwh. which was finally reduced to 1,250 million kwh.

Mr. GONZÁLEZ MOLINA asked whether it would not be possible, in the event of a river being lower than the town, to use refuse-water for the production of hydro-electric power after the town supply had been taken off.

Mr. KARPOV replied that that had been done at Fez in Morocco and Munich in Germany.

Mr. WIRTH presented his paper on the "Recreational Use of Water" and explained its salient points. He outlined the increasing importance of organized sports and leisure occupations as the population concentrated in the large cities and civilization became increasingly mechanized. In the United States it had been realized that the organization of sports and leisure occupations made an invaluable contribution to the national life. In the past fifty years leisure time had almost doubled, increasing from twenty-five to forty-six hours a week, while at the same time there had been an enormous increase in the productivity of labour. In view of the increasing role of leisure in modern life, all the possibilities offered by technical progress should be used to develop recreational activities. The utilization of artificial lakes and waterways created or improved in the multi-purpose development of river systems was of considerable importance.

Valuable as recreation was, its advantages were very difficult to assess in monetary figures. An estimate could doubtless be made of the amount spent by the public for certain recreational purposes such as tours, purchase of sports equipment, etc. That expenditure, however, would not provide even an approximate estimate of the value of recreational facilities. To give a more exact idea of their importance and use, it would be better to quote figures. In 1948, for example, 110 million persons visited the State Parks in the United States and over two and a half million persons visited one artificial lake created by the building of a dam. In spite of the importance of recreational facilities as represented by those figures, however, they were not given sufficient consideration.

It had, however, become customary in the United States to consult recreational experts, particularly in planning great river-development projects. Those experts should be brought in at the very inception of the over-all planning, so that they could, for example, study the site of the proposed work and decide whether its construction would be beneficial or injurious to the recreational possibilities of the area. That had always been borne in mind in the work done by the TVA, and the Tennessee Valley had thus become one of the areas of the United States with the best recreational and sports facilities, consequently attracting a large number of tourists.

The CHAIRMAN emphasized the importance of Mr. Wirth's point of view and of the extent to which those considerations had already been put into practice and should be implemented in the future, particularly in the multi-purpose development of the great river systems.

Mr. DAHLBECK gave a brief summary of the papers by Mr. Alm and Mr. Hamilton on the "Protection of Fish in Sweden" and the "Protection of Wild-life in Sweden".

Fishing was a very important industry in Sweden and brought in a total of 10 to 15 million dollars per annum.

The stocks of the most important species of salmon, trout, char, whitefish, pike and eel were frequently impaired through various kinds of interference from man.

Through hydro-electric power-stations and lake regulation the spawning and breeding places were destroyed, particularly for the salmon, whose ascent was thus hindered, for the trout and char and sometimes also for the whitefish. Every effort was being made to prevent stocks of fish being adversely affected by various methods such as the installation of salmon ladders, transport of salmon, the setting out in rivers of sizable young salmon, the breeding of salmon, trout and sometimes whitefish and the transport of young eels.

Pollution, particularly in the case of small rivers during the dry season, resulted in the death of the fish, mainly owing to the lack of oxygen in the water. The recovery of waste and the use of various methods of purification made it possible to reduce pollution, and research in that field was being intensified.

Timber floating, which was carried out on a large scale, caused a certain amount of damage owing to bark waste, which sometimes polluted the spawning ground of salmon and whitefish, but mainly because of the regulation of lakes and rivers, which interfered with the breeding of pike, and the canalization of small rivers which then became unsuitable for trout and char.

The lowering of lake levels frequently caused damage to the fish, especially to pike.

In order to study the most practical ways of preventing or counteracting those harmful influences, the Fishery Board, the Regulation Associations, the Migratory Fish Committee and the Swedish Salmon and Trout Association were carrying out intensive research programmes.

Mr. HORA summarized the paper prepared by Mr. Prashad and Mr. Job on the "Protection of Wild-Life and Fish in India".

The conservation of wild-life and fish had until recently received comparatively little attention in India. The paper discussed briefly the inadequacy of the machinery for the enforcement of the legislative measures enacted for that purpose. It was hoped that the Dominion's new Constitution would make adequate provision for the preservation of the country's wild-life resources. Very little attention had been given in India to the problem of the effects of the construction of dams on fish conservation. In some dams, however, fish-ladders and passes had been provided, more or less on the models of similar devices in the United States and Europe, without adequate knowledge of the biology and bionomics and leaping capacity of the fish in question and their possible ability to negotiate the gradients. As such, those passages and ladders had for the most part proved ineffective. The need to conserve fish had now been recognized, and the engineers who planned the construction of dams collaborated with fishery experts whose duty it was to advise them on the possibility of using the works for fish culture. Mention is made of the proposed programme of investigations relating to fishery requirements in connexion with various dam projects.

Mr. DETWILER presented his paper on "The Protection of Fish and Wildlife in Water Use Projects". The development of river-basins for the welfare of man and not only for the exploitation of their resources should include measures to protect fish and wild-life.

In river-development projects the needs of navigation and irrigation were paramount, and improvised measures, such as the installation of runways, fish-ladders, lifts etc. were necessary if fish and wild-life were to be protected. Such steps had been taken primarily in order to appease coastal river fishing interests which had been threatened. If fish were to be protected, their habits must be studied over a long period and it must be ascertained in what environment they developed best. Water-development projects completely changed the conditions in which they lived and it was consequently essential that engineers should have the assistance of piscicultural experts.

The protection of fish and wild-life should be made compulsory in every river-development project.

There were two reasons for protecting fish and wild-life: commercial interests, which could be reckoned in terms of money; and the recreational interests of such sports as fishing and hunting, the monetary value of which, the author maintained, could not be entirely assessed in money, but which, nevertheless, play a role of ever-increasing importance as the idea of leisure is integrated with that of labour. In so far, however, as the monetary evaluations of the sports of fishing and hunting are possible, and within certain limitations they were presumed to be, to that extent, at least, they should be given due consideration when the advantages and costs of water-use projects come under advisement. This did not, however, preclude an effort to provide for the aesthetic values that resist evaluation in terms of money.

He quoted the Manitoba Central Basin Project in Canada as an example; fishing and hunting played a considerable commercial role in that project.

The Muskingum Watershed Conservancy District in Ohio was an excellent example of the development of a river-basin where the necessity for preserving fish and wild-life had been taken into account. The dams which had been installed had cost 45 million dollars, but the annual value of the Muskingum Lakes for recreational uses was estimated at 807,000 dollars.

It was the more important to develop river-basins in such a way as to preserve fish and wild-life since that could often be done without increasing the cost of the projected works.

Mr. GABRIELSON summarized his paper on "Hydro Power and Other Water Uses: Protection of Fish and Wild-life". River-development projects necessarily had some effect on fish and wild-life. His paper began by giving the principal effects, and went on to describe the procedure laid down in Washington under which plans for the protection of fish and wild-life were discussed before water-development projects were put into effect.

As a general rule, fishing was excellent in the years immediately following the construction of a dam, but fish production subsequently decreased rapidly. Plans should not therefore be drawn up until specialists on fish protection had been consulted.

The paper described the devices at present employed to enable fish to breed in favourable conditions and to emigrate. Methods which enabled wild-life to find new habitats when dislodged from its original habitat by the construction of river-development works were also described. Experience had shown that by drawing up plans in consultation with piscicultural experts it was sometimes possible to obtain better conditions for the fish than those which had existed in the basin before the work had been undertaken. It was important to avoid sudden changes in the water-level and to maintain the water-level below the dam above the minimum level necessary for fish-breeding.

It was impossible to give any general formula which could be applied to all plans, since every case must be solved on its own merits. Nevertheless, it could be said that it was better to consider the development of a river-basin as a whole rather than plan for isolated projects.

Now that hydraulic engineers and piscicultural experts co-operated from the very outset of the plan, it would be possible for the first time to eliminate the harmful effects of building dams and even to ensure that development would improve original conditions, from the point of view of fish-breeding.

Mr. SAIN spoke from the point of view of the engineer and pointed out that the question of fish conservation had been raised many times in India during the last twenty-five years. When the first water-development works had been undertaken, the staff of the Fisheries Department had been consulted and fish-ladders provided in accordance with their advice. It was, however, found that the cost of installations to preserve the fish was too high and that the installations which had been constructed had not given the desired results. It was true that at that time studies on the habits of fish had not been in such an advanced stage as they were now. Any projects at present being studied would include installations for the protection of the fish. Since, however, the dams now being constructed were high ones, the engineers must not be asked to provide for over-complicated or expensive installations. If they were forced to include such installations the project might have to be abandoned for economic reasons. He therefore asked the specialists to make a study of installations the cost of which would be in proportion to the advantages derived from them.

Mr. DE LA TORRE thought that the following measures should be taken to preserve fish and wild-life:

1. An educational programme by means of scientific publications, films, the radio and expert advice;

2. The building up of funds. That could be done through the United Nations by setting up an organization similar to the International Bank for Reconstruction and Development. The countries concerned could exchange reserves they possessed which other countries might need. Furthermore, the body in question could encourage the conclusion of agreements providing for the opening of credits; lastly, it could grant loans itself, as did the International Bank for Reconstruction and Development.

He urged that the Conference's work should be followed up by a permanent organization to develop world resources for the greatest good of all nations.

Mr. OLDS wished to make two comments, one on the paper written by Mr. Wirth and supplemented by Mr. Detwiler, and the other on the remarks made by Mr. Sain with regard to Mr. Olds' paper.

He recommended those concerned with the development of river basins for recreational purposes to find some way of estimating the economic advantages to be derived from that development. Those who decided to carry out such a plan were, in point of fact, guided by a comparison between the cost and the advantages.

With regard to Mr. Sain's comments on his paper and on the necessity for avoiding changes in the water-level in order not to interfere with navigation and irrigation projects, Mr. Olds drew Mr. Sain's attention to the way in which that problem had been solved in the cases of the basins of the Alabama-Coosa River, the lower Arkansas and the Kings River. The latter project was of particular interest to Mr. Sain. In order to regularize the flow of water, which varied with the needs of power production, and to render the discharge usable for irrigation downstream, a site for a reservoir had been found at the point where the river left the mountains.

Mr. BOWMAN, Chief Editor of the *Engineering News Record*, was happy to note that those who had taken part in the Conference were well aware of the gravity of the problems with which they were confronted; this international Conference, more than any other, had taken to heart its task of providing for interchange of facts and philosophies relative to multi-purpose reservoirs. He was also pleased to call attention to the excellent way in which the Conference had been organized, and to the effectiveness of the simultaneous translation system.

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