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IMPLEMENTATION OF GENERAL ASSEMBLY RESOLUTION 3337 (XXIX): INTERNATIONAL CO-OPERATION TO COMBAT DESERTIFICATION

DESERTIFICATION: AN OVERVIEW
FIRST DRAFT

Note by the Executive Director

In its resolution 3337 (XXIX) of 17 December 1974 convening the United Nations Conference on Desertification, the General Assembly emphasized "the need to ensure that all available knowledge in this area is fully utilized". In seeking to fulfil the General Assembly's wishes, the subject of desertification was analysed into four components, and internationally recognized experts were commissioned to write component reviews on each of these four sub-topics. These reviews, which have been completed and will be available to the Conference as background documents, are: Climate and desertification, Ecological change and desertification, Population, society and desertification, and Technology and desertification. These technical and scientific studies have been synthesized into one document, prepared in a more narrative and readable style. 1/

1/ In view of the limited number of available copies of the report, it is being distributed on a limited series only and members are requested to bring their copies with them to the meetings.

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UNITED NATIONS CONFERENCE ON DESERTIFICATION

DESERTIFICATION: AN OVERVIEW

FIRST DRAFT

SUBMITTED FOR DISCUSSION AND COMMENT TO
THE REGIONAL PREPARATORY MEETINGS
FOR THE CONFERENCE

ITEM 4

OF THE PROVISIONAL AGENDA FOR THE PREPARATORY MEETINGS FOR

THE AMERICAS
Santiago, Chile, 23-26 February 1977

AFRICA SOUTH OF THE SAHARA
Nairobi, Kenya, 12-16 April 1977

THE MEDITERRANEAN AREA
Algarve, Portugal, 28 March-1 April 1977

ASIA AND THE PACIFIC
New Delhi, India, 19-23 April 1977

Secretariat of the United Nations
Conference on Desertification
P.O. Box 30552
Nairobi, Kenya

January 1977

NOTE TO THE REGIONAL PREPARATORY MEETINGS FOR THE UNITED NATIONS CONFERENCE ON DESERTIFICATION

The attached Overview is presented to the Regional Preparatory Meetings for the United Nations Conference on Desertification for discussion and comment in conformance with Item 4 of the Draft Provisional Agenda for those meetings.

The Overview has two primary purposes to which discussion and criticism should be directed:

(1) It should provide a readable but scientifically accurate summary of the causes and processes of desertification and of the steps that can be taken to combat such processes and, where possible, reverse them.

(2) It should provide justification for the recommendations contained in the proposed Plan of Action to Combat Desertification, a draft of which will be discussed under Item 5 of the Provisional Agenda for the Regional Preparatory Meetings.

Comments made at the Regional Preparatory Meetings will be taken into account in the preparation of the final draft of the Overview.

The soil which kept breaking away from the highlands ..... keeps continually sliding away and disappearing into the sea ...... What now remains, compared with what existed, is like the skeleton of a sick man, all the fat and soft earth having wasted away and only the bare framework of the land being left ...... What are now mountains were lofty, soil-clad hills; the stony plains of the present day were full of rich soil, the mountains were heavily wooded -- a fact of which there are still visible traces. There are mountains in Attica which can now support nothing but bees, but which were clothed, not so very long ago, with fine trees suitable for roofing the largest buildings -- and roofs hewn from the timber are still in existence ..... The country produced boundless pasturage for cattle.

The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over the denuded surface into the sea, but was received by the country, in all its abundance, into her bosom, where she stored it in her impervious clay and so was able to discharge the drainage from the heights into the hollows in the form of springs and rivers with an abundant volume and a wide territorial distribution. The shrines that survive to the present day on the sites of extinct water supplies are evidence for the correctness of my present hypothesis.

-- Plato
The Critias

PREFACE

In December 1974, the United Nations General Assembly passed resolution 3337(XXIX) calling for an international Conference on Desertification, to be held in 1977. The General Assembly specified that to prepare for this conference a world map should be developed showing areas vulnerable to desertification, all available information on desertification and its consequences for development should be gathered and assessed, and a plan of action to combat desertification should be prepared with emphasis on the development of indigenous science and technology. In a subsequent resolution 3511(XXX), the General Assembly stressed the need "for additional research to clarify a number of fundamental problems of desertification".

This additional research took the form of case studies directed toward key aspects of the desertification process. Six such case studies were financed and carried out by the specialized agencies of the United Nations system. They analyzed the process of desertification in (1) Chile and (2) Tunisia, both with predominately cold-season rainfall, in (3) India and (4) Niger, both with predominately warm-season rainfall, and in (5) the Indus Valley and (6) the Tigris-Euphrates Valley, both irrigated areas subject to waterlogging and salinization. In addition, a number of Governments co-operated by developing associated case studies focused on desertification problems within their borders. These governments include Australia, China, Iran, Israel, the Soviet Union and the United States.

Another set of studies relates to the possibility of co-operative, transnational efforts to combat desertification. These so-called feasibility studies, prepared by specialists, concern the construction of greenbelts on the northern and southern rims of the Sahara, the management of groundwater aquifers in northeast Africa and the Arabian peninsula, the monitoring of desertification processes in South America and the Middle East, and livestock and rangeland management in fragile, dryland ecosystems.

The accumulation of the currently available information on desertification may be said to include the requested desertification maps. A world map of areas vulnerable to degradation was prepared by UNESCO and FAO at a scale of one to 25 million and maps of the desert areas of north Africa and South America have been prepared at a scale of one to five million. In addition, some of the case studies were accompanied by more detailed maps of the areas under consideration.

To present the available information in a coherent way, the broad subject of desertification was broken down into four major elements, and recognized specialists were commissioned to write a review of each element. The authors of these four component reviews received the advice and assistance of an international panel of experts. The review are entitled Climate and Desertification, Ecological Change and Desertification, The Demographic, Social and Behavioural Aspects of Desertification, and Desertification Technology.

This *Overview* seeks to provide a brief account of the main findings of the four component reviews. To do so properly, it has sometimes gone beyond the component reviews, as, for example, in making reference to the case studies and the feasibility studies. Limited in length, the *Overview* cannot be regarded as a summary of all aspects of desertification. Its viewpoint is more specifically directed to showing how the elements of the Plan of Action to Combat Desertification, as submitted to the conference, emerge directly from the information presently available and from past efforts to combat desertification, as carried out in many parts of the world. In the same sense, the Plan of Action has served as the focal point around which all preparations for the conference have been organized.

The four component reviews, together with the *Overview*, represent an attempt to provide the delegates to the Conference on Desertification with a more organized kind of documentation. It is the hope of the Conference Secretariat that the delegates will find this system more useful and convenient than the more customary procedure of providing an extended catalogue of documents each of which covers one miniscule aspect of the subject under consideration.

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I

The Problem of Desertification

The Sahel - a region at risk

In the Sahel, as in other drylands, rainfall is scanty and highly variable. For as long as history remembers, nomads have pastured their herds in the arid grasslands that rim the southern edge of the Sahara desert; they have seemed suitable for little else, since only nomadism can take full advantage of the fact that the rain, unreliable as it is, may fall in one place and not in another. Yet even so, the pastoralists of the Sahel live under the constant threat that the rains, such as they are, will fail, and that the land will be affected by drought. Major drought struck the Sahel in 1913 and again in 1940.

This great drought, 1968-1973

In 1968 it happened again. At Rosso in western Mauritania, which receives an average (1935-72) of 284mm of rain a year, only 122mm fell in 1968. This seemed at the time to be a mere quirk in the as yet unpredictable weather patterns, since the rainfall returned to normal in 1969 with 295mm. But in 1970, the rains failed again with a mere 149mm, then again in 1971 (126mm) and worst of all in 1972 (54mm). By 1973 the situation in the Sahel was catastrophic. It provided a spectacle of death, disease and migration that served as the immediate stimulus for the 1974 call by the United Nations General Assembly for international co-operation to combat desertification, including a world conference on desertification to which a plan of action would be submitted.

What had happened to the Sahel by 1973, the fifth year of drought? Lake Chad had shrunk to one-third its normal size. In the preceding winter, the great Niger and Senegal rivers had failed to flood, leaving much of the best cropland in five countries (Niger, Mali, Upper Volta, Senegal and Mauritania) cracked and barren. The water table dropped, drying up shallower wells throughout the Sahel's five million square kilometres and placing the nomadic pastoralists in deadly peril. After consuming the last accessible shreds of dried-up vegetation, famished herds were sold, slaughtered or driven southward in a fruitless search for pasture. Behind them was a stripped landscape, baking in the sun, where patches of newly-created desert seemed to grow and link up, producing an impression that the great Sahara desert was "marching southward".

Also by 1973, the last year of the drought, a large programme of international assistance had been mounted for the distressed countries of the Sahel. Contributions, in cash, but mainly in food, by Governments, the United Nations system and private individuals approached a value of $200 million by 1974. This was emergency relief, primarily intended to prevent starvation. It could do little about the destruction of the agricultural base of five countries (Mauritania, Upper Volta, Mali, Niger and Chad), already among the poorest nations in the world, and severe damage to the agricultural base of two other (Senegal and Gambia). For these countries, the destruction of agriculture meant a loss of their tax base and a situation close to bankruptcy. In the absence of reliable statistics, especially difficult to obtain among nomadic peoples, it is not easy to say how many people died as a direct result of the drought but estimates have ranged between 100,000 and 250,000. That the toll of death was not higher could be attributed only to the relief programme. The amount of drought-induced disease is also impossible to calculate precisely. Malnutrition was rife among children, especially among the nomads, and outbreaks of measles took on epidemic proportions. The loss of livestock was appalling, with estimates reaching as high as 90 per cent in Mali.

Climatologists are asking whether the prolonged drought in the Sahel signified a long-term climatic shift to more arid conditions in this immense territory that supports 25 million people. But a review of recorded climatic fluctuations in the area has led to a conclusion that the Sahelian drought, however severe and however unexpected it may have seemed to the inhabitants of the Sahel, must probably be regarded as a predictable event under the climatic regime that existed formerly, something to be expected at long intervals, perhaps two or three times a century.

The great drought in the Sahel also gave rise to a number of other questions. Can such occurrences be predicted so that people can prepare for them? What should be done to see people through such successions of lean years, in the form both of emergency relief and long term actions? What are the best rehabilitative measures to be applied after such an event? These questions are the more pertinent because the Sahel drought coincided with rainfall failures, loss of crops and livestock, and famine and death in other parts of the worlds drylands, including particularly East Africa and the deserts of Pakistan and India.

Drought and desertification

The drought has ended and favourable rainfalls have returned to the Sahel since 1974, but at least a decade will be required to restock the pastures and at least as long again before the ravaged land returns to something like its former state. It is this long-term spread of desert conditions in formerly more productive lands that we call desertification, to distinguish it from the temporary climatic phenomenon of drought.

Desertification is far from a novel experience for mankind. It has been a major factor in the destruction of human civilization from the earliest times. For example because of improper drainage, salts concentrated in the lands irrigated by the Sumerians and Babylonians, thus destroying their agricultural productivity. Prolonged and intensifying desiccation of the land ruined the agricultural basis of the Harappans, who had constructed a pre-Aryan civilization in what is now Pakistan. The Mediterranean littoral of Africa was certainly more productive in Roman times than it is today.

It is possible that the area lost to man's use in this way may be of the same order of magnitude as the total amount of land left in crops or pasture today. There is general agreement that the rate of loss of land or productivity through desertification has increased significantly during the last decades to the order of almost 50,000 km. squared per year and that 30 million km squared are vulnerable to desertification in a world likely to be faced increasingly with food shortages.

Although deserts are not without life, they can be viewed as areas with extremely limited agricultural potential. There is a variety of desert types, hot and cold, stony and sandy, but all are characterized by rainfal deficiencies so marked that cultivation or stock-rearing are possible only with special adaptations. Desertification, as the extension or intensification of desert conditions, diminishes the productivity of the land, and it is this which makes it fundamentally a human problem. Desertification affects the whole global community; for example lowered wheat yields in the drylands affect all who depend on wheat as food. But the human impact of long-term desertification is far greater on the people who live where it is happening and who depend upon arid lands for their livelihood, particularly in the developing countries. There desertification can bring poverty, malnutrition and disease, erosion of the economic base, and the further deterioration of social services already hampered by remoteness and the uncertainty of the environment. It breaks up families and may wipe out whole cultures. It lowers resistance against the impact of succeeding droughts, each of which may bring famine, death and the collapse of livelihood systems, and each of which in turn tends to advance further that degradation which is implied in process of desertification.

The wide impact of desertification

Vulnerability to desertification and the severity of its impact are partly governed by climate, in that the lower and more uncertain the rainfall, the greater the threat of desertification, but other natural factors also come into play, such as the seasonal occurrence of rainfall, as between hot season and cool season, the structure and texture of the soil, the topography and the types of vegetation to be found. Additionally, liability to desertification increases as pressures on the land increase, as reflected in density of population or livestock, or in the extent to which agriculture is mechanized.

Areas regarded as subject to desertification on these various grounds are shown on the World Map of Desertification. It shows that areas assessed as being at high or very high risk occupy most of the arid and semi-arid regions and extend into adjacent subhumid zones. Neglecting the extreme deserts and the very cold deserts, which are severe and little-used environments unlikely to undergo further significant deterioration, there remains an area of potentially productive but threatened drylands covering 30 million square kilometres, or 19 per cent of the earth's land surface. These occur so widely that at least two thirds of the 150 nations of the world are directly affected. Through its sheer extent, therefore, desertification is shown to be a global problem.

It must also be borne in mind that desertification has an impact far beyond the lands immediately affected. Dust storms can move great distances, and increased flooding may occur far downstream due to overly rapid runoff from lands denuded of trees and plants in catchments undergoing desertification. Nor should desertification be thought of as a process that takes place only on the fringes of remote wastelands, for it has been a major factor in the destruction of human civilizations.

Risk to people, production and environment

If desertification were allowed to develop or proceed further on the geographical scale suggested by the World Map of Desertification, almost the entire population of the earth's drylands could be said to face eventual risk. They contain between 600 and 700 million people, and in terms of broad areas and livelihood systems their numbers are as follows:

TABLE 1
ESTIMATES OF DRYLAND 1/ POPULATIONS
BY REGION 2/ AND LIVELIHOOD GROUP
(in thousands)

Region	Drylands Total Population 3/	Livelihood Populations in Drylands: Urban Based	Agriculture Based	Animal Based
Mediterranean Basin	106 800	42 000 39%	60 000 57%	4 200 4%
Sub-Saharan Africa	75 500	11 700 15%	46 800 62%	17 000 23%
Asia and the Pacific	378 000	106 800 28%	260 400 69%	10 300 3%
Americas	68 100	33 700 50%	29 300 43%	5 100 7%
	628 400	194 200 31%	397 100 63%	37 100 6%

1/ Meigs classification (1953) including extremely arid, arid and semi-arid areas.

2/ Grouping as designated by UNEP Governing Council for regional meetings.

3/ Total world population was estimated to be 3.86 billion in 1974.

The drylands under threat must be seen for what they are, the home of one sixth of the world's population and regions of great agricultural production, especially of meat, cereals, fibres and hides, and of even greater potential for production. The problem of supplying everyone with adequate food shelter and clothing is now recognized as an urgent world problem, one that will increase in difficulty as the world's population continues to expand. Efforts to resolve this problem without the enormous output of the drylands would be tinged with the most sombre prospects. The world simply cannot afford to abandon its drylands to desertification.

The drylands also serve as reserves sheltering an important range of plant life, including the genetic material from which have been developed many of mankind's staple grains - wheat, barley, sorghum and maize. The Green Revolution has focused new attention on the critical importance of this botanical heritage, particularly as a resource which can be used to keep highly cultured strains, such as the so-called "miracle wheat", resistant to destruction by disease. As ecotypal reserves of a variety of interesting and useful natural settings, the drylands constitute a precious human heritage. In recent years, they have come increasingly to serve as areas to which people go - and where they often remain - in quest of health and recreation.

Land and people already affected

But desertification is more than a threat. A great many people live in drylands that are now undergoing desertification, and their livelihoods are already affected. It is difficult to determine how much land is being lost to agriculture at the present time, but there is no question that a great deal of once-productive land is currently being lost to desertification. Widely accepted estimates place the annual loss of arable land alone at between five million and seven million hectares. This would be from all causes - road construction, industry and urban expansion as well as grazing and cultivation. Other estimates are more pessimistic, suggesting that the world will lose close to one-third of its arable lands by the end of the century if losses continue at the present rate. Such losses, of course, are taking place at a time when populations are growing rapidly, with the expectation that the food requirements of the human race will rise by at least one-third, and probably more, by the end of the century. Further, if cultivable land be valued at an average of $1,000 per hectare, then the annual loss would amount to $50 million, a sum far in excess of the predicted costs of the programmes to combat desertification. Of course losses may be in pasture valued at much less than arable land. But as the desert encroaches on pasture on one side, arable land on the other is degraded to pasture, keeping total losses close to the estimate.

Unfortunately some of this land has already deteriorated to the extent that for all practical purposes, rehabilitation is economically impossible.

The numbers of people immediately threatened, their general location and livelihood systems, are as follows:

TABLE 2

ESTIMATES OF POPULATIONS AND LIVELIHOODS RESIDENT IN AREAS RECENTLY UNDERGOING SEVERE DESERTIFICATION 1/
(in thousands)

Region	Total Population	Urban Based	Agriculture Based	Animal Based	Area (km^2)
Mediterranean Basin	9 820	2 995 31%	5 900 60%	925 9%	1 320 000
Sub-Saharan Africa	16 165	3 072 19%	6 014 37%	7 079 44%	6 850 000
Asia and the Pacific	28 482	7 740 27%	14 311 54%	6 431 19%	4 361 000
Americas	24 079	7 683 32%	13 417 56%	2 979 12%	17 545 000
	78 546	21 490 27%	39 642 51%	17 414 22%	30 076 000

1/ As estimated by H. Dregne (includes both severe and very severe categories)

Of these 78 million, about a third may be in a position, because of income or other circumstances, to avoid the worst consequences of desertification. This still leaves about 50 million people who are immediately menaced by malnutrition and disease, the destruction of their livelihoods, the collapse of such social services as health care and education, and by the grim prospect of uprooting themselves from everything familiar and of migrating to other areas usually ill-equipped to receive them.

Urgency of the problem

This review of the problem shows that desertification is more than a global threat to the people of the drylands and to the world community in general; it is an active process already destroying the land and livelihood of tens of millions of people. The need for action to combat desertification is all the more urgent because the process is a dynamic one, self-accelerating as it feeds on itself. With delay, rehabilitation becomes increasingly lengthy and expensive, and degradation may relatively rapidly reach a threshold beyond which it is irreversible in practical and economic terms. Fundamental preventive measures should be introduced as soon as possible in the form of land-use practices which are both socio-economically and environmentally appropriate, and which prevent desertification from making its first encroachments.

II

Processes of Desertification

Water and energy balances

To see precisely what happens when desertification occurs, attention should be focussed on that shallow interface where soil and atmosphere meet, and where a balance must be maintained between incoming and out-going energy and between water received and lost.

When rain falls, some of the water is taken up directly by the plants, some infiltrates into the soil, where it may remain in storage, and the rest evaporates or runs off. Some soil moisture, and that intercepted by the plant, is breathed back into the atmosphere, by the plants in transpiration, and some of the soil moisture may seep into deeper layers to collect in underground reservoirs or aquifers.

The soil-air interface also shares in an energy balance activated by the rays of the sun or through atmospheric heating. Some energy is reflected back into the atmosphere and into space. Some is held by the soil in storage, thereby warming the earth, and it is this energy and that from the sun directly that is used by the plants to carry out the processes of photosynthesis and growth. Some of the plants are eaten by grazers or browsers, and these in turn may be eaten by carnivores, with all animals returning energy and moisture to the atmosphere in respiration. The excreta of animals, their decomposing carcasses and the decomposition of plants supply the soil with nutrients, most densely in the topmost layers and thinning out below. (These relations are illustrated in the following diagrams.)

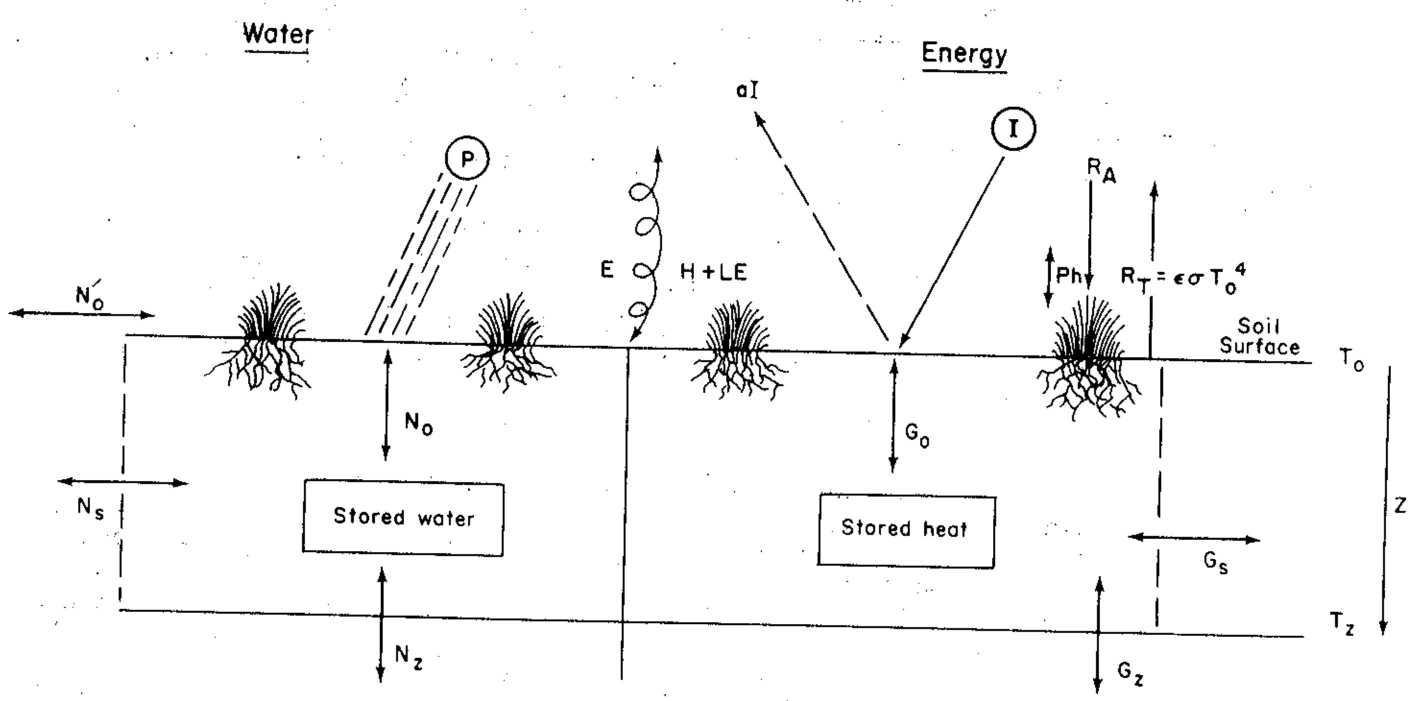
Adaptation to the arid environment

In arid situations the cycling of water and energy takes on special characteristics because of deficient and variable rainfall and abundant solar energy from cloudless skies. Vegetation is generally sparser than in humid areas, provides less cover to the ground surface and returns less organic matter to the topsoil. During occasional intense rainfalls runoff may occur in spate, and in the long intervening dry spells the surface is parched and heated by the powerful sun.

Despite its sparsity however, the dryland vegetation constitutes a fundamental resource which transforms solar energy into food and which also protects and stabilizes the ground surface. It survives by adapting to water deficit in ways which are important because they determine seasonal differences in the usefulness of dryland pastures.

Part of the plant population consists of short-lived ephemerals which germinate and complete their life cycle rapidly after rain, remaining as seed through intervening dry periods. Such plants are commonly fleshy and palatable and are preferred by grazing animals. Other plants, such as perennial grasses, wither and die back to the root stock in dry spells and shoot anew with fresh rains. These plants form more durable pastures and are attractive and palatable for stock when green, and may provide valuable hay,

Figure 1



Water exchanges are on the left, energy on the right. The diagram refers to a partly vegetated surface whose temperature (for radiative emission and convective forcing) is T_o. Most natural surfaces in dry climates have extensive areas of bare soil, as shown.

The water exchanges are forced by precipitation, P, a very intermittent input. The water reaching the surface may percolate, N_o, or run-off at the surface, N_o'. The soil layer, of depth z, stores water - typically of order 10 cm of precipitation when wet. If storage is full, the remaining rainfall may outflow laterally, N_s, or percolate to ground water. With high water tables on sloping sites, N_o', N_s and N_z may all reverse, so that there is run-on. Total water surplus $N = N_o' + N_o + N_z$. If there is no change in storage, P = N + E, where E is the evapotranspiration.

The energy exchanges are forced by global solar radiation, I, direct (shadow-casting) plus diffuse, a fraction (a, the albedo) of which is reflected, aI. The surface temperature is mainly a function of the absorbed solar radiation I(1 - a). There is diffuse infrared radiation received from the atmosphere, R_A, and infrared is emitted from plants and soil, $R_T = \epsilon\sigma T_o^4$, where ε is the emissivity (usually >0.9), σ is the Stéfan-Boltzmann constant, and T_o is surface temperature. $-R_T + R_A$ is the net longwave heating, generally negative. The net radiation is $R = I(1 - a) - R_T + R_A$. A small part of R, G_o, is conducted to the soil, where it may be stored. If level z is the depth at which there is no annual temperature cycle, $G_z = 0$, and G_s is negligible. Hence G_o virtually vanishes over the year. The remaining heat, $R - G_o$, feeds convective fluxes, H of heat, and LE of latent heat. If $T_o < T_A$ (air temperature), H is negative, though small, and LE may also be negative (dew formation). In this case the convective fluxes force the net radiation, rather than the reverse - the typical nocturnal condition. Ph is the net photosynthesis, generally 2 orders of magnitude smaller than R (see component review on ecological change). If there is no change in storage, and no net synthesis, $R = I(1-a) - R_T + R_A - G_o = H + LE$.

Note that a, the albedo, is a function of the state of the vegetation and soil, tending to rise from values near 0.17 in fresh green savanna to ~0.35 in sandy deserts (Oguntoyinbo, 1974). Degradation of vegetation in general raises the albedo, as does drying the surface. Absorbed solar radiation, and hence surface temperature T_o, are functions of a, as are net longwave cooling ($R_A - R_T$), the soil heat flux G_o, the convective fluxes of heat and latent heat, H + LE, and net photosynthesis, Ph. Hence changes in albedo drastically alter the entire energy and water balances.

Increases in soil compaction due to overstocking, use of vehicles, drought contraction or pan formation decrease the infiltration rate, and hence increase N_o' at the expense of N_o, so increasing the chance of sheet erosion and gullying. They also alter the thermal conductivity, and hence G_o. These processes are discussed in the component review on ecological change.

T_o is low by day when the soil is moist, and higher when it is dry - by 20 to 30C in tropical conditions. With moist soil and low surface temperature, R is large, and the Bowen ratio H/LE is very low - of order 0.10. With dry soil and high surface temperature, R is lower, and the Bowen ratio rises to very high values.

but are of little pastoral value when thoroughly dried out. Nevertheless their extensive fine root systems remain to bind the topsoil and contribute importantly to its organic food store. Lastly, there are the longer-lived perennial plants which resist water loss by adaptations such as woody stems and leathery leaves. These naturally include the larger plants such as shrubs and trees. They are often nutritious and provide an important food source to browsing animals during the dry periods, although their adaptations may reduce their palatability and attractiveness for some stock, and they have the additional and essential role of protecting the ground surface and preserving an environment which favours the response of important shorter-lived plants. It is this function that is threatened when desert pastures must support large stock numbers during drought.

Impact of land use on equilibrium on dryland ecosystems

Under natural conditions and through appropriate strategies, the dryland ecosystems maintain a balanced exchange of water and energy, but this equilibrium is readily disturbed by man's use of the land. For example where meagre vegetation is further reduced to expose the ground surface, rain falling directly on the soil may form a thin crust which prevents water from sinking. As the water budget deteriorates in the soil beneath, the level of groundwater in nearby wells may fall. The water lost to the soil store now contributes to over-rapid runoff, and where the surface is loose or disturbed the topmost soil layer, that with the best structure and containing the bulk of plant food, may be washed away, or blown away in dust storms. The denuded soil is increasingly exposed to the direct rays of the sun and its reflectivity may increase, with strong heating at the soil-air interface. All these changes constitute a change towards a more hostile environment for plants, with the result that the vegetation responds less well to rains and produces less nourishment, and many plants will tend to die off at an increasingly early stage of drought. Such changes constitute desertification.

Drought as an engine of desertification

In its initial stages, desertification may merely involve a shift to a more desert-like and less productive ecosystem, with water and energy balances less favourable to plant growth than before. But land use in arid regions poses problems which continually menace the prevailing equilibrium. This is primarily because of fluctuations in rainfall between drought and abundance which, not yet predictable, are difficult for the land user to respond to effectively. For example, in dryland pastoral economies, large numbers of stock tend to build up during runs of good years, far too many to be supported through the inevitably ensuing drought. There is a natural reluctance to cut back on stock numbers in the first dry year, and a tendency to hang on until drought is seen to be established. But by this time dryland pastures are probably being ravaged by overgrazing beyond hope of complete regeneration, while the last shreds of plant cover are being trampled to death and the soil pulverized and rendered vulnerable to wind erosion in mini-deserts around watering points or wherever stock congregate. By this time too, prices for surplus stock will probably have shrunk and destocking through sale of surplus numbers will be opposed by economic forces. The unwanted solution, death of livestock, may become inevitable. Thus the delayed response of the land user through cycles of good and bad rainfall may convert periodic drought into a true engine of long-term desertification.

The main processes and stages of desertification can be summarized as follows. Initially, and especially in dry periods, there is a deterioration in the composition of desert pastures subject to excessive grazing, particularly a reduction in the proportion of edible perennial plants and an increase in the proportion of inedible invaders usually with less resistance to drought. The thinning and death of vegetation in dry seasons increases the extent of bare ground, and this is followed in turn by a deterioration in the soil-surface conditions vital to plant growth, particularly an impoverishment of plant-water relations. The response of ephemerals to rain suffers accordingly. With consequent increase in runoff, sheet and gully erosion set in on sloping ground, and the topsoil and its organic store are lost. All these changes mean a decrease in productivity, palatability and durability of the native pastures. With continuing erosion, formerly productive lands may be lost through soil stripping and gully extension, or through siltation in valley bottoms. These changes are even more drastic where devegetation occurs in strategic areas, as on watershed uplands, and the processes are naturally advanced where soils are exposed and disturbed in dryland cultivation.

Wind and water erosion work together, as stripped surfaces and redeposited silt are increasingly liable to wind transport. The finer soil particles, including organic plant food, are blown away as dust, and the coarser fragments are drifted along as sand, which may accumulate into dunes, locally helped where shrubs trap the moving sand. Not only are shifting sands sterile and difficult to colonize by plants, but as advancing dunes they may overrun and destroy valuable nearby cropland.

As soils dry out with desertification, soluble salts are no longer so readily leached away and may concentrate near the surface through evaporation. Salinization and alkalinization of soils may eventually exclude all but worthless vegetation and advance the process of erosion by causing the soil to crack and crumble. This desertification phenomenon is naturally most developed, and most costly in its consequences, on poorly drained irrigated lands, where salts introduced by irrigation cannot be leached from the soils.

Desertification feeds on itself

Desertification tends to be self-reinforcing, to feed on itself, as soils denuded of plant cover are stripped to impervious, sterile horizons or powdered to fine dust. Biological degradation is followed by accelerated physical erosion by wind and water. Comparatively easy to deal with in its initial stages, desertification becomes increasingly difficult to treat as the process advances, with the costs of reclamation rising exponentially, until the stark equilibrium of extreme desert is reached and the land has for all practical purposes passed beyond hope of rehabilitation.

The advance of desertification

The spatial dimension of such changes can be seen in a progressive extension of desert lands, as subhumid areas take on a semi-arid character and semi-arid ecosystems deteriorate to arid status. In considering the area under threat, we must therefore include the subhumid margins of the deserts, as well as the semi-arid and arid regions. Only the hyperarid areas of extreme desert may be considered beyond care; elsewhere, combative measures are called for to halt and reverse the processes of desertification, and conservational management of the land to maintain productivity.

The advance of desertification should only rarely be thought of in such theatrical images as dunes advancing over productive soil. It is usually a more insidious and irregular progress, and for that reason more difficult to come to grips with. It seems to attack on all sides, with areas of degraded vegetation or denuded soil developing here and there, far in advance of any nebulous 'front line'. This is because arid lands are patchworks of small environments of differing vulnerability to desertification as determined by local topography, soil and microclimate, and it is the more vulnerable pieces that first succumb. As desertification proceeds, the denuded patches may link up and the desert extends, but more like a skin disease than as a wave-like front.

III

The Causes of Desertification

Desertification is a problem of interaction between a difficult and unreliable dryland environment and the impact of man's use and occupation of it in his efforts to make a living. Some understanding of the controls of dryland climates helps towards an appreciation of climatic factors in desertification.

The desert belts

Although their boundaries have shifted over time, deserts must always have characterized the earth's subtropical zones. Global patterns of air circulation dictate that the subtropics are regions of subsiding air. When air subsides it warms up and its capacity to hold moisture increases, so inhibiting the formation of rain. This accounts for a prevalence of dry climates between latitudes 15 and 25 degrees north and south of the equator. However the dry climates are extended and their patterns complicated by additional factors, such as distance from the rain-supplying oceans or mountain barriers which spill air downward on their lee sides, creating rain shadows.

The play of these factors is evident in the distribution of deserts as shown on the World Desertification Map. There are five main desert belts: (1) the Sonoran Desert of northwestern Mexico and its continuation in the desert basins of the southwestern United States; (2) the Atacama desert, a thin coastal strip running west of the Andes from southern Ecuador to central Chile, whence dry climates extend eastwards into Patagonia; (3) a vast belt running from the Atlantic Ocean to China and including the Sahara, the Arabian desert, the deserts of Iran and the USSR, the Rajasthan desert of Pakistan and India, and the Takla-Makan and Gobi deserts in China and Mongolia, (4) the Kalahari and its surrounding deserts in southern Africa, (5) most of the continent of Australia. Outside these principal desert regions there are isolated patches of very dry lands in many parts of the world, such as the Cuajira Peninsula in Colombia, southwestern Madagascar and part of northeastern Brazil. Within the desert belts there are many climatic contrasts resulting from differences in temperature, from season when rain falls (if any) and from degree of aridity. At one extreme are the intensely cold deserts such as those of Siberia or the Tibetan plateau, where occupation is precluded by low temperatures and where the environmental degradation is accordingly small. On the other are hot deserts such as the inner Sahara, where plant growth and land use are absent because of hyperaridity. These extreme deserts do not concern us - they are not subject to further desertification - and they remain unclassified, in neutral grey on the World Desertification Map.

More extensive than the extreme deserts are the world's arid lands, those with up to 200 mm of rain falling annually in definite seasons, with sufficient vegetation to support extensive pastoralism, although necessarily on a nomadic basis in the drier parts. Outside these are the semiarid lands, with as much as 600 mm of rain, depending on temperature and season, where cultivation of drought-resistant crops is generally possible with the use of moisture-conserving practices. Finally, on the greener margins of the dryland belts are the drier parts of the subhumid zones, where land use and settlement become more intensive, but which must be considered as ultimately threatened if desert conditions are permitted to extend. Altogether the usable drylands occupy 45.6 million square kilometres, or 30 per cent of the world's land area. It is here, where desertification is taking place, that its causes must be sought.

Shifting limits of dryland climates

Despite figures on areas, it is evident that the boundaries of the dryland belts are not fixed eternally on the map. Much of the Sahel for example consists of old sand ridges, now quite fossil under cover of vegetation, which indicate a former extension southwards of Saharan climates and moving sands, some 500 km beyond their present limit, about 20,000 years ago. In the same region, Lake Chad was much more extensive 10,000 years ago, indicating semiarid or subhumid conditions in what is now arid. These climatic changes have been shown to be part of global shifts of the climate belts, relating to changes in the earth's atmospheric circulation. They are linked to the great changes of the Ice Age and of subsequent millenia, during which temperature shifts are known to have been accompanied by changes in rainfall patterns.

Such changes, with durations of several centuries, have continued and have directly affected the possibilities of man's occupance and use of the drylands in the past. For instance much of the presently hyperarid Sahara was open to pastoralists and hunters under semiarid conditions about 8,000 years ago. Unfortunately the definite records of later changes are mainly from higher latitudes and give temperatures rather than rainfall; from 1600 to 1850 for example those latitudes in the northern hemisphere underwent a cooling known as 'The Little Ice Age', then followed a warming which continued into the 1940's, since when temperatures have again declined. It is being suggested that this cooling may mark the resumption of another 'Little Ice Age' in the north.

Climatic change as a cause of desertification

From this arises the question: "Do recent droughts in the Sahel and elsewhere form part of a change to a more arid climate, expressed as an equatorward shift in the limit of the dryland belt?" Those replying yes would note that over the same period deficiency of rainfall in the drylands was compensated by greater rainfall in the wet equatorial belt. The consequences would be that the dryland inhabitants would face a long period of increased aridity in their part of the world following a century or more of relatively favourable climate. It would imply that man might be a victim of recently accelerated desertification rather than its active agent. Clearly the answer to the question has great significance for strategies to combat desertification.

Unfortunately the question cannot be answered with confidence because the events are too recent to serve as a basis for prediction, particularly with our present inadequate understanding of the global mechanisms of atmospheric circulation. The latest Sahelian drought was far from unprecedented, even in the relatively short historical record, and it cannot alone form evidence of a change of climate. At the same time, it would be unwise to rule out the possibility of change, and the consequences of change should be looked at, particularly in areas of strong rainfall gradient such as the Sahel. It would certainly mean that droughts would become more frequent and more severe, and that plans for land management should take into account the possibility of an even more rigorous climate in the future.

Man made climatic change

Linked with this postulated swing to increased aridity is the suggestion that man himself may have contributed to such changes through modifications in the energy exchange that have followed man's degradation of desert ecosystems. These modifications include an increase of dust in the upper atmosphere, noted particularly in association with the recent African and Asian droughts, and the increased reflection of solar energy from denuded dryland surfaces. It has been argued that these factors have contributed to a lowering of temperatures above dryland surfaces and diminished convection in the atmosphere, with an ensuing reduction in the frequency of rainstorms.

At this time, however, the direction in which these factors move remains in doubt. It may be realistic to grant that man has accentuated climatic stresses but it is most unlikely that the factors named have been prime causes of any general deterioration of dryland climates, which are, after all expressions of fundamental patterns in the circulation of the atmosphere. It is also probable that the direct physical consequences of the man-made changes, such as the adverse effects of surface denudation on the local water balance, are many times more important than any indirect climatic effects.

Climatic fluctuation contribute to desertification

Climatic boundaries in the drylands are also subject to shorter-term shifts, corresponding to sequences of lean years and fat years. In general, the drier the climate, the greater the rainfall variability and the higher the drought risk. Such fluctuations are expressed in expansions and contractions of the dryland belts, such that a semiarid region may experience arid conditions at one time and subhumid conditions at another.

These fluctuations, although not so regular as to be predictable, may nevertheless be classed as short-period, say two to four years, which merely introduce periodic stress into livelihood systems, and those of greater amplitude and duration which lead to significant changes in the patterns and structure of land use, such as extensions of cultivation or large build-ups in stock numbers. These changes can result in a potential imbalance which may not be promptly adjusted when drought inevitably follows. It is at such times, when dryland ecosystems are stretched to the limit of their resilience by water deficiency, that the pressure of unbalanced land use can be disastrous. Recovery from such degradation will be slow. If land use pressures conti ue unabated recovery may be partial only, to a lower plane of productivity than formerly. Desertification will then have occurred.

Fragility of dryland ecosystems

Desertification may proceed relatively rapidly in dryland ecosystems because of their fragility under land-use pressure. They generally support only scanty amounts of plant and animal life, and because life is thinly spread, the soils are poor in organic nutrients, usually found only in the thin topmost layers. Thinly buffered by a skimpy plant cover, the soil is exposed to erosion which removes nutrients and results in structural deterioration. Lack of leaching and strong evaporation leave unwanted salts on the surface.

All this creates ecosystems delicately balanced on the furthest edge of biological possibility, particularly during drought. Their necessary adaptation to water stress restricts dryland ecosystems to a limited range of response and hampers their flexibility. Life forms are limited in variety and highly specialized, and when one species is eliminated there may be nothing to replace it. Such systems have little slack as it were, and their recuperative processes are slow. They are especially vulnerable to the impact of land use.

Misuse of drylands

Any use of drylands that does not take account of this fragility and of their extreme variability in biological production will constitute misuse. This variability demands a flexibility and promptness to react which desert livelihood systems have rarely shown, a response which is, indeed, very difficult to carry out in the absence of long-range weather forecasting.

The situation is complicated by overoptimistic assessments, often made on the basis of remembered best years, of the potential of the land for sustained production. Excess optimism often results from pressures to which arid-land agriculturalists are increasingly subjected - from population growth, from distant commercial markets, from their own rising expectations.

Frequently, too, there is a failure to appreciate the relation between these particular environments and their use. Herdsmen, for example, tend to see their ultimate resource, their wealth, in their breeding flocks or herds rather than in the land and vegetation that support them.

Pastoralists often herd several kinds of animals, each capable of profiting from different portions of the ecosystem, just as dryland cultivators have tended to plant a mixed crop. Out of the push towards maximum output and toward the environmental limits of land use, the current trend is toward specialization, which fails to spread the risk and lessens flexibility. This is particularly so under the impact of commercial ranching and farming. Flexibility may also be hindered by inequitable systems of land ownership and land tenure.

Techniques such as deep ploughing or clean tilling have on occasion been introduced into dryland agriculture even though they are unsuitable there. Projects have sometimes been undertaken without full regard for the tenuous equilibrium of these ecosystems. For instance, deep tube wells introduced into pastoral areas have indeed improved the availability of water but at the same time have had the effect of increasing herd size while decreasing herd mobility, leading to local overgrazing and excessive trampling of the soil. Technological changes can give rise to desertification through increased, even excessive demands on limited natural resources.

The misuse of arid lands is by no means restricted to inappropriate agricultural practices. Modern man is threading the arid lands with roads and highways; he is exploring them for mineral resources, opening mines, sinking oil wells, constructing pipelines and canals, establishing factories, and building cities in them. Increasingly, he is intruding into arid lands for purposes of health and recreation. These activities are seldom undertaken with full understanding of or proper regard for the delicate natural balances that prevail there. Many such activities have been made possible by advanced technology, but it is this same ever-growing technological capacity that so enhances man's ability to disrupt and damage a sensitive environment.

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All such activities must take full account of the fact that the drylands reach to the edge of biological possibility. Generally impoverished soils, scanty amounts of life and tenuous biological linkages among the life forms that do exist there make the drylands critical areas, their condition becoming ever more critical as aridity increases. In such situations, very small changes can trigger profound effects. Where the equilibrium is delicate, even a small change in one component will radiate effects through the entire ecosystem. Drylands are extremely sensitive to tiny changes in their water and energy balances. Changes brought on by seemingly minor events can follow with startling rapidity, sometimes sufficient to throw the system beyond the critical threshold whence recovery will not naturally occur.

It might be objected that the drylands, with their highly variable rainfall and periodic drought, are continually subjected to extreme conditions, and the question arises, how do their life forms persist at all? It has been shown how plant life in arid lands is naturally adapted to such circumstances, Animals in arid lands are characterized by similar adaptations and often by great mobility. When rain returns after a drought, the water store is replenished in the soil, the vegetation recovers and the animals wander back. The extent and rate of restoration are a measure of the resilience of the ecosystems. All drylands exhibit ecosystems with natural resilience, although the process of natural restoration is sometimes very slow. If left alone, they will almost always return to what they were.

Full restoration will not take place if an area is undergoing climatic change in the direction of greater aridity. But climatic change takes place at a tempo which allows time for human adaptation.

Desertification: a product of the interaction between man and a difficult environment

More commonly, failure in resilience arises from severe disturbance and such disturbances, in the present world, are almost always the work of man. Human activities may have less disastrous impact in more flexible environments, where a greater richness of land and life forms aids the process of restoration. Lands on the margin of life lack these resources. Disturbances there can easily become permanently destructive, as evidenced by desertification.

If man is the chief instrument of desertification, the process should not be viewed exclusively from the human side. Desertification results from the interaction between man and a difficult and changing environment. It occurs when man penetrates such environments and acts there without an understanding of or proper regard for their sensitivities and limitations.

IV

Desertification in Action

Desertification and livelihood systems

The interaction between man and a difficult environment - since that is the main engine of desertification - can well be examined in terms of what man does in the drylands, how he wrests a living from this environment, as difficult as it is.

Dryland agriculture takes three main forms; pastoralism or the herding of livestock, rain-fed agriculture, and irrigation agriculture. All these systems have evolved strategies and traditional skills to cope with the stresses and risks imposed by dryland environments. Such tested practices should not be lightly dismissed; indeed, they should be regarded as a basis for further development.

Yet it cannot be said that any such practices have been so self-regulating or so far-seeing that they have incurred no cost to the environment. Desertification has accompanied all of them although its effects may have been less destructive in the past. The accelerated desertification of recent years may in part be attributed to breakdowns in traditional practices. The old ways have come under intense pressures which have eroded ancient social, economic and political constraints. Such pressures have come from population growth, the integration of the drylands into money economies, aspirations toward higher standards of living, the introduction of technological innovations and the incorporation of dryland agriculture into often remote commercial systems, into marketing systems where prices fluctuate.

Dryland pastoral systems

General aspects

The extensive pastoral systems characteristic of the drylands use grazing or browsing animals to harvest a thin crop of natural vegetation.

In semi-arid lands, stock raising is increasingly integrated with crop production. In arid regions, beyond the reach of the farm, pastoralism is dominant, and here the herdsman is subject to the extremes of climatic hazard.

Herdsmen have found many ways of coping with the climatic stress that typifies arid zones. Ordinarily, they spread their stock thinly over large areas so that grazing pressure is lightened and they can take advantage of the patchwork ecosystems of arid lands. They are highly mobile, often traversing great distances to reach seasonal pastures.

They usually employ some measures to modify the ecosystems in which they function. They will limit the size of their herds, if necessary by selling off surplus animals. They will exercise some control of pastures by deferred or rotational grazing or by spelling certain rangelands to allow them to accumulate moisture over several years. They will develop additional watering points, extending the area and duration of grazing and diluting the pressure on older pastures. They sometimes burn pastures to facilitate the growth of more palatable plants. Sometimes, too, they will provide supplementary feed by cutting hay or growing forage crops under irrigation.

Some herdsmen have access to alternative sources of income. They might engage in hunting and gathering, or perhaps commerce, a natural adjunct to their mobility. They sometimes develop handicraft industries.

Pastoral systems can range from traditional subsistence systems, often nomadic, through more sedentary systems closely linked with cropping, to the great commercial ranches which mainly serve as exporters from the arid zones. All tend to have links with the outside where the chief markets are to be found - for hides, wool and stock on the hoof. In the more commercial pastoral systems, stock will be bred in the arid zones and fattened in areas closer to the market. As breeding areas, arid zones have certain advantages, such as freedom from disease, long outdoor range periods and high protein levels in pastures.

For all its hard-won skills, pastoralism frequently betrays failures of perspective. Identification of the breeding stock, rather than the land and its vegetation, as the ultimate resource leads to a poor understanding of the ecology of the plant communities on which the stock feed. Comparatively little attention may be paid to the performance of pastures under stress, to the requirements for successful germination or to the impact of selective grazing on the whole plant community.

Nor do pastoralists always appreciate the difference between average stocking rates and what happens where animals cluster together, as around watering points or settlements. Concentrated grazing and excessive trampling will focus degradation on such spots.

Pastoralist systems are generally afflicted with what might be called a time-lag problem. Increased stock numbers built up in favourable years persist into drought, and conversely, herds reduced by dry years will confront the return of better grazing with numbers too scanty to take full advantage of it. The kind of flexibility that would make a fully opportunistic use of the land is difficult to introduce into stable pastoral systems.

Such misapprehensions and difficulties mean that pastoral lands exhibit a full range of desertification, advanced where pressures on the land are concentrated, less in the more remote and least attractive sections.

When deterioration comes to grazing land, it is particularly important to observe its first stages in vegetation, not only because plants are the basic grazing resource but also because of the part they play in the stability of dryland ecosystem.

First to be consumed are the more desirable plant species leaving the terrain to less desirable invaders. During drought stress when they constitute the only feed, valuable, soil-holding perennials can be grazed to extinction. Invasions by xerophytes are a sign of increasing salinization. The exposure of ever more bare ground diminishes the response of green feed following the rain and hinders the return of desired perennials. Stripped earth becomes particularly noticeable around concentration points, such as watering places, where trampling is severe.

Nomadic pastoralism

Stock-herding nomads have found ways of using land too arid for any other agricultural purpose. With a diet obtained from their herds and supplemented by food gathering, wandering pastoralists have achieved standards of health and nutrition often superior to their more sedentary neighbours.

It is, of course, mobility that provides the nomad with his principal weapon against a harsh environment. His wanderings may be continuous, or he may move back and forth between fixed seasonal pastures. Flocks and herds are generally owned by families, but other resources - pasture, watering places, fuel - are often communal and their use regulated by custom.

Almost all nomadic pastoralists have mutually beneficial relationships with the farmers on their periphery. Such links may include nomadic ownership of cropland, provision of seasonal labour to oasis settlements and the right to graze stubble in exchange for the manure naturally dropped by grazing animals.

If the resiliency of nomadic pastoralism resides principally in mobility, which spreads pressure on the land and dilutes risk, the system also contains other important adjustments. Nomads often herd a variety of animals, each species capable of exploiting a different portion of these mixed environments. They may do some rain-fed cropping on the edge of the migratory range. As stated, they may supplement their diet by hunting and gathering, and they may have beneficial relations with adjacent farmers. As an adjunct to mobility, they may play a role in transportation in desert areas and its associated commerce. They may earn income through handicrafts. Finally, some of their numbers may emigrate to outside employment, whence they remit funds home.

Yet for all its resilience, pastoral nomadism has not avoided all damage to its environment. If its impact has been less in the past, there is still evidence, as in the Bible and elsewhere, that damage has occurred in ancient as well as modern times.

Increasingly over the past fifty to one hundred years, pastoral nomadism has found itself at bay. The political status of the nomads had declined, and with it, their control of grazing rights, their relations vis-à-vis adjacent crop-based systems, and their role in desert transport and commerce. Their essential mobility has come into disfavour for political and administrative reasons, and has proved to be an obstacle in providing them with education, health care and other essential social services.

In addition, imbalances have arisen in systems of pastoral nomadism which have heightened their potential for desertification. Among nomads, too, modern health care has reduced mortality and given rise to population growth even if at a lesser rate than among their neighbours. Population growth has been a factor, together with improved veterinary care, leading to an explosion in livestock numbers. Expansion of the systems, together with breakdowns in traditional authority, have affected rational management and make improvements difficult within the existing structure. Traditional subsistence activities have increasingly fallen into a neglect hastened by the use of money. Sedentarization, whether voluntary or enforced, has resulted in severe degradation around permanent settlements where former nomads continue to herd livestock. Technology has been introduced without concern for all factors in the environment. The use of off-the-road vehicles for hunting or fuel gathering has been particularly destructive. The provision of large central watering points, out of harmony with traditional migration patterns, have led to unusual concentrations of stock and extreme local degradation. Grazing ranges have shrunk because of invasion by crop-based systems or political restrictions on the movements of animals.

That nomadic pastoralism is in trouble is evident in increasing desertification associated with such systems. Pastures have widely deteriorated, showing increased surface instability especially in their more vulnerable elements, such as once-vegetated sand dunes. Advanced physical degradation around watering points, stalls and settlements and along paths of stock movement is marked by accelerated wind erosion and local dune encroachment. Even though limits are imposed more by lack of fodder than lack of water, an over-exploitation of groundwater reserves has lowered watertables and affected water quality. Pastures show themselves to be increasingly vulnerable to drought with all that this implies - destruction of livestock, enforced abandonment of grazing lands, deterioration in the diet and health of the people involved. Increasingly, former nomads are migrating out of the rangelands, and there is some suspicion that the migrants are largely the young and the more innovative.

Traditional more sedentary pastoral systems

Sedentary pastoralism is usually supported by rain-fed cropping. Evidence of stock losses during the recent drought in Somalia suggests that these systems are less resilient than nomadic pastoralism.

Because it is sedentary, this style of pastoralism usually encourages localized degradation wherever the livestock tend to concentrate. Desertification also arises from the cropping elements in these systems, usually practiced on the most marginal farm land, where the herdsman-farmer may constitute an impoverished part of a commercial system. The farming, a secondary activity, may suffer from a shortage of labour, sometimes due to out-migration.

Commercial ranching systems

Commercial ranching tends to specialize in one kind of animal or breed, selected usually for marketing reasons rather than because the animal is physiologically efficient in converting the local dryland vegetation into need.

Such systems compensate for environmental risk and low productivity by adopting very low stocking rates (lower than those of nomadic pastoralists, for example). They are rarely sited in the most arid, remote or infertile regions. Yet since land is a low-cost item, commercial ranches tend to be large units put together out of the vagaries of competitive stress.

Such ranches tend to minimize labour costs, especially in high-wage economies. Stock is set to graze in large, fenced enclosures and controlled with a minimum of handling, although winter stalling and feeding may be required in temperate to cold drylands. The comparatively small labour force is highly mobile, whether on horseback, driving off-the-road vehicles or piloting aircraft. For special tasks, such as such as fencing or shearing, or at times of seasonal demand, contract labour will often be employed.

These systems have inherent weaknesses, one of them stemming from animal specialization, which increases environmental risk and commercial vulnerability and results in inefficient use of the pasture complex.

Laxity in grazing control is often combined in commercial ranching with ignorance of the impact of grazing on pastures. Despite the expansion of extension services, comparatively little attention may be paid to the relative performance of pasture species under grazing stress and to the requirements of soil and plant life as they relate to grazing management - what is needed, for example, for the successful germination of desirable perennials. Since land and vegetation are the low-cost elements, they are not always viewed as the ultimate resource base, the livestock itself being so regarded.

Commercial ranching is dependent on external markets whose forces may or may not be in harmony with wise stocking policies and practices as called for by the local environment. The tendency to maximize profits can readily lead to poor ecological management and overstocking within short-term perspectives. Such ranching is often controlled by corporate managers or absentee landlords who tend to be less immediately concerned with the state of the range.

These systems enhance their vulnerability by ignoring subsistance elements. Food and supplies are purchased at the market.

The growth of large units and the labour economies imposed on them lead to a progressive decline in the populations they support with consequent out-migration, particularly of the young and landless. The populations of ranching areas are generally on the decrease, with an accompanying decline in secondary service centres.

Capitalization and technical improvements tend to buffer commercial ranching against the immediate consequences of overgrazing, and high prices for its products will yield cash returns which may further delay a response. Since a determination of range trends is difficult in any case, delay can lead to irreversible deterioration of pasture long before economic collapse occurs or even before the situation is truly appreciated.

The weaknesses of commercial ranching have their inevitable sequence in desertification. Poor grazing control results in deterioration of pastures which can be severe at the most vulnerable spots and around places where livestock congregate and further the process by trampling the soil.

Unlike more traditional systems, commercial ranching makes large-scale use of heavy machinery for construction and road building. Such machinery disturbs the environment, producing localized degradation.

The greater capacity for ecological manipulation in these technically advanced systems may have drastic feedback consequences. For example, the control of brush fires has resulted in invasions by undesirable scrub in such places as southern Australia and the south-western United States.

Commercial ranching tends, as time passes, to deplete the soil of nutrients and organic matter. These elements can conveniently be returned to the soil wherever winter stall feeding is practised. Even if it might seem economically impractical to spread barn and feedlot manure on rangelands, such a practice may be an essential health measure if cities are nearby or water supplies threatened with contamination.

Depopulation might be listed as a desertification phenomenon characteristic of commercial ranching, even though it may be caused by market forces working independently from land degradation.

Rainfed cropping systems

Rainfed agricultural systems, referred to in general as "dry farming", are typical of the semi-arid lands, which include those regions in which agriculture was first practised by man.

Rainfall in such regions, although generally more abundant than in lands dominated by pastoralism, is still limited. Farming is possible there only through the adoption of special techniques whose primary objective is the collection, storage, protection and utilization of every drop of water. Drought-resistant crops are selected for planting, notably the cereals - wheat, barley, rye, sorghum - so typical of dry farming.

Special techniques and careful crop selection have carried dry farming to the climatic limits set by rainfall - its amount, seasonal incidence and variability - and by the length of the growing season, as fixed by the duration of rainfall and, in high latitudes, by light and temperature.

This push toward the climatic limit has carried rainfed agriculture deep into areas that were once exclusively pastoral, displacing the herdsmen and pushing them ever further into drier lands. Although the productivity of dry farming is low when compared with irrigated agriculture, its returns are usually much higher than pastoral yields.

Dry farming compensates for climatic risks by producing crops of high quality, hard wheats for instance, which can command good prices. The semi-arid regions are free from disease, notably rust. They provide extensive stretches of sparsely settled land suitable for tillage by large-scale mechanized agriculture. The cereal crops produced are easily handled, transported and stored.

Clearing for agriculture involves a much more drastic transformation of natural ecosystems than does pastoralism. Dry farming exposes and disturbs the soil, increasing the risk of erosion. Some dry farming techniques enhance this risk.

Shallow ploughing, for example, or loosening of the soil in the preparation of seedbeds can set the stage for erosion, just as does tillage of the subsoil to return organic matter to depth and to facilitate root penetration and moisture availability in soils that tend to form lime or clay pans. Bare-fallowing is also a common practice. Here the land is left stripped of vegetation to allow the infiltration of an additional season's rainfall and to minimize losses through transpiration. Such fields are also fine-tilled to prevent capillary loss of moisture and to promote the aerobic nitrification of organic compounds.

Many of these systems spread across open plains which are already subject to wind erosion. The wind picks up the silty soils, creating a dust nuisance and sometimes dust storms. Sand drift and dune formation are common on the sandier alluvial soils near old river channels. All such effects are enhanced by the removal of trees and high-standing vegetation over extensive areas.

Dry farming tends to specialize in both crops and techniques, and it does so at the expense of mixed farming, which would include crop rotations involving legumes and the raising of animals. This results in an undue removal of organic material, transported away in the off-farm sale of grain and in the burning of straw and litter after harvesting with combines. Decades of producing one specialized crop have resulted in the depletion and breakdown of many semi-arid soils that once possessed excellent structure and fertility. When this happens, yields decline and erosion increases especially on finer textured soils such as those lying on wind-blown parent material (loess).

These systems support much denser and more settled populations than do pastoral systems. Man and his works therefore exert a much stronger impact in them. Many such systems have been worked for millenia and provide a history of land use and of land deterioration extending over thousands of years.

Regional Problems in rainfed cropping

Rainfed cropping systems comprise several types as determined by climate and other environmental conditions. Each is marked by its characteristic crops, technology and cultural setting. Each is vulnerable to desertification, which takes on distinctive forms in each setting and calls on distinctive measures to combat it.

The Mediterranean region

The Mediterranean is a semi-arid region with winter cyclonic rainfall and warm to subtropical temperature régimes. It is a hilly region with degradable limestone soils in which cultivation has been extended into areas of very low rainfall (locally less than 200mm annually). Winter cereals may alternate with summer crops. Farming is often combined with animal husbandry, especially of sheep and goats. Tree farming is particularly important. Connexions between rainfed and irrigated cropping are particularly close in the Mediterranean, with the former also deeply involved in water management, as in the terracing of slopes whose upkeep requires not only much labour but social stability as well.

The Mediterranean has a long history of land use by fairly dense populations. Its history is also one of cities, many of them large and important. Man has thus had a profound impact on the Mediterranean ecosystems, which provide, in fact, the longest historical record of desertification. Land degradation appears to have been associated with the spread of sedentary agriculture and its related settlements. In some parts of the Mediterranean, desertification has reached advanced stages.

It appears there in the deforestation of once-wooded uplands. Forests have given way to dwarf, leather-leaved dryland shrubs, or to bare earth, with soil sometimes stripped completely from slopes to uncover calcareous crusts or naked rock.

This stripping of upslope watersheds has severely damaged downslope water régimes. In many places, runoff has become ephemeral and spasmodic, sometimes giving rise to catastrophic flooding in the lowlands and to increased deposition of silt in valley bottoms. Siltation, which was a problem in ancient days (as among the Nabateans of the Negev) continues to pose a major threat, as for example to the useful life of large reservoirs in modern water-control schemes.

The region shows broad deterioration in groundwater reserves accompanied by a lowering of groundwater tables and a decline in water quality. Some areas, such as the coastal plain of Israel, have suffered invasions of seawater.

Cultivated footslopes often show marked gullying, particularly where cultivation has been unwisely extended over the past 50 years because of rising population pressure. The loss of soil has been considerable and with it, the loss of potentially cultivable land.

Despite growing populations, labour shortages have developed as a result of heavy migration to cities and settlements, and water management has been affected. Terraces and qanat systems have suffered from lack of proper maintenance.

The removal of trees and shrubs has accelerated wind erosion of light soils, stripping them of nutrients. In many places, as in southern Tunisia, wind erosion has led to the formation of coppice dunes and made the land unsuitable for cultivation.

Some lowlands soils, particularly in basins of interior drainage, have suffered from the spread of salinization.

Mediterranean-type regions

Other areas with a Mediterranean-type semi-arid climate are distributed around the world. Such regions include, for example, semi-arid portions of southern Australia, southwestern Cape Province in South Africa and the Colombia Plateau in the northwest of the United States.

These are typically regions of highly mechanized agriculture producing cereals for export. Their devotion to monoculture has resulted in a lack of leguminous rotation crops and a virtual absence of animal husbandry, thus limiting the return of organic matter to the soil. This, associated with the export of the crop and the removal or burning of the vegetable litter produced by mechanical harvesting, has depleted the soil of mineral and organic nutrients. Light-textured gray-brown or black-earth soils, depleted of nutrients, have increasingly been subject to wind erosion. Deterioration following continuous cropping was reflected in the inter-war years by falling yields.

Depending on the setting, desertification in various forms has made its appearance in all Mediterranean-type regions.

Extensive gullying of slopes, as in Cape Province and the Colombia Plateau, has become a particular handicap to mechanized agriculture.

Tilled but unvegetated surfaces that occur where dead-fallowing is practised have been extensively subject to general sheet erosion by water.

The almost complete clearance of vegetation associated with large-scale mechanized agriculture has resulted in wind erosion of light soils and once-stabilized dunes, causing sand drift and the mobilization of fresh dunes as in, for example, the Mallee region of South Australia.

The clearance of deep-rooted shrubs and their substitution by crops or fallow has reduced transpiration in favour of evaporation and increased runoff from cleared slopes. This has altered the water balance in valley soils and brought on salinization. Such effects are particularly noticeable in areas of sluggish natural drainage, as in northern Victoria and southwestern Western Australia where saline groundwater has come to the surface with increased effluent seepage from lower slopes.

Subtropical to warm-temperate regions

In subtropical to warm-temperate regions of dry farming, transitional rainfall régimes are characterized by winter and summer rainfall. Under such conditions, winter cereals can be combined with a variety of spring-sown crops, such as cotton in the southwest of the United States or sugarbeet and sunflower between the Ukraine and the Caspian Sea, resulting in a favourable mixed agriculture with a more continuous cover. Such farming systems are generally young, having been established over the past two centuries in such rich soils as the black earths of the southern USSR.

In these systems, soil depletion with falling yields has only recently become evident. The application of mineral fertilizers and the replacement of organic losses are increasingly required.

The plains topography of these regions, characterized by an absence of trees, has promoted desertification through wind erosion.

Erosion, together with reduced yields, has also been encouraged by a moderate salinization and alkanization, arising from limited leaching, that have affected the drier parts of these regions.

Cool temperature semi-arid regions

Cool-temperature semi-arid regions typically have rain in spring and early summer. They include, for example, a broad strip from southern Siberia into Manchuria and the dry prairies of Canada, where exposed surfaces, severe winter temperatures and sunlight limitations result in a short growing season restricted to spring cereals and great difficulty in introducing cover crops other than grass. Under such conditions, animal husbandry is also very difficult.

Wind erosion is the characteristic form of desertification in such regions of open plains. Most affected during the dry winters or late summer are the light-textured soils often lying on a carbonate or hardpan layer.

Tropical semi-arid summer monsoon regions

Tropical semi-arid summer monsoon regions are typified by the Sudanian belt, with its 300mm to 600mm annual rainfall, to the south of the African Sahel. They also include the margin of the Rajasthan Desert in northwest India and parts of northeastern Brazil. They tend to grade into subhumid savannas, lands which must also be considered at risk.

In these regions, open savanna woodland is cleared, usually by burning to provide a seedbed, although clearance is not complete and many large trees may be left standing. The pattern is generally that of shifting agriculture. Four to five years of continuous cropping are followed by abandonment, when successional regrowth may be harvested, gum arabic for example, or grazed by cattle, with the growth of grass encouraged by burning.

This is mainly subsistence farming by peasants, who grow grain crops such as sorghum or millet. The warm climate may allow a second crop, such as groundnuts or cotton in Africa, increasingly grown for cash. Adjacent pastoral peoples may introduce an element of animal husbandry into these systems, with the rights to graze on stubble obtained through various types of exchange or through cash payments.

During periods of above-average rainfall, these systems have tended to encroach on neighbouring animal-based systems because of the pressures of population growth or for the extension of cash cropping. Such encroachments are successful until the rains fail, as they inevitably do. The severe imbalances which then appear can act as a major accelerator of desertification, as they did in the recent Sahelian drought, affecting not only the farmland itself but also the pastoral areas which farming had invaded.

Desertification in these systems often appears as a marked decline in fertility following the loss of organic matter and a deterioration in the structure of the typical red, sandy subtropical soils. This often comes about because population pressures and a resulting land hunger act to speed up the agricultural cycle, bringing the farmer back to the same piece of land in fifteen years, say, instead of twenty. The rise of cash cropping accelerates the removal from the soil of mineral and organic nutrients. The introduction of equipment unsuited to the particular conditions of these regions has resulted in deeper tillage and aeration and a consequent pulverization of the soil.

As fertility declines, crop yields are less, and adverse impacts become self-accelerating. To make up the difference, the land is worked even more intensively.

Rainfall in these regions, while localized, is often intense, causing pluvial erosion of cultivated surfaces. Soil surfaces become puddled and soil structure severely damaged. The dry spells that alternate with the onset of rains bake a crust on the surface, hindering the germination and development of seedlings.

During the dry winters, wind erosion lifts clouds of dust from these lands, sometimes transporting it over enormous distances. Soils in the Caribbean islands have been enriched by what has been lost from distant northern Africa.

Irrigated cropping systems

Irrigation provides the main basis for agriculture in arid regions and serves as a vital supplement to crop production in semi-arid regions. About 13 per cent of the world's cultivated lands are irrigated. Although not all of these 200 million hectares are located in drylands, still that is where the impact of irrigation is greatest.

World food production must increase if present nutritional deficits are to be corrected and an expanding world population adequately nourished. A 30 per cent increase in cereal production alone has been projected as essential between 1970 and 1985. Some of this increase will have to be obtained by further development of irrigation.

Compared with rainfed agriculture, irrigation can lead to a six-fold increase in yields of cereals and a four-to-five-fold increase in root crops. The importance of irrigation to agricultural development is revealed by the fact that the irrigated harvest area in developing countries is expanding at a rate of 2.9 per cent per year compared with an annual expansion of 0.7 per cent for rainfed crops. Irrigation in arid lands can therefore be expected to play a critical role in satisfying the world's food requirements. Measures to combat desertification in such systems are accordingly of the utmost urgency.

Its remarkable productivity is one aspect of the importance of irrigation in arid lands. The productivity of rainfed cropping as carried out in areas with less than 250-400mm of annual rainfall, is much lower because of this limitation in available moisture. Not only does annual irrigation increase yields but it also allows the replacement of fallowing systems by annual cropping.

The increased stability of crop systems with the removal of drought risk and uncertainty is another advantage of irrigation.

Animal-based systems are made more stable and efficient when they are carried out adjacent to irrigation, which can provide them with forage crops as supplementary feed and can store reserves against the threat of drought.

Irrigation increases the efficiency of cropping systems. For instance, the application of fertilizer and the planting of higher-yield crop varieties are greatly facilitated wherever productivity is not limited by the availability of water.

Irrigation diminishes the risk of desertification in cropping systems. The planting of trees and a more consistent vegetation cover replace fallowing and the open and exposed landscapes characteristic of other dryland systems. Irrigation provides water which can be used to reclaim desert lands, whether by supporting a plant cover or by the leaching of salinized soils.

As rich producers of cash crops, irrigation systems serve as important economic resources for arid lands. They provide a basis for dense settlement and its related social amenities in regions that once supported only sparse populations. As such, irrigated lands can be used for the resettlement programmes that desertification elsewhere sometimes makes necessary.

It is not merely because they are short of rainfall that arid lands are particularly suited to irrigation. Situated as many arid regions are in the cloudless subtropical zones of atmospheric subsidence, they are favoured with long hours of sunshine. This makes irrigated lands suitable for multicropping and the growing of early maturing, warmth-demanding crops that command high prices in regions that are not so sunny. Algeria or Israel, for instance, produce winter and spring flowers and tropical fruits that are shipped off for sale in Europe.

Again, under conditions of low rainfall, carefully irrigated soils suffer only limited leaching of fertilizers and nitrogen. Plants grown in low atmospheric humidity are relatively free of diseases, such as rust in cereals, that flourish in moister conditions.

Arid lands are rich in terrain and soils, such as sloping piedmont plains of interior, well-drained river systems, that are remarkably productive when water is brought to them. Many such places still remain to be exploited by intensive cropping.

Irrigation, however, is often a costly, technically complex procedure that requires skillful management and sound experience if its full advantages are to be realized. Furthermore, it gives rise to changes in all the major ecosystem régimes - soil, water and atmosphere - that may introduce unwanted effects leading to desertification unless appropriate precautions are incorporated into the system.

A failure to apply efficient principles of water management will lead to water wastage and hence loss of productivity. Such wastage can occur at any point in the system - through seepage and evaporation during storage, conveyance or distribution or as a result of bad timing in water application, of over-watering or poor techniques of field application.

Poor application can result in waterlogging of soils, which reduces productivity through inadequate aeration and its associated salinity, eventually leading to the loss of irrigated lands. This is a problem locally associated with low-lying tracts and areas of heavy soils. Waterlogging is more generally related to the artificial raising of water tables because of seepage, inadequate drainage and over-watering. It is a major factor in the salinization of irrigated soils.

When soils are inadequately leached of the minerals contained in irrigation water, then excess evaporation and transpiration will result in salinization and alkalization of soils. Where drainage is inadequate, whether natural or artificial, salts accumulate. The process commonly begins where natural seepage occurs, as along the margins of irrigated land commanded by higher ground, in an irrigated terrace for instance, or where there is seepage from a network of channels. It spreads where irrigation has been carried into areas of unsuitable soil, such as alkaline clays, or into unsuitable terrain, such as flood plain sumps or the higher parts of poorly levelled lands. In such situations, when leaching is inadequate, salt crystals will appear on the surface.

Salinization and alkalization become general problems wherever artificially raised water tables, associated with waterlogging, capillary rise or pollution from salinized outflow, prevent the proper leaching of salts. Salinization also occurs when the irrigation water is too salty or when there is not enough of it to leach the salts from the soils. It has been estimated that half of all irrigated soils in arid lands are affected by salinization to some degree. The eventual result can be found in lowered yields, restrictions in the choice of crops and the final loss of irrigable lands which can only be reclaimed at great expense. In monetary terms, no type of desertification is more costly to man.

Alkalization, improper watering, inappropriate tillage of moist soils and the leaching of soils containing gypsum can lead to a deterioration of soil structure and compaction. This results in poor aeration, reduced transmission of irrigation water and finally to lowered yields. Suffusion of the soil with water that fails to drain properly can lead to catastrophic subsidence of the ground. Further irrigation then becomes impossible without expensive relevelling.

Recycled irrigation water may become progressively more salty, aggravating a tendency toward salinization. Excessive watering can remove essential nitrogen from the soil.

Since irrigation provides a basis for intensive agriculture in arid lands and for dense settlements there, often including people who lack traditional experience in agricultural methods and their associated societies, the development of irrigated agriculture often brings social problems to arid lands. These problems are linked to profound modifications in local or adjacent ecosystems, notably soil and water régimes, involved in the development of irrigation.

Irrigation calls for particular skills in the application of water and the tillage of watered soils if its great potential for increased productivity is to be developed and sustained. The efficiency of irrigation schemes rests in the last analysis on the individual cultivator. When cultivators lack the appropriate agricultural experience, irrigation systems and the lands they water can suffer great damage.

Potentially beneficial to health through improved nutrition and water supplies, irrigation can also give rise to serious health problems. It can increase the risk of water-borne, directly transmitted diseases such as bilharzia, malaria and typhoid fever. Malaria has been identified as a problem in the early irrigation civilizations of the Nile and the Tigris-Euphrates. The transmission of disease is facilitated by water mismanagement which results in the formation of stagnant pools and by a lack of hygiene and sanitation under conditions of dense settlement. Chronic ill health gives rise to losses from labour inefficiency.

Laws and traditions can present obstacles to efficient irrigation by establishing curious restrictions on water use, illogical subdivisions of the land or contractual limitations on tenant activities.

Irrigation gives birth to cities in arid lands and to the social stresses that arise when peoples of diverse backgrounds come into contact with one another in a new social and economic environment. Dense settlements have a profound impact on the surrounding desert environment, and this impact can be very damaging where populations have no tradition of close settlement.

Irrigation systems can be based on surface waters or on ground water. Each type brings with it its own characteristic problems.

Systems involving the use of surface waters range from flood farming or flood-recession agriculture in floodplains, through annual basin irrigation using flood banks, to perennial irrigation using manmade storage reservoirs and canals. Systems of the last type, based on rivers flowing through or on large upland sources of runoff, support the largest populations and the most intensive agricultural production in the arid lands. Such systems call for advanced, large-scale management.

Devegetation, surface deterioration or gullying due to overgrazing or the extension of croplands, the breakdown of works such as terracing intended to control runoff, all give rise to problems in the management of surface water. All such deterioration promotes increasingly spasmodic and violent local flooding which complicates water management and gives rise to flood damage and siltation in storage reservoirs and on irrigated lands. It may also lead to a decline in water quality through the exposure of saline soil layers.

Irregularity of water supplies is a frequent problem in such systems. Studies indicate that a given quantity of water is two to three times as effective if applied regularly and consistently rather than via a one-time flooding.

Systems employing surface waters are confronted with problems of storage. Reservoir capacity can be lost to siltation in erodible desert watersheds. Seepage can involve the loss or salinization of irrigation water. Evaporation, too, can enhance salinity.

Such systems are also confronted with problems relating to water conveyance. Water losses in travel, averaging fifty per cent, arise from seepage and evaporation in networks of channels. Such problems can become acute in very large systems containing long distribution channels.

Irrigation water can become increasingly saline as it is recycled in surface runoff or subsurface flow, when it becomes contaminated by saline soils, particularly where discharge declines as the water moves down valleys.

When surface-water systems are adjacent to large rivers, they are subject to a risk of flooding. When they are located in large desert river basins, they always involve problems of water resources and water rights at local, regional and international levels.

Systems involving the use of groundwater suffer from their own distinctive set of problems. These are usually smaller schemes than the often elaborate systems that draw on surface water. All told, they probably amount to less than 10 per cent of the extent of surface-water systems, but they are particularly important within oasis settings, including those within extreme deserts. Such systems sometimes exploit shallow subsurface water by means of hand-dug wells. In other settings, they go deeper and require the use of pumps. They may tap artesian supplies or they may "mine" non-renewable deep-water sources.

Groundwater is commonly more saline than surface water. Limitations in supplies and difficulties in terrain may present great difficulties in obtaining effective leaching and drainage. Salinization of soils, often working through the mechanisms described in connexion with surface-water use, is a frequent problem in groundwater systems.

Problems also arise from over-exploitation of limited supplies. As water is used up, shallow sources may be abandoned, and pumping becomes increasingly expensive as draw-down affects marginal wells. Less favourably sited wells may become so drained that marginal lands will be abandoned. Heavily exploited water may suffer from an increasing accumulation of salts through recharge by salinized water, thus aggravating the problem of soil salinization. Seawater may encroach on aquifers that are intensely exploited in coastal drylands.

Problems can arise in groundwater systems due to the raising of the watertable as supplies are brought up from depth. When drainage is hindered, this can lead to the pollution of aquifers by saline soil water.

Conversely, watertables may be lowered in aquifers as supplies are drawn from them. This can cause land subsidence on a major scale, as in California's Central Valley.

Here, too, problems can arise in connexion with water management and water rights leading to conflicts and resulting in inefficiencies.

Fishing, hunting and gathering

There are communities that persist in gaining their subsistence by traditional methods of hunting, fishing or gathering or some combination of these activities. More often, however, such pursuits are supplementary to agricultural systems of livelihood, and when compared with the latter, their environmental impact is generally local and slight. When these activities are affected by desertification, it is likely that they have been damaged by adjacent agricultural systems.

Since diminished biological productivity is the hallmark of desertification, that label can be applied to circumstances leading to reductions in wildlife populations or to the loss of their habitats.

In addition to its value as a food supplement, dryland wildlife, an intrinsic part of its ecosystems, constitutes a vital element in the natural environmental balance. Its presence may therefore be essential in restorative measures to combat desertification. As part of the world's ecotypal heritage, wildlife is intrinsically worthy of preservation. As a tourist attraction, dryland animals may also serve as an economic resource.

The larger native herbivores in dryland ranges have become reduced in numbers almost everywhere. Some species are threatened with extinction.

This is in part due to heightened hunting pressure as man increasingly intrudes into the more remote dryland refuges in search of oil, minerals or pleasure. Such intrusions are increasingly made in the off-the-road cross-country vehicles by men carrying sophisticated weapons.

It is also due to deterioration of animal habitats as described in connexion with animal-based livelihood systems. As their situations become ever more precarious, dryland animals decline in both vigour and numbers.

Competition with domestic animals, whether real or merely perceived, is a factor leading to deliberate reductions in the populations of larger animals or to their exclusion from habitats they formerly occupied.

Under these worsened conditions, the impact of supplementary hunting by pastoral peoples has become increasingly severe, especially when accelerated by the general increase in human populations.

Dryland fishing communities, without considering ocean fisheries off coastal deserts, as in Peru, which are outside the scope of this review, are also subject to desertification.

Desert lakes, coastal lagoons and perennial dryland rivers support fishing industries which contribute important amounts of protein-rich supplements to local diets. For example, the Lake Chad fisheries reportedly produce an annual yield of 100,000 tonnes.

Lake Chad, however, was much reduced during the recent Sahelian drought, since drought reduces discharge by rivers and shrinks the lakes which they feed. Shallow bodies, such as Lake Manchar in Pakistan, will suffer shrinkage when the waters that feed them are diverted for other purposes such as irrigation.

Lakes and lagoons can be salinized by excessive evaporation, by the increased salinity of entering waters in irrigated regions or by the encroachment of seawater. The Aswan dam, for example, has prevented Nile sediments from reaching the beach barriers that once protected the lakes in the delta and has allowed seawater to penetrate them.

The degradation of river catchments increases siltation and generates turbidity in the lakes and lagoons fed by such rivers. This acts to kill aquatic vegetation and causes a decline in fish catches. (Conversely, the sardine fisheries in the Eastern Mediterranean failed after the Aswan Dam cut off the Nile-borne nutrients that once supported them.)

The desertification of watersheds brings on adverse changes in river régimes leading to increasingly spasmodic discharge, to siltation or flood scour in river channels and to the destruction of aquatic ecosystems.

Mining, tourism and recreation

These livelihood systems are practised in all types of climate and environment, but they take on special importance in the drylands as alternative resources in conditions of relative scarcity. Oil revenues, for instance, have fundamentally improved the prospects of a number of developing desert nations and indeed have given them the means to combat desertification. These activities have provided a fundamental impetus to the establishment or development of dryland settlements and communications. Yet they have not been carried out without environmental impact, especially in the very fragile ecosystems that make up the drylands.

Mining and mineral based industries, including the extraction and processing of oil, cause direct disturbance of vegetation, soil and terrain, not only in the actual mining operation itself, but also in such ancillary activities as the construction of roads and pipelines and the development of heavy vehicular traffic.

Disturbed and denuded soil is subject to wind erosion with increasing dust nuisance and sand drift. Disturbed ground is also vulnerable to accelerated water erosion, with consequent siltation and obstruction of surface drainage. These problems are exacerbated in drylands where water for irrigation is in short supply and where denuded ground is recolonized by vegetation only at an extremely slow natural rate.

Airborne or waterborne mining or industrial wastes cause pollution of soils and groundwater, a particularly hazardous problem in the drylands where there is rarely enough water to remove pollutants through leaching or surface drainage.

The patterns of air circulation over drylands are characterized by limited atmospheric mixing and frequent temperature inversions which hold the lower layers of air firmly in place. In such conditions, atmospheric pollution tends to hang on instead of being carried away. Held in place under brilliant sunlight, pollutants are then subject to photochemical synthesis which can transform them into even more noxious substances.

Mineral industries can bring about desertification by intense, localized competition for scarce resources such as water, wood (for fuel and construction materials), energy sources and labour. Such competition is often detrimental to local agricultural livelihood systems.

Problems arise from the impact of mining settlements in drylands. Apart from the physical impact and demands common to settlements anywhere, dryland mining towns bring with them an array of social problems related to their often temporary character, their remoteness, and to the unusual and changing composition of populations which may be wholly or partly foreign to the dryland setting.

Tourism and recreation have been drawn to deserts and drylands by warm sunny climates, a dry healthy atmosphere and natural landscapes with distinctive life forms where parks and reserves can be easily established. Drylands contain archaeological and folklore attractions and they provide ideal settings for certain kinds of sanatoria. Their popularity as tourist and recreation areas has been aided by the development of communications to and within them and has risen steeply with the increasing leisure and affluence of industrialized societies, especially those that experience cold winters. The tourist industry is an increasingly important source of revenue and employment in drylands, although complaints are often heard that the control and benefits of tourism remain outside the dryland communities. Tourism and recreation can also serve as active agents of desertification.

The construction of tourist roads and camps and the resulting increase of traffic, particularly by cross-country vehicles, is disturbing to and destructive of vegetation and soil cover in the usually sensitive landscapes that constitute the scenic attractions. This leads to accelerated erosion.

Attractive plant or animal species can be reduced or even wiped out by the uncontrolled gathering of wild flowers or by disturbing animals at critical periods in their life cycles.

Tourist settlements give rise to problems of health and sanitation, and these can be exacerbated through contacts between tourists and local populations.

Commercial tourism can have an uncontrolled impact on traditional communities resulting in interactive social complications, including the resentment of local populations at being regarded merely as objects of interest. Seasonal labour requirements have great effects on local life systems as does an increased demand for local craft products.

Dryland settlements

Aridity stimulates the formation of nucleated settlements since their necessary supports, such as water and agricultural land, tend to be localized in deserts and drylands. Depending on how "urban" is defined, between 20 per cent and 30 per cent of the 680 million people living in drylands are urban. Dryland cities include some of the oldest in the world. Today they function as irrigation centres (including oasis settlements), garrisons, communications and caravan centres, political, administrative and regional services centres, or they may be focused on tourism, sanatoria, mining or other industries.

Deserts and drylands have been subject to an accelerated urbanization over the past 50 years, often superimposed on general population increases. In Iran, for example, where the population has tripled since 1900 to a present total of almost 30 million, the percentage of urban population has increased from 20 per cent to 40 per cent. Today, the world's drylands contain nine metropolitan centres with more than one million people each. Expanding dryland cities share many of the problems of cities in more humid lands. But situated where they are, they have additional problems as agents of desertification.

Dryland communities have a direct and often adverse impact on the lands surrounding them. As concentrations of people and traffic, including livestock traffic in agricultural settlements, they are often surrounded by naked perimeters of bare ground subject to constant disturbance. Movement on such perimeters is rarely confined to established roads or tracks. The result is intensified dust nuisance and localized sand drift. After rains, these bare surfaces become muddy and filled with stagnant pools which can constitute a health hazard. Such conditions may extend right into settlements built on an open grid pattern of large blocks, like most Australian outback towns, which contain extensive uncontrolled surfaces which cannot be grassed because of water shortages.

Waste disposal in dryland settlements is confronted with particular difficulties. The disposal of domestic or industrial wastes is hampered by a lack of water for flushing or leaching, by slow rates of biodegradation and by problems in revegetating waste dumps. This leads to chemical and bacterial pollution of soils and groundwater with attendant health hazards, particularly in more primitive conditions. Included in this problem is the impact of feedlots and slaughterhouses located in town perimeters.

Rubbish is often dumped on the outskirts of dryland towns in sparsely settled areas difficult to supervise. Dumping is encouraged by a widespread attitude that desert land is inexhaustible and otherwise worthless.

Atmospheric pollution from vehicles or the burning of fuels in cities is aggravated by the same dryland conditions that affect atmospheric pollution from mining or industry - low ratios of atmospheric mixing, temperature inversions and a high level of photochemical synthesis.

Like all towns, dryland settlements make demands on their hinterlands, and more so in developing nations where communications may be poor. Desert towns in developed economies may import many of their necessities from far away. Under any circumstances, however, the impact of the modern city on its surroundings is considerable.

Per capita consumption of water increases with urbanization, and to meet its domestic, industrial and power-generating needs, the town may compete for water with adjoining agricultural systems, as Mexico City does. Where a city is dependent on groundwater, its rising needs may lead to a lowering of regional watertables, as in the Tucson basin of Arizona, with adverse consequences for surface water régimes.

In developing countries especially, demand for wood and charcoal tends to devegetate an expanding area around the city with the usual adverse consequences. As time passes, supplies must be brought in from farther and farther away at continually rising cost to the consumer.

The expanding settlement may engulf the cultivated land that supported its earlier growth. Unrealistic land-boom sales in the United States have caused lots and roadways to be scraped out of distances often remote from towns, where they lie stagnant without further development, constituting a source of accelerated erosion. Although the growth of cities in deserts or drylands may entail smaller losses in agricultural productivity than in humid areas, such losses occur in environments that are very sensitive to disturbance and they may be very important locally.

The demand for labour by urban services and industries, reinforced by higher wages, may draw workers from adjoining livelihood systems to their great detriment. Forms of agriculture requiring intensive upkeep, such as rainfed terraced agriculture or qanat-fed irrigated cropping, have suffered particularly from labour shifts of this kind.

Just as settlements have an impact on their surroundings, so desertification of a region has an impact on cities and settlements located within or near it.

During droughts, rural peoples suffering desertification stress migrate in large numbers to nearby towns. This happened in the recent Sahelian drought, where urban population growth rates, already very high at 10 per cent per year, briefly doubled. Although towns provide a successful escape for the migrant in terms of wages and welfare, such movements impose severe burdens on urban housing and services and tend to intensify the adverse environmental impacts that cities and towns already exert.

The accelerated growth of cities, so characteristic of the contemporary world, places continuous stress on urban water resources, a stress that is aggravated in periods of low rainfall. When desertification affects the hinterland or surrounding regions, the city's water supply can be further stressed by increasing siltation in surface water storages, reducing their useful life, and by lowered groundwater tables and a deterioration in water quality.

Desertification of surrounding lands will heighten environmental stress within the settlement. The town may experience hot winds and more frequent dust storms, particularly in periods of summer drought when local shade and shelter will also have diminished. These impacts will be most strongly felt when settlements and houses are unsuitably designed and particularly in the temporary dwellings of newly arrived urban immigrants.

V

The Human Consequences of Desertification

The impact of desertification on man

Desertification is a human problem. Its most important aspect lies in its impact on man himself - on the individual, the family, the community or the nation. The environmental degradation, the biological and physical stress described as desertification in the different dryland livelihood systems have their direct counterparts in physical, emotional, economic and social consequences for man.

As with the environmental manifestations, the impact of desertification on human beings shows a corresponding vulnerability, chronic or progressive, upon which are superimposed those critical periodic stresses that result in human disaster. Unless long-term remedies are found and applied, the passage of each crisis must leave dryland communities further weakened and still less equipped to deal with stress conditions or to confront the next crisis, which will inevitably occur, bearing with it its potential for catastrophe.

The Sahelian drought, for example, meant a drastic slash in productivity and income in the six countries most affected. Two million nomadic pastoralists lost more than half of their livestock - in the worst local situations losses exceeded 90 per cent. For almost 15 million villagers, harvests yielded less than half of the usual crop during most of the years between 1968 and 1973. The result was the destruction of already low standards of living. The repercussions were felt not only by individuals and families but resounded as disastrous cuts in national incomes.

The consequences of the Sahelian drought cannot be grasped solely in terms of its severity. It must be appreciated that even before 1968, the six Sahelian countries and the people who live in them were already among the poorest in the world. In the list of the 13 least developed countries, four of them are in the Sahel. These countries have gross national products that amount to less than $100 a year for each inhabitant. Chronic poverty and lack of capital are characteristic of desert and dryland communities in developing countries. This is a major reason why they are so vulnerable to drought disaster.

As the Sahelian drought advanced, food stocks dwindled to extinction, and famine, prevalent by 1971, was general throughout the area by 1972. It is estimated that 100,000 people died of starvation and associated disease, most of them young children. Typically, famine and disease did not strike those who had been healthy and well-nourished; it ravaged populations already debilitated by malnutrition.

Seasonal hunger and epidemic disease are facts of life among desert and dryland peoples in developing countries, where health services are usually inadequate if they exist at all. Malnutrition and low resistance to disease are among the more insidious aspects of desertification. They reduce the capacity of dryland communities to cope with periodic hardship, and they sap the will of dryland peoples to improve their condition. They must be dealt with as part of any set of measures to combat desertification.

In the pastoral areas worst affected by the Sahelian drought, there was a complete breakdown of livelihood systems and a mass exodus to towns and refugee camps located in the less affected south. Some parts of Upper Volta lost 80 per cent of their inhabitants. Many died on these migrations, but to a large number of nomadic refugees, the journey brought survival, since they found food, medical care and eventually wage employment in the towns toward which they headed. Surveys have since shown that a sizeable proportion of the pastoralist refugees may never return to their former homelands. Thus it is that the drought brought about what must be viewed as a social revolution.

On the other hand, it is possible to view such an exodus as a temporary magnification of a regular and pre-existing out-migration, both seasonal and permanent, of the nomads to the towns. Although the pastoral systems receive some benefit from the remittance of money sent from wage-earners in towns, still, even before the drought, out-migration had reached levels sufficient to cause local weaknesses and stagnation in the pastoral systems. Such movements, persisting through good years as well as bad, suggest chronic instability and the land's lack of capacity to support its populations. It is something that must be taken into account in remedial policies.

The Sahelian drought generated an international relief effort which eventually reached substantial size. Nonetheless, the effort suffered failures indicative of underlying weaknesses which existed before the drought crisis and which have undoubtedly survived it. That food and medicine could not be brought in time to those who needed them most underlines the remoteness of such regions and their lack of transport facilities. Administrative failures and bureaucratic obstacles hampered relief operations locally. Such matters must be dealt with if measures to combat desertification are to succeed.

The traditional antagonism between nomad and peasant in the Sahel, which led to inequities in the distribution of food to refugees, draws attention to the kinds of cultural conflicts and political bias which also face anti-desertification programmes. A lack of effective communication between refugees and those who were supposed to be helping them serves as a reminder that literacy rates in affected countries are sometimes very low, below 10 per cent in most countries of the Sahel, and that programmes of education must accompany measures for improving land use.

Just as dryland ecosystems react with greater or lesser sensitivity to climatic stress and the pressures of land use, suggesting an order of priorities for measures directed toward physical improvement, so differences in the inherent vulnerability of dryland communities, as reflected in the greater or lesser sufferings of their inhabitants, suggest priorities on human grounds. Full consideration should be given to whether or not international action should be directed toward the most vulnerable nations, and national action to the most vulnerable communities, rather than to areas of the greatest ecosystematic disturbance, although, of course, the two categories might on occasion coincide.

However they are ordered, remedial programmes should have as their perspective the treatment of long-term disabilities, not merely relief from temporary hardship.

Human and social manifestations of desertification

While the adverse human and social consequences of desertification become critical in periods of stress, their persistence provides evidence of chronic disabilities in marginal dryland communities. As such, they may not be specific to desertification but broadly common to families and livelihoods on the margin of the modern world, particularly in remote and hazardous environments and where tradition, social inequality or political indifference further isolate people and systems from the resources and capacity needed to effect improvement.

Among these adverse consequences are hunger, disease and premature death brought on by continued crop failure or the massive destruction of livestock, particularly in marginal subsistence societies where transport facilities are inadequate. Malnutrition increases vulnerability to epidemic diseases such as measles. Few diseases are specific to desertification, eye diseases such as trachoma marginally so, and certain diseases, such as bilharzia, are linked with inefficiencies in irrigation systems. Debility leads to further inefficiencies in another kind of cycle that may become self-accelerating.

In developed nations, such as the United States or Australia, the first noticeable sign of desertification may be loss of income. In subsistence societies, loss of income gives rise to acute problems of physical well-being and becomes increasingly important when income is dependent on the sale of crops or livestock. Loss of income is a constant problem in marginal societies, and there are a number of devices for coping with it, such as the sharing of resources or seasonal out-migration.

When drought is long-continued, there may be an incipient breakdown in livelihood systems. In nomadic societies, this stage may be marked by self-enforced sedentarization, settling down on agricultural land. Out-migration to the towns, both seasonal and permanent, may show a marked increase on the part of nomads and of those who work traditional cropping systems as well. This offers immediate relief in the form of remitted wages, but it can easily reach the point at which the local livelihood systems suffer from labour shortages, thus weakening them further. Although traditional societies have various ways of coping with such problems, some are particularly vulnerable to them, those especially which have become commercially or technologically more specialized or those in which traditional social bonds have broken down.

When the stage of incipient breakdown was reached in the disaster of the Sahelian drought, nomadic pastoral communities generally fared better than sedentary agriculturalists. In developed countries, buffering of the livelihood system at this stage may take the form of government drought relief and loans. It is likely that indebtedness will increase and the less viable holdings abandoned. Selective depopulation will occur in rural settings, while the local towns based on rural services and industries will suffer economic depression.

This process can proceed until livelihood systems collpase utterly. When this stage is reached, the greatest hardships fall on those communities that are most exposed environmentally and least equipped to transfer to a new livelihood system. At this point in the Sahelian drought, the nomadic pastoralists suffered most, with many areas experiencing a mass exodus. As stated earlier, there are indications that many of these refugees have permanently abandoned their former livelihood systems.

Apart from the physical hardships involved, such an upheaval brings with it severe emotional stress. Those most hard hit may succumb to an apathy stemming from their felt loss of status. Social disasters of this magnitude are more characteristic of marginal societies in marginal lands. Industrialized societies have access to resources that can blunt the impact of disaster.

VI

Measures to Combat Desertification

Principles which should guide all measures against desertification

Any measures undertaken to combat desertification must be informed by certain principles long recognized by the Member States which compose the United Nations. While some such principles may seem predominantly humanitarian in character, the fact is that they are also intensely practical. Desertification is a human problem, and measures to combat it involve people, especially those most affected, who must be convinced of the virtue and practicality of participating in the measures proposed.

Measures to combat desertification must be seen as having human and social objectives. They must be inspired by an acknowledgement of the right of people living in drylands to acceptable standards of health education, livelihood and social well-being, consistent with human dignity.

Account must be taken of traditional social values and an appropriate respect shown for life styles and ancient knowledge developed in harmony with the dryland environment.

Priorities in programmes to combat desertification should be influenced by the severity of its impact on the populations concerned, and by the degree of their vulnerability.

The approach should be an integrated one, in which proposals involving technological or environmental change are linked with social and economic measures.

Measures to combat desertification will not succeed without the willing participation of local communities. The need must be recognized to work through existing livelihood systems and established social patterns. The involvement of the community must be sought, as by enlisting the example of local leaders. Educational and publicity programmes must be designed with this in mind.

It may be necessary to create incentives toward community participation. The practicality and advantages of proposed measures should be demonstrated at the earliest stage through realistic pilot projects.

From the outset, programmes should contain some measures selected because they relate to immediate local problems, because they demonstrate prompt action within the community, because they are possible with existing resources, and because they promise convincing results within a reasonable time.

Advantage should be taken of crisis situations, when societal and livelihood systems have been disrupted and people are more prepared to consider change and to carry out whatever restructuring of dryland livelihood systems that conditions may call for.

Campaigns against desertification must be realistic and planning should not set goals which can neither be supported nor achieved in regions of essentially low productivity.

The ideal objective is the recovery and maintenance of ecological balance in the drylands in the interests of sustained productivity, but this must be reconciled with the needs of local populations. Some degree of environmental disturbance must be tolerated in land management.

On the other hand, it must be accepted that land-use pressures have been a major factor in existing problems of desertification. Any effort to improve conditions must recognize that fact. ccordingly, changes in land use will be required, and these bring with them a need for corresponding social changes. Some element of control will obviously be required, but it will not succeed without a sympathetic community response. This must be sought through education, demonstration projects, and a sense of involvement and shared decision among the local people.

Where limits are set by rainfall, the productivity of drylands per unit area will never be anything but low. Such lands can command only modest investments in keeping with their productivity. Reclamation and preservatory measures should be designed in accordance with this outlook, as should the goals of redevelopment schemes.

Since rainfall will remain variable in the drylands, they will continue to be high-risk areas for most land-use systems, and this should be reflected in development plans. However, measures to stabilize their livelihood systems and buffer them against periodic drought should not deprive them of their flexibility and the risk-spreading strategies characteristic of traditional dryland practices.

Apart from limitations set by climate, dryland ecosystems will remain sensitive to land-use pressure because their soils and dynamics are delicately balanced. The best designed dryland livelihood system will still require constant surveillance if balance is to be sustained. It is therefore essential that campaigns against desertification should not be presented as sets of single episodes. Development plans must incorporate systems of monitoring and maintenance. This requirement strongly underlines the need to develop indigenous science and technology.

The drylands and their threatened margins cover more than a third of the earth's land surface. As might be expected, a scope so immense comprises a vast variety of biophysical, economic and social settings. Desertification and its problems are correspondingly varied and complex. Any plan of action to combat desertification will recognize this, and with it that there can be no single set of remedies. Recommendations must take account of different situations and be flexible enough to encompass a wide range of conditions.

Review of the desertification problem strongly supports the contention that past failure to maintain balanced livelihood systems in drylands is the outcome of an inability to apply existing knowledge of physical processes rather than from any lack of understanding of what the processes are. The same appears to be true of the design of measures to combat desertification. Accordingly, plans of action should address themselves particularly to the removal of obstacles to the application of existing knowledge, to the adaptation of existing knowledge to local situations in the social as well as in the physical sphere, and to problems of acceptance and participation among local communities. Plans of action should stress action rather than future research.

It should not be taken for granted that action to combat desertification will take first place among national commitments. The Plan of Action to Combat Desertification should not appear to pre-empt already established national priorities. Nevertheless, it should be kept in mind that action on the ground will largely be carried out by national organizations, and presentation of the plan should accordingly aim to influence national governmental attitudes toward the problem of desertification and should seek to secure the active commitment of governments. This is most likely to occur when combative measures are linked to broad national plans for development and appear to be consistent with national goals.

Because dryland ecosystems are fragile, they are particularly vulnerable to misapplied technology. Techniques and equipment tried with success in more humid regions have contributed to desertification in drier environments. When innovations are suggested, attention should be paid to the impact they will have on the dryland environment and to their adaptability to local livelihood systems. In developing countries, attention must also be paid to low cost, simplicity of operation and acceptability by the local community. It follows that modifications of existing technology and practice are likely to prove more effective than radical innovation.

Beyond these guiding principles, measures to combat desertification must take as their point of departure the identification of the process when it occurs and the assessment of its nature and severity.

Identification and assessment of desertification

Experience indicates that the long-term progressive deterioration of areas that constitutes desertification may not be readily identifiable against the background of short-term environmental fluctuations that spring from periodic shifts in the rainfall. There is a consequent need for regular monitoring of the status of dryland ecosystems to provide early warning of trends, to identify areas in which change is taking place, and to provide a basis for the investigation of causes and processes. It is in terms of such information that measures for prevention or reclamation will ultimately be designed.

Because the problem is global, calling for international effort and a worldwide exchange of information, monitoring should be established in the form of uniform, worldwide surveillance. Such arrangements might usefully be identified and co-ordinated as a "world desert watch".

Global surveillance of the status of dryland ecosystems and of land use can be achieved most economically through the remote sensing powers of specialized orbiting satellites. The so-called LANDSAT system, already in operation, has this capacity. LANDSAT now provides imagery at a scale of 1:250,000, with prospects that a scale of 1:100,000 will soon be achieved.

The first step in the use of a satellite such as LANDSAT is to employ it for the identification and mapping of distinct units on the ground. This can be carried out in false colour imagery (LANDSAT bands 4, 5 and 7) or in black and white. Much of the world's drylands, perhaps 85 per cent, is already covered by LANDSAT. The mapping would define functional environment types as determined by their geology, landform and surface drainage, each type characterized by certain soils and vegetation cover. The characteristics of each unit would be established from imagery and supported by already existing information on geology, soils and vegetation. The findings would be validated on the ground, this so-called "ground truth" being determined by field sampling and traverses.

Initial demarcation of the topographical and soils units by a skilled photo-interpreter would be inexpensive, costing in the order of some dollars per thousand of hectares. The building up of ground truth would be a separate and continuing operation. Different combinations of boundaries would allow the information so obtained to be expressed in terms of a variety of references, such as pasture land, vegetation or salinity. The achievable scale would be adequate for general surveys of land status, for planning for extensive land use such as pastoralism, or as a first stage in the identification of likely areas for more intensive kinds of land use. The maps obtained could provide a framework for the interchange of experience between comparable environments.

To fix trends in dryland ecosystems repeated monitoring on a uniform basis is required. This can be obtained from the LANDSAT system via remote sensing satellite-to-ground receiving stations. Each of these has an effective radius of about 2,700 km. but at the present time, only a part of the drylands is properly covered. Access to a ground receiving station provides an opportunity for manipulating the data output to conform with local needs.

The storage, handling and reproduction of the data from the ground-receiving station, and its integration with data from other sources, calls for linked computer-based data systems which will generally form part of a national land-data system. Information can be related to a given topographical unit or to another geographical subdivision by the use of a standard system, and experience suggests that a one-to-two kilometre grid provides adequate definition for the general surveillance of drylands.

A feasibility study set in South America is proposing to validate a transnational approach to monitoring desertification on the above basis. The annual cost of establishing a ground receiving station and linked data system would be $2 million, which amounts, as suggested, to dollars per thousands of hectares covered. The establishment and validation of such a system using pilot test areas would take about three years, and such systems are not likely to be generally established before five years. It looks as if world coverage would be most economically achieved through regional groupings of countries.

LANDSAT imagery will have to be reinforced by ground truth from periodic field surveys, measured transects and other types of ground-based reporting.

The further investigation of areas revealed by LANDSAT as undergoing desertification or as potentially suitable for more intensive land use will call for mapping and monitoring at the finer scales provided by conventional air photography.

The evidence obtained from satellite imagery and other sources, linked through the data bank, should provide the basis for a number of important activities.

The first of these should be the construction of a map showing types of desertification present and the relative vulnerability of the demarked ground units to further desertification. Then regional plans can be formulated for measures to combat desertification, linked with plans for improved land use, for resettlement, or for whatever else conditions call for. Following the regional plan, specific combative measures can be designed and sites selected for demonstration or pilot projects.

Monitoring will continue, both to maintain surveillance of land use systems and to provide assessment of the progress of combative measures.

The conditions of dryland people must also be assessed.

If measures to combat desertification require continuous assessment of vulnerable lands, they demand also a comparable understanding of the people who live in such places. Experience with existing programmes has indicated that physical problems associated with desertification are commonly more amenable to solution than the typically human problems.

Assessments of physical conditions should therefore be accompanied by efforts to obtain a more precise understanding of the state of dryland peoples. Surveys should be undertaken, perhaps through a strengthening of census services and techniques, of their demographic characteristics, of the state of their health, and of their social and economic circumstances. On the basis of what the surveys reveal, measures can be designed to combat malnutrition, ill health, poverty, illiteracy and other social and economic disadvantages commonly suffered by people living in the drylands. Social and economic changes, such as resettlement or alternative livelihood systems, should be presented and proposed as integral parts of a plan to improve conditions and not as mere afterthoughts to environmental measures.

If plans are to succeed, they must be acceptable to local communities. Social, economic and technological acceptance are likely to be as important as environmental compatability in determining the effectiveness of what is proposed. Studies should be directed toward uncovering obstacles to community acceptance and to ways in which acceptance can be gained.

In order to obtain the agreement of local communities and their participation in measures to combat desertification, the planning process should maintain close contact with community leaders and involve them at all stages, while preparatory studies are looking into a number of matters directly involving the local people.

One such matter would concern how people can be best be approached through publicity and education on the nature and consequences of desertification and the need for action to combat it. A study might by made of what social and economic incentives would best contribute to community participation.

Some demonstration projects should be designed and executed that are easy to do and produce prompt and desirable results. People must be persuaded that action against desertification will work, that it will improve their lives and that such campaigns are more than idle talk.

Whether they concern land or people, plans must be flexible. They should incorporate periodic checks on the progress of measures put into operation and should allow for concurrent reassessment of the problem in human as well as in physical terms.

Measures to combat desertification will take on distinctive characteristics depending on the nature of the land and the livelihood systems practised there.

Measures to combat desertification in extensive pastoral systems

In pastoral systems, desertification makes its appearance primarily in the degradation of natural pastures following over-grazing. It shows itself in wind erosion, sand drift and dune advance, in gullying where stock have concentrated and trampled the earth or where cutting or uprooting of woody vegetation has laid bare the surface.

To combat desertification in these circumstances means in general to adopt grazing practices that will allow the native vegetation to recuperate. In areas too dry for rainfed cropping, the natural vegetation usually forms the most efficient pasture in terms of upkeep, grazing returns and protection of the soil surface. The maintenance of a plant cover that will sustain the pastoral system under most conditions is the obvious goal of combative efforts. Anything more - intensive reclamation, for example, by planting programmes or mechanical controls - will be feasible only in restricted areas where the physical processes of desertification threatens installations, communications, settlements or valuable cropland.

It is basic that pastoral systems accept the principle that their fundamental resource resides in the dryland pasture rather than in the livestock. The experience of the Sahelian drought indicated that the death of livestock was chiefly due to the failure of pastures rather than of water supplies. Accordingly, conservation measures should be introduced for the control of grazing access to dryland ranges where such measures do not exist, including fencing when necessary.

As a first step, surveys should be initiated to determine the useful productivity of the main varieties of dryland pasture under differing seasonal conditions, the requirements of pasture plants for successful regeneration under grazing, and the dimensions of the grazing impact of a proposed system composed of certain animals in certain numbers. Surveys must take into account the dual rôle of perennials as surface protectors and as fodder during drought. A logical first step in the assessment of dryland pastures is to map them, indicating the distinct topographic, soil and water conditions. Maps can be prepared inexpensively from satellite imagery or conventional air photographs.

Surveys lead to assessments of carrying capacity under a variety of conditions and these, in turn, form the basis of appropriate grazing strategies. Such strategies should include a number of elements.

They should incorporate possibilities for deferred or rotational grazing and for the establishment of protected reserves as seed reservoirs, grazing reserves in the event of drought, and plant and wildlife refuges in which genetic variety can be conserved. As far as possible, they should preserve the mobility, flexibility, diversity and low stocking rates traditional in dryland grazing systems. Consideration should be given to fencing those parts of the rangeland subject to concentrated stock movements, those made up of particularly vulnerable pasture types because of soil or the formation of the land, or such sensitive areas as town perimeters.

Opportunity should be taken to enrich natural pastures locally by developing simple water-harvesting schemes, such as by the construction of trenches and flood banks in areas of natural flooding. These areas should generally be treated as controlled reserves, available for the breeding of animals, as a resource against drought and for the harvesting of forage. Consideration should be given to using such areas for subsistence cropping. They should be fenced off from the open range and their use integrated into the general grazing scheme.

Range conditions should be periodically surveyed to determine what grazing pressures are doing to the land and vegetation and with a view to adjusting the grazing system when required. Satellite imagery and air-photographs are now in use for continuing assessment of plant cover and productivity, but remote sensing must be supplemented by ground surveys in carefully selected areas.

While grazing strategies refer to average stocking rates, attention must also be given to localized concentrations, as along tracks and around watering points and settlements, and measures should be taken to avoid intensive local grazing and trampling. An example might be the establishment of watering points of moderate size in a network that gives adequate access to all pastures being grazed. Measures should be introduced for the controlled and responsible use of such watering points, including the levying of charges on graziers who use communal supplies.

When the trend of rangeland conditions indicates that grazing pressure should be reduced, a number of measures can be taken. They might include the improvement of transport facilities, assistance with breeding programmes to improve productivity per animal and measures to reduce the risk of losses from breeding herds. Marketing outlets should be established for the efficient disposal of surplus animals, for example in stratified management programmes as suggested by the SOLAR feasibility study, with subsidies and price supports where necessary.

Although pastoral systems have proven efficient in their use of extreme environments, experience indicates that these livelihood systems share fully in the climatic risks of such environments, with adverse human and physical consequences. Although they should not be buttressed to the point of losing their adaptive flexibility, they need help in coping with recurrent drought stress. A number of measures can be taken to provide this help, such as the setting aside of grazing and forage reserves, the provision of transport facilities for the movement of stock, financial assistance to restore herd numbers following drought, and insurance against drought losses.

Mutual support from adjoining crop-based systems has traditionally provided pastoralists with an important safeguard. Such arrangements should be maintained and strengthened where possible. They have included market exchanges, arrangements for stubble or fallow grazing (in exchange for natural fertiliser), and the introduction of forage crops into crop-based systems. Arrangements vary widely, from the incorporation of seasonal nomadic pastoral systems into schemes for irrigated agriculture, as in the south-eastern USSR, to the integration of animal-based and rainfed crop systems in zones of controlled land use, as in green belts around the Sahara.

Measures to combat desertification nomadic pastoral systems

Recent years have shown an increased tendency for pastoral nomads to settle down in fixed habitations. This happens because of changing personal goals or attitudes, because of drought disaster, or as a result of government programmes. Nomadic herding is then left to part of the former community, which comes increasingly to resemble more settled pastoral systems. These changes will continue, and assistance should be given to accommodate them.

Such assistance might take several forms. Consideration might be given to the establishment of properly designed settlements equipped with water supplies and community services. Nomads can be aided to develop ancillary farming, whether irrigated or rainfed, particularly for subsistence or forage crops. Wherever nomads have settled down, measures should be taken to reduce the environmental impact of stock concentrations or fuel-gathering activities among people unaccustomed to living in permanent settlements. Woodland or range reserves can be established near settlement perimeters.

Over recent years, nomadic pastoralists have been increasingly at a disadvantage relative to adjacent farmers, particularly during periods of above-average rainfall when cropping tends to encroach on pasture lands. Care should be taken to preserve the traditional access by pastoralists to rangelands and watering points, by legislation or taxation policies if necessary.

Little had been done to strengthen nomadic pastoralism by using traditional practices, with all their adaptations, as a base. Measures could be taken to improve livestock quality through breeding programmes in an effort to increase yields from smaller herds and decrease losses through disease. Control of grazing can be effected through technical advice, preferably directed toward the reinforcement of traditional practice and authority. Breeding and marketing schemes can be developed in harmony with traditional systems. Additional watering points can be provided that are moderate in size, cheap to construct and easy to maintain. Here the use of windpumps should be investigated. The use of such waters should be controlled to conform with broad grazing programmes and should aim to bring all pastures into effective use.

These animal-based systems are often at the extreme edge of environmental productivity and are therefore vulnerable to periodic extremes of protracted drought. This situation should be recognized by setting aside food reserves and in the advance planning of emergency measures.

The seasonal or permanent out-migration characteristic of these communities has long provided them with supplementary income in the form of remittances from once-nomadic wage earners. Plans to combat desertification should seek to accommodate and assist such population movements through appropriate resettlement schemes. Alternative sources of livelihood might be provided in the local setting, as through employment in tourism, craft industries and services or through the establishment of new industry or agricultural activities. Attempts should be made to reduce the selective out-migration of the most able workers whose loss tends to impoverish the local community.

Measures to combat desertification in commercial ranching systems

Commercial ranching differs from more traditional animal-based systems, and often in ways that make it more vulnerable to desertification.

Commercial ranching tends to be more settled, less free ranging, with greater likelihood of disturbance around fixed installations. Attention should be given to arrangements for moving and yarding stock, and some installations, such as yards, paddock gates and troughs, may have to be shifted periodically to avoid extreme effects.

The use of mechanized transport and other equipment characterizes commercial ranching. Care should be taken in routing and grading tracks and roadways, especially where protective stone covers are involved. Attention should be paid to possibilities of stabilizing surfaces as an alternative to grading fresh routes. Particular care is required where runoff is channeled along tracks or their margins.

High labour costs in commercial ranching mean a minimum use of manpower, which causes difficulties when labour-intensive measures, such as planting, are called for. Proposals for pastoral development should include an assessment of environmental impact and an estimate of the likely costs of reclamation measures, an expense that may be made tax-deductible.

Vulnerability to price fluctuations, including those on distant, international markets, introduces an additional hazard into commercial ranching systems, reinforcing the hazard of climatic variability. Depressed markets may lead to the abandonment of properties and the loss of installations and may discourage appropriate long-term investment. Government-assisted marketing and price-stabilization schemes should be introduced when necessary.

At the same time, commercial ranching has some characteristics which give it advantages in combating desertification.

These include lower stocking rates, better control of stock movements and watering points, and improved facilities for the transport of stock and forage by road or rail. Such advantages point to the need for more imaginative stocking policies, particularly those that avoid extreme grazing pressure. Enlightened policies would include the maintenance of grazing reserves on the ranch and even more extensively on the unalloted or public rangelands within the pastoral district. Provision should be made in advance for the transport of stock to such reserves when circumstances require it, for de-stocking in times of drought and for re-stocking when the rains return, and for access to forage when drought occurs. Such provisions may call for outside assistance.

Mechanized equipment can be used to counter extreme desertification in local situations. Encouragement should be given to research on improved methods of revegetation, including soil treatment, pitting or furrowing, seeding and fertilizing. Assistance might include technical advice, the loan of plant stocks, the provision of seeds and fertilizers, and financial subsidies for approved measures.

In operation, commercial ranching can take advantage of economies of scale. It is also more subject to governmental regulation, either directly through lease provisions or indirectly through financial or taxation policies. Recommended stocking practices can be enforced through these means, which can also be used to achieve the subdivision or amalgamation of holdings so as to favour operations on recommended lines.

Combating desertification in rainfed cropping systems

Rainfed agriculture, embracing much of the world's production of staple cereals, extends across semi-arid and sub-humid lands subject to brief but intensive rainfall. In these systems, exposure and loosening of the ground surface facilitates erosion by wind and water. When the systems are mechanized, extreme clearing increases the impact of wind. Desertification appears in the blowing away of topsoil, in sand drift and the local growth of coppice dunes, in sheet erosion and gullying on sloping ground and the deposition of infertile alluvium on bottom lands. When these events occur, productivity declines and croplands are abandoned.

Although it covers less territory than pastoral systems, rainfed cropping supports larger dryland populations, and the potential losses through desertification, in terms of both capital and livelihood, are correspondingly greater. The impact of desertification is intensified because denser settlements and more intensive communications are associated with rainfed agriculture.

Great problems have arisen through incursions by cropping systems into areas of excessive climatic risk. This commonly happens during wetter years, when farmers are attracted by the prospect of short-term gains. Such invasions are usually made at the expense of adjacent pastoral systems, and they commonly end in the collapse of the intrusive cropping system when drier years return, sometimes with the land so damaged that it is no longer suitable for grazing.

Studies of the relation between agriculture and climate, such as those carried out by the World Meteorological Organization in Western Asia and Saharan Africa, have done much to determine the connexions between climate and the water needs of cereal crops, thus fixing the probability of the occurrence of effective seasons on the basis of climatic records. These studies should be extended and improved through additional meteorological recording and investigations into the water requirements of crops at different stages of growth and under a range of soil conditions.

Such studies, by providing good estimates of climatic risk, will support policies of land zoning, and measures should be taken to discourage the extension of cropping beyond certain climatic limits.

At the same time and because cropping represents a more productive use of the land, attempts should be made to expand the safe-cropping area by introducing strains or types of crops that are more resistant to extreme conditions and through improved methods of cultivation and water conservation. Such actions should be supported by demonstration projects and extension services.

Research should be encouraged that will lead to improved weather forecasting with accompanying warning systems, particularly for such critical periods as seeding, germination and harvesting.

Rainfed systems have also been extended onto steep slopes and very fragile soils and into areas subject to flooding, particularly under the pressures of population increase. The result has been accelerated erosion, lowered yields and the loss of cultivable land. These are common occurrences when uplands have suffered deforestation with a consequent increase in runoff and water erosion at lower levels. Such developments are well exemplified on the Mediterranean margins of the Old World deserts.

It is essential that plans for the reclamation and improved use of rainfed croplands should form part of integrated schemes for the use of functional areas such as drainage catchments and which recognize the interdependence of upland, piedmont and valley with their associated land use.

A first step in formulating a plan is to map land types and land use at a scale appropriate to cropping (1:50,000 to 1:250,000, depending on conditions); The land units mapped should be classified according to potential use as determined by the existence of hazards, such as steepness and length of slope, the presence of stones or rocks, the risk of flooding, the quality of the drainage and vulnerability to wind erosion.

Recommendations as to how the various parts of the land should be used will constitute the plan, which must recognize appropriate limits to rainfed cropping, as determined by rainfall, terrain, soils and relationship with adjacent land uses such as forestry or grazing. The marginal lands outside these limits should be removed from cropping by acquisition, such measures as financial inducements or by the establishment of forest, grazing or water-catchment reserves. When such measures involve the disruption of traditional livelihood systems, they are unlikely to succeed unless they form part of larger schemes of rural reconstruction involving appropriate changes in land tenure, such as the consolidation of holdings, or resettlement schemes offering alternative livelihoods.

Clean fallowing, or allowing a field to rest while stripped of vegetation, provides a way of conserving the moisture in the soil. Like several such techniques, clean fallowing happens to increase the land's vulnerability to desertification. Safeguards can be erected by improved methods of rainfed cropping, measures which maintain ground cover and improve soil structure. The things that can be done to counter risks and improve productivity vary considerably among different situations and different systems of rainfed agriculture.

In regions of a Mediterranean type, traditional combinations of tree and field crops should be encouraged. An element of livestock husbandry should be retained, increasing the diversity of these systems, their resilience, and hence their resistance to climatic stress.

In some Mediterranean regions, decay and disuse have affected certain traditional methods for the conservation of soil and water, such as terracing and water-spreading systems. These old systems should be brought back into service, maintained and even improved, and assistance should be provided for such purposes. Tree planting should be encouraged, whether in shelter belts or in coppice groves for firewood. Tillage should avoid powdering light topsoils, and farm machinery, some of which may have to be designed, should be suitable for working such situations as terraced slopes. Strip cropping should be introduced as a counter to wind erosion. More use should be made of crop rotations, including legumes, at the expense of fallow.

Crop rotation, including cover crops to be ploughed back into the soil, should also be introduced into mechanized systems of rainfed monocropping. Such systems should restrict the burning or removal of litter, and livestock should be introduced to graze on feed crops or crop residues. Strip cropping should be encouraged, with inducements on occasion, as well as the planting of shelter belts on open plains. To combat salinization on valley floors, deep-rooted varieties or salt-tolerant pasture can be planted.

In the swidden system, the slash-and-burn agriculture so typical of rainfed cropping in drylands with summer rain, the farmer will return to a particular plot after its vigour has been restored by extended fallow, often after as long as twenty years. Shortening the cycle, coming back too soon, can have adverse effects on plant recovery and regrowth and on soil fertility. When this happens, measures should be taken to restore the cycle to its older rhythm, perhaps by expanding the area available to cultivation or by removing population pressures through resettlement or the development of alternative livelihoods.

In these systems, valuable substances, such as gum arabic, can sometimes be extracted from the natural regrowth during the fallow part of the cycle. Steps can be taken to increase the value of regrowth by introducing new trees or by adopting good forestry practices.

Traditional crops and ancient tillage practices have sometimes become fixed in these systems where new varieties and alternative techniques would work better to maintain the fertility and structure of tropical soils and to diminish the effects of pluvial erosion and soil crusting. Swidden agriculture should be closely scrutinized everywhere with a view to reducing its impact on the land.

Once rainfed cropland has been degraded, efforts to rehabilitate it should form part of larger actions directed toward water management, improved land use and the control of erosion. Within broader plans, quite definite actions can be taken depending on the form that degradation takes.

Gullying, a particularly unsightly form of erosion, can be arrested by planting trees in upper catchments and along gully margins and by grassing areas that feed the gullies with flows. Also helpful are the construction of diversion banks and furrows across gully heads and the installation of check dams and silt traps along gully courses. Under favourable conditions, gullies can simply be filled in and their banks regraded.

Sheet erosion, which scours topsoil from wide areas, can be countered with contour banks and ditches, with grassed contour strips and by means of terraces.

Wind erosion, which blows soil away from rainfed cropland and which causes sand drift and dune encroachment, can be countered by planting shrubs and trees in shelter belts (at a spacing four times as far apart as their eventual height).

Fences can be constructed or lines of resistant shrubs and trees planted as barriers against oncoming sand, upwind of threatened areas. Bare sand can be covered with matting, bituminous coating or mulches of vegetation litter.

Sand surfaces can be stabilized by seeding and planting proper successions of vegetation, including plants which thrive in sand, legumes and cover plants in association with shrubs and trees, supported by irrigation where necessary. Finally, dunes can be levelled or reshaped to remove slip faces.

Combating desertification in irrigated cropping systems

On turning to irrigation systems, a harsh fact is promptly encountered. The amount of irrigated land lost annually to desertification (some hundreds of thousands of hectares) is probably about equal to the amount of land newly brought under irrigation each year. Great costs are involved in the breakdown and abandonment of such intensive, highly-capitalized agricultural projects. Irrigable land is scarce, and new enterprises are enormously expensive. Such considerations stress the importance of maintaining existing irrigation schemes by countering desertification whenever it affects them.

The most prevalent form of desertification in irrigated cropping systems occurs when waterlogging causes salts and alkalines to infect soils, particularly where drainage is poor and proper leaching fails to take place.

That particular problem emphasizes the importance of preliminary surveys and testing of proposed irrigation projects to assure adequate design. Most salinization problems arise from design deficiencies.

Good design should be based on an understanding of how much water is available for irrigation and its silt and salt loads, including seasonal variations. A close study must be made of the soils in the area embraced by the project, their texture and salinity, and especially of their water properties, as these will determine drainage requirements and how much water will be available to crops. Water requirements should be determined for proposed cropping systems. The position and salt content of the groundwater table should also be determined as well as seasonal fluctuations in both. This will require some understanding of the hydraulic properties of the soil's lower layers, or how those layers store and transmit water.

These investigations should yield a map showing salt hazards and how they might restrict the proposed cropping system. On the basis of the map and the surveys, design work can continue with particular emphasis on the distribution of the water and effective drainage systems and the subdivisions of the system as determined by estimated water needs. Finally, design should take account of the services and communications the system will require and the settlements that serve and are served by it.

Whether under development or in operation, irrigation schemes should be run by operating authorities equipped with professional staff, adequate funding and the powers to control land use. As a way of proceeding, especially with new schemes, the authority should undertake pilot projects which can be expanded into research and demonstration projects as they prove their worth.

Irrigation schemes require extensive maintenance. The main distribution canals should be properly banked and lined, as with concrete, to reduce seepage. Canals and drainage ditches should be kept clear of silt and weeds and pools of stagnant water eliminated. Take-offs or turnouts, where water is drawn into the system, should be designed and maintained to keep silt loads to a minimum.

The plots to be irrigated should be levelled to ensure even watering and leaching, and where local subsidence occurs, levelling should be carried out periodically. While provisions and requirements for adequate leaching should be maintained, there should also be checks a against over-irrigation.

Irrigation schemes are sometimes established where farmers have neither familiarity with nor tradition in this type of agriculture. Yet the tillage of heavy soils under irrigation calls for particular skills, as does the application of irrigation water at prescribed stages in the development of the crops. Extension services must be provided if irrigation schemes are to work successfully. Land-holders should also be given assistance in the form of credit, purchasing and marketing plans, and where suitable and desirable, in the development of agricultural co-operatives. Improved land use should be encouraged through such measures as economic incentives and tax concessions.

When irrigation schemes are designed, individual or family holdings should be shaped to ensure an appropriate level of intensive use, without being too large to preclude effective maintenance. Encouragement should be given to an appropriate balance of subsistance and cash crops, tree and field crops. Forage crops may be included if circumstances favour a livestock component. Great care should be taken in the allocation of holdings and in the formulation and administration of regulations for their proper management.

When successful, irrigation schemes inevitably give rise to close settlement, to towns, usually inhabited by people unaccustomed to congestion and its attendant problems. Housing should be planned for and provided at the same time that land holdings are allocated. Houses should be equipped with potable water and sanitation services, and all the more so here, where diseases can be transmitted through the irrigation system itself. Indeed, new communities should be provided with all the standard community services, including health, education, welfare and cultural centres, and these should be sited as part of the land settlement plan. Transport services should be established.

Irrigation projects based on groundwater supplies encounter special difficulties because groundwater quality is usually lower than that of surface waters and the threat of salinization is generally higher. Limitations in groundwater supplies may hinder proper leaching. Groundwater supplies must be kept in balance with the requirements of land use, and enough water must be provided for both irrigation and leaching. Generally, discipline applied to water use must be stricter when irrigation is based on groundwater rather than surface water.

Such discipline may include central control over the siting of bores and wells and the installation of pumping equipment. Monitoring must be constant of such factors as groundwater levels, draw-down and salinity, and the proper staff must be on hand to conduct such monitoring or any other investigations as required.

When based on groundwater supplies, irrigation schemes often suffer from poor drainage, with increased chances that the groundwater supplies will be contaminated by saline irrigation runoff. Such schemes are often characterized by networks of small distribution channels under individual control affected by wastage through seepage and higher risks of salinization.

Many such problems arise because older groundwater-based irrigation projects often grew up without any planning, and their operations remain hampered because of entrenched rights to land and water. Some of these old projects should be rationalized, with compensation when necessary. Groundwater assessment together with the mapping and classification of land types - the information used to plan a new system - would provide a basis for rationalizing older systems and for their continuous reassessment.

When irrigated lands have suffered salinization or other forms of desertification, they should be surveyed as a first step to reclamation. By determining what topographic changes have occurred, the degree of salinization of soil and groundwater amounts and levels, an estimate can be made of what is needed to leach and drain affected lands and what else might be required to restore the system - by relevelling of ground surfaces, for example, or renewal of irrigation channels. How drainage will be effected - whether by tube wells, tile drainage or open ditches - will depend on groundwater conditions, soil properties and costs of land and labour.

When the situation has been made clear, decisions can be made on priorities, which might include abandonment of lands most severely affected, and a reclamation programme designed in terms of the availability of water, labour and capital. After the programme has been implemented, reclaimed lands can be re-allocated, but not without clear regulations on what can be done with them. Reclamation provides an occasion for the enforcement of practices that will prevent desertification from recurring.

Combating desertification in mining

The drylands have always held vast treasure in mineral resources, including the modern world's petroleum, and it can be expected that new discoveries will be exploited there in a now familiar pattern: Revenues will be large compared with other local sources of income; direction and financing will come from outside the region, and almost all financial benefits will be exported away.

In the past, or so it generally seemed, such resources would have been exploited whatever the local human consequences and environmental impact. Nowadays, it is agreed that the region and the local community should be protected from the worst consequences of such exploitation, which is indeed expected to make a proper contribution to regional development and welfare. To assure this, mining proposals must contain an assessment of their environmental impact, and the proprietors of the mines will be expected to meet the full costs of environmental protection and reclamation. Their operations must be so conducted that they contribute to the general development of the region.

It may be difficult to maintain principles when great riches are involved, but in any competition for scarce resources, such as water or land, the rights and needs of the local community should receive priority. When mining or drilling operations are about to be introduced, the local people should participate fully in planning and in all other decisions that concern them, and arrangements should be made for continuing consultation.

The drylands should be favoured with the same standards of environmental protection that are applied in more humid areas. Indeed, drylands may require additional precautions because of the special sensitivity of the arid environment, its susceptibility to air pollution, groundwater pollution, dust nuisance and surface disturbance. As an example, restrictions should be placed on the grading of unsealed roads in drylands and on their use by heavy vehicles.

The activity of mining or drilling and the people who carry it out, many of them brought in from outside, will have all sorts of effects on the surrounding region. Plant and animal reserves may have to be established on the perimeter of the activity, with restrictions on hunting or plant removal over a wider surrounding area. Employees brought in from outside should be placed in suitably designed settlements equipped with proper services.

Mining or drilling ventures will view local communities as a source of labour and a supplier of food and materials, and fulfilling these rôles can affect a community adversely. It sometimes happens that a once-isolated, traditional society is brought into sudden contact with people of a very different kind, often rootless, sometimes violent, accustomed to a transient, unstable society. It will be difficult to maintain the principle that the rights and needs of the local community should be protected and local people are given every opportunity to participate in and benefit from the new development.

Combating desertification associated with tourism

Many of the considerations relating to mining and drilling have equal application to tourist activities and installations in deserts and drylands. Local communities should share in the benefits of tourism. It should provide them with opportunities for employment, improved communications and access to other support services and improved markets for local products, including those of craft industries. But before local communities can share in the benefits of tourism, they may have to be protected from it.

For example, local livelihood systems, such as pastoralism, may have to be protected from interference by tourist activities. The information tourists are provided should include comments on the local people, their customs and way of life, to help ensure respect for their practices and for themselves as persons. Protection may have to be given to sites and objects of traditional cultural importance. In the competition for scarce resources such as water, land and pasture, the needs of local communities should be assigned first priority. This viewpoint and the protection required may best be achieved when local communities participate in the planning and management of tourist activities.

The natural environment will also require protection against tourist activities. Great care must be taken in the siting, design and maintenance of tourist roads, camps and rest areas. Traffic restrictions will be needed, particularly on the use of cross-country vehicles, and roads subject to heavy traffic will have to be paved. Lodges and camps will have to be served with proper facilities, for water, sanitation, rubbish disposal and the control of local traffic. Penalties should be applied to combat littering. Plants and animals will require protection, particularly of endangered or attractive species. Archaeological and scientific sites, interesting geological formations and natural monuments will all require special protection.

The concept of environmental management, so important to sustaining productivity in agriculture, should be extended to the tourist industry. This might involve the establishment of reserves or wilderness areas from which tourists would be excluded and which would serve as refuges and sources of regeneration for plants and animals. Or it might embrace the concept of natural parks for controlled tourism in which the tourist could view an interesting and typical range of natural ecosystems without causing them damage. The management of such parks should incorporate the concept of "recreational carrying capacity" with "deferred" or "rotational" uses to allow for the seasonal vulnerability of species and to spread the impact of tourism. It is obvious that such parks must be adequately staffed with professionals capable of providing tourists with expert guidance.

The development of tourism should be generally controlled in the interest of environmental protection. Such control can be exercised by tourism ministries or tourist boards on which local communities and land users are represented or can be heard. Each tourism proposal should be required to incorporate an environmental impact study, and approval of the proposal should be subject to the provision of adequate environmental protection. The costs of such protection and of reclamation, if subsequently needed, should be borne by the project.

Combating desertification associated with human settlements

Dryland settlements can range all the way from the one-family homestead with its thorn-tree fencing to great, modern cities with millions of inhabitants. The usual dryland settlement, however, will be a village or small town that has grown up to serve the needs of the livelihood systems practised in arid settings. A number of measures can be taken to improve conditions in such settlements and reduce their adverse impact on the environment.

Reserves should be established surrounding settlements and extending for a few kilometers out from their limits and within which grazings, farming and fuel gathering are restricted. Such reserves must be well fenced on their boundaries and wherever they are traversed by roads. They should be regarded as areas affording regeneration of natural vegetation, but they may be subject to land treatment and planting where degradation is advanced.

Special measures will be required to check active physical degradation around settlements when it threatens urban land and gardens. It may be necessary, for example, to stabilize moving sands and to che k gullies or fill them in.

Roads in and near settlements should be paved or otherwise improved. Traffic should be confined to roads by fencing.

Open areas inside settlements which form sources of dust nuisance or which retain stagnant water after rain should be brought under control. Grassing and planting of shelter belts may be required, but attention should be given to types of wind-stable ground cover which require little maintenance and consume little water, as for example gravel surfaces relieved by the planting of local trees and shrubs.

Adequate storm drainage should be provided to handle the runoff from rains which if infrequent are often intense when they come.

Services such as water supply, sanitation, waste disposal and street maintenance should not only meet general standards but should be reinforced to cope with the special stresses due to the desert environment.

Assistance and encouragement should be given to residents to improve conditions in and around their own homes. Insulating or screening materials might be provided or help given in the reconstruction of homes or in the establishment of gardens, shelters and shade belts.

If much can be done to improve the conditions of existing settlements, control must be exercised over their further growth.

Proposals to expand settlements or to establish new towns should incorporate environmental impact assessments which take into account the possibilities for desertification that such activities bring with them. The assessments should include estimates of future demand for water and energy and for land presently used for other purposes, and of the consequences of these projected demands. They must include estimates of requirements for waste disposal, sanitation and other services.

New housing and settlements should be designed to reduce stresses imposed by the desert environment, for example by the layout and orientation of houses, by screening, insulation and cooling devices and the provision of outdoor living areas, all planned to be compatible with local life styles. Roofs should be designed to catch and store stormwater and should be adaptable to the use of solar heaters. Settlements should incorporate shelters and the control of open spaces to reduce the threat of wind, dust and moving sand. Perimeter reserves and controlled recreation areas should be included as a normal part of urban plans.

Research should be encouraged into architectural and living problems in desert regions. Studies should be made of the use of solar energy at various scales for domestic needs and industry, of the use of wind energy in small installations, and of other alternative energy sources which can reduce the use of wood as fuel. Local materials should be studied for their use in construction. Progress can be made in improving insulation and cooling systems, including those employing solar power. Trees and shrubs should be examined for their suitability as protection and ornaments in deserts settlements. Research should continue on techniques for the desalination of water, on recycling water, and on the use of brackish water in sanitation and industry. Studies can result in improvements in subsurface water storage and the purification of water supplies. Methods of waste disposal can be more compatible with the arid environment.

Some control needs to be exercised over the relationships between settlements and their hinterlands. In recent decades, urban growth in and near deserts has been linked to out-migration from nearby rural areas. Since such migration will continue, it should be anticipated in plans for housing and community services. Urban development plans should form an integral part of regional development and resettlement schemes.

Urban development, with its demands for water, fuel, construction materials, land and labour, should not be carried out to the detriment of adjacent livelihood systems. The prior needs and rights of those systems should be protected from the environmental impact of planned settlement growth, and the siting and design of settlements should be influenced by such considerations. At the same time, rural people should be made aware of the possible advantages to them of nearby settlements, and they should be involved in planning new communities and preparing for the growth of established settlements.

In Conclusion

This survey of desertification contains many suggestions, both explicit and implicit, for combating the process and for reclaiming land that has suffered the ravages of degradation. Many of these suggestions appear as recommendations in the Plan of Action to Combat Desertifcation that will be submitted to the United Nations Conference on Desertification to be held in later summer of 1977.

Some suggestions call for additional research and an improved understanding of ways in which desertification operates and of methods for combating it. This is all to the good, as is any proposal that would make the task of land reclamation easier. But the fact is that most instances of desertification can be dealt with through knowledge and experience that are available right now. The Romans applied terracing to convert the North African littoral into the breadbasket of the Mediterranean. Good land-use practices transformed the Great American Desert into the wheat empire that it is today. The SCARP project in Pakistan has reclaimed 45 per cent of one million waterlogged acres of once-productive irrigated land.

The immense changes affecting the contemporary world have brought the problem of desertification into sharper focus than ever before, just as pressures on the sensitive dryland ecosystems are more intense than ever before. Desertification can be halted and ravaged land reclaimed in terms of what is known now. All that remains is the political will and determination to do it.