Distr.
LIMITED

E/ECWA/NR/L/1/Rev.1
January 1981

Original: ENGLISH

UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC COMMISSION FOR WESTERN ASIA
NATURAL RESOURCES, SCIENCE AND
TECHNOLOGY DIVISION

ASSESSMENT OF THE WATER RESOURCES SITUATION IN THE ECWA REGION

81-4474

CONTENTS

PART A

CONTENTS

PART B

CONTENTS (Cont'd.)

CONTENTS (Cont'd.)

CONTENTS (Cont'd.)

ABBREVIATIONS

a.s.l	Above sea level
atm.	Atmospheres
bcm	Billion cubic meter (Thousand million cubic meter)
c-14	Carbon-fourteen
Ec	Electric conductivity
gpm	Gallon per minute
gpd/ft	Gallon per day/foot
K	Hydraulic conductivity or permeability
Km^2	Square kilometer
Km^3	Cubic kilometer
l/s	Liters per second
l/s.m	Liters per second per meter
m	Meters
m/d	Meters per day
m^3/s	Cubic meters per day
mg/l	Milligrams per liter
mm	Millimeters
mm/a	Millimeters per annum
MCM	Million Cubic Meters
MCM/a	Million Cubic Meters per annum
MIGD	Million Imperial Gallon per Day
Q	Rate of discharge
ppm	Parts per million
swl	Static water level
S	Storage coefficient
T	Transmissivity
TDS	Total dissolved solids
BRGM	Bureau de Recherches Géologiques et Miniéres de France
FAO	Food and Agriculture Organization
HKJ	Hashemite Kingdom of Jordan
IGS	Institute of Geological Sciences of United Kingdom

MEW	Ministry of Electricity and Water of Kuwait
NRA	Natural Resources Authority of Jordan
PDRY	People's Democratic Republic of Yemen
UAE	United Arab Emirates
UNWC	United Nations Water Conference
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
WMO	World Meteorological Organization
YAR	Yemen Arab Republic.

CONVERSIONS

Measuring systems used in member countries are often retained. Hence both the metric and imperial systems are used in the report. The following conversions are given for the readers' convenience:

Cubic measure and capacity

yd^3	ft^3	in^3	m^3	cm^3	gallon Imp.(GB)	gallon U.S.	liter
1	27	-	0.765	-	168.2	202	-
-	1	1728	2.83x10−2	-	6.23	7.48	28.32
-	-	1	-	16.39	-	-	-
1.308	35.315	-	1	10^6	220	264.2	10^3
-	-	6.1x10−2	-	1	-	-	
	1.605x10−1	277.4	-	-	1	1.2	4.546
-	1.34x10−1	231	-	-	8.33x10−1	1	3.785

Volumetric flow

ft^3/sec cusec	m^3/h	I/sec	Imp.g.p.m.	U.S.gpm
1	102	28.32	374	449
9.81x10−3	1	2.78x10−1	3.67	4.403
-	3.6	1	13.20	15.85
2.68x10−3	2.73x10−1	7.58x10−2	1	1.2
2.23x10−3	2.27x10−1	6.31x10−2	8.33x10−1	1

1 m^3/d/m = 0.0929 ft^3/d/ft (for transmissivity)

1 MCM/a = 0.6x10^6 imp.gal./day.

GLOSSARY

(Terms used in the text)

Term	Definition
Aquiclude	A geologic formation which contains water but cannot transmit it rapidly enough to furnish a significant supply to a well or spring.
Aquifer	A geologic formation which contains water and transmits it from one point to another in quantities sufficient to permit economic development.
Drawdown	Change in surface elevation of the groundwater resulting from withdrawal of water from a well.
Equipotential line	A contour line which represents or traces the equal head in the aquifer.
Fossil or Connate Water	The groundwater which occurs in the rock at its formation and frequently highly saline.
Permeability	The capacity of a porous medium (aquifer) for transmitting water.
Piezometric level	The elevation to which the water level rises in a well that taps an artesian (confined) aquifer.
Safe yield	The rate at which water can be withdrawn for human supply without depleting the source to such an extent that withdrawal at this rate is no longer economically feasible.
Specific capacity	The yield per unit of drawdown in a pumping well.
Storage coefficient	The volume of water released from storage, or taken into storage, per unit of surface area of the aquifer per unit change in head.
Transmissivity	The rate at which water will flow through a vertical strip of the aquifer with unit length wide and extenting through the full saturated thickness, under a hydraulic gradient of 1.00.

Term	Definition
Baseflow	Part of the flow which enters a stream channel from groundwater.
Isohyetal Map	The map which defines or describes rainfall distribution and behaviour in a given period. Isohyets: lines of equal rainfall amount.
Manning Roughness Coefficient	Characteristics of boundary conditions in a stream channel regardless of its slope and size or depth of water flow.
Meteoric Water	Derived from precipitation.
Runoff Coefficient	The ratio of surface runoff volume to total volume of storm rainfall over an area and depends on the characteristics of the drainage basin.
Surface Runoff	That part of storm precipitation which flows over the land surface before it reaches definite channel or stream.
Live Storage	Volume or cubic capacity of a lake or reservoir between the normal maximum and minimum operating levels.
Electric conductivity	Reciprocal of electrical resistivity of water. It is measured as indicators of water quality and is expressed in micro-mhos.
Parts per million (ppm)	It denotes water quality in weight-per-weights units. One part per million represents 1 milligram of solute in 1 kilogram of solution.
Total Dissolved Solids	Total weight of dissolved mineral constituents in water per unit volume or weight of water in the sample.

List of Figures

List of Tables

List of Tables (Cont'd)

P R E F A C E

The United Nations Water Conference, held in Mar del Plata, Argentina, March 1977, recognized that a proper assessment of water resources at national levels should be undertaken in all countries of the world, and in particular in developing countries. The conference considered that this assessment can be achieved only if all countries strengthen and co-ordinate arrangements for the collection of data and dissemination of information in the field of water resources development, conservation and management[1/].

A programme element entitled "Assessment of Water Resources Situation in the ECWA Region" has been implemented as one of projects included in the 1978/1979 work programme[2/]. It was approved by the member governments at the fourth session of ECWA. The objective of this element was to establish a basic survey of the available and potential water resources and to arrive at appropriate plans of actions and recommendations to develop them. The implementation of the element required a field mission to the region with the intention to collect the necessary information and data and to establish contacts with the authorities concerned in each member country. It should be noted that the information contained in this study is primarily based on the analysis of the available water resources literature, official country documents and data released to ECWA staff by officials of the member governments.

The study is presented in two main parts: A and B;

Part A contains the introduction, state of art, method of implementation and regional review and appraisal of the main aspects having relevance to the water resources assessment process. It also includes a regional outlook of the water resources (surface and groundwater) and it ends with proposed actions and recommendations at national, subregional and regional levels. These last two categories of actions are based on the analysis contained in Part B of the report.

1/ United Nations Report of the UNWC, Mar del Plata, 14-25 March 1977, E/CONF.70/29, Res. I p. 66.

2/ United Nations Report of the fourth session of ECWA, Vol. II, Programme of Work and Priorities, 1978/1979, E/5969/Add.1, p. 97.

Part B presents the predominating hydrological and hydrogeological conditions at national levels. The analysis are made on a country-by-country basis and covers surface water, groundwater, non-conventional water resources and country's major water areas. Each country section ends with the main findings of the analysis. Emphasis is placed on the findings having subregional and/or regional parameters.

I. INTRODUCTION

Most of the ECWA region belongs to the arid or semiarid zones which are characterized by scarce or limited water resources. The growing demand for water supply as a result of the rapid socio-economic development in the region, is restricted by serious problems related to the availability of water resources. Hence, the region as a whole suffers or will soon suffer from acute overdraft conditions, exemplified by water quality deterioration and/or resources depletion due to excessive exploitation. These conditions are likely to grow even worse for many reasons among them are the following:

- The general absence of national planning and well-designed policies that would bring the exploitation and allocation of the available water resources in line with the overall socio-economic development plans.
- The lack of awareness in the private sector and in some cases the public sector, of the need for the rational use and management of water resources.
- The lack of adequate knowledge of the available and potential water resources in quantity and quality.
- The general absence of effective and central institutions responsible for co-ordination of related water activities at national levels.
- The lack of public awareness in conserving water and of using methods which minimize usage as well as the lack of publicity for saving water through radio, television and newspapers.

Among the primary requirements involved in planning for optimum utilization and efficient allocation of water resources is a sound quantitative and qualitative knowledge of the available and potential water resources. In its first resolution the United Nations Water Conference held in 1977 stressed the need for assessment of water resources at national level. It recommended that member States should give

../...

high priority to initiating programmes for collection, processing, storage and dissemination of hydrological and hydrogeological data and to formulating long-term monitoring and following-up programmes so as to arrive at realistic assessments of the available water resources and the means to developing them.

I.1 Water resources assessment programme[3]

The objective of assessment of water resources are: to determine the sources, its quantity and quality, dependability of water supplies and the parameters on which an evaluation of the water supplies can be based. The evaluation of the available and potential water resources of a basin is a continuing activity through which the assessment process is to be refined so as to secure adequate, continuous and safe water supply in line with the progressive economic development.

Water resources assessment programmes may be undertaken in three main stages: During the first State evaluation of the available hydrological and hydrogeological data is the primary job to be undertaken. Processing, interpretation and analysis of the existing water records will lead to proposing and establishing the minimum required hydrometeorological networks in accordance with the WMO Guide to Hydrological Practices. For easy understanding of the water resources situation, at the national level, tentative subdivisions of the country should be worked out during this stage. The criteria for subdividing the country should rely mainly on hydrologic, hydrogeologic, climatologic, topographic and socio-economic factors. The final outcome of this stage is a preliminary evaluation of the available water resources based on the existing and collected water data and on assumptions made from experience. A preliminary plan of action should be drawn to deal with proposals related to data collection, processing, availability of manpower and institutional arrangements and networks.

3/ More details in United Nations, UNESCO/WMO Paper on Assessment of Water Resources, E/C.7/78.

During the Second Stage the following activities may be considered:

- Network improvements, modification and extension in accordance with the outcomes of the first stage[4/].
- Refining of the country's subdivisions and delineation of major water balance areas bearing in mind the possible water engineering projects and economic feasibilities.
- Monitoring and updating of water data and hence refining or reevaluation of the available water resources accordingly.
- Delineating the potential water resources based on long-term and detailed hydrologic and hydrogeologic investigations.
- Construction of water resources and economic digital models or others relying on the available data and the future socio-economic modalities. These models will furnish long-term predictions of the national water resources situation in response to various socio-economic aspects.
- National water master plans may be drawn afterwards. The plans will deal with all aspects related to: manpower, institutional arrangements, design of integrated surface and groundwater development projects, monitoring programmes, allocation of water resources for various sectors, economic use of water, water strategies, environmental conditions, etc...

The Third Stage is primarily operational, monitoring and management activity. The objective is to conserve the available and develop the potential water resources to cope with the rapid socio-economic development in the region. A prime requirement in this stage is to avoid over exploitation of resources, exemplified by quality deterioration and/or depletion of the sources. Long-term plans may be continuously refined. Updating the water records, systematic analysis, storage and retrieval of water data, modification of networks if necessary, updating

---

4/ In this connexion consult: United Nations, WMO, Case Book on Hydrological Network Design Practice, WMO - No. 324, 1978.

and modification of the constructed models, reviewing and proposing efficient institutional arrangements, water legislation and educational institutions and keeping up with applications of modern technology in various water aspects, are all items to be considered during this stage.

It is evident that the water resources assessment programme is a continuing activity and should be firmly considered as an integral part of all national development plans. It is supposed to deal with every aspect that has in one way or another a certain impact on the water resources development. The topic is so wide that it may be beyond the scope of the present study. Nevertheless the following items are believed to be the most important ones involved in the implementation of the assessment programmes.

I.1.1 Basic data collection, processing, storage and retrieval and related services

(a) Observational networks and data collection:

Regarding observation of water data the following may be considered: Networks inventory, adequacy, reliability and distribution; plans for future improvement, modification and expansion; adequacy of manpower to operate and maintain the existing and future networks and measuring and recording instruments in quantity and quality.

Regarding data collection the basic elements to be considered are; precipitation, infiltration, soil moisture, surface runoff, sediment transport, river stages, groundwater levels, well logs, aquifer parameters, water quality and pollution. Time length of intervals to observe and collect water data, is also to be considered.

(b) Data processing, storage and retrieval:

- Availability and adequacy of data processing facilities and software; availability of trained manpower, water data banks, availability of computers; plan for future expansion of facilities and improvement of software; dissemination of information.

(c) Workshops, laboratories and related services:

Water quality laboratories; facilities and staff of maintenance and repair workshops for hydrological and hydrogeological equipments and instruments; plans for future expansion of facilities and training of personnel.

I.1.2 Administering and management of assessment programmes

(a) Institutional arrangements

Identification, description and evaluation of existing and planned agencies and institutions responsible for water related activities; budgetary situation and the rate of expenditure on the ongoing water related projects and future expenditure.

(b) Water legislations and management

Identification of water regulations, legislations, ordinances decrees etc..; national water policies strategies and planning for water resources development; any bilateral and/or multilateral co-operation in water resources activities, including research, manpower training, operational services and dissemination of information.

I.1.3 Areal assessment of water resources

(a) Surface water

Topographic maps and areal photos; previous bydrological and hydrometeorological investigations; availability of thematic maps; applications of remote sensing and modelling; execution of water projects by national or foreign consultants; plans for future water resources assessments; status of assessment programmes.

(b) Groundwater

Hydrogeological, geological and topographic maps; previous investigations; applications of remote sensing, geophysical techniques and modelling; availability of thematic maps; use of national or foreign consulting firms for geohydrogeological areal assessments and test drilling; plans for future assessments.

I.1.4 Research, education and training

Existing and planned research programmes related to the various elements involved in water resources assessment, such as hydrological, hydrogeological, geophysical, hydrochemical and biohydrological researches; identification and accessibility of research facilities and use of computers; availability of specialized manpower, scientists and laboratory technicians; disseminations of recent scientific developments through refresher courses, workshops, seminars and international contacts; national universities and institutes dealing with water related subjects; training facilities; plans for enhancing the scientific capacity and training aspects at national level (participation in regional and overseas training programmes).

I.2 The present study

The present study deals mainly with the availability of the water resources in the ECWA region. The primary objective is to provide a regional assessment of the water resources situation. It may not add much at national level, but it may be considered as a first step towards better understanding of the resources availability and probably potentiality at regional level.

As mentioned earlier the "assessment of water resources" deals with all aspects pertaining to the water sector. Hence this study may be considered as complementary to the other studies implemented in the 1978/1979 work programme, aiming at an integrated plan for water resources assessment in the region. These studies pertained to: Manpower needs and problems in the field of Water Resources, Projection of water Demand by the year 2000 and Collecting, Compiling and Analysis of Water Data. This integrated programme will also include the topics planned to be undertaken in the forthcoming work programmes namely: "Water Legislation and Administration", "Economic Use of Water" and "Dissemination and Exchange of Information in the Water Field".

The study was carried out through the following undertakings:

1. Setting up and distributing questionnaire relating to the main aspects of water resources availability and potentiality at the national level.

2. Field mission to the member countries to collect data and information and to consult the concerned Government Officials. The data collected was based on its availability and the willingness and co-operation of the Officials to reveal the necessary information.

3. Consulting relevant literature, country reports and documents, made available through direct contact and/or correspondence with the concerned government authorities, United Nations specialized agencies, consulting firms and other knowledgeable individuals. Every effort was made to make use of the latest information available, and

4. Evaluation and interpretation of the collected data and information and then formulation of the regional outlook of the water resources situation.

The country-by-country discussion in part B of the report followed almost the same pattern. The main topics discussed and presented in a countrywide manner were based on the collected water data and the relevant available information on the water resources situation in each member country is totally based on the official literature, country reports, documents and water data made available to ECWA staff during their mission to member countries. When the data is not available or inadequately presented in one country, the discussion and presentation of the topic is based on hydrological and hydrogeological correlation with those prevailing in the neighbouring member countries whenever possible.

The occurrence, movement, accumulation and some physical characteristics of both the surface and groundwater resources are highly affected by certain primary physiographic features; namely: climate, topography and geology. Hence it is envisaged that it is worthwhile to present these primary features in a very brief manner. Under geology the stratigraphy of the rock sequences and the major geologic structures were discussed briefly so as to arrive at a comprehensive understanding of the water bearing formations at national levels. Accordingly, a regional hydrogeologic correlation and delineation of the shared major aquifers in the region, was anticipated.

More emphasis was placed in the text regarding the Geologic Conditions (stratigraphy and geologic structure) in Saudi Arabia and Jordan. The former shows a great resemblance to most of the geologic sequences croping out at the surface or existing in the sub-surface of the entire Arabian Peninsula and even in south west of Iraq and south and south east of Jordan; the latter shows to a certain extent some affinity to those geologic conditions occuring in Lebanon and Syria. In addition, the predominating geologic structures: the Arabian Shield in Saudi Arabia and the Rift Valley System which encompasses the Gulf of Aqaba - Wadi Araba - Dead Sea - Jordan Valley - Beka'a - Ghab and Massyaf Depression were described. These structures have a major role on the occurrence, accumulation and movement of water (surface and subsurface) and aquifers areal extent in the Arabian Peninsula, Jordan, Lebanon and Syria.

Particular attention was paid to the hydrologic and hydrogeologic conditions whenever the data was adequate. The activities pertaining to desalination and sewage effluent treatment plants were tackled under non-conventional water resources. The text in each country statement ended up with certain conclusions which are believed to be of interest at national and regional levels. The outcomes of these conclusions enlighten the way to formulating the regional outlook of the water resources situation.

II. REGIONAL REVIEW AND APPRAISAL
(In relation to Water Resources Assessment)

Many countries of the ECWA region have recognized the urgent needs to develop, conserve and manage their vital water resources. Water assessment and planning to determine the most appropriate allocation of the resources to the various water users as well as to formulate medium and long-term water policies and guidelines for the exploitation, utilization and subsequent management of the water resources, were the objectives and targets undertaken during the last decade in some member countries of the ECWA region.

The progress observed pertaining to the primary areas of specific concern as related to water resources assessment activities in the region, may be described briefly as follows:

II.1 Basic data adequacy and reliability and networks

In general, in many countries of the region, there are serious inadequacies in the availability of the basic hydrologic, hydrogeologic and hydrometeorologic data. Even if data is available, it lacks the use of proper modern techniques to make use of the available data. They are scanty and widely distributed in space and time, and if they are available, they are often of not long enough records particularly in People's Democratic Republic of Yemen, Yemen Arab Republic, Oman, United Arab Emirates, Qatar and Saudi Arabia. In Iraq, Lebanon and Syria the hydrogeological data and information are inadequate while the surface water data has been well undertaken.

Programmes pertaining to measurements of basic water data from networks of meteorological, hydrological and hydrogeological stations, collection, processing storage and publications of basic data were undertaken in recent years in many countries of the region. Plans to strengthen and modify the existing networks. are being considered in some countries such as Jordan, Syria, Qatar and Saudi Arabia.

Countries with adequate networks are Qatar, Lebanon and Jordan. Poor networks exist in Bahrain, Oman, People's Democratic Republic of Yemen and Yemen Arab Republic. Fair or acceptable networks occur in Iraq, Kuwait, Saudi Arabia, Syria and United Arab Emirates.

New and latest techniques were employed in some countries in the region to analyze water data and to assess their water resources. Isotope analysis, groundwater modelling (analogue and digital), geophysical prospecting and remote sensing were applied in water resources investigations in some basins in Jordan, Syria, Iraq and Saudi Arabia.

II.2 Progress in the organization of water resources administration and management

II.2.1. Institutional arrangements

At the national level good efforts have been made in some countries to inventory and administer the available and potential water resources: However in spite of all the work already carried out, the countries are far from achieving an integrated management of their total water resources.

In some countries of ECWA region steps to unify and centralize their national water institutional arrangements were undertaken, like Jordan, Sultanate of Oman, Yemen Arab Republic and Syria. In other countries various water related institutions are still existing.

The formation of national committees to deal with other regional and international programmes has been created in some countries as a result of UNESCO Hydrologic Programmes, as in Jordan, Iraq and Syria.

II.2.2. Water legislation

Water legislation in the region is in most cases complex and outdated compared to modern water management practices and techniques and perpetuates an undesirable fragmentation of administrative responsibilities. Provisions which regulate water resources development and management are often contained in different laws and regulations.

Many countries in the region are making critical examinations of legislation rules, regulations, customs, decrees, ordinances and other measures of control in the water resources field. Saudi Arabia, Iraq, Jordan, Oman and United Arab Emirates are actively engaged in such review. The conference of the Ministers of Agriculture of the Gulf states and the Arabian Peninsula had underway a proposed model of subregional legislation for the area.

II.2.3. Water planning and policies

Jordan has established an overall national water master plan early in 1977. The plan aims at the best use of the available resources (water, funds, manpower and other relevant means), the most suitable methods and operations and as far as practicable the reuse and renewal of the resources, Kuwait is another country in the region now having a national water policy. In Oman a draft statement on a national water policy has been prepared. Other countries such as Iraq, Saudi Arabia and Syria have the subject under consideration. These national water policies are expected to encompass many aspects of the water resources fields that aim at wise management, conservation and development of this vital resource.

II.2.4. Education, training, research and manpower

Education and Training in the water resources field is becoming recognized as one of the vital needs of the ECWA region. To satisfy these needs several universities have incorporated into the curriculum many courses related to the various aspects of water resources. The University of Baghdad, for example, since 1942 has offered a B.Sc degree in irrigation. Universities in Iraq, Syria, Kuwait and Jordan offer B.Sc degree in Civil Engineering and include many water related courses in the curriculum. The Water Resources Development Centre in Kuwait offers a technician's degree in the theory and operation of desalinization plants. Technical training in water related fields is also offered in Saudi Arabia, Iraq, Syria and Jordan. Other countries such as Democratic Yemen have specialized training in soil and water analysis and irrigation water use. Many countries have on-the-job training while others rely on outside sources for all higher education and technical training.

Various research programmes are planned or are underway throughout the ECWA region. Presently Saudi Arabia has an Agricultural Research Centre in Riyadh and a Marine Sciences Institute in Jeddah. The College of Science at Jeddah will conduct studies on water pollution, fisheries development, water resources development and on meteorology through the period 1975 to 1980. A research programme is scheduled to be initiated for environment and water resources in 1978-1979 at the University of Petroleum and Minerals in Dhahran. Other research centres are in planning stages.

Iraq now has a foundation for Scientific Research which includes water related research. Also underway in Iraq is a new Irrigation Water Research Centre. Other water related research is underway at university level. Qatar has similar research activities underway at university level. Kuwait has the existing Water Resources Development Centre which promotes programmes for research and maintains a library that is available to others. Also located in Kuwait is the EUROARAB Institute for desalinization. In the United Arab Emirates and in Kuwait the FAO maintains an agricultural experimentation farm to conduct research programmes related to water in agriculture. Several other research centres exist in Democratic Yemen. These are located at Al-Code, Saion and Hauta as part of the Nassar College of Agriculture.

During the past few years, the ECWA region has experienced a rapid increase in manpower demand due to the improvement and modernization in various sectors of water resources development and management. A serious shortage of skilled manpower in water related fields was revealed.

II.3 Status of the water resources investigations

As can be revealed from the discussions presented in Part B of this report, the extent of water resources investigations carried out, varies from country-to-country in the region. It varies in coverage, kind and reliability. In Iraq, Lebanon and Syria, appreciable hydrological studies were undertaken as early as 1940's. The groundwater studies in these countries are almost spotty like in Iraq or limited as in Syria and Lebanon. In Jordan and Qatar good coverage and relatively reliable hydrologic and hydrogeologic investigations were conducted. In Oman, Saudi Arabia, People's Democratic Republic of Yemen and Yemen Arab Republic the water resources investigations, primarily groundwater, were undertaken in a spotty manner bearing in mind the socio-economic constraints. These local studies were carried out based on short-term observations and several assumptions. Hence they are at best indicative and sometimes misleading. In Kuwait and Bahrain appreciable hydrogeologic studies were undertaken. Non-conventional water resources investigations and productions was a topic which had a great deal of undertakings in Kuwait, Saudi Arabia, United Arab Emirates, Qatar and Bahrain during the last decade.

III. REGIONAL HYDROGEOLOGY AND AVAILABILITY OF WATER RESOURCES

III.1 Geologic setting

The regional geologic conditions, stratigraphy and structure; and the prevailing physiographic features have the major role in the occurrence, movement and accumulation, in quantity and quality, of the surface and groundwater resources of the region. A brief note on the regional geologic setting is noteworthy mentioning here, aiming to better understanding of the prevailing hydrogeologic conditions in the region.

In the North and North East, the Arabian Peninsula is framed by the Arch of the Anatolian and Iranian Fold Mountains. South of these mountains, the Mesopotamian Foredeeps are located, a zone of marginal troughs with thick Mesozoic and Cenozoic sediments of marine geosynclinal facies. The thickest accumulation of sediments occurs at the eastern side of the Arabian Gulf. The thickness decreases in north-westerly directions and the zone becomes somewhat shallower and narrower till it forms in the north in Syria a small seam along the southern margin of the folded mountains. The marginal troughs gradually pass southwards into the wide zone of the unstable shelf of the Arabian Platform. The sediments of this zone represent the transition from geosynclinal facies to the predominantly continental deposional environment in the foreland of and on the Nubian-Arabian shield. It is the area where marine, mainly neritic successions of mostly carbonate rocks were deposited. The unstable shelf is subdivided into local basins and swells in Syria and Jordan, the eastern province of Saudi Arabia and in the Gulf states. The basins offered locally favourable conditions for the accumulation of euxinic rocks and the swells areas were subjected to terrigeneous influence.

The transition zone from the unstable to the stable shelf extends approximately north-north-eastwards from Central Sinai to the Gulf of Aqaba and from there follows the Wadi Araba Depression in Jordan; in south Syria it trends eastwards and south-eastwards; in Saudi Arabia, it trends southwards and approximately parallels the Arabian Gulf in the Riyadh area. In the zone of the stable shelf, neritic, littoral and continental sediments are interfingering.

The south Sinai Peninsula, the areas adjacent to the Gulf of Aqaba and the Red Sea as far as approximately the northern border of the Yemen Arab Republic, are occupied by the Nubian-Arabian Shield, which regionally emerges south-westwards. Clastic sediments of continental origin and rocks of the Pre-Cambrian basement complex charcterize this area[5/].

Based on the hydrological and hydrogeological conditions, the region can be grouped into two main categories:

- The Arabian Peninsula Block which encompasses Saudi Arabia, the two Yemens and the Gulf states.
- The northern and north eastern Arabian Platform which encompasses Jordan, Lebanon, Syria and Iraq.

III.2 The Arabian Peninsula Block

The major geologic structures which occur in the Arabian Peninsula Block and have direct control on the water resources conditions are:

1. The Arabian Shield lies on the west and south of the region. It forms the almost straight 2000 km. long eastern shore of the Red Sea and about 1500 km. long northern shore of the Arabian Sea and extends in land for about 700 km. to form the great Najd area towards Riyadh and to form the 300 km. wide plateau in the Yemen Arab Republic. It has three major components:[6/]
   - The Western Arabian Shield forming the central Najd-Hijaz and Asir highlands.
   - The Yemen Plateau which extends to Aden.
   - The Southern Arabian Shield along the Arabian Sea Coast.

5/ Bender, F. "Geology of Jordan", 1974 pp. 16-17.

6/ Abdel Basset El-Khatib, Saudi Arabia "Seven Green Spikes," 1974 pp. 3-5.

These components are the uplifted areas of the region and mostly composed of basement complex which often do not contain water. They receive the relatively high annual rainfall and encompass the major active recharging zones to the aquifers that occur in: the intra mountain plains, flood plains, within the sedimentary sequence that occur at the mountain slopes away from the basement complex and within Tehama, Arabian Sea and Batinah coastal plains. Most of the surface runoffs originate from these components and flow towards the coastal plains or inland areas.

2. The Arabian Shelf: It is formed predominantly from sedimentary sequence which encompasses all the water bearing formations (aquifers) in the Arabian Peninsula Block. As mentioned before, these aquifers are recharged from the highland components of the Arabian Shield and from the surface runoffs along the drainage pattern originated from the shield and cut through the sedimentary plains of the Arabian Shelf.

   The Arabian Shelf comprises three main components:

   - The Interior Homocline which resulted in a wide synclinarium in the north in Wadi Sirhan (in Saudi Arabia and Jordan), in a broad anticlinarium in Hail (Saudi Arabia) and in Central arches and in a gentle synclinarium in the Rub-el-Khali.
   - The Interior Platform caused by horst-type block movements on the very east and along the Arabian Gulf.

     Qatar, Bahrain and Kuwait belong to this platform.
   - The Basins which are: Rub-el-Khali, the northern Arabian Gulf, the Dibdiba and the Wadi Sirhan-Turaif basins in the north of Saudi Arabia.

Rainfall in the subregion is generally low and scarce and of mediterranean type in the north and monsoonal in the south. It is more arid than semi-arid. Rainfall volume over the Arabian Peninsula is estimated at 214 bcm/annum. High rainfall zones occur over the uplifted mountains of the Arabian shield along the Red Sea Coast, the Gulf of Aden, the Arabian Sea and the Gulf of Oman. The climate is generally hot, tropical and dry in summer and moderate to cold in the inland areas in winter, with daily high temperature differences in most of the subregion.

In the Arabian Peninsula Block, surface water resources are limited and rely on the eratic, irregular, sporadic and un-predictable floods. The possibility of making use of these floods may be useful and appreciable in some localities such as Tehama and the Batinah coastal plains in Oman and United Arab Emirates.

The drainage pattern in the subregion may be described as follows:

- The coastal plains wadis which originate from the western slopes of the Arabian Shield and flow towards the Red Sea.
- The inland wadis which issue from the internal slopes of the Shield and flow southwards to the Arabian Sea or eastwards towards the Arabian Gulf.
- The closed inland wadis which originate also from the internal slopes of the Shield and flow mainly to the Rub-el-Khali Basin or the Azraq Basin (Jordan) in the north.

Groundwater and non-conventional water resources (desalted and treated sewage effluent) are the major components of the water supply in the Block. The main producing aquifers in the subregion belong to Paleozoic sands, Mesozoic sand and carbonate rocks, tertiary carbonate rocks and quaternary alluvium. Groundwater quality deteriorates generally as one goes further from the shield towards the inland basins or the sea coasts.

The hydrogeologic setting in Saudi Arabia discussed in Chapter IX of Part B presents the primary features of the groundwater conditions prevailing in the Arabian Peninsula. Table A.1 (a) shows the hydrogeologic correlations of the major aquifers in the subregion. These aquifers can be grouped into:

- Volcanic rocks group which predominantly occurs in the Yemen Plateau and contributes highly to the groundwater resources of the Yemen Arab Republic.
- Sandstone group: It has a wide occurrence in the Arabian Shelf and is characterized by its uniform distribution, artesian conditions and contains good groundwater potential and of relatively good quality.
- Carbonate rocks group: It also has a wide occurrence in the Arabian Shelf but with less uniformity in its groundwater potentiality and quality. It is generally of artesian conditions.

The limited water resources of the subregion could not meet the increasing water demand due to the rapid socio-economic developments which the countries of the Arabian Peninsula have experienced in recent years. This situation led the concerned authorities particularly in the Gulf states, to explore additional water resources to meet their water demand through desalination of sea water. At present the total estimated desalinated sea water production in the subregion is about 142 MCM, of which 103 MCM is being produced in Kuwait, 17 MCM in Saudi Arabia and 10 MCM in Qatar. It is expected that the rate of desalinated sea water production would reach 236 MCM by the year 1985.

Table A.2(a) shows a summary of the available and potential water resources of the subregion.

III.3 The Northern and North-Eastern Arabian Platform

The predominating geologic structure which affects directly the water resources conditions are:

1. The NE Secondary Split of the African Rift Valley System which starts by the Gulf of Aqaba and terminates in Karasu Depression in Turkey.

This major geologic structure comprises the Wadi Araba - Dead Sea - Jordan Valley - Lake Tiberous - Hula - Beka'a - Ghab and Massyaf Depression (Geologic Graben) in Jordan, Lebanon and Syria. The structure trends almost in a NNE direction and is bounded in the west and east by uplifted blocks which receive the highest annual rainfall in the subregion (600-1800 mm/a). Active recharging zones coincide with the peaks of these highlands on both sides of the Graben. Sub-surface flows occur in easterly and westerly directions away from the uplifts recharging the aquifers that occur within the highlands, in the coastal plains, the structural depressions and to the east in the inland basins.

The hgihlands are lithologically composed of Basement complex in southern Jordan, Jurassic - Cretaceous - Paleogene carbonate rocks in Jordan, Lebanon and Syria and Green Volcanics in the north of Syria. They are trancated by almost uniform E-W and W-E drainage patterns along which surface runoffs flow towards the coastal areas, to the structural depression and to the inland areas. Another flow direction is almost NNE along the Geological Graben. Such as the flow of Al-Asi, Litani, Hasbani and Jordan rivers in Syria, Lebanon and Jordan.

TABLE A-1 (a) REGIONAL HYDROGEOLOGY (contn'd)

Geologic Time Scale: ERA	PERIOD	EPOCH	THE ARABIAN PENINSULA BLOCK — SAUDI ARABIA: Formation	Lithology	Aquifer charact.	QATAR and BAHRAIN: Formation	Lithology	Aquifer charact.	OMAN and U A E: Formation	Lithology	Aquifer charact.	YEMEN ARAB REPUBLIC: Formation	Lithology	Aquifer charact.
CENOZOIC	Quaternary			all.			sandy marl and sandy l.s	fair to good	Holocene	sand,gravel congl.silt and evap.	good		alluvium Basalt	good
	TERTIARY Neogene	Pliocene & Miocene	Hofuf	l.s.,gyp. sandy marl,l.s		Fars						Trap series	volcanics	fair to good
			Dam	marl,sh.,s.			marl,sh.s.s.			marl,clay evap.			sand,gravel,cl. and l.s.	
			Hadrukh	calc.slt.s.						limestone	fair		volcanics	
	Paleogene	Oligocene												
		Eocene	Dammam	l.s. dol.	fair	Dammam	Dol.l.s.,l.s.		Dammam	l.s.,massive				
			Rus	marl,chk.l.s.		Rus	l.s.,dol,gyp	good	Rus	marls,gyp.				
		Paleocene	Um er radhuma	l.s.dol.l.s.	good	Um er radhuma	Dol.,chert,marl clay		Um er radhuma		good	Majd-zir	Coarse clastics	
MESOZOIC	CRETACEOUS Upper	Meastrichtian Campanian Santonian	Aruma gp	l.s.		Aruma gp	calcarenites &		Fiqa Muti Qumayra ?	Samail gp basic, ultra basic rocks; shales and l.s.	fair	Tawilah	quartz s.s. with red fine clastics	variable
		Taronian ? ?	Mishrif Rumaila Ahmadi (Wasia Group)	sandstone with shale	good	Mishrif	limestones &							
		Cenomanian	Wara			Khatiah	dolomites	saline water	Wasia gp.	Hawasinah gp unknown age ?; l.s.	fair			
			Mauddud Safaniya			Mauddud Nahr Umr	& sandstone & shale							
	Lower	Albian ? ? Aptian ? ?	Riyadh	sandstone & shale	fair	Shuaiba Hawar Khoraib			? Kahmah gp.	? l.s.,shale dolomite (Hajar Super Group)		? ? ? ? unnamed ?	shale, marl, carbonates,evap.	
		Neocomian	Buwaib	calc.l.s.										
			Yamama	Calcerenite		Yamama								
	? JURASSIC Malm	Berriasian Tithonian	Sulaiy Hilth Arab	chk.l.s. anhydrite calcarenite & l.s.		Sulaiy Hilth Qatar Fahahil	carbonate rocks		?		good in Oman	Amran	evaporites and related carbonates	
		Kimmeridgian Oxfordian	Jubaila Hanifa Twaiq	Aphanitic l.s		Darb Diab			Sahtan gp	shale,l.s. and dol. ?			marine carbonates	
	Dogger	Callovian Bathonian	Dhruma	Aphanitic l.s and s.s.	good	Uwainat						Kholan	continental quartz s.s. with red fine clastics	fair to good
		Bajocian				Izhara								
	Lias	Toarcian	Marrat	shale and l.s		Absent								
	TRIASSIC Up.		Minjur	s.s. and sh.		Gulailah	*	*	Mahil	Dolomite	fair	Absent		
	Mid.		Jilh	Aphanitic l.s and s.s.&sh. shale		Suwel								
	Low.		Sudair			Khail Sdair								
PALEOZOIC	Permian carboniferous Devonian Silurian Ordivician Cambrian		Khuff Wajid Jauf	l.s.,sh ands.s. sandstone	good	Khuf Prekhuf			Saiq	Dolomite		Wajid	Clean quartz s.s.	?
			Tabuk Saq	l.s.,sh. s.s. sh. s.s.	v.good									
PRECAMBRIAN				Basement Complex						Basement Complex			Basement Complex	

all. alluvium
arg. argillaceous
calc. calcareous
cl. clay
chk. chalk
cht. chert
congl. conglomerate
dol. dolomite
evap. evaporites
gyp. gypsum
l.s. limestone
sh. shale
s.s. sandstone
volc. volcanics

2. The zone of Mrginal Troughs, Thrusts and Neogene folding in eastern Iraq, North and North East of Syria and South of Turkey.

The surface water flowage in the Tigris and Euphrates rivers and their tributaries originates mainly from the high rain and snowfall zones which occur in the mountain regions which result from these major geologic structures. Active recharging zones to the aquifers in Eastern Iraq and North Eastern Syria occur in these areas.

In this subregion surface water resources are predominant. Groundwater resources do occur and are well developed in Jordan, Syria and to a less extent in Lebanon.

In Iraq surface water resources development are well undertaken yet groundwater resources are not developed or identified.

The maritime zones of the subregion are rather humid to semi-arid. The inland areas are arid to semi-arid. The climate is predominantly Mediterranean, hot dry summer and rainy winter with variable fluctuations of the daily temperature difference which is reported to be high in Iraq and in the inland areas in Syria and Jordan.

Surface water resources in the subregion are appreciable and represented by the main rivers of: Euphrates, Tigris and Tributaries, Yarmouk, Al Asi, Barada, Litani, Hasbani, Jordan River, the Lebanon rivers and others (Tables III.2 page 81, X.2 page 215 and annexes 2 and 5.

Groundwater resources occur in Paleozoic sandstones, Jurassic - Cretaceous - Paleogene carbonate rock aquifers. Tertiary volcanics and Quaternary alluvium. The quality is excellent to brackish. Good quality occurs at the foothills of the active recharging zones and deteriorates generally eastwards in the inland basins and areas in Syria and Jordan, and westwards from the Zagros mountain in Iraq. There is appreciable potential groundwater in Lebanon and to a less extent in Syria. In Iraq more investigations are needed to judge. The subregional hydrogeologic correlation is shown in table A.1(b).

The practice of regulating flood waters and developing the surface water resources are remarkable in the subregion as represented by Al-Tabaka Dam in Syria, Qaroun Lake in Lebanon, and others in Jordan and Iraq as shown in table III.3 page 82, annexes 3 and 13.

The estimated availability of the water resources based on the various hydrologic and hydrogeologic investigations carried out in the subregion and presented in Part B of this report, may be summarized as shown in table A.2(b).

TABLE A-1 (b)

REGIONAL HYDROGEOLOGY

Geologic Time Scale: ERA	PERIOD		EPOCH	SYRIA: Formation and Lithology	SYRIA: Aquifer charact.	LEBANON: Formation and Lithology	LEBANON: Aquifer charact.	JORDAN: Formation	JORDAN: Lithology	JORDAN: Aquifer charact.	IRAQ and KUWAIT: Formation	IRAQ and KUWAIT: Lithology	IRAQ and KUWAIT: Aquifer charact.
CENOZOIC	Quaternary			all., marl. congl.	poor	alluvium	fair to poor	Alluvium	soil, s., gravel		Dibdibba	sand & gravel with sandy cl. and gyp.	good
CENOZOIC	TERTIARY	Neogene	Pliocene & Miocene	clay, s.s., l.s., congl. with volc. FARS l.s., cl., marl, gyp. cl. marl, l.s., l.s. arg., s.s. and cl.	fair	l.s. and marl clastics, gyp., marl l.s. marl, l.s.	fair to poor	Jordan Valley	marl, cl., and evaporites conglomerate with silicious sand, gravel	poor / fair	L. Fars / Ghar	calc. s. & gravel quartzitic sand & gravel, silt	fair
CENOZOIC	TERTIARY	Paleogene	Oligocene	L.S. arg., s.s.	good	Absent	fair	Balqa					
CENOZOIC	TERTIARY	Paleogene	Eocene	l.s. arg. l.s. l.s., marl, chert marl, chalk, clay	good	l.s., chert l.s., marly l.s. chert, marl, chert l.s.	fair	Balqa	l.s, chk, marl / cht & l.s. chk, marl &	poor / good	Dammam / Rus / Um Er Radhuma	limestone / marl, clay / limestone	fair to good
CENOZOIC	TERTIARY	Paleogene	Paleocene		poor								
MESOZOIC	CRETACEOUS	Upper	Meastrichtian Campanian Santonian	chk, marl, marly l.s. cht. chert chk	fair	CHEKKA chk. marl l.s., phosphorous chk. l.s.. cht	fair	Balqa	marly l.s. cht., l.s., phos. chk, marl, marly l.s.	poor / good / poor	Tayarat / Qurnah / Hartha / Sadi	limestone / marl / limestone / limestone	*
MESOZOIC	CRETACEOUS	Upper	Taronian ? ?	l.s., marly l.s.	good	GHAZIR l.s., marl	v.good	Ajlun	l.s., dol. & Cht. l.s., marly l.s. dol., dol. l.s. marl, marly l.s. l.s., dol. l.s.	good	Magwa	marl and marly l.s.	*
MESOZOIC	CRETACEOUS	Upper	Cenomanian	l.s., marl and local volc.	good	SANNINE l.s. l.s., dol l.s. marl and cht	v.good	Ajlun		good	Ahmadi / Wara / Mauddud	marl / debris / limestone	*
MESOZOIC	CRETACEOUS	Lower	Albian	l.s. arg., l.s., marl	poor	s.s., l.s. marl and marly l.s. JEZZINE sand arg. s. l.s., l.s. s.s. and evaporites	fair to poor	Kurnub	sand shale	poor	Burgan / Shuaiba / Zubair	debris / limestone / debris	*
MESOZOIC	CRETACEOUS	Lower	Aptian ? ?	sh., l.s., s.s. & volc.	poor		fair to poor	Kurnub	clay and sandy	poor			*
MESOZOIC	CRETACEOUS	Lower	Neocomian	not recognized	poor		fair to poor	Kurnub	limestone	poor	Ratawi / Yamama / Suialy	marls / marly l.s.	*
MESOZOIC	JURASSIC	Malm	Berriasian Tithomian	" "		Salima Volc. l.s., marl. oolitic l.s. karst. BHANNES volc and marl BIKFAYYA l.s. and dol. l.s.	v.good	Kurnub	sandstone marl and shale	poor	Gotnia	marly l.s. sandstone quartzitic	*
MESOZOIC	JURASSIC	Malm	Kimmeridgian	limestone			v.good	Kurnub		poor			*
MESOZOIC	JURASSIC	Malm	Oxfordian	limestone, clay			v.good	?		poor	Najmah	limestone	*
MESOZOIC	JURASSIC	Dogger	Callovian	dolomitic l.s.	good in maritime area	KESROUANE l.s. and dol. l.s.	v.good	Zarqa	limestone, marl stone, sand-stone and shale	poor	Sargelu	marly l.s. l.s. and clay	*
MESOZOIC	JURASSIC	Dogger	Bathonian	and	good in maritime area		v.good	Zarqa		poor			*
MESOZOIC	JURASSIC	Lias	Bajocian Toarcian	limestone ?	good in maritime area			Zarqa		poor	Alan / Mus	marl / sandy l.s.	*
MESOZOIC	TRIASSIC	Up.		exotic blocks,	poor	*	*	Zarqa	limestone, shale sandy limestone marl and evaporites	poor	Adaiyah / Butmah	limestone shale	*
MESOZOIC	TRIASSIC	Mid.		ophiolites-	poor	*	*	Zarqa		poor	Baluti to	and sand-stone	*
MESOZOIC	TRIASSIC	Low		radiolites	poor	*	*	Zarqa		poor	Mirga Mir		*
PALEOZOIC	Permian Carboniferous Devonian Silurian Ordivician Cambrian			marly limestone with spiriferous and l.s. ?	?			? / Khreim / Disi	? / s.s., slts, shale quartzite, s.s. arkose	v.good	Chia Zairi / Harur / Ora / Kaista / Pirispiki / Khabour	limestone / limestone / shale / Red beds / Quartzite, sh.	*
PRECAMBRIAN									Basement Complex			Basement Complex	

* Not available
all. alluvium
arg. argillaceous
calc. calcareous
cl. clay
chk. chalk
cht. chert
congl. conglomerate
dol. dolomite
evap. evaporites
gyp. gypsum
l.s. limestone
sh. shale
s.s. sandstone
volc. volcanics

TABLE A-2

AVAILABLE AND POTENTIAL WATER RESOURCES IN THE ECWA REGION

(Thousand Million Cubic Meter)

(a) THE ARABIAN PENINSULA BLOCK | (b) THE NORTH AND NORTH-EASTERN SUBREGION

		Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	United Arab Emirates	PDRY	Yemen Arab Republic	Total (1)	Iraq	Jordan	Lebanon	Syria	Total (2)	Grand Total (1)+(2)
Rainfall volume		0.0096	2.3776	14.966	0.1882	126.786	2.4790	21.079	46.0856	214	105.880	8.000	9.700	45.000	168.580	382.58
Surface runoff		0.0002	0.0774	0.4500	0.0056	2.2330	0.2647	0.6760	1.5000	5.21	106.000 including Euphrates	0.880 including Yermouk	4.025	31.445 incl. Yarmouk & Euphrates	115.900	121.11
Surface Water	Available	-	-	0.010	-	2.233	0.264	0.676	0.750	3.930	43.200	0.715	2.925	13.445	60.285	64.22
	Utilized	-	-	0.010	-	0.200	-	-	0.30	-	41.100	0.230	0.665	6.903	49.000	?
	Max. Possible	-	-	0.450	-	2.233	0.264	0.750?	1.50?	5.20	67.700	1.000	4.300	20.700	93.700	98.90
Ground-Water	Annual Recharge	NA	NA	1.409	0.0318	0.911	0.387	NA	NA	2.74?	-	0.580	0.600	1.625	2.805	5.55?
	Utilized	0.199	0.130	0.781	0.0496	1.758	0.239	0.350	0.440	3.95	1.20	0.257	0.420	2.528	4.405	8.36
	Stored	NA	NA	NA	2.500	201.126	5.280	NA	NA	?	-	12.000	-	-	?	?
	Possible Usable	0.199	0.155	0.628	0.0318	20.112	0.387	0.350	0.900	22.763	2.00	0.421	3.000?	1.625	7.046	29.81
Non-conventional water resources	Present	0.008	0.103	0.025	0.039	0.500	0.002	-	-	0.68	-	-	-	-	-	0.68
	Future	0.024	0.450	NA	0.053	0.837	NA			1.36?						1.36?
Total available water resources	Present	0.207	0.233	0.816	0.089	4.491	0.653	1.026	1.190	8.71	44.400	1.215	3.345	15.973	64.93	73.64
	Future	0.223	0.605	1.103	0.085	23.182	0.653	1.10	2.400	29.35	69.700	1.421	5.080	22.325	98.530	127.28
Present Water Use	Irrigation	0.166	0.130	0.420	0.043	1.700	0.207	1.000	0.730	4.40	39.530	0.405	0.640	6.900	47.475	51.88
	Domestic	0.020	0.075	0.087	0.004	0.830	0.081	0.020	0.007	1.12	0.580	0.040	0.040	0.400	1.060	2.18
	Industry	0.013	0.008	0.033	0.002	0.150	0.013	0.006	0.003	0.23	2.240	0.006	0.145	1.413	3.804	4.03
	TOTAL	0.199	0.213	0.540	0.049	2.680	0.301	1.026	0.740	5.75	42.350	0.451	0.825	8.713	52.339	58.09
Future Water Use (2000)	Irrigation	0.126	1.150	0.420	0.055	3.240	0.409	2.570	0.960	8.93	52.000	0.730	1.500	18.000	72.230	81.16
	Domestic	0.075	0.075	0.189	0.010	1.822	0.032	0.302	0.446	2.951	1.500	0.300	0.365	1.500	3.665	6.62
	Industry	0.015	0.050	0.266	0.003	1.048	0.010	0.297	0.685	2.374	7.139	0.030	0.120	5.191	12.480	14.85
	TOTAL	0.216	1.275	0.875	0.068	6.110	0.451	3.169	2.091	14.255	60.639	1.060	1.985	24.691	88.375	102.63

The table is based on:

- Arab League "Food Security in the Arab States" Part I, June 1980 (Arabic).
- References cited in the Bibliography, Numbers 6, 11, 13, 16, 35, 42, 46, 53, 57, 76, 78 and 103.

NOTE: NA= Not available.

IV. PROPOSED ACTIONS AND RECOMMENDATIONS

IV.1. Recommendations at national levels

The country-by-country discussions in Part B lead to the following suggestions for actions:

IV.1.1. The State of Bahrain

- Country wide groundwater observation networks should be intensified.

- Detailed hydrogeologic investigations should be updated and a national water master plan is recommended to be drawn up. This should aim at meeting the growth in demand by an optimum use of the potential usable groundwater in conjunction with an increase in desalted water production, thus preserving the hydraulic state of equilibrium which is believed to exist at present.

IV.1.2. The People's Democratic Republic of Yemen

- A country wide water resources assessment programme should be initiated.
- Updating the previous water resources investigations carried out in some localities to arrive at more realistic knowledge of the country's water resources should be undertaken.

- Investigating the possibility of carrying out artificial groundwater recharge projects to make use of the sporadic flood waters in the major valleys like: Tuban, Abyan, Hajor and other to alleviate the prevailing overdraft conditions in these areas. Without some action to deal with the overdraft conditions, the position will become steadily worse, so these projects should be given priority.

IV.1.3. The Republic of Iraq

- Carrying out country-wide hydrogeological investigations to indentify and develop the potential groundwater resources particularly in the east, west and south west of Iraq, may be considered.

- Projects where the integrated use of surface and groundwater is possible should be given priority.

- Hydrochemical investigations should be carried out on a long-term basis to keep track of changes in the water resources quality and behaviour. In particular the object should be to arrive at optimum application of water in various sectors so as to alleviate salt accumulation in soils, groundwater and river waters especially in southern Iraq.

IV.1.4. The Hashemite Kingdom of Jordan

- Instigating the most economic and feasible ways and means for better allocation of the country's water resources considering priorities and graded purposes should be undertaken.

- The possibility of desalting the brackish groundwater which exists on a considerable scale in Jordan Valley and at depth in the eastern plateau, using low cost methods, for domestic and industrial purposes, should be investigated.

- The possibility of utilizing the flood waters occuring in the desert areas through artificial groundwater recharge, diversion to other areas or locally in dry farming projects may be studied.

- Execution of further projects where surface and groundwater resources may be utilized in an integrated manner, like in Southern Ghors and Wadi Araba areas should be enhanced.

IV.1.5. The State of Kuwait

- Making use of the sporadic floods to recharge the Kuwait aquifers artificially and improve the groundwater quality should be considered. This practice would mean that the desalination plants would start with better water quality and hence the cost of desalted water production out of brackish water would be reduced.

IV.1.6. The Lebanese Republic

- Detailed hydrogeologic investigations are required so that a realistic knowledge of the country's groundwater resources is attained.

- Integrated use of surface and groundwater resources projects should be given priority particularly in Bekaa area and the coastal plain.
- Development and application of appropriate water regulations and legislations seen to be essential to conserve and administer the national water resources. Centralising and/or unifiying the water related institutional arrangements are desirable for efficient allocation and management of water resources.
- Efforts should be made to make use of the considerable quantity of flood waters and subsurface flows which are being lost annually into the Mediterranean.

IV.1.7. The Sultanate of Oman

- Establishment of hydrological and hydrometeorological networks as an initial step for a country wide water resources assessment programme is highly required.
- Detailed hyrogeological investiations covering the whole of Oman may be desirable, for a better understanding of the country's water resources.
- Artificial groundwater recharge projects and dams construction to make use of the potential floods which often occur in the Batinah, Dhahira and Sharqiya areas, whould be very beneficial particularly to lessen the rate of the growing overdraft conditions and flood hazards.

IV.1.8. The State of Qatar

- Continuous monitoring of the groundwater level and water quality modification is highly required.
- Studying the possibility of making use of the sporadic floods to recharge the usable aquifers artificially to help in overcoming the prevailing overdraft conditions in some localities in the Peninsula should be undertaken.

- Construction of a mathematical model to simulate the hydrogeologic conditions of the Peninsula may be desirable to determine the optimum groundwater withdrawal on a long-term basis and to show how much of the growing demand must be met by desalination.

IV.1.9. The Kingdom of Saudi Arabia

- Establishment of one central water authority may be very fruitful to deal with all aspects related to water resources exploration, development and management.
- Development of suitable water legislation and rules may be desirable in order to conserve and manage the country's water resources efficiently by the entrusted authority.
- Continuation of establishment and recording of hydrological, hydrometeorological and groundwater observations networks for recording and observing water related basic data, are required.
- Hydrochemical investigations should be undertaken periodically to keep track with water quality modifications in the major well fields like Riyadh Basin.
- The use of sporadic floods in Tehama Plain may be beneficial to recharge the alluvial aquifer so as to alleviate overdraft conditions.
- Further desalination plants should be put in hand in good time to cope with the rising demand for water.
- Treatment of sewage water to secondary stage and re-using water in agriculture and industry must take place.

IV.1.10. The Syrian Arab Republic

- A national water master plan is required to streamline the use of the country's water resources in an integrated mannaer. The plan should involve detailed hydrologic and hydrogeologic investigations in a countrywide scale so as to determine the optimum safe yield of the potential groundwater resources, to make use of all possible floods as presently planned and for better allocation and most economic use of water resources for various sectors.

- Centralizing and/or unifying the responsibilities of the existing water related institutions into one body responsible for all aspects daling with the country's water resources conservation development and management, should be considered.
- Review of the existing water legislations is required to improve its scope to include aspects pertaining to well drilling, groundwater extraction, protection of quality like in Euphrates basin within Syria, prevention of pollution like in Barada River waters and others.

IV.1.11. The United Arab Emirates

- Detailed or updated hydrogeologic investigations seem to be desirable to determine a realistic knowledge of the country's groundwater resources and the optimum safe yield.
- Groundwater monitoring programme to define the water level and quality behaviour is required so as to be aware of the resources'response to exploitation.
- Further desalination plants should be put in hand in good time to cope with the rising demand for water.

IV.1.12. The Yemen Arab Republic

- A water resources assessment programme should be initiated as soon as possible as a prerequisite to identifying the country's water resources in quantity and quality.

IV.2. Subregional and regional proposed actions and recommendations.

Some of the major surface and groundwater basins in the region extend beyond the national bounderies. The actual knowledge regarding national water resources, including the shared resources, varies from one country to the other. On the other hand, a lot of investments and efforts can be more effectively undertaken through mutual co-operation for the development of these shared resources. The findings or the outcomes of the investigations conducted at national levels on the common surface and/or groundwater basins often proved to be incomplete or misleading as a result of the unilateral hydro-logic and hydrogeologic data used in these studies. Moreover, unilateral development of the resources of one member country may have serious impact on the water resources of the other neighbouring states.

Co-ordination on the application of modern techniques such as : remote sensing, desalination, energy resources and dissemination of information in relation to water resources at regional or subregional levels will contribute appreciably to multidisciplinary orientation for shared basin management and provide basis for integrated surveys of land, surface and groundwater resources.

Hydrogeologic and hydrologic investigations carried out in the region at national levels (as revealed in Part B of this study) proved the existence of major shared water basins, the development of which may require co-operative efforts at subregional, regional and international levels.

These major basins are:

IV.2.1. Groundwater basins:

The following are the major shared aquifers occuring in the region.

IV.2.1.1. Paleozoic-Mesozoic sandstone aquifers

The aquifer is best represented in Saudi Arabia, Jordan, Kuwait, Bahrain, Qatar, United Arab Emirates, Oman and People's Democratic Republic of Yemen. In Saudi Arabia there are several known members of this sandy aquifer namely: Saq, Tabuk, Wajid, minjur and Wasia - Biyadh aquifers. The last member is the most important aquifer in the Eastern Province of the country. It has a thickness of about 1000 m or more and its average transmissivity ranges from 260-17000 $m^3/d/m$. Water quality is fair but deteriorates towards the Arabian Gulf 8/. In Bahrain the Wasia member was recognized and reported to contain groundwater of more than 6000 ppm but is unidentified. In Jordan, good quantity, about 35-50 MCM/a estimated recharge, and excellent quality, less than 500 ppm are reported. Thickness ranges from 200-500m 9/.

8/ For more details see Chapter IX of Part B.

9/ See Chapter IV of Part B.

In the People's Democratic Republic of Yemen where theaquifer is known as Mukalla sandstone which extends to Rub elkhali and Ramlet Al-Sabatyn in Yemen Arab Republic, fair to good groundwater potentials are reported and of good quality (440-900 ppm)10/. No estimates of the groundwater recharge were made.

IV.2.1.2 Carbonate rocks aquifers:

They are of three different groups:

(a) Um-er-Rhaduma - Dammam limestone complex (Paleocene-Eocene Tertiary) which occur in Saudi Arabia, Kuwait, Bahrain, Qatar, UAE, Oman and PDRY.

Um-er-Radhumaaquifer is of major importance in the eastern province of Saudi Arabia and in Rub el Khali Basin. It is composed of crystalline dolomite, dolomitic limestone and limestone with average thickness of 490m. Transmissivity ranges from 300 - 37000 $m^3/d/m$. Water quality ranges from 900-1300 ppm of T.D.S.11/. It deteriorates eastwards along the Gulf coast.

The Damman aquifer is of less importance than the Um-er-Rhaduma aquifer. It is composed of chert and siliceous limestone, marles, shale and has a maximum thickness of 51 m. Its transmissivity is 20-1260 $m^3/d/m$. In Kuwait the Damman aquifer has a thickness range of 180-220m and contains groundwater of 2500-4500 ppm of T.D.S.12/. The tapped groundwater is being mixed with produced desalted water. In Oman the aquifer is known to have good potential in Khofar and Majd areas.

(b) Carbonate rock aquifers which belong to Upper Cretaceous-Paleocene time scale and occur in Jordan - Saudi Arabia, Iraq and Syria in Hamad Basin. This is also represented by the Aruma and Umm er-Radhuma aquifers in Eastern Saudi Arabia. A joint project to investigate the potentialities of this Basin was undertaken by the member countries involved under the auspices of the Arab Centre for the Studies of Arid Zones and Dry Lands since 1979. The potential

---

10/ Remote sensing centre, Academy of Scientific Research and Technology, Feasibility Study of a Proposed Transnational Project,"Management of the Major Regional Aquifers in NE Africa and the Arabian Peninsula" August 1976, p.19-23.

11/ Ibid., p. 27-29

12/ Ibid., p. 27.

groundwater is unknown in quantity and quality. The aquifers are mainly composed of two main pay zones. The upper is hydraulically connected with the overlying volcanic (basalt) rock aquifer which occurs in Jordan and Syria. The Carbonate aquifers are composed of Chert limestone in the upper zone and predominantly limestone massive with chert in the lower zone.

(c) Jurassic - Cretaceous - Karstified limestones and Dolomites. The main occurrence of this aquifer is in Lebanon, Syria and Jordan in the highlands of the uplifted blocks that are bordering the Rift Valley system on both sides. The aquifer is of great importance in all sharing member countries as it feeds most of the large springs occuring in the area, with almost regular flows (refer to country sections). It is believed to encompass good groundwater potential in Lebanon, Syria and Jordan but only rough estimates of its potentiality were made. Excellent quality, generally of less than 1000 ppm of TDS was encountered in this aquifer.

The primary objectives of investigating the above-mentioned shared major aquifers are:

- To delineate the aquifers areal extent, potentiality, storage capacity and its dependability in space, time and quality.
- To study the possibility of trapping or capturing the wasted submarine flows which some of the mentioned aquifers are undergoing. The Damman - Um-er-Radhuma aquifer is undergoing heavy waste and quality deterioration through submarine flowage into the Gulf area in Bahrain, Qatar, UAE and in the eastern coast of Saudi Arabia. Mesozoic karstified carbonate aquifers are proved to have similar submarine waste flows into the Mediterranean Sea in Lebanon and Syria. The same aquifer is undergoing quality deterioration and/or drainage by subsurface flow into the brackish groundwater reservoir in the Jordan valley depression.
- To formulate and execute plans of actions to develop the potential water resources in the shared aquifers, from which more than one member country can benefit through joint fair planned development schemes.

- To harmonize the status of hydrogeologic investigations carried out in these aquifers and to fill the gaps in these studies.
- To initiate plans and programmes for future joint monitoring, data updating and development of these aquifers.

IV.2.2. Surface water basins

The following are the major shared water-shed areas.

IV.2.2.1. Euphrates river basin

This is an international river basin which Iraq, Syria and Turkey share. It has a catchment area of about 444000 km^2 which lies in Turkey and Syria where the mountainous region in the former produces most of the river flow. The three sharing countries have already constructed several hydraulic structures on the river to regulate floods, power production or implement irrigation schemes. These structures were executed at national levels to satisfy each country's objectives. River basin development in a sound and comprehensive manner may not be achieved without effective mutual co-operation between the sharing countries.

IV.2.2.2. Yarmouk river basin

This has a catchment area of about 7250 km^2 in Syria and Jordan. The average annual flow is in the order of 425 MCM/a. Jordan and Syria are actively engaged nowadays in executing a joint project to construct the Maqarin Dam on the Yarmouk river to make use of the river flows in irrigation and power production. The shared project is being undertaken in accordance with the Treaty signed in 1953 betwwen Jordan and Syria 13/. A joint commission composed of concerned government representatives (expert level) to supervise the execution of the project was recently appointed.

13/ Safadi, "Water Resources of the Syrian Arab Republic", 1979 pp. 31.32 (Arabic).

IV.2.2.3. Al-Asi and south Al-Kabir river basins

Syria and Lebanon share the two rivers. Al-Asi river flows (about 512 MCM/a) into the Mediterranean Sea in Syria after crossing the fertile areas in northern Beka'a (Lebanon) and Ghab Plain (Syria)[14/]. Several hydraulic strucutres have been constructed to regulate the floods of Al-Asi river in Syria like Homs Lake, Rustum and Muharradah Dams.

Al-Kabir river has an average annual flow of 190 MCM/a[15/], A joint project is being investigated between Syria and Lebanon to make use of Al-Kabir river waters to irrigate Akkar Plains in both countries[16/].

IV.2.2.4. Wadi Tuban, Wadi Bana and Wadi Beiham water-sheds

These are non-perennial streams originating from the high rainfall zones in the Yemen Arab Republic from where they depouch into the PDRY. The available and the potential water resources, surface and groundwater are not well defined or developed. Unilateral developments of these basins might result in conflict. Because of the interactive nature of water resources projects in both Yemens, unilateral plans should be part of subregional schemes which are best attained through integrated joint development plans.

IV.2.3. Non-conventional water resources (Desalinated Water)

The lack of conventional water resources in the Economic Commission for Western Asia region has focused the attention of some member countries like Saudi Arabia and the Gulf States, on the non-conventional sources. Desalinated water has been in progressive production and use in the region during the last two decades. At present Kuwait and Saudi Arabia are considered as the world's leaders in this aspect.

14/ Sharaf-Eddin, "Water Situation in Lebanon", 1971, Table 5 (Arabic).

15/ *Ibid.*, Table 2.

16/ Safadi, *op. cit.*, p. 37.

Mutual co-operation and co-ordination for developing and managing the above-mentioned shared water sheds and river basins are extremely beneficial. The ultimate goal of shared basin development is a comprehensive and many-sided plan dealing with all measures to ensure rational development, utilization and conservation of the water resources taking into account the socio-economic factors prevailing in the concerned member countries.

It is needless to say that unilateral development of the common water resources will never reach its ultimate usefulness and totality without full knowledge of the shared water sheds' main parameters, which include: geomorphology, hydrology, hydrogeology, hydrometeorology, agrometeorology, climate, soil, vegetation and the socio-economic conditions prevailing in the whole water shed area. The knowledge of these parameters will render the basin development much easier, more realistic, possible and reliable on a long-term basis. Moreover unilateral development will inevitably be guided mainly by the interest of the country taking the action, with little regard for those of the other countries involved, and this may give rise to undesirable political problems which can be so intractable that they stop all forms of joint actions. Donating governments or agencies would be hesitant to finance unilateral projects which may result in conflict.

In order to agree upon joint actions for shared basin development, negotiations may be conducted. In these negotiations, the upstream country might seem to be in a very strong negotiating position, but one needs to consider the whole field of relations among the countries involved; if one country abuses its position over water, it may well suffer from relations with the neighbouring countries in some other fields such as trade affairs. It is clearly very important that the negotiations should be conducted in a spirit of regional co-operation, possibly with resort to a neutral country and/or a knowledgeable team of experts to suggest what would be equitable and beneficial for all countries concerned.

Bearing in mind the preceding discussion, the following course of action are recommended to be considered by the involved member countries to develop their shared water resources, surface an/or groundwaters:

- Set up joint advisory steering committees responsible for co-ordination, following-up and exchange of information regarding water shed investigations. These committees are composed of the governments concerned.

- Constituting national teams of experts to operate collectively, where possible, to standardize and establish technical basic data on all relevant water shed parameters. A representative of these national teams delegated by his government should be a member in the steering committee mentioned above.

- Formulation of joint programmes for basic data collection, inventory, publications, required mapping, appraisal of existing projects, training requirements and facilities, research and its mechanism, basin development and management and design and executing relevant pilot projects of common interest.

- Sponsoring studies and research, if necessary, with the help of international agencies and other bodies as appropriate to compare and analyse existing institutions for managing and developing shared basins.

- Formulation of subregional plans and designs including alternative schemes for water resources development and allocation policies.

- Efforts should be undertaken at subregional level under the leadership of Kuwait and Saudi Arabia and other interested members of non-member countries, to initiate a wide spectrum of research programmes dealing with topics related to the use and production of non-conventional water resources, so as to make the use of these techniques possible for those who have financial constraints and limited water resources. Such topics among other ones are:

  (a) Exploration of non-conventional sources of energy to be used in desalination plants especially in non-oil countries.

  (b) Continued research to reduce the cost of tertiary and advanced waste water treatment processes.

(c) Continued research to develop new techniques to reduce the cost of present desalination techniques with particular reference to the treatment of brackish groundwater.
It would seem highly desirable that countries with financial constraints should receive international aid in introducing schemes to develop non-conventional water resources, possibly from international organizations.

- For the major river basins in the region, it is recommended that efforts should be directed towards the establishment of a Joint River Basin Authority as appropriate and in full agreement with the concerned member governments. This kind of authority proved to be very efficient in other regions. It will provide a full co-operation, co-ordination and monitoring mechanism involving all areas in relation to water resources development in a sound and comprehensive manner for the benefit of all countries involved.

  The main duty of this proposed river basin authority at least at the initial stages will be concerned with all basic data collection, processing, analysis, interpretation evaluation and fact findings.

IV.3. Proposed actions for the promotion of subregional and regional co-operation in the field of water resources development

Subregional co-operation in the field of water resources in other regions has proved to be fruitful in planning, co-ordination, management and promotion of water projects, Examples of such multilateral co-operations were experienced in Europe, USA, USSR, Africa and in some parts of the Arab world[18/].

18/ Such as: (a) Ohio River Commission (USA) where 11 States participate.
(b) Co-operation among CMEA member countries in the field of water management as the co-operation of five interested countries (Hungary, Romania, USSR, Czechoslovakia and Yugoslavia) on the River Tise.
(c) European convention for the protection of "International Water Courses Against Pollution" recommended by the Consultative Assembly of the Council of Europe, May 1969.

../...

18/ (d) The River Nile Water Committee in which Egypt and Sudan participate.

(e) UNESCO's IHP (International Hydrological Programme) which calls for regional and international co-operation in the field of water resources assessment, and through which a number of projects could be implemented. The UNESCO Major Regional Project on Traditional Waterworks, currently in force, being an example.

(f) The ACSAD (Arab Centre for the Studies of Arid Zones and Dry Lands) as one of the regional organizations involved in water resources assessment studies.

(g) Co-operation of the countries of the Arab peninsula under the FAO Regional Project for Land and Water Use. The responsible intergovernmental unit is the Secretariat of the Congress of Ministers of Agriculture in the Gulf States and the Arabian Peninsula for whom FAO carried out the survey and evaluation of available data on shared water resources in the Gulf States and the Arabian Peninsula.

In order to promote regional co-operation in the field of water resources, the ECWA secretariat has proposed the Establishment of a Regional Water Resources Council at the First Regional Water Meeting held at Baghdad in December 1977. The subject was further discussed in the ECWA Second Regional Water Meeting in Riyadh between 28 December 1978 and 3 January 1979. An *ad hoc* Intergovernmental Committee was subsequently formed and met in Damascus to discuss the possibility of establishing this Council.

In pursuance to the recommendations of this *ad hoc* Committee Meeting, the Councils's tasks will mainly focus on co-ordination and co-operation in water related activities at regional and subregional levlels.

In this connexion the following three alternative proposals are recommended for the terms of reference of the Council:

IV.3.1. ALTERNATIVE I:

The Regional Water Resources Council shall not be an executing agency but shall function as a co-ordinating body for water resources matters at regional level. It will be an independent functional body with ECWA serving as its secretariat during the initial take-off stage after which the Council will develop into a fully independent and autonomous intergovernmental mechanism with its own secretariat support.

IV.3.1.1. Functions of the Council:

The main functions of the Council shall be to:

1. Water Resources Planning and Development

- Initiate and co-ordinate applied scientific and technical research themes related to conservation, development and management of water resources.

- Draw up plans for water uses (irrigation, industry, community water supply, fisheries, hydroenergetics and recreation) based on the regional development plans and in consultation with the concerned water bodies of the member states and the UN Specialized Agencies.

- Supervise and follow-up the implementation and execution of regional or subregional water projects, as and when requested.

- Initiate a common framework to guide the water related activities in such a way as to ensure the highest possible level of efficiency for the benefit of all member states.

- Review, improve, update and activate the subregional water plans and projects in light of current investigations and evaluations of the water resources situation in the region. Post-evaluation of water projects may be undertaken by the council in co-ordination with the concerned water bodies of the member countries, as and when requested.

- Co-ordiante, stimulate and monitor water activities and findings experienced by the national water bodies within the member countries, so as to initiate joint plans or subregional water projects and recommend order of priorities.

2. Water Policies, legislations and regulations

- Provide guidance for the initiation and formulation of national water policies and water legislation and regulations pertaining to rational water uses, water abstraction, pollution and pollutants, water metering systems, water pricing, water standards for various uses, and water protection areas. The council should attempt to harmonize national water legislation and regulations within the region as and when requested.

3. Educational and Training Arrangements

- Hold periodic technical seminars' workshops and symposia on water related problems, in co-operation with the member states and other interested Arab and international organizations.

- Initiate in consultation with interested member states for on-the-job training programmes and encourage the regular exchange of skilled manpower and expertise in water related matters within and outside the region.

4. Financial Matters

- The council may, subject to the approval of Member States, arrange for the provision of united financial aids, loans or grants from donating agencies within or outside the region for the formulation and execution of water projects/programmes for the benefit of the ECWA region.

5. Water Data

- Formulate programmes to establish, modify and/or improve:

(a) Hydrologic and hydrogeologic observations network so as to ensure efficient and integrated coverage of the region.

(b) Methods, procedures and techniques used in water resources data collection, compilation, processing, analysis, publication, storage and retrieval.

- Activate the establishment of a regional water data bank and documentation centre to facilitate exchange of information on current and planned water related projects within and outside the region.

- Initiate plans to harmonise methodologies and instrumentations used in water data collection and processing in the region.

6. International Agreements

- International, regional or subregional water agreements may be reviewed or implemented through the council but only upon the request of the concerned member states.

7. Emergency Cases

- In case of force majeure or emergency situation, the council may, in co-ordination and consultation with the concerned member countries, recommend certain measures at regional, subregional or even national levels so as to safeguard the water resources.

- In case of conflicting interests, with respect to common or shared water resources, the Council may, upon request, act as a guiding or mediating agency to resolve the conflict and contribute to the optimum development of the shared water resources.

IV.3.1.2. Organization and Composition of the Council

The Council shall have:

1. A Board of Representatives

The board of representatives will be composed of one representative from each member state of ECWA that decides to become member of the Council. Representatives of member states in the Council should be at a high policy making level and authorized to speak for their countries on water related matters.

The board of representatives is the highest responsible authority in charge of implementing the functions and activities of the Council and of taking appropriate decisions so as to achieve the Council's objectives.

2. A Supporting Technical Staff

The supporting staff will be formed of a team of highly qualified experts specialized in the various aspects of water resources development. The number and fields of specializations of the technical staff will be identified at a later stage taking into consideration the number of the member states of the Council and hence its territorial coverage as well as the nature and scope of the functions and activities to be undertaken by it.

IV.3.1.3. Other organizational, procedural, administrative and legislative provisions pertaining to the establishment and functioning of the Council will be formulated after the decision to establish this institutional mechanism is adopted by some or all of the member states of ECWA.

IV.3.2. ALTERNATIVE II:

The Regional Water Resources Council shall not be an executing agency but shall function as a co-ordinating body for water resources matters at regional level. It shall be an independent functional body with ECWA serving as its secretariat and shall be composed of a Board of Representatives and a Supporting Technical Staff as described in Alternative I. The main functions of the Council shall be to:

- Initiate, carry out and co-ordinate water related activities to promote co-operation among ECWA member states in the field of water resources conservation, development and management.

- Concentrate its activities on water policy problems, taking into account the economic and technical aspects of these problems and implement these activities in consultation and close co-operation with the national water authorities and concerned international and Arab organizations.

- Assist and facilitate the exchange and dissemination of information and sharing of experiences on the formulation and application of national water policies and the exchange of expertise in this field within and outside the region.

- Promote regional and subregional co-operation in the field of water resources development, particularly for the development of shared water shed areas.

- Perform as a regional focal point in water resources for the co-ordination of water related activities, currently or planned to be undertaken at the national level within the ECWA region.

- Keep an updated register of relevant activities completed or planned by the ECWA member states, UN or Arab regional organizations and international consulting firms operating in the region and to take appropriate steps to harmonise regional efforts and avoid unnecessary duplication in the water resources field.

- Establish focal points within the ECWA member states and convene meetings, seminars, symposia, study tours, expert groups, etc. as deemed necessary in co-operation with these countries for the purpose of studying the concepts and methods required for the analysis of the situation and development of water resources in the region.

- Prepare technical and progress reports on its accomplishments and findings and submit these reports periodically to the ECWA regular sessions and to the meetings of the board of representatives as deemed necessary.

- Study, review and evaluate progress in water resources development in the region.

- Recommend policies, strategies, methods and techniques for the proper investigations, development and utilization of water resources.

- Assess and promote the sharing of experience among member states and between them and other developing regions for the purpose of improving the formulation and implementation of water projects at the national, subregional and regional levels.

IV.3.3. ALTERNATIVE III.

The activities of the Regional Water Resources Council shall focus on co-operation and co-ordination in all aspects and areas relating to water resources development in the ECWA region. The Council shall then be viewed as a vehicle for mobilizing regional co-operative efforts in the water resources field. This functional body which may either be independent or attached to ECWA, and composed of representatives of member states, shall perform the following:

- Draw up master plans and joint programmes for the study of subregional and/or regional water resources projects for the benefit of the member states of the Council.

- Collate and co-ordinate the activities of the major existing and planned drainage basin bodies (surface and groundwater).

- Compile, classify and disseminate all basic data on the major water sheds and facilitate exchange of information among member states.

- Undertake and promote research programmes as appropriate in relation to the assessment of water resources supplies, their use, development and management.

IV.3.4. Arrangements adopted by the ECWA's Seventh Session, pertaining to the Council

The establishment of a Regional Water Resources Council was recently discussed in the ECWA's Seventh Session held in Baghdad, April 1980. The Secretariat of ECWA prepared and submitted document E/ECWA/96 for the consideration of the session. The document summarized the Commission's follow-up actions in compliance with the resolutions and recommendations adopted previously by the ECWA's regional and intergovernmental meetings in this connexion.

During the session, the secretariat of ECWA called upon the member states to take a decision regarding the establishment of the proposed Council. The three alternative proposals, concerning the mandate and terms of reference of the Council, as mentioned earlier, were considered by the session. In the course of the discussion, most of the delegates to the session, ascertained the need for regional and subregional co-operation in the field of water resources development. They supported the establishment of the Council, provided that its mandate was restricted to the co-ordination of the established activities of Arab and international organizations and authorities active in water affairs in the region. The Council should discharge its task by compiling information concerning those activities, for discussion at its periodic meetings, and should provide appropriate advice. The third alternative cited in the previous section, was supported by most of the delegates as it accorded with their views pertaining to the functions of the Council.

Finally the session adopted the resolution 83 (VIII)[19/] wherein its operative paragraphs state as follows:

1. Decides.

(a) That the Regional Water Council shall be established;

(b) That the competence of that Council shall be restricted exclusively to the co-ordination of the efforts of the regional organizations and bodies active in the field of water resources in the region and to the conduct of activities that complement the work of these organizations;

(c) That the Council's co-ordination efforts shall be discharged through the compilation of information concerning the organizations active in the region and the discussion of that information at its periodic meetings;

(d) That the Council shall meet once a year, the exact date to be agreed upon between the secretariat and the member States, and that this meeting shall be held at least four months prior to the date of the regular session of the Commission.

19/ Full text of the resolution is shown in Annex 1.

2. Requests the Executive Secretary:

(a) To assess the financial implications of the present resolution and to explore with the member States, regional and international funding agencies, other countries and development institutions the possibility of raising and securing the necessary funds that will enable the secretariat of the Commission to provide adequate secretarial support to the Council;

(b) To report to the Commission at its eighth regular session on the progress achieved regarding the establishment of the Council, and in particular on the implementation of the tasks mentioned above.

PART B

I. THE STATE OF BAHRAIN

Population: 341384[1/] based on 1978 estimates
Area: 622 square kilometers

I.1. General

The State of Bahrain is composed of thirty three islands in the Arabian Gulf, about 32 km from the Saudi Arabian Eastern Coast and slightly more distant from the Qatar Peninsula, Fig. VIII.1. Page 166.Five principal islands comprise 90 per cent of the total area of the country. The largest is Bahrain Island which is about 48 km long and 13-16 km wide.

Topographically, there is little pronounced variation in the elevation of the land surface above mean sea level. About 19 kilometers from the northern end of the Bahrain Island a rolling terrain occurs with peaks reaching 125 meters a.s.l., the highest being the Jabal ad Dukhan.

Along the northern coast a narrow plain extends inland up to 5-6 kilometers where a rocky area starts. The rocky area varies from 30-45 meters a.s.l. and extends southwards for several kilometers east and west for the great part of the Island's width. The central elevated area gives way to a low-lying area of salt flats. The Island terminates at its southern extremity in a long sandy spit known as Ras al Barr.

In Muharraq Island the ground level is generally less than 5 meters a.s.l. but with heights reaching up to 7.9 - 9.75 meters, a.s.l.

The climate of Bahrain is basically hot and humid. During the summer months May-October the daily maximum temperature consistently exceeds 30°C. The winter months are considerably cooler with temperatures often around 20°C and less.

1/ Bahrain, Ministry of Works Power and Water, "Policy on Water Distribution, Blended Supplies and Capital Investment Requirements". January 1979.

Daily maximum himidity exceeds 95 per cent with some regularity in winter, but average humidities are generally much lower allowing a fairly high rate of evaporation. The summer months are characterised by high temperatures and lower relative humidity and hence higher evaporation rate than the winter months. The average evaporation figures for July are computed at 7 mm/day and for January at 2 mm/day.

Rainfall as in the rest of the Arabian Gulf, is low, the average annual precipitation being 75 mm. Complete rainfall records for the period 1946-1976 have been compiled by the Meteorological Department and no rainfall was ever reoorded in the months of June, July, August and September whilst showers occuring in May and November are infrequent. The highest totals of daily precipitation occur more consistantly in December, January and February. Total rainfall volume over Bahrain is estimated at 9.57 MCM/annum[2/].

I.2. Geology

The geologic sequence existing in the State of Bahrain is very similar and shows great affinity to that existing in the Qatar Peninsula and along the eastern coast of Saudi Arabia.

Bahrain Island consists of an elongated anticlinal dome locally known as Dammam dome of Eocene limestone dipping 1°-5° and covered at its periphery and unconformably by more recent deposits. It rises above sea level to about 125 meters at the highest peak, Jabal ad Dukhan as mentioned earlier. The rock units outcrop in a concentric manner around Jabal ad Dukhan, the older formation comprising the centre. Remnants of the younger limestones remain to form the peaks of Jabal ad Dukhan itself. The central area of the older rock units (Rus formation) is surrounded by the Saila and Midra Shale members with Alveoline limestone. The next and most important horizon is the limestone of the Khobar member. The Quaternary superficial deposits cover most of the remaining area of the country with occasional isolated protrusions of the Khobar dolomitic limestone. The Quaternary surface strata is of eolian sand and sandy loam.

2/ Arab League, "Food Security in the Arab States", Part 1, January 1980. (Arabic).

I.2.1. Stratigraphy[3/]

In Bahrain, like in the eastern coastal belt of Saudi Arabia, rock units range from lower Eocene to Pleistocene - Holocene in geological time scale. Table I.1 summerizes the geological sequence existing in Bahrain (After Italconsult, 1971).

The discussion below presents briefly the main characteristics of the geological column existing in Bahrain:

(i) Um-er-Radhuma Formation (Pleocene)

It consists of limestone alternating with skeletal-detrital, partly dolomitized limestone, porous and vesicular, with beds of dolomitic sand and lenses of gypsum and anhydrite. Thickness is about 320 m near the coastal belt of Saudi Arabia. Outcrops occur in Dammam dome and the central part of Bahrain anticline.

(ii) Ras Formation (L. Eocene)

It consists of carbonate and evaporitic sediments alternated with marls and clays.

Thickness is variable ranging from 35-70 meters.

(iii) Dammam Formation (Lower - Middle Eocene)

It is carbonate sequence intercalated with argillaceous in the lower and middle parts. It comprises: Midra-Saila shale, Alveoline limestone (10-25 m) Khobar limestone to dolomitic limestone with bands of chert (30-45 m) and Alat member which is marly at bottom and limestone at top and maximum thickness is 90 m.

(iv) Neogene Complex or Miocene:

It is clayey marly and sometimes sandy rocks (Hadrukh) and mainly limestone with marl and sandy limestone (Dam). It is generally argillaceous sediments at bottom and calcareous at top. Its thickness is about 90 m in Bahrain while it is about 120 m in Saudi Arabia.

3/ For more details see: ITALCONSULT, "Water and Agriculture Studies in Bahrain" Final Report, Vol. I, Rome, September 1971.

Table I.1[4/]

Epoch	Formation			Description	Aquifer Characteristics
Pleist-Holocene	Quaternary + Recent			Recent sand & Loam	
Miocene-Pliocene	Neogene Complex	Dam		Limestone cemented-sand with marls and clays	
		Hadrukh			
Eocene	Dammam	Alat	L.S.	White limestone partly dolomitic	A. Aquifer, Thickness ± 80 meters Depth to aquifer less than 50 m Quality, 2000 ppm/wells. provides low yielding
			Marl	Grey shale, orange marl	Aquiclude
		Khobar		Brown crystalline limestone	B. Aquifer, thickness 40-55 m Quality 2000-5000 ppm Provides high yielding Wells. Depth to aquifer 20-110 m
		Alveoline Saila Midra		Shark tooth Shale	Aquiclude
	Rus			Chalky zone	
Paleocene	Um-er-Radhuma			Dolomitic limestone with lenses of gypsum and anhydrite Harder Dolomitic	C. Aquifer Thickness 350-400 m Quality 10000-33000 ppm Depth to aquifer 110-300 m It forms large ground-water reservoir

4/ ITALCONSULT, "Water and Agriculture Studies in Bahrain", Final Report, Vol. 1, Rome, September 1971.

(v) Quaternary and Recent

It consists of eolian sands and sabkhah deposits. It is composed of unconsolidated foramineferal limestone with thin interbeddings of marls and shaly and coral limestone. The sabkhah sediments consist of eolian deposits mixed with evaporites.

I.2.2. Geological Structure

Bahrain geological structure as that of Qatar belongs to the Interior Platform structure of Saudi Arabia as per the definition of Powers et al (1966). The Platform is characterised in regional terms (refer to IX.2.2 page and VIII.2.2 page) by tranquil structural conditions with strata dipping gently towards the east. The Monoclinal structure is disturbed locally by almost parallel striking anticlines with N-S axis. Three main anticlines are recognised and set on echelon: Qatif, Dhahran and Bahrain anticlines. The general dips of the anticlinal limps do not exceed 3°.

I.3. Hydrogeology

Several hydrogeological investigations were carried out in Bahrain during the last 50 years period. The Bahrain Petroleum Company (1928-70) Italconsult (1971), Dr. Wright of IGS[5/] (1967-1972) and recently the International British Consulting Company G.D.C. (since 1978) have carried out the main investigations and provided the bulk of information relevant to water resources of Bahrain. Unfortunately most of the relevant information was not available to the writer. However, during the short ECWA staff mission to the country, and through direct communications with the concerned Government officials afterwards, some information on the water resources of Bahrain could be assembled.

I.3.1. Aquifers

There are three principal aquifers recognized in Bahrain, namely: Alat (Aquifer A), Khobar (Aquifer B), and Umm-er-Radhuma (Aquifer C), Table I.1. Another aquifer is recognised at greater depth; the Wasia sandstone aquifer having a TDS of 6000 ppm but not developed yet.

5/ Institute of Geological Science of Britain.

A. Alat Aquifer: It is the upper aquifer. It occurs at the periphery of the Island and encompasses a great area in northern Bahrain and at shallow depth reaching down to 50 meters.

It contains groundwater of relatively acceptable quality (about 2000 ppm of T.D.S.) but well productivity is low. The aquifer thickness is about 80 meters.

B. Khobar Aquifer: It is the most important aquifer in Bahrain. It occurs at depths ranging from 20-110 meters. The aquifer depth to the south of Manama is between 50-75 meters whereas it occurs at a shallower depth several kilometers to the south-west of the Capital. Its thickness is 40-55 meters.

The aquifer provides high yielding wells from which most of the groundwater is obtained with a T.D.S. ranging from 2000 to 5000 ppm and reaching up to 10000 ppm in some localities.

C. Um-er-Radhuma Aquifer: It exists at greater depth ranging from 110 to 300 meters and forms the largest groundwater reservoir in Bahrain, being 350-400 meters thick, but with poor water quality. The T.D.S. ranges from 10000 ppm in the north-west to about 33000 ppm in the south-east with high contents of H_2S[6/].

D. Wasia Aquifer: It occurs at depths ranging from 400-700 meters below ground level. The groundwater quality tapped in this aquifer is relatively good (less than 6000 ppm). Water bearing characteristics of this aquifer is not yet identified but it is known to contain high temperature water in Saudi Arabia[7/].

I.3.2. Groundwater Conditions: The three main aquifers: Alat, Khobar and Um-er-Radhuma are hydraulically connected and often form one aquifer system. Indications also showed that the Eocene aquifer system is in connection with the deeper aquifer system of the middle cretaceous sandstones and sand (Italconsult 1971).

6/ Government of Bahrain, Ministry of Works, Power and Water, "Water Resources Situation" Memorandum No. 6, 1979, pp. 1-12 (Arabic).

7/ Ibid.

The Eocene aquifers (A & B) have transmissibility of about 3.6×10^{-3} m^2/s whereas the transmissibility of the lower aquifer (C) is about 3.9×10^{-1} m^2/s[8/].

In their study on the groundwater quality, Italconsult, 1971, indicated that there are three major factors affecting the water quality: Sea water intrusion due to the prevailing overdraft conditions; upward leakage from the deeper aquifer (C); and the return flows of irrigation water to the shallow aquifer system.

It is generally reported that the aquifer systems in Bahrain are recharged indirectly in Saudi Arabian territory. This was proved by the recognized regional groundwater movement in the north-west from Saudi Arabia towards the south-east in Bahrain. They are of a depleting type as the annual recharge is essentially lower than the natural and artificial discharge. Most of the natural discharge occurs through the existing vast sabkha areas where the impervious cover of the Eocene aquifer system is not perfect and results in huge groundwater loss by evaporation from the shallow and the deep artesian aquifers. Other natural discharge occurs through the existing inland and submarine springs. Italconsult reported that over the last 30 years the lowering of the hydraulic head was constant with time without any sign of reaching equilibrium conditions, and that a general deterioration in water quality has occured over the same period.

8/ Government of Bahrain, J. Dard D.M. Watson, "Bahrain Sewage Project", Vol. 1, Master Plan, October 1975 p. 2-4.

Table I.2[9]

Deterioration of Sodium Chloride (NaCl) Contents during the period 1954-1978

Area	Sodium Chloride Contents in ppm				
	1954	1970	1973	1976	1978
Sitra	-	2820	2884	3315	3596
Adhara Spring	1820	2260	2360	3783	4063
Zallaq	1870	1900	1920	-	-
Wasmiya	1860	2320	2380	3631	3958
Badia	1360	1909	1943	2192	2241
Muharraq	1410	1909	1934	2649	2686
Manama	2170	2708	2814	-	-
Kharijiya	-	3610	3614	-	-

Table I.2 shows the quality deterioration as indicated by the NaCl content, during the period 1954-1978. Furthermore, Italconsult indicated that the head decline trends suggest that water levels could fall to sea level by about the end of the century. This statement was based on scanty hydrogeologic data and it is possible that it is not definitive but indicative.

9/ Government of Bahrain "Water Resources Situation in Bahrain" op. cit., p. 2 Table I.

The outcomes of the investigations carried out (during 1967-1972) by the Institute of Geological Sciences of London and the studies of G.D.S. in 1978, have indicated that the regional groundwater conditions reached the equilibrium state as of the mid-sixties. This was proved by the steadiness of the water level and the water quality. It was also deduced that wise utilization of the stored groundwater, will render the equilibrium state to last for an appreciable life length. The annual water consumption was estimated at 112 MCM in 1952 and 199 MCM in 1976[10/].

I.3.3. Submarine Springs

In the course of its studies in 1953, the Bahrain Petroleum Company discovered about 20 major submarine springs. Other six springs were reported to exist 10 to 20 kilometers north-east of Muharraq. The estimated annual flowage from these springs is about 9.6 MCM.

I.4. Desalination

Bearing in mind the limited water resources of Bahrain and the prevailing overdraft situation in quality and quantity wise; the Water Supply Directorate of the Ministry of Works, Power and Water, have made considerable progress on desalination in recent years so as to provide blended water supply having a T.D.S. Content not exceeding 1000 ppm.

Desalinated sea water is being produced at the Sitra power/water station where there are two distillation units of rated capacity of 2.5 mgpd each. During the period May-September 1978 the average fresh water production was 1.6 mgpd and the peak production recorded was 2,13 mgpd over a period of one week. In addition to the existing two distillation units at the Sitra Station, plans were approved to instal a further three distillation units each having a rated capacity of 4 mgpd giving rise to a maximum distillate capacity at Sitra to 17 mgpd, with an average output over any year of 11.5 mgpd and during peak demand, of 14.5 mgpd[11/].

10/ Government of Bahrain "Water Resources Situation in Bahrain" op. cit., p. 2 and Table 2.

11/ Government of Bahrain, Ministry of Works, Power and Water "Policy on Water Distribution Blended Supplies and Capital Investment Requirements", January 1979, p. 1, 8.

1.5. Conclusion

As in most of the Gulf States, groundwater is the major water resource available in Bahrain. The aquifer system is composed of Alat, Khobar and Um-er-Radhuma carbonate rocks. The former two members provide low to high yielding wells and the quality range is 2000 - 5000 ppm. The third member is known to contain good quantity but poor quality (10000-33000 ppm). A fourth aquifer occurs at depth, Wasia sandstone having a TDS of 6000 ppm or less, but it has not been developed or identified yet. The aquifer system in Bahrain is indirectly recharged in Saudi Arabian Territory and naturally discharged by the existing sabkhas, the inland submarine springs and evaporation. Hence, it is of a natural depleting type resulting in continuous water level decline and quality deterioration. It is believed that a sort of equilibrium state was reached, as from the mid-sixties, with the increase in water demand being met by the increased output of the desalination plants.

Bearing in mind the above, a country-wide groundwater observation network should be intensified. Detailed Hydrogeological investigations should be updated and a national water master plan should be drawn so as to arrive at an optimum use of the potential usable groundwater in conjunction with desalted water production in an integrated manner to keep up with the state of equilibrium if it still does exist.

II. THE PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN

Population: 1.796 million[1/]

Area : 289690 square kilometers

II.1. Geographical environment

The People's Democratic Republic of Yemen (PDRY) occupies the extreme south-western and the southern portion of the Arabian Peninsula along the Gulf of Aden. It lies approximately between latitudes 13°00' and 19°10' North and Longitudes 43°30' and 53°50' East.

The western part of the country is composed of a well-defined coastal plain along the Gulf of Aden extending about 50 km in lenght Inland, the country becomes hilly rising to the ranges forming the Yemen frontier with the YAR. The central part of the country is backed by a plateau of about 1300 meters a.s.l. stretching to the north to Ramlat Sab'atayn sand and the Rub Al-Khali. The eastern part of the country consists of a discontinuous coastal plain of variable width bordered by the coastal mountain belt rising in some places to about 2000 meters a.s.l. and extending into the YAR and Saudi Arabia in the north.

Most of the PDRY is characterised by a hot tropical climate throughout a great part of the year. The coastal areas have more uniform temperatures and are more humid than the interior. There is a wide variation in temperature in the highlands between summer and winter and the diurnal change in temperature is about 10°C. The hotest months are May to September with a maximum temperature of 43.3°C in June. The coldest months are January and February[2/].

The PDRY being in the monsoon belt, is mainly affected by south-east winter monsoonal winds during October to April and North-East summer monsoonal winds during June to August. An intermediate or transitional period can be recognized between the two main monsoonic periods that is from April-June.

1/ World Development Report, the World Bank August 1978.

2/ PDRY, "A brief Report on the Geology and Mineralization in PDRY", no date, pp. 3, 4.

In the hilly and mountain regions of the country the south west monsoon brings heavy rainfalls accompanied by thunderstorms. The coastal plains get very little precipitation (0-50 mm) annual average. It increases towards the northern part of the country. The western part of the highlands receives 750-800 mm annual average rainfall[3/]. The eastern hilly region gets less, about 50-100 mm per annum. The total volume of annual precipitation over the country is estimated at 21.1 MCM[4/].

II.2. Geological environment[5/]

II.2.1. Stratigraphy:

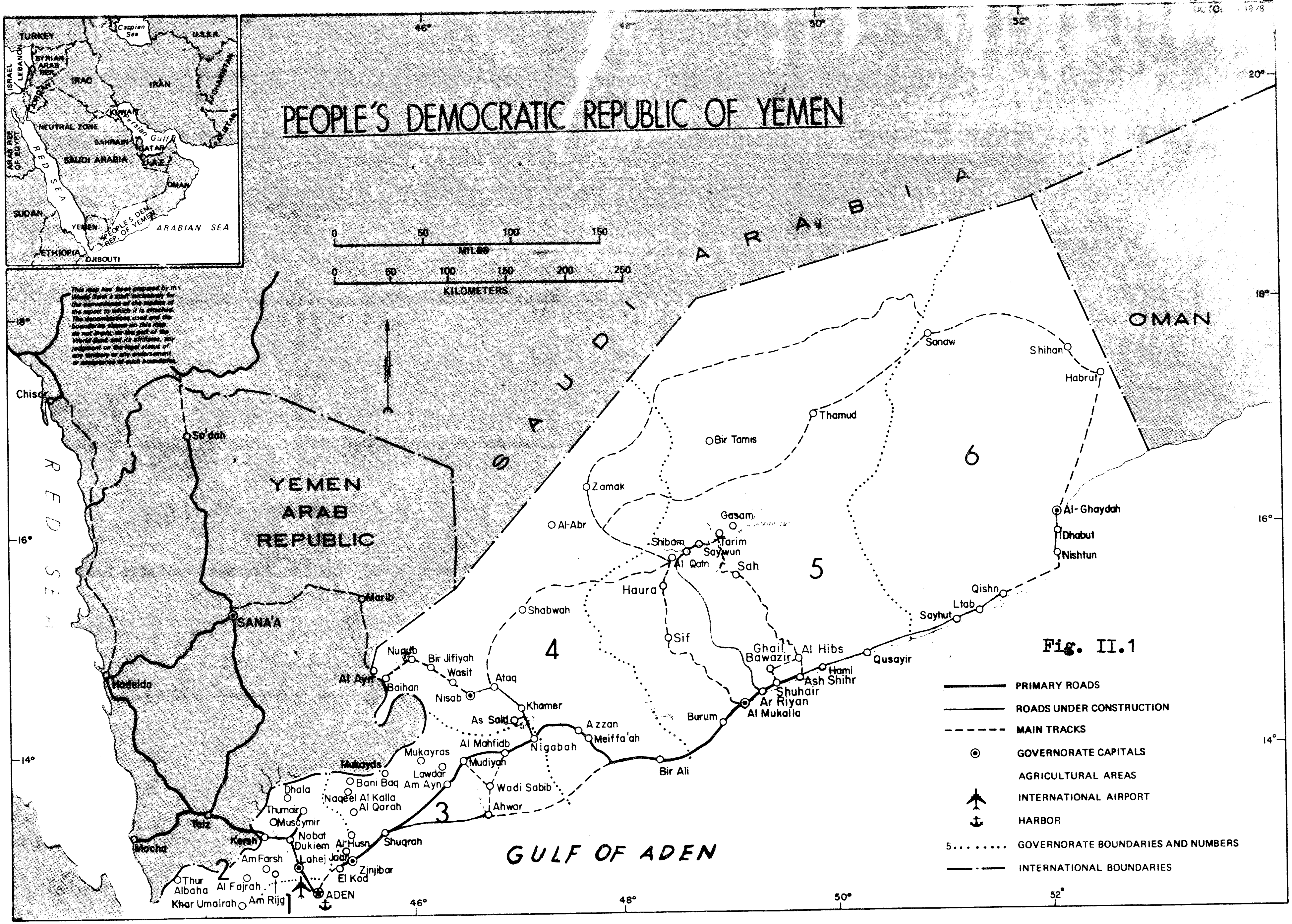
As in the YAR, the stratigraphy of the PDRY generally shows a great affinity to the rest of the Arabian Peninsula. Rock units form Jurassic to recent geologic age outcrop or occur in the subsurface of the PDRY. Basement complex of Precambrian age and consisting of igneous and metamorphic rocks outcrops in the south and south western part of the country.

Sandstone formations of Cambrian age, locally called W jid formation (350 m thickness) occur in the country and overly the basement complex. Red shales interbedded with limestone represent the Permian age (150-200 m thickness). This means that Ordovician, Silurian, Devonian and Carboniferous geologic time scales are missing in PDRY (Z.R. Beydoun 1960-1966 and others).

3/ ADAR Corporation "Integrated Resources Survey Programme, Wadi Beihan Region" (PDRY, YAR), Part II, 1976.

4/ Arab League, "Food Security in the Arab States" Part 1, 1980.

5/ "A brief Report on the Geology and Mineralization in PDRY". *op.cit.*, pp. 6-12.



PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN
IBRD
SAUDI ARABIA
OMAN
YEMEN ARAB REPUBLIC
RED SEA
GULF OF ADEN
0 50 100 150
MILES
0 50 100 150 200 250
KILOMETERS
TURKEY
U.S.S.R.
Caspian Sea
SYRIAN ARAB REP.
LEBANON
ISRAEL
JORDAN
IRAQ
IRAN
AFGHANISTAN
KUWAIT
Persian Gulf
NEUTRAL ZONE
BAHRAIN
QATAR
U.A.E.
ARAB REP. OF EGYPT
SAUDI ARABIA
SUDAN
ETHIOPIA
DJIBOUTI
YEMEN
PEOPLE'S DEM. REP. OF YEMEN
ARABIAN SEA
Chisoz
Sa'dah
SANA'A
Marib
Hodeida
Taiz
Mocha
Kerah
Al Ayn
Baihan
Nuqub
Bir Jifiyah
Wasit
Nisab
Ataq
Khamer
As Said
Shabwah
Al-Abr
Zamak
Bir Tamis
Thamud
Sanaw
Shihan
Habrut
Al-Ghaydah
Dhabut
Nishtun
Qishn
Ltab
Sayhut
Qusayir
Hami
Ash Shihr
Al Hibs
Ghail Bawazir
Shuhair
Ar Riyan
Al Mukalla
Burum
Bir Ali
Azzan
Meiffa'ah
Nigabah
Al Mahfidb
Mudiyah
Wadi Sabib
Ahwar
Mukayras
Lawdar
Am Ayn
Mukayds
Bani Baq
Naqeel Al Kalla
Al Qarah
Dhala
Thumair
Musaymir
Nobat Dukiem
Al Husn
Jaar
Lahej
Zinjibar
El Kod
ADEN
Am Farsh
Al Fajrah
Am Rijq
Thur Albaha
Khar Umairah
Shibam
Sayhun
Tarim
Gasam
Al Qatn
Sah
Haura
Sif
1
2
3
4
5
6
46°
48°
50°
52°
14°
16°
18°
20°
PRIMARY ROADS
ROADS UNDER CONSTRUCTION
MAIN TRACKS
GOVERNORATE CAPITALS
AGRICULTURAL AREAS
INTERNATIONAL AIRPORT
HARBOR
5 GOVERNORATE BOUNDARIES AND NUMBERS
INTERNATIONAL BOUNDARIES

Fig. II.1

The rest of the stratigraphic column in the PDRY can be summarized in an ascending age as follows:

Geologic Time Scale	Brief Description
Jurassic, Lower	Missing
Middle	Coarse grained sandstone interbedded with conglomerate, limestones and marls (80-180 m thickness, Kohlan Series)
Upper	Limestone, marls, dolomites and shale with evaporites (up to 1000 m thickness, Amran Series)
Cretaceous, Lower	Limestones and sandstones (Mukalla type, reaching 1000 m in thickness)
Upper	Basaltoid sedementary rock units, volcanic and lava with shale and limestone ranging in thickness from 1500-1800 m (Wasia and Aruma groups).
Tertiary	Um-er-Radhuma limestone and dolomite
Eocene	Limestone, evaporites and topped with marl
Oligocene-Miocene	Conglomerates, sandstones interbedded with limestones. Tertiary deposits thickness is about 1000 m.
Quaternary	
Pliocene to Recent/	Occur in the coastal plain of the Gulf of Aden, in Ramlat Sabatayn sand plain, the northern slopes of Hadramout and in the valley fills. Consist predominantly of alluvium and eolian deposits of variable thickness.

II.2.2. Geologic structure

Structurally the PDRY lies in the southern part of the Arabian Megablock of the Afro-Arabian platform. The country can be divided into: (1) Hadramout Arch which is a sedimentary plateau encompassing the eastern region; (2) the uplifted main basement block of the western region and (3) the depressed area covered by volcanic rocks of the Aden Trap Series in the south-west.

To the west of Longitude 50° East, the regional structure is trending North-South approximately parallel to the Arabian Shield trend and is represented by the Mukalla Arch and Mafidh High with the Madbi depression in between. To the east of this longitude the trend is North East, South West and almost parallel to the Gulf of Aden and is represented by the North Hadramout Arch (Z.R. Beydoun) where Jeza'a Depression lies in between. To the north of the North Hadramout Arch lies the interior Homocline of the Rub Al-Khali Basin.

II.3. Groundwater resources

Several hydrogeologic investigations have been carried out in the PDRY by different consulting firms under the auspices of FAO, Arab Funds and other technical assistance from some donating countries. These studies were mainly carried out in the wadis of: Hadramout, Tuban watershed area, Abyan delta and Wadi Meafah Area.

Unfortunately, the compiled data relevant to water resources of the PDRY during the ECWA mission was not sufficient to describe adequately the water resources situation of the country. However, analysis of the available data on the subject may furnish an indicative presentation of the water resources of a great part of the country.

II.3.1. Wadi Hadramout and Northern Areas[6/]

Wadi Hadramout and the Northern Areas represent about 40 per cent of the entire area of the country. About 2600 wells were drilled and the total amount of groundwater extraction for irrigation is about 50 per cent of the estimated annual recharge to groundwater resources in the area. The valley fill deposits are the main water bearing formation in the area. About 25-30 per cent of the total valley floor area contains groundwater of inferior quality.

6/ For more details see: K. Klimacki, UN, OTC, "Rural Development in Valley Hadramout and Northern Areas" December 1973, pp. 14-46.

II.3.1.1. Principal aquifers in the area

The main water bearing rock units recognized in the area can be described as follows:

(a) Valley fill deposits (Quaternary)

It is predominantly alluvium consisting of sand, gravel and clay or sandy clay deposits. The existence of the clay or the sandy clay subordinates within the deposits results in semi-confining conditions but generally the deposits represent one single aquifer under water table conditions.

The aquifer's total thickness is highly variable and not well defined, the same goes for the aquifer transmissivity (T) which is reported to range from 140 to about 1300 $m^3/d/m$ relying on the fine-coarse percentage distribution within the aquifer. The average hydraulic gradient, as indicated by the various piezometric maps drawn for the aquifer, is 1.1 to 1.2 m/kilometer.

Depth to water level along the central area of the Wadi Hadramout ranges from 10-20 meters and is a function of topography.

Wells tapping water from this aquifer have low to moderate yielding capacity less than 10 m^3/hr. The deposits in Wadi Hadramout and along the lowest reaches of its major tributaries namely: Wadis Idim, Jaymi, congluence of wadis Amd, Duan and Al-Ain form the best yielding aquifer within the area.

The valley fill deposits in the Northern Areas of the Country are very thin and due to the poor groundwater recharge in these areas, do not contain much groundwater.

(b) Rus-Jeza deposits (Eocene)

It is composed of limestone, chalk, marl and gypsum intercalations with dolomitic and silicified limestone. It is impervious and contains no water in Hadramout Basin.

In the Northern Areas (North of Hadramout Basin) the aquifer is composed mainly of 2-15 m thickness of semi-impervious shales, marls and clays sandwiched with beds of limestone-dolomite deposits at fairly regular intervals. The thickness of the aquifer is unknown.

Groundwater tapped by the shallow wells at Sanaw, Hulya and Thamud indicates that the chalky and marly limestone of the upper 45-60 m of the Rus-Jeza deposits do contain water which follows and is issued from the fissures and cracks occuring within the aquifer. The occurrence of this water-bearing zone is irregular and of patchy type. Exploratory drilling in these formations (123 wells) have indicated that the deeper regional groundwater level varies in depth from 60-120 m relying on the ground elevation of the well coller.

Water yielding capacity of the Rus-Jeza formation in the Northern areas is reported to range from 200-400 g/hr. In general the zone below the regional deeper groundwater level offers better prospects of striking groundwater than the top patchy zone. To reach this deeper zone in the Northern Areas, well drilling has to be carried out to a depth between 90 to 150 meters.

Direct groundwater recharge to the deeper zone is expected to be very poor. The expected well yield from this zone may be expected to range between 300-600 g/hr. (0.38 - 0.76 1/s).

(c) Um-er-Radhuma limestone deposits (Paleocene)

It is composed of massive beds of limestone and marly limestone, occasionally fractured and solution-channeled. In Hadramout Basin the Um-er-Radhuma limestone was proved to be of low permeability and does not contain sufficient water which could be economically extracted by wells.

In the areas to the north of Hadramout basin the water bearing properties of the Um-er-Radhuma limestone are not well known. Exploratory drilling in the formation showed the existence of a meager quantity of groundwater. Direct recharge to the deposits is limited. Recharge by leakage from the overlying Rus-Jeza deposits is not possible due to the occurrence of the shale beds in between.

(d) Mukalla sandstone: (Cretaceous)

It is predominantly sandstone, very fine grained, uniform and of moderate permeability at top. Thick beds of shales, siltstone and occasionally marls and clays occur in these deposits. The lower zone of this aquifer is of lower permeability.

Artesian conditions prevail particularly in the areas to the north of Hadramout Basin. Depth to water level ranges from 50 m to about 100 m and it is generally deeper in the Northern areas. Wells tapping water from Mukalla Sandstones are generally deep (200-300 m). The yielding well capacities range between 30-60 m^3/hr. Groundwater quality is in the order 440-1000 ppm of total dissolved solids (T.D.S.).

II.3.1.2. Groundwater quality[7/]

The quality of groundwater in Wadi Hadramout was investigated in detail by the Russian mission. Based on these studies it was concluded: Groundwater of fair quality 1000-3000 ppm occurs mainly along the flood plain of the Wadi Hadramout and at the confluence of and up its tributaries. The central part of the Wadi mostly contains poor quality water (3000-5000 ppm) and becomes more saline (5000-14000) ppm as one goes away from the central areas.

Groundwater encountered in Mukalla Sandstone, is of very good quality (440-1000 ppm). It deteriorates when mixed with waters from valley fill deposits.

In the Northern areas the groundwater tapped within Rus-Jeza deposits is of moderate quality with TDS ranging from 1400-3700 ppm. But groundwater from the deeper zone, is in general of better quality than that encountered in the shallow one.

II.3.1.3. Groundwater recharge in Wadi Hadramout

Based on the hydrogeological findings furnished by the various investigations about the Hadramout Basin, K. Klimaki 1973 made very rough estimates for the possible contribution to the recharge of the groundwater in the Basin as 190 MCM as follows:

7/ Ibid., pp. 30-31.

- Wadi Hadramout area 6450 km^2 with estimated rainfall volume of 387 MCM/ annum.

- Inputs

From rainfall	97.0 MCM
From surface runoff	
from the southern Plateau	75.0 MCM
from the northern Plateau	20.0 MCM
From surface inflow from tributaries	1.3 MCM
From Sabatayn surface runoff and subsurface inflow	1.0 MCM
TOTAL	194.3 MCM

- Outputs

Surface outflow to Wadi Masila	?
Subsurface outflow to Masila	0.04 MCM
Downward leakage to Mukalla Aquifer	Nil
TOTAL	0.04 MCM

- No estimate was made for the groundwater recharge in the Northern Areas, but it is expected to be lower (67 MCM/Annum) based on 1% of the total rainfall volume contribution to groundwater.

II.3.2. Wadi Tuban Water Shed Area[8/]

Extensive hydrogeological investigations were carried out in Wadi Tuban Water Shed area by ITALCONSULT during the 1972-1974 period. A mathematical model to simulate the hydrogeological conditions of the area was established. Based on these studies the hydrogeology of Wadi Tuban area can be summerized by the following text.

8/ UNDP/ITALCONSULT, PDRY. "Soil and Water Utilization and Conservation in the Wadi Tuban Watershed Area" Hydrological Report, Vols. I and II DP/PDY/71/508/IAGL, Sep. 1975.

The total catchment area of Wadi Tuban is about 5600 km^2. Rock units ranging from Precambrian complex, Mesozoic and Paleocene sedimentary formations, Mesozoic trap series and Quaternary volcanics and sedimentary formations, occur in the Alluvial plain (1800 km^2) of Wadi Tuban.

II.3.2.1. Aquifers

The prinicpal aquifer in the area occurs in the alluvial deposits which consists of an alternating series of highly transmissive coarse clastics and less permeable silt and clay. Its thickness ranges from 150 m in the upper reaches of the Wadi to about 500 m in the lower Delta. The aquifer is essentially unconfined with local confined or semi-confined conditions in the lower part of the Tuban Delta.

The main aquifer characteristics can be summerized in the following table II.1

Table II.1

Parameter / Area	Depth to water/m	Av.Depth of wells (m)	Water Temp. oC	Gradient %	Transmissivity m^2/S(T)	Storage Coeff. (S)	Average Permeability
Upper Delta	20-30	Dug wells 35 m	35°	.8-12	$1.1x10^{-2}$	$1.2x10^{-1}$ to	8-10m/day
Central Delta	15-20	Tube wells					
Lower Delta	5-10	60-70 m	40.5	2.5-1	$2.4x10^{-2}$	$7 x10^{-2}$	

Nothing is known about the deaper aquifers in Wadi Tuban Delta. In general the deeper zones of the aquifer have very poor water bearing characteristics.

II.3.2.2. Groundwater quality

Groundwater quality varies widely throughout the Wadi Tuban Delta. Three main water quality zones are recognized: (1) Along a narrow strip in the upper course of Wadi Tuban having total dissolved solids (TDS) ranging between 650 ppm to 1000 ppm. (2) The central part of the Delta where TDS increases from 1200 to 1600 ppm. (3) In the lower reaches of the Delta, the water quality becomes saline and renges in TDS from 3200 ppm to about 9000 ppm.

In the lower part of the Wadi Tuban Delta, Sheikh Othman well field groundwater quality deteriorated as a result of utilization and sea water encroachment. In 1947 water quality was measured at 1300-2000 ppm; during 1965-70 at 2000-3200 ppm; in 1973 at 3200-4500 ppm.

II.3.2.3. Groundwater recharge

Groundwater recharge to the alluvial aquifer of Wadi Tuban is mainly from the main Wadi and its tributaries or from the spate irrigation waters diverted to the areas of cultivation. Estimates of groundwater recharge to the aquifer were made by ITALCONSULT based on water level fluctuations recorded throughout the Wadi Tuban Delta. It was estimated at 25.0 MCM in 1973 and about 26.5 MCM in 1974.

From the mathematical model interpretation, it was deduced, considering a long-term basis, that the annual recharge to the aquifer system of Wadi Tuban is in the order ranging from 40-60 MCM. Hence the average annual groundwater extractions should be kept within the estimated annual recharge range (40-60 MCM) so as to avoid any bad outcomes as a result of over extractions.

II.3.3. Wadi Meafa'h

The aquifer system of Wadi Meafa'h is predominantly alluvium consisting of clastic deposits of boulders, cobbles, gravels and silt in varying proportions. It is generally coarse clastic in the upper reaches of the wadi and gets finer at the lower Delta interfingered and in lenticular spread of coarse materials as it often occurs in delta deposits.

The aquifer thickness is variable and not well-defined. The permeability of the aquifer varies continuously according to the percentage of silt and clay contents, horizontally and vertically. The average depth to water level is 12-38 m and the average depth of wells tapping water in the Wadi Meafa'h is about 60 m. Water yielding capacity of wells is generally fair.

Groundwater quality is medium to high salinity, low alkalinity, and it is very poor in some parts of the Wadi particularly in the areas away from the Wadis' main course reaching up to 10000 ppm of total dissolved solids. Water quality along the wadi course ranges between 1000-2000 ppm of T.D.S.

Potential groundwater utilization from Wadi Meafa'h alluvial aquifer was estimated at 22 MCM/Annum. This was based on the following estimates of probable groundwater recharge made by the Hungarian Technical Team who investigated the area (1976).

Probability %	Annual Runoff MCM	Recharge to Aquifer MCM
90 dry year	80	40
50 average year	100	45
2 wet year	165.7	60.8

II.4 Surface water resources

The drainage system of the PDRY is mostly made up of dry water courses or wadis which flow only after heavy rains which result in flash floods. Wadi Hajar is the only perennial one in the country. It gets its water from a hot spring issuing at Sidara about 100 km from its mouth. Other large wadis: Tuban, Bana, Ahwar Hadramount, Masila and Meafa'h are lamost dry during some parts of the year though they may contain isolated pools of water sometimes.

Investigators have indicated that floods in the main wadi in the country may occur at any time from the end of February to mid-April and more often in July-September. Flood flows may last for few minutes to few hours only. Flood waters rapidly disappear in the valley fill deposits and never reach the sea.

In a country-wide hudrologic investigation Dar el Handasah cons ilting firm (1972), has estimated the flood volumes that flow annually in the main wadis of the PDRY as indicated by table II.2. These estimates are based on weighted average annual rainfalls, the watershed areas of the main wadis and assumed runoff coefficients. In general, streamflow records in the country are scanty and inadequate to provide reliable estimates of the surface water resources of the Republic.

Table II.2 9/

Surface Water Flows in the Main Wadis

Area	Wadi	Annual Flood Volume (MCM)	Electric Conductivity Million ohms/CM
Subeihi	Maadin	12	1.50
Dhali'a	Azarik	12	0.44
Al-Jabolein /	Rabwah	10-15	0.62
Dafinah	Thurah) Tarran)	10	-
	Harran) Tu'a) Kabran)	10	-
Misab	Wajar	10	-
	Der'a	9	0.62
	Abadan	7	0.62
Said	Yesham	7	-
Meafa'h	Meafa'h	30	-
Ghasil) Bawazir)	Shueib	0.75	-
Masila) Delt)	Masila	28	1.25
Gheidah	Jeza	100 ?	-
Qasim	Al Wadi	12	-
Beihan	Beihan	54	0.5
Ahwar	Ahwar	75	1.78
Hajar	Hajar	230	-
Hadramout	Aden) Sirr) Ben Ali)	144	0.55
Tuban Delta /	Tuban	210	-
Delta Abyan	Bana)	176	-
	Hassan)	30	-

9/ Dar Al Handasah, "Preliminary Country-Wide Study on the Soil and Water Resources of PDRY", 1972.

II.5 Dams

In recent years the PDRY has paid noteworthy attention to make use of the flood waters flowing in the main wadis, by construction of small earth dams, mainly diversion, to regulate floods and to provide adquate water supply for irrigation. Plans to construct eight small dams in the country, in co-operation with USSR technical aid, is being implemented since 1977. No data is available about these dams. It was understood from the government officials that the Dams Construction Projects involve also constructing irrigation canal distribution.

II.6 Conclusion

Hydrogeologic and hydrologic data in PDRY are scanty and widely spaced and do not have enough long records. Water resources assessment was carried out in some localities based on short term observations and several assumptions. Hence, they are almost indicative and sometimes misleading.

The country relies mainly on groundwater as its major resource. The main occurence of the potential groundwater is along and within the deltas of the major wadies originating from the northern Yemen highlands. Groundwater of good to moderate quality occurs in the upper reaches and along the main wadi courses and deteriorates away from them and near the coastal strip. Groundwater potentiality is not identified. Estimates for groundwater recharge were made in some localities as Wadi Hadramout 257 MCM/a, Wadi Tuban 40-60 MCM/ a and Wadi Meafa'h 22 MCM/a. Overdraft conditions, quality deterioration and water level decline, were experienced in most of the well developed localities. This is a dangerous situation which points to growing difficulties in the future unless action is taken, especially if demand increases.

The availability of the surface water resources in PDRY relies on the erratic rainfall that the country receives. The resources are not identified and not yet developed. The possibility of utilizing the sporadic flood waters is appreciable.

It would be desirable to initiate as early as possible a country-wide water assessment programme involving all the natural parameters that are affecting the availability of the resources. In areas where preliminary investigations were carried out, updating of the data is required. Artificial groundwater recharge, utilizing the flood waters in the major wadis like Tuban, Abyan, Hajar and others to alleviate overdraft conditions should be considered a priority project. Dam construction over the major wadis, as presently planned, should be enhanced. Hydrogeologic investigations in the shared water shed area with North Yemen should be carried out jointly through mutual co-operation.

III. THE REPUBLIC OF IRAQ

Population: 11.5 million
Area : 435000 square kilometers

III.1 General [1/]

The Republic of Iraq lies to the north east of the Arabian Peninsula between the latitudes 28°59' and 37°7' north and longitudes 38°49' and 46°40' east. Figure III.1.

III.1.1 Topography:

Five major phisiographic units are recognised:

The mountaineous area (Zagros Mountains) with maximum elevation of about 3700 m a.s.l. The area is characterised by high annual rainfall that ranges from 500 mm to more than 1000 mm/a. Several canyons and wadis cut through the area.

The mountain foot hills which lie to the south west of Zagros - Torous Range. The average annual rainfall ranges from 300 to 500 mm.

Al-Jazira Area which lies to the south of the mountain foot hills area. Its elevation ranges from 50 to 500 m a.s.l. and mostly desertic except the strip along the river.

The River Plains Area which comprises the plains between the Tigris and Euphrates Rivers. It slopes gently towards the Arabian Gulf. Average annual rainfall over the area is about 150 mm, and

The Desertic Area lies to the southwest of the Euphrates River. Rainfall is less than 100 mm/a on average.

III.1.2 Climate:

The climate of Iraq is semi-arid, sub-tropical with hot dry summers and cold winters. Shade temperature may reach up to 50°C in summer and

---

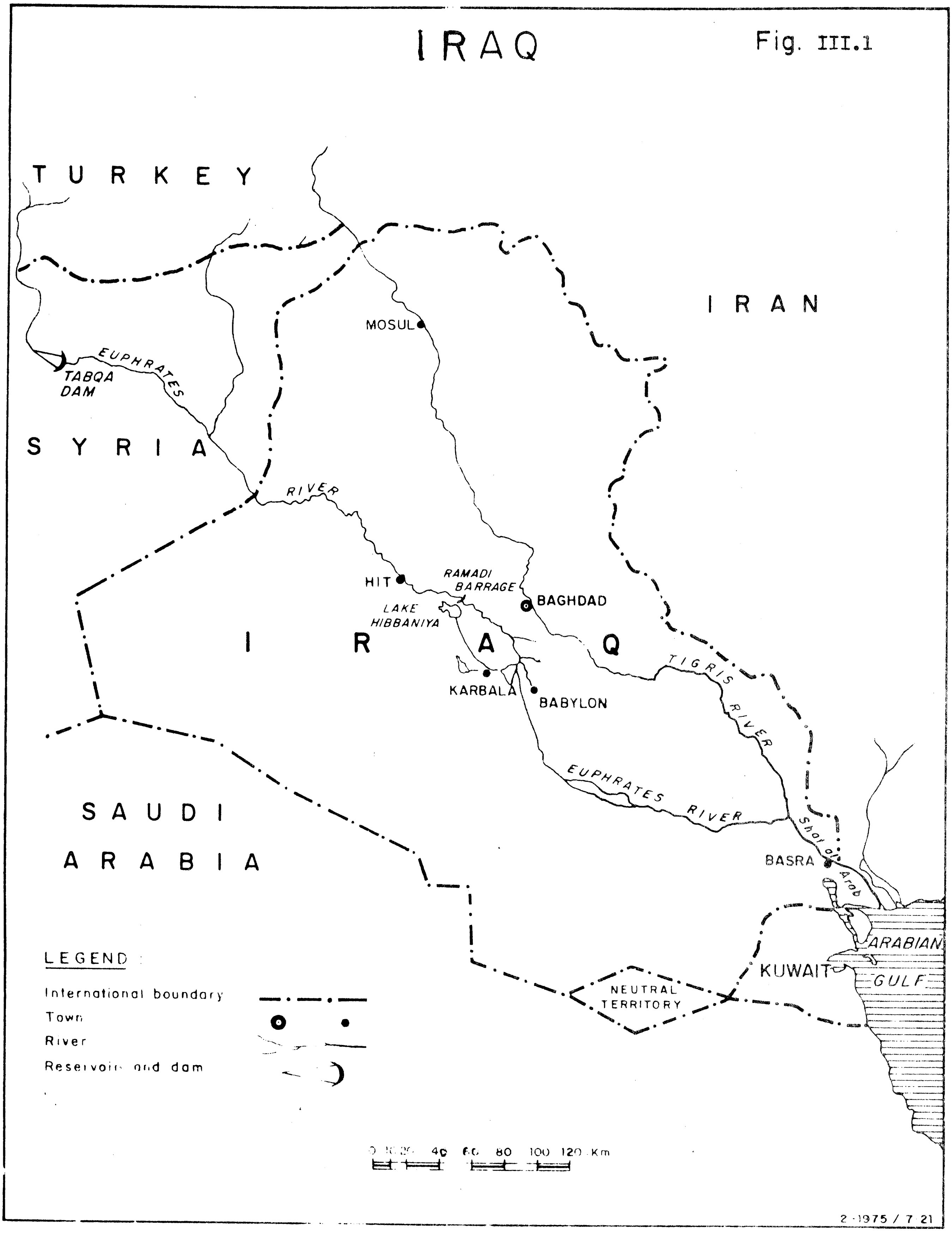
1/ Government of Iraq, Ministry of Irrigation "Country Statement to ECWA Second Regional Water Meeting", January 1979 (Arabic).

decreases down to -8°C in winter. Hot intervals may occur during winter in the centre and south of Iraq. Rainfall is generally scanty over most of the country except in the north east. It ranges from 100-150 mm/a in the centre and south of Iraq and goes up to 1000 mm/a in the mountaineous areas. Relative humidity is about 65 per cent in winter in central Iraq and 16 per cent in summer. Annual evaporation ranges from 2000 to 2500 mm and the average annual wind velocity is 3.6 m/s.

III.2 Geology

III.2.1 Structure:

The Republic of Iraq, as indicated by the regional geology of the East Mediterranean, is situated at the north-eastern rim of the unstable shelf of the Arabian Shield. A major geosyncline trending NW-SE comprising most of Iraq is the predominating geologic structure which has the primary control on both the surface and groundwater occurrence and movement in the country. This structure and the resultant synclinariums and anticlinariums have been formed when the earth crust in Iraq was subjected to the tangentianal forces originated in the Iranian Plateau and blocked by the Arabian shield in the south. The geosynclinal belt formed starts away from the Arabian shield and extends into the south and south west of Iraq with a general thickening of the sedimentary sequences in the central part of the country.


IRAQ
Fig. III.1
TURKEY
IRAN
SYRIA
EUPHRATES
TABQA DAM
MOSUL
RIVER
HIT
RAMADI BARRAGE
BAGHDAD
LAKE HIBBANIYA
I R A Q
KARBALA
BABYLON
TIGRIS RIVER
EUPHRATES RIVER
SAUDI ARABIA
BASRA
Shat al Arab
ARABIAN GULF
KUWAIT
NEUTRAL TERRITORY
LEGEND
International boundary
Town
River
Reservoir and dam
40 60 80 100 120 Km
2-1975 / 7 21

III.2.2. Stratigraphy:

What follows is a brief account of the stratigraphical sequences in Iraq:[2/]

Era	Period	Lithology		Main Occurrence
Cenozoic	Quaternary	Alluvium, river deposits and eolian sands and detritus		River plains area
	Tertiary	Pliocene:	sandstone, shale and conglomerate	In the mountains area
		Miocene:	sandstone, shale, limestone, gypsum and anhydrite	In south, south eastern Iraq
		Oligocene:	limestone	Limited in the mountains
		Eocene:	limestone	In the mountains, southern and northern deserts
Mesozoic	Secondary	Cretaceous:	limestone, shale and marl	wide occurrence in the mountains and north of Ratba (3000-10000 m thickness)
		Jurassic & Triassic	Limestone, dolomite, shale, marl & occasionally gypsum	In the mountains and north of Ratba
Paleozoic		limestone, shale and red volcanics		Very limited in the north in Habajah and Amadiya area

2/ - Arab League "Food Security in the Arab States", Part I, 1980.
- Geol. Survey of Austria "Explanatory text to the Synoptic Geol. Map of Kuwait" 1968, pp. 15-18, and
- Government of Iraq, Min. of Development - Mineral Survey, Geol. Map of Iraq, 1960.

III.3 Hydrogeology:

III.3.1 Introduction

The ministries of: Irrigation, Agriculture and Agrarian Reform and the Soil and Land Reclamation General Corporation are the main Government Agencies that deal with exploitation, development and management of the Water Resources of Iraq. It was reported that hydrogeologic investigations were carried out in some localities of Iraq and not on a country-wide scale. This is probably attributed to the fact that the country relies mostly on its surface water as a resource rather than on groundwater.

III.3.2 Aquifers 3/

There are five major aquifers known to exsit in Iraq. They are:

III.3.2.1 Quaternary alluvium

It consists of alluvial deposits, sand, gravel and clay. It may provide good groundwater potential when it is thick and contains less precentage of fine sediments. Groundwater quality is variable. The aquifer occurs mainly along the Wadi courses and river flood plains in the mountain areas and in the north and east of Iraq. It has a maximum thickness of about 1000 m near Amara area.

III.3.2.2 Bakhtiari formation (pliocene)

It is one of the major aquifers in Iraq and provides good groundwater potential in quantity and quality in the Arbil plain. It occurs also in Kufra, Karkuk, Sinjar, Zakho, Takrit and Samirra areas. The aquifer consists of conglomerate and gravel interbedded with clay layers and has a thickness of 3000 m in the mountain area; then decreases towards the rivers plains.

III.3.2.3 Upper fars formation (U. Miocene)

It is of great importance in Sinjar area where it provides good groundwater potential in quantity and quality. It consists of sand, sandstone with clay and silt layers. Fair to good groundwater quality may be encountered and ranges from 500-1000 ppm of T.D.S. Aquifer productivity is reported to be fair in other parts of Iraq with some local good producing zones.

3/ Arab League "Food Security in the Arab States", Part 1, Land and Water Resources" 1980, pp. 731-739 (Arabic) and A.M. Dakhil "Groundwater in Iraq" pp. 1-7 (Arabic)

III.3.2.4 Euphrates limestone formation (L. Miocene)

It is about 180 m thick and occurs mainly in the northern areas and to the west of Euphrates. The major springs existing in Kubaisa and Nasiriya may be fed by this aquifer. Good groundwater quality is often encountered from the aquifer with salinity ranges from 500-1000 ppm of T.D.S. It is equivalent to Ghar formation aquifer in Kuwait.

III.3.2.5 Dammam-Um er Radhuma Aquifer (Paleocene=Eocene)

It is composed mainly of limestone, dolomite, dolomitic limestone beds fractured, fissured and karstified with clay, marl and chalky limestone layers. The aquifer's main occurrences are in the central and western part of the southern desert along the Iraqi-Saudi Arabian borders. It occurs also in the north western and central west of Iraq.

The aquifer furnishes the main groundwater resources of the western desert of Iraq. The lower pay zones (150-300 m) of the aquifer are recharged indirectly by subsurface flow from Saudi Arabia. The upper zones (15-50 m) are directly recharged from rainfall over the western desert.

III.3.3 Groundwater areas 4/

Based on the lithostratigraphic characteristics and the predominating phisiographic features the country has been divided into five major groundwater areas: The mountains, the foot hills, the Delta Plain, Al-Jazira and the Desert Areas. The first and the second areas are known to store and to provide good groundwater potential in quantity and quality. The others are known to be moderate to fair groundwater producing areas.

Groundwater in Iraq is not well developed and not totally identified. It is being locally used for irrigation in distant areas, for domestic purposes and rarely for industry. Recently, the government agencies have paid good attention to explore the potential groundwater resources in certain areas of the country, like the desertic and the foothill areas.

4/ Ibid. pp. 735 and 736.

Rough estimates of the available groundwater resources which may be utilized annually, were made by the concerned officials of the Ministry of Irrigation and found to be in the order of 1000 to 1200 MCM of which only about 40 per cent is being utilized at present. Future plans to develop the groundwater resources of Iraq are being undertaken to raise this resource up to 2000 MCM/a by the year 1995[5/].

III.4. Surface water resources

As mentioned earlier, the Republic of Iraq relies mostly on the surface water rather than on the groundwater resources of the country. The Tigris and Euphrates rivers and their tributaries are the major contributors to the surface water resources. 50 per cent of the total volume of the Iraqi rivers' waters are provided from the rivers' basins occuring in Turkey, 30 per cent in Iran and 20 per cent within Iraq. The table below indicates the total and the contributing catchment areas of these rivers[6/].

5/ Government of Iraq, Ministry of Irrigation "Country Statement to ECWA Second Regional Water Meeting", January 1979, p. 21

6/ *Ibid*. pp. 5 and 7.

Table III.1

River Basin	Total catchment Area Km^2	Subtotal Catchment Area in	Subtotal Catchment Area Km^2	Subtotal Catchment Area % of total	Contributing Catchment Area in	Contributing Catchment Area Km^2	Contributing Catchment Area % of sub-total	Contributing Catchment Area % of total
Tigris	471606	Iraq	253000	53.6	Iraq	83237	33	17.6
		Turkey	57614	12.2	Turkey	57614	100	12.2
		Syria	834	0.2	Syria	834	100	0.2
		Iran	160158	34.0	Iran	130158	813	27.6
Euphrates	444000	Iraq	177000	40	Iraq	-	0.0	0.0
		Turkey	125000	28	Turkey	125000	100	28.0
		Syria	76000	17	Syria	76000	100	17.0
		Saudi Arabia	66000	15	Saudi Arabia	-	0.0	0.0
TOTAL	915606		915606	100		472843		51.6

Approximately 70 per cent of the surface water available reaches Iraq from neighbouring countries through the two major rivers the Tigris and Euphrates. The remaining 30 per cent is contributed by the northern tributeries of the Tigris which rise also outside the country. Flow is generally sustained through snow melt in the mountaineous regions providing continuous flow conditions throughout the year.

Generally the water resources of Iraq are estimated at 106 Km^3/a. About 80 Km^3/a of this total volume flows through the Tigris and Euphrates Rivers before entering their delta in the lower Mesopotamian plains in the vicinity of Baghdad. The remaining 26 Km^3/a is brought into the country from other sources south of the Capital. These waters may not be considered of good value as they pass through saline courses and marshes, locally known as Hors.

Considering a probability of 50 per cent and an estimated volume of water loss through evaporation of about 10 MCM/a the safe yield of the available surface water is estimated at 43200 MCM/a.

There follows a brief description of the main river basins that contribute to the surface water resources of the country[7/].

7/ Ibid. pp. 8-15

III.4.1. River Tigris

The river issues from the southern slopes of the Torus Range in Turkey. One of its main tributeries originates at elevations of 1000-1500 m.a.s.l. and the other, Butman river, originates from higher altitudes 2500-4500 m. Its total length is 1718 Km of which 1418 Km is within Iraq. Mean annual rainfall over the river basin is about 800 mm and ranges from 440 to 1600 mm/a.

Floods occur in Tigris River during winter and spring seasons as a result of the rainfall and snowmelt over the mountainous area (166155 Km^2) in Turkey, Iran and north east of Iraq. The average annual volume of surface water flow through the River and its tributeries is about 48.69 Km^3. The minimum measured flow in 1930 was 19 Km^3 while it reached 106 Km^3 in 1969. At Mosul the maximum recorded flow was 7539 m^3/s. and the minimum flow was 88 m^3/s. Flood probability analysis indicated that the River Tigris has a probable maximum flow which may reach up to 30000 m^3/s.

The estimated annual safeyield of the River Tigris alone, without considering the constructed dams, is about 15.6 Km^3/s. It reached 23.1 Km^3 after construction of Derbandi Khan and Dukan dams, and it will reach 31.7 Km^3 when the Mosul Dam has been completed. Bekhma dam construction will raise the estimated safe yield of the river up to 34.5 Km^3.

III.4.2. Greater Zab River

It is the largest tributery of the River Tigris. Headwaters originate from Ararat Mountains in Turkey where the altitudes rise up to 4636 m.a.s.l. The total river basin catchment area is 25810 Km^2. The river length is 392 Km and meets the Tigris 49 Km south of Mosul.

The average annual volume of the river discharge is about 13.18 Km^3. The maximum recorded river flow is 10570 m^3/s while the minimum flow is 67 m^3/s. The maximum probable peak flow is 22000 m^3/s.

Bekhma dam of 8.3 Km^3 capacity is planned to be constructed at the river to meet the irrigation water requirements, power production and to control floods in the Tigris river.

III.4.3. Lesser Zab River

It issues from the Iranian territory north of Dokan area and meets the Tigris north of Fatha. The total river basin area is 21475 Km^2 and its length is about 400 Km.

The annual river discharge is 7.17 Km^3, 17.01 Km^3 and 3.02 Km^3 for the average, maximum and minimum respectively. The recorded maximum river flow before the contruction of Dokan Dam was 3420 m^3/s. The annual safe yield after the Dam construction (6.8 Km^3 capacity) is about 5.07 Km^3.

III.4.4. Al-Adheim River

The river headwaters originate from Kura Dagh and Shwan highlands. Its basin area is totally from Iraq and is about 13000 Km^2. The river length is 330 Km.

Annual discharge is 0.79 Km^3, 1.85 Km^3 and 0.18 Km^3 for the average, maximum and minimum respectively. The surface water flowage relies on the rainfall behaviour over the river basin. It may have no flow during the period June-October of the year. Studies are being undertaken to construct flood control dams over the river to regulate the floods which may reach up to 13000 m^3/s.

III.4.5. Dayala River

It issues also from Iranian territory. The basin area is about 31896 Km^2. The river length is 386 Km and meets the Tigris at Baghdad.

River discharge is 5.74 Km^3, 14.27 Km^3 and 2.44 Km^3 for the annual average maximum and minimum flows respectively. The maximum probable peak flow at Derbandi Khan dam is 2500 m^3/s. The annual safe yield of the river after dam construction is about 2.02 Km^3.

III.4.6. Rivers of Taiyb and Doweirij

Total basin area is about 10500 Km^2 of both rivers. The average annual discharge is in the order of 2.0 Km^3. They enter Hor Sanf north of Amara. Low flow intervals may occur during summer and the water quality is generally fair.

III.4.7. Karkha River

Headwaters are from the western slopes of Zagros mountains in Iran. The basin area is about 46000 Km^2 and the annual average discharge is about 6.3 Km^3 and terminates in Hor Hweiziya.

III.4.8. Karon River

Headwaters are from the Zagros mountains in Iran. The river basin area is 58100 Km^2. The average annual discharge is 24.7 Km^3 in Ahwaz. It enters Shatt el Arab south of Basra and has a length of 630 Km. It has a positive effect on the quality improvement at the Shatt el Arab waters.

III.4.9. Shatt el Arab River

It is the river that is formed by the meeting of both the Tigris and Euphrates rivers at Al Qurna. The contributing catchment area is about 808000 Km^2. The annual average discharge at Basra is equal to 21.0 Km^3 and 35.2 Km^3 when it enters the Arabian Gulf at Fau.

III.4.10 Euphrates River

The Euphrates river is about 2300 Km long of which about 1200 Km lie in Iraq. Its catchment area is about 444000 Km^2. Almost all the contributing water shed which is about 45 per cent of the river basin, lies in Turkey and Syria where the mountaneous region in the former produces most of the river's annual flow. The river derives its flows mostly from snow fall and partly from rainfall. Floods normally occur in late spring-early summer when heavy rains may coincide with snow melt. The river flow almost abruptly drops in late June to reach its lowest level in September. Discharge records at Hit gauging station shows that maximum flow of the river was 63.2 Km^3 which occured in 1968/69 while the minimum was 13.3 Km^3 in 1929/30. The average annual discharge of the river at Hit is about 28.67 Km^3. Table III.2 and Annex 2 show the discharge records of the major rivers in Iraq.

III.5 Dams and Reservoirs

The Iraq concerned government authorities have paid great attention to control floods and lessen their hazards. Appreciable efforts were made to develop their water resources. A number of surface water reserviors have come into existance, while work on new projects is being undertaken. The Government plans are to arrive

Table III.2

Main Rivers in Iraq

River	Catchment Area Km^2	Discharge Rate Km^3			Length (Km)	Peak flow m^3/s	Remarks
		Minimum	Maximum	Average			
Tigris	471606 with tribut.	19	106	48.69	1718	30000	Annual safe yield with dams 34.5 Km^3
Greater Zab	25810	8.7	24.2	13.18	392	22000	
Lesser Zab	21475	3.02	17.01	7.17	400	3420	Safe yield 5.07
Al-Adhaim	13000	0.18	1.85	0.79	330	13000	It may have no flow during summer
Diyala	31896	2.44	14.27	5.74	386	2500	Safe yield 2.02
Taiyb and Doweirij	10500	-	-	2.0	-	-	Low flows in summer
Karkha	46000	-	-	6.3	-	-	
Karon	58100	-	-	24.7	630	-	It improves the water quality of Shatt el Arab.
Shatt el Arab	808000	-	-	35.2	-		
Euphrates	444000	13.3	63.2	28.67	2300	-	

at a total live storage capacity of 55 Km^3/a in addition to the Tharthar Lake and the existing marshes. The estimated total storage capacity of the existing and future reservoirs when completed is in the order of 93 Km^3/a. Tharthar Lake and Dokan dam of the Tigris, Darbandi Khan at Deyala and Habaniya and Abu Dibs Lake of the Euphrates are the major existing reservoirs in Iraq. Fatha, Mosul, Bekhma, Himrin and Haditha are other hydraulic structures planned to be implemented in the country. Table III.3 shows a summary of the existing and the planned water structures. On completion of these structures the country will meet its overall water requirements which is about 67.6 Km^3 by 1995[8/].

Table III.3[9/]

Hydraulic Structures in Iraq

(Existing and planned)

Structure + Name	Normal retention level (m)	Dead storage level (m)	Maximum retention level (m)	Designed Storage Capacity Km^3			Remarks
				Normal storage	Live storage	Reserve storage	
Structures At Tigris River							
Dokan	511	479	512.5	6.8	5.5	0.4	Existing 1959
Tharthar	62	42	65.	77.6	38.5	7.8	Existing 1956 Rehabilitate 1972, 1976
Fatha	177.5	148.2	179.9	23.3	19.3	2.7	Planned
Mosul	329	300	333.5	10.7	9.7	1.8	Planned
Bekhma	550	470.8	554.8	8.3	7.8	0.6	Planned
Structures At Diyala River							
Derbandi Khan	485	434	493.5	3.●	2.5	1.1	Existing 1961
Himrin	104	92	107.5	3.95	2.3	1.4	Planned
Structures At Euphrates River							
Hadithah	147	118	151	8.2	7.5	2.2	Planned
Habbaniyah	51	42.5	-	3.3	2.7	-	Existing 1956 Rehabilitate 1969
GRAND TOTAL				145.15	95.8	18	

8/ Ibid. p. 6.

9/ Badri, M., M.S. Mahdi and J. Khawar, the Foundation of Scientific Research, "Water Resources and their Balance in Iraq" No date, p. 16 (Arabic).

III.6 Water quality

As mentioned before, the major rivers of Iraq originate from rainfall and snowmelt over the mountaineous areas in Turkey, Syria and Iraq. Hence they contain water of high quality in their upper reaches. As the waters proceed south and westward their quality deteriorates, and a pronounced increase in total dissolved solids is being observed. Water quality deterioration may be attributed in part to the techniques applied for irrigation. Excessive irrigation water results in raising the water table in the irrigated areas and allowing salts to be brought up to the surface by capillary action. Depositions of salts are also activated by the high evaporation rate which prevails in most of the country. The final destination of these deposited salts are the main rivers by leaching. Other factors for quality deterioration are: the sub-surface flow of poor quality groundwater towards the main rivers particularly in south Iraq, the mineralised and thermal springs water from the east and inadequate sanitation facilities in some areas.

The level of soluble salts concentrations vary appreciably through the seasons. In the Tigris at Ninewah the level ranges between 225 ppm in the summer to 425 ppm in the winter, while at Meisan comparable figures show values of 350 ppm and 1300 ppm. The pH value of the Tigris lies in the range 7.7 to 8.5 and alkalinity is between 120-180 mg/1 as calcium carbonate.

The Euphrates displays a higher mineral content which varies from 300 ppm to 700 ppm through the summer and winter seasons. Variations between the North and South are observed but are not of any real consequence. The pH range of the Euphrates is between 7.5 to 8.5 and alkalinity is in the range 100-190 ppm as calcium carbonate.

The other principal rivers, Diyala, Greater Zab and Lesser Zab, exhibit T.D.S. ranges from 250 ppm to 500 ppm and have pH values of between 7.5 to 9.5.

Groundwaters of Iraq are generally high in mineral content. The total dissolved solids ranges from 500-1000 ppm. Sulphates of alkali metals form the greater constituent of groundwater and arise through the contact with gypsum, anhydrite and/other water bearing formations. Chloride is relatively high in some areas where Halite (NaCl) is encountered as in Hatra, Bussaya and west of Euphrates between Hit and Kerbala. Shallow wells water in areas neighbouring Hors contains high levels of chlorides. High levels of nitrates are observed in some areas like Al-Jazira deserts and near Samara.

III.7 Conclusion

Iraq relies mostly on its surface water which forms the major source of the country's water resources. Groundwater is not fully developed and is a largely unidentified resource. Five major groundwater areas are recognised: the mountaineous, the foothills, the delta plains, Al-Jazira and the desert areas. The first two are known to store and provide groundwater of appreciable quantity and quality. The others are fair to moderate groundwater producing areas. The annual exploitable groundwater volume is estimated at 1000-1200 MCM and may be raised to 2000 MCM/a after developing the resources.

The Euphrates and Tigris and their tributaries are the major contributors to the surface water resources. About 70 per cent of the available surface water reaches Iraq from the neighbouring countries mainly Turkey and Iran. The estimated volume of the resources is 106 Km^3/a. Appreciable efforts were made and are still in progress to control floods and develop the country's water resources, through the construction of dams and surface reservoirs. The estimated total storage capacity of the existing and future reservoirs when completed is in the order of 93 Km^3/a.

Efforts should be made to conduct a country wide hydrogeological investigation as a first step to identify and develop the country's groundwater resources, particularly in the east, west and southwest of Iraq. Co-operation with Syria, Jordan and Saudi Arabia would be highly beneficial to identify the potential groundwater in the shared aquifers. Projects where the integrated use of surface and groundwater is possible, should be practised.

Hydrochemical investigations are required to keep track with the water quality behaviour. A hydrochemical digital model may be beneficial, if established, to assess and predict water quality on a long-term basis. Optimum application of irrigation water, particularly in southern Iraq would be fruitfull to alleviate salt accumulation in the soil, groundwater and river waters.

IV. THE HASHEMITE KINGDOM OF JORDAN

Population: 2.8 million
Area : 96500 square kilometers

IV.1 General

The Hashemite Kingdom of Jordan is situated between latitudes $29^{\circ}30'$ and $33^{\circ}30'$ north and longitudes 35° and 39° east.

IV.1.1 Climate

Mediterranean climate dominates most of the highlands on both sides of the Jordan River and in the mountain chains east of the Dead Sea and Wadi Araba extending as far south as Ras el Maqb. Dry summers with average maximum annual temperature of 38.8° C occur during April to October. In winter months from November till March, average minimum annual temperature is + 0.5° C.

The Climate of Jordan ranges from Mediterranean to desert. Except for the West Bank highlands, only the Rift Valley and the East Bank highlands belong to the semi-arid climate zone. The mean temperature in the dry season varies from 28° C in the west to 32° C in the east. The average temperature in the wet season rises from the sea to the Jordan valley and falls again to the eastern plateau[1/].

IV.1.2 Topography

Three major landscapes occur in Jordan. They are; (a) the low land areas; (b) the highlands and (c) the eastern upland plateau.

(a) The low-land areas comprise Jordan Valley - Dead Sea - Wadi Araba depression which extends about 360 kilometers from Lake Tiberias to the Gulf of Aqaba.

In Jordan Valley the land surface is generally flat with ground surface elevation ranges from 200 to 392 m (Dead Sea level) below sea level. Jordan River crosses the Valley at its central portion for a distance of about 105 Km.

1/ HKJ, NRA, National Water Master Plan of Jordan, vol. III, 1977, p.3

The Dead Sea which forms the middle zone of the Depression, covers about 997 square kilometers, it is 80 Km long and on average 15 Km wide[2].

In Wadi Araba the landscape is almost flat with slightly rolling terrain at its middle zone between the Dead Sea and the Gulf of Aqaba. The ground surface elevation ranges from 250 meters above sea level to 392 meters below sea level at its northern end near the Dead Sea. Its width within Jordanian territory ranges from 5 to 20 Km approximately.

(b) The Highlands: It comprises the western escarpment and the eastern escarpments which flank the Jordan Valley - Dead Sea Depression on both sides. The eastern escarpment extends southwards to flank the Wadi Araba area.

Small to large canyons cut through the western and eastern highlands bordering the Jordan Valley - Wadi Araba Depression forming intricately dissected ridges and rugged topographic relief. The western highlands are drained eastwards to the River Jordan and westwards to the Mediterranean by several wadis.

The eastern highlands are breached by a number of western draining valleys in the zone between the Syrian border to the southern end of the Dead Sea. The largest of these are: Yarmouk River, Wadi Zarqa, Wadi Mujib and Wadi Hasa. They are drained eastwards to the upland plateau by small and shallow streamwashes.

Maximum elevation along the crest of the western highlands is about 1000 m near Ramalla. In the eastern highlands the peak elevation is 1856 meters a.s.l. west of Maan 2.5 Km north of Taiyiba[3].

(c) The eastern upland Plateau: It borders the eastern highlands from the west and extends to the Saudi Arabian border. It is a gently dissected plateau formed from flat lying sediments which have been eroded to form a cuesta landscape. The ground surface elevation ranges from about 1000 meters at the foothills of the adjacent highlands to less than 600 meters in the Wadi Sirhan depression near the Saudi Arabian border. Mudflats or Playas which form the foci of internal drainage basins occur in the plateau, such as Q'a (Mudflat) Azraq, Q'a Jafr/and Q'a Disi.

2/ F. Bender, Geology of Jordan 1974, p. 6-11

3/ Ibid.

The land rises northwards from Q'a Azraq towards the Jabal Druze in Syria where the land surface elevation reaches up to 1850 meters a.s.l.

IV.2 Geology

IV.2.1 Stratigraphy

Rock units ranging from Pre-Cambrian to Recent outcrop or exist at the subsurface in Jordan.

In the western highlands, calcareous sediments of the Upper Cretaceous and lower Tertiary age are exposed. Limestone to dolomitic limestones with marl, shale, chalk and chert of the same age occur in the eastern highlands and the eastern plateau covering an area of about 45000 sq.km. Total thickness range is reported to be 150-800 meters.

Sandstone and sandy facies with some shale at top covers an area of about 8000 sq.km. with about 1900 meters in total thickness. 1600 meters belong to early paleozoic and about 300 meters belong to lower cretaceous.

Basalt outcrops overlie the fluviatile gravels of the Middle Pleistocene. It occurs mainly in the area comprising the southern extension of Jabal Druze till Wadi Sirhan Depression near the Saudi Arabian border.

Coarse to fine clastics of marine to continental origin belonging to Neogene - Quaternary ages occupie a great part of the Wadi Araba - Jordan Valley Depression. They exist also in the flood plains of the main rivers and wadies and Jafr and Azraq depressions.

The Pre-Cambrian basement complex occupies the extreme south western corner of Jordan along the Gulf of Aqaba and in the eastern escarpment of Wadi Araba. The estimated outcrop area is about 70 sq. km.[4/]

IV.2.2 Structure

The Jordan Valley - Dead Sea - Wadi Araba depression forms the northern extension of the African Rift valley system as a secondary split through the Gulf of Aqaba. It is primarily a down throun block or a graben bordered on both the east and west sides by fault line scarps of major longitudinal faults[5/].

4/ *Ibid.* pp. 8 and 9

5/ Hirzalla, Groundwater Resources of the Jordan Valley 1974, (pp. 96-100).

Block foldings, undulations and flexures occur to the east of the major structural graben of Jordan Valley - Wadi Araba. The dominent trends of the structural elements in the northern part of the eastern plateau are NE-SW. The major structural features recognized in east Jordan and have direct control on the groundwater occurrence are: The NE trending upwarp of the Ajlun structure with extensive fault zones in its western flank; the salt Sweilih flexure; The Amman Zarqa Flexure; the major NW-SE fault system from Karak to the Saudi Arabian border; and the Quweira - Mudawwara structure.

In west Jordan parallel anticlinal and synclinal structures occur with a general trend of NE-SW. Traversal fault systems and flexures dissect these structures and trend SE-NW.

The major Jordan valley - Wadi Araba Graben forms a big drain to most of the aquifers occuring within the eastern and western highlands of Jordan.

IV.3 Hydrogeology

IV.3.1 Introduction

Natural Resources Authority, Jordan Valley Authority, Water Supply Corporation of the Ministry of Rural Affairs and Amman Water Supply and Sewerage Authority are the main institutions dealing with water resources development and management in Jordan. Extensive hydrogeologic investigations have been undertaken in Jordan as early as the 1960's. A detailed National Water Master Plan was recently drawn in 1977. The preparation of the plan involved a comprehensive assessment of the available and potential water resources, present and future water demands, formulation of medium (1985) and long-term (2000) water policies, and guidelines for the exploitation, utilization and efficient allocation of Jordan's water resources. A greatpart of the following discussion is based on the National Water Master Plan of Jordan (Vol. I-VII) and other references cited.

IV.3.2 Aquifer Systems

Based on the various hydrogeological investigations carried out, the following are the major aquifer systems in Jordan:

1. Quaternary - Tertiary Aquifers
2. Carbonate Rocks Aquifers
3. Sandy Facies Aquifers

Table IV.1 shows the main hydrogeologic characteristics of the main aquifers and their areal extent in Jordan.

IV.3.2.1 Quaternary-Tertiary Aquifers

(a) The shallow aquifer system consists of sedementary rocks and alluvial valley fills of tertiary and quaternary age, such as the valley fills of Jordan Valley and Wadi Araba and limestones, chalk, marl and sand and gravel layers in Jafer, Azraq and Sirhan areas. Groundwater contained in this aquifer originates from the wadi floods and from the subsurface flow from the highland areas. Groundwater quality is highly variable and relies on the recharge modes, the salt contents within the aquifer like in the Jordan Valley and Azraq areas and the rate of evapotranspiration like in Azraq area.

Aquifer parameters are also variable and rely on the percentage of the fine material content.

(b) Basalt Aquifer System

It extends from the Syrian Border southwards to the Azraq and Wadi Dhuleil areas and occupies about 11000 square kilometers in northeastern Jordan. It contains groundwater of very good quality and in some localities it possesses extremely high permeability that makes it possible to extract large quantities of water. The aquifer is naturally discharged as baseflows in three main zones: the upper Yarmouk River Basin, the Wadi Dhuleil - Wadi Zarqa basin and the Azraq basin. It is generally a water table aquifer and hydraulically connected with the underlying chert - limestone aquifer particularly in Wadi Dhuleil area. In Azraq area th Basalt aquifer is in connection with other tertiary and quaternary water bearing sediments forming almost one aquifer system.

ERA	PERIOD	EPOCH	GROUP	FORMATION		Aquifer System	Hydraulic Complex
CAINOZOIC	Quaternary	Holocene	Fluviatile, lacustrine and eolian mantle rocks		R	I, II	
		Pleistocene		Jafr ≏ Azraq	Ja Az	III	shallow aquifers hydraulic complex
			Volcanics	Basalts	Ba	IV	
	Tertiary	Pliocene, Miocene		Sirhan ≏ Dana	Si Da		
		Oligocene	Volcanics	Basalts	Ba		
		Eocene	Belqa	Wadi Shallala	B5		
		Paleocene		Rijam	B4		
MESOZOIC	Upper Cretaceous	Maestrichtian		Muwaqqar	B3		
		Campanian		Amman	B2	V	upper cretaceous hydraulic complex
		Santonian		Wadi Ghudran	B1		
		Turonian	Ajlun	Wadi Sir A7	Fassua A		
		Cenomanian		Shueib A5-6			
				Hummar A4			
				Fuheis A3		VI	
				Naur A1-2			
	Lower Cretaceous	Albian	Kurnub	Subeihi	K2	VII	deep sandstone aquifers hydraulic complex
		Aptian, Neocomian		Aarda	K1		
	Jurassic		Zerqa	Azab	Z2		
	Triassic			Main	Z1		
PALEOZOIC	Permian						
	Carboniferous				Cb		
	Devonian						
	Silurian		Khreim		Kh	VIII	
	Ordovician						
	Cambrian		Disi		D	IX	
PRECAMBRIAN	Late Precambrian		Saramuj		S		
	Early Precambrian		Basement Complex		Bc		

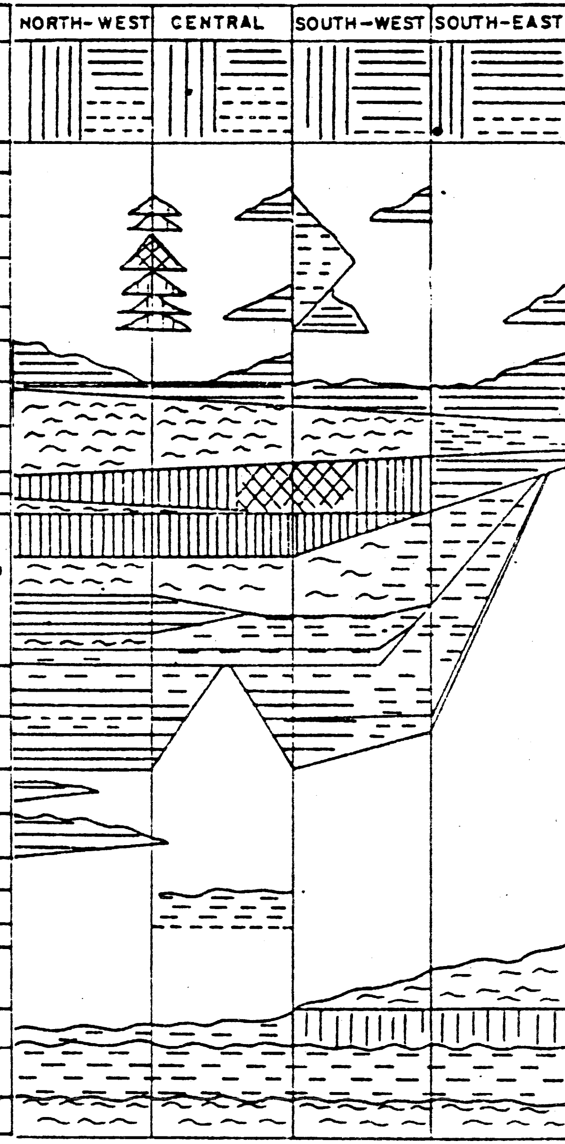
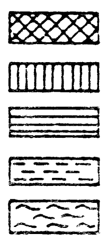


Table IV.1



Very high potential aquifer
High potential aquifer
Medium potential aquifer
Low potential aquifer
Aquiclude

ref. NRA/FAO
Sandstone Project Report 1971

Aquifer parameters are extremely variable relying on thickness of the scoriaceous basalt within the aquifer. The specific capacity of wells drilled in the aquifer ranges from 0.07 to 3352 $m^3/hr/m$. The transmissivities range from 2 to 113000 $m^3/d/m$ or even more. Water quality is often good (500-1000 ppm of TDS).

IV.3.2.2 Carbonate Rocks Aquifers

Limestones, chert limestones, sandy limestones of the upper cretaceous, locally known as Amman-Wadi Sir aquifer system (B_2/A_7) forms the most important aquifer which has the largest extent in both the east and the west banks of Jordan. Groundwater contained in this aquifer originates from the high rainfall zones of the eastern and western highland areas. Indirect recharge may occur from other aquifers. The vertical boundaries of the aquifer are composed of thick marls of the overlying Muwaqqar and the underlying Shueib formations. The aquifer parameters are variable as they are a function of the rate of fracturing and solution channels within the carbonate rocks. The transmissivity (T) ranges from 1-46000 $m^3/d/m$. The specific capacity recorded from about 125 wells drilled in this aquifer ranges from 0.02-2100 $m^3/hr/m$. The storage coefficient is in the order of 1 to 10 per cent depending on the degree of karstification.

The Amman-Wadi Sir Aquifer is underlain by a sequence of marls and limestones, locally marked as A_1 to A_6 members. The limestone layers of Hummar (A_4) and Na'ur Formations ($A_{1,}$ 2) form potential aquifers of local importance. Direct recharge of these aquifers is limited due/to small outcrop areas. They are almost under artesian conditions with piezometric level at or close to the groundsurface in some localities.

Groundwater flow in the B_2/A_7 aquifer system is directed from the recharge mounds within the highland areas towards the eastern plateau and westwards to the Jordan Valley through the main tributaries of River Jordan such as Yarmouk, Zerqa, Mujib and Hasa.

Depth to water in the carbonate aquifers is generally within economic reach in most of Jordan, often less than 150 meters. Groundwater quality is generally good (less than 1000 ppm of total dissolved solids).

IV.3.2.3 Sandy Facies Aquifers

It is the deepest and the oldest water bearing formations in Jordan. They are composed of two groups: The Disi and the Kurnub Groups.

(a) Disi Group Aquifer: It is of Paleozoic age consisting mainly of sandstones and quartzites with average thickness of about 350 m. The main outcrops of the aquifer occur in the south western part of Jordan in a strip 20 Km wide on the eastern edge of the basement outcrop between Ras en Nagb in the north and the Um Sahm mountains in the south. It is believed to exist at great depth underlying the Mesozoic - Cenozoic sediments in the eastern plateau area, but it may contain saline water. It forms the most important fresh-water producing aquifer in the area that extends from Upper Wadi Yetim-Qa Disi - Mudawwara in South Jordan. Depth to water ranges from 60-80 meters. Groundwater quality ranges from 170-1020 ppm of TDS. Aquifer permeability ranges from 0.34-1.0 m/d. Long-term pumping test data indicated that the mean transmissivity of this aquifer system is 720 $m^3/d/m$ and the mean storage coefficient ranges from 0.01 to 0.03.

(b) Kurnub - Zarqa Group Aquifer: It also extends almost over the whole Jordan. It consists of sand, sandy limestone with clay and shale of cretaceous - Jurrassic age. It crops out in the lower Zarqa River and along the eastern flanking escarpment of the Jordan Valley-Dead Sea - Wadi Arab Graben. In south Jordan Kurnub sandstone overlies the Disi Group aquifer system. Wells drilled in this aquifer are poor yielding wells and of poor water quality more than 2000 ppm of T.D.S. except in Baq'a area where the Kurnub - Zarqa aquifer is being well exploited and has better water quality and well yields.

The Kurnub-Zarqa Aquifer system is underlain by the Khreim Group (Sandstone, siltstone, and shales) separating it from the underlying Disi Group aquifer.

The sandy facies aquifer system (Kurnub - Disi) forms a huge groundwater reservoir of great extent in East Jordan. Nothing is known about this system in west Jordan. Restrictions on its development are imposed by the drilling depths, high pumping lifts which render water abstraction uneconomic and finally the contained water quality.

Groundwater recharge to this aquifer system occurs primarily in the large outcrop area on the southern borders with Saudi Arabia. Another source of recharge of unknown extent is by downward seapage from the overlying carbonate aquifer system.

Natural groundwater discharge occurs as subsurface outflow to the east and reappears along the rift valley as spring discharge and base flows.

IV.3.3 Groundwater Quality:

Groundwater quality is generally of Calcium Bicarbonate type. With increasing salinity Sodium and Magnesium become the dominant cations, and Chlorides the main anions. Sulphate content is generally low except in the Jordan Valley and Wadi Araba areas where the evaporite sediments are the source of the groundwater salinity.

Good groundwater quality zones of about 500 ppm of TDS are recognized in the areas close or at the foothills of the highland regions, the extreme north extending from Syrian Jabel Druze southwards to Azraq and Wadi Dhuleil areas, and the extreme south, extending northwards from Um Sahm mountains to Qa-Disi-Mudawara region. These areas are almost coincident with the recharge zones of the country.

Poor groundwater quality, generally more than 2000 ppm of TDS, occurs in Jordan Valley - Wadi Arab area, most of the eastern plateau except in the Basalt aquifer in the north and the Disi group aquifer in the south. Possibilities of encountering localized good quality water do exist.

Deterioration of water quality due to overdraft conditions occured in Jordan valley area resulting in salinity increase up to 4000 ppm of TDS in some localities. Recycling of excessive irrigation water in some areas such as Jafer and probably in Dhuleil areas resulted also in water quality deterioration.

In highly populated areas like in Amman - Zarqa and Salt regions, an indication of water pollution by sewerage and waste water disposals was recognized by the increasing chloride, sodium and nitrate ion contents and bacteriological contamination of the groundwater body underneath.

IV.3.4 Groundwater Resources Situation

Based on the groundwater divides configuration, 12 major groundwater areas were defined. For the computation of the groundwater budget in each hydrogeologic balance area; natural and artificial discharge, evapotranspiration, subsurface outflow natural and artificial recharges and subsurface inflow were considered. The streamflow data (section IV.4) was employed. Natural groundwater discharge was determined through considering the mean annual baseflow measured at gauging stations during the dry season and adding the upstream consumed irrigation waters plus the springs and seeps flow. Artificial discharge was computed through the estimation of well abstraction and the resultant reduction in springs discharge was considered.

Natural recharge by direct precipitation and indirectly by infiltration from surface runoff into the aquifers was determined in long-term basis and balanced with the reappeared discharged waters. Returned water through irrigation losses, and waste water downward infiltration and surface resevoirs losses into the aquifers plus the subsurface inflow from adjacent aquifers or areas were items also considered in the groundwater budget computation.

Table IV.2 presents a summary of the groundwater resources situation as computed for the National Water Master Plan. Most of the groundwater flow in East Jordan especially in the north-western part discharges as surface runoff (baseflows). Hence, by groundwater exploitation the spring and stream

Table IV.2[6]

Groundwater Resources, Present Situation
MCM/annum

Groundwater Area	Total G.W. Recharge	Baseflow Discharge	Underflow	G.W. Replenishment	Exploitation G.W.	Available Stored G.W
Yarmouk Basin	37.2	34	2.0	3.2	15	600
East Jordan Valley	123.5	91.1	29.6	32.4	18	0
Jordan Valley	91.2	56.0	2.0	35.2	18	3550
Zerqa River Basin	90.4	35.8	1.0	54.6	55	1700
Dead Sea Basin	157.2	137.5	7.0	19.7	53	2900
W. Araba Basin (N)	35.7	14.7	1.0	21.0	8	1000
Red Sea Basin	9.1	0.6	1.0	8.5	8	450
Jafer Basin	67.8	2.4	61.0	65.4	42.0	4400
Azraq Basin	86.4	15.1	58.0	71.3	20	1680
W. Sirhan	39.5	-	35.5	39.5	5	50
W. Hammed Area	15	-	5.0	15.0	5	0
Total East Jordan without Yarmouk (M)	753	387.2	203.1	365.8	247	16330

Out of the total estimated groundwater subsurface flow 33.5 MCM/annum flows towards the Red Sea, Dead Sea and Saudi Arabia, leaving 169.6 MCM/annum as internal underflow within the country's basins. Hence the groundwater recharge for East Jordan is in the order of 580 MCM/annum (583.4).

6/ National Water Master Plan of Jordan, vol. IV, 1977 baseflows will be affected sooner or later. The net groundwater resources appearing in table IV.2 is equivalent to the total annual groundwater recharge minus the present groundwater discharge (measured baseflows during the dry season). Out of the total annual groundwater replanishment which is estimated at 580 MCM, some 380 MCM appear as annual surface baseflow leaving the rest of about 200 MCM/year as net groundwater resources, based on the water budget computation. The available water resources is the estimated amount of groundwater exploitable in the balance area without medium and short term bad results. The available groundwater resources based on the above-mentioned computed water budget is estimated at 220 MCM/year for east Jordan[7/].

The available groundwater storage is the estimated groundwater volume of groundwater retained in the balance area in aquifers down to a depth of economic reach (150 m) below ground surface. The volume of stored groundwater according to definition introduced by the National Water Master Plan is in the order of about 12000 MCM[8/].

Although great efforts have been made for the groundwater budget computations, the sources of errors are still apprecialbe in some balance areas. These sources are attributed primarily to inadequacy and occasional unreliability of data relevant to: spring and baseflow measurements, irrigation water abstractions, well abstractions, in and out subsurface flows based on illdefined aquifer parameters, return flows, dam waters losses and the estimated natural recharge into the aquifers.

IV.4 Surface Water Resources:

A detailed analysis of the various components of the surface water resources were undertaken through the preparation for the National Water Master Plan of Jordan. Based on the available information on rainfall, evapotranspiration, streamflow and suspended loads, and on the analysis of factors affecting the total volume of runoff in each catchment area, an assessment of the potential surface water resources of Jordan, applying statistical techniques and probabilistic concepts have been made. Where hydrological data is inadequate, the determination

---

7/ Ibid. "Groundwater Resources" Vol. IV, pp. 47- 48

8/ Ibid. "Main Report" Vol. I p. 13.

of mean annual streamflow was made by utilizing an empirical function relating the mean annual runoff coefficient C to the so-called Basin-Climate-Index (BCl) introduced by R.L. Smith 1973[9/].

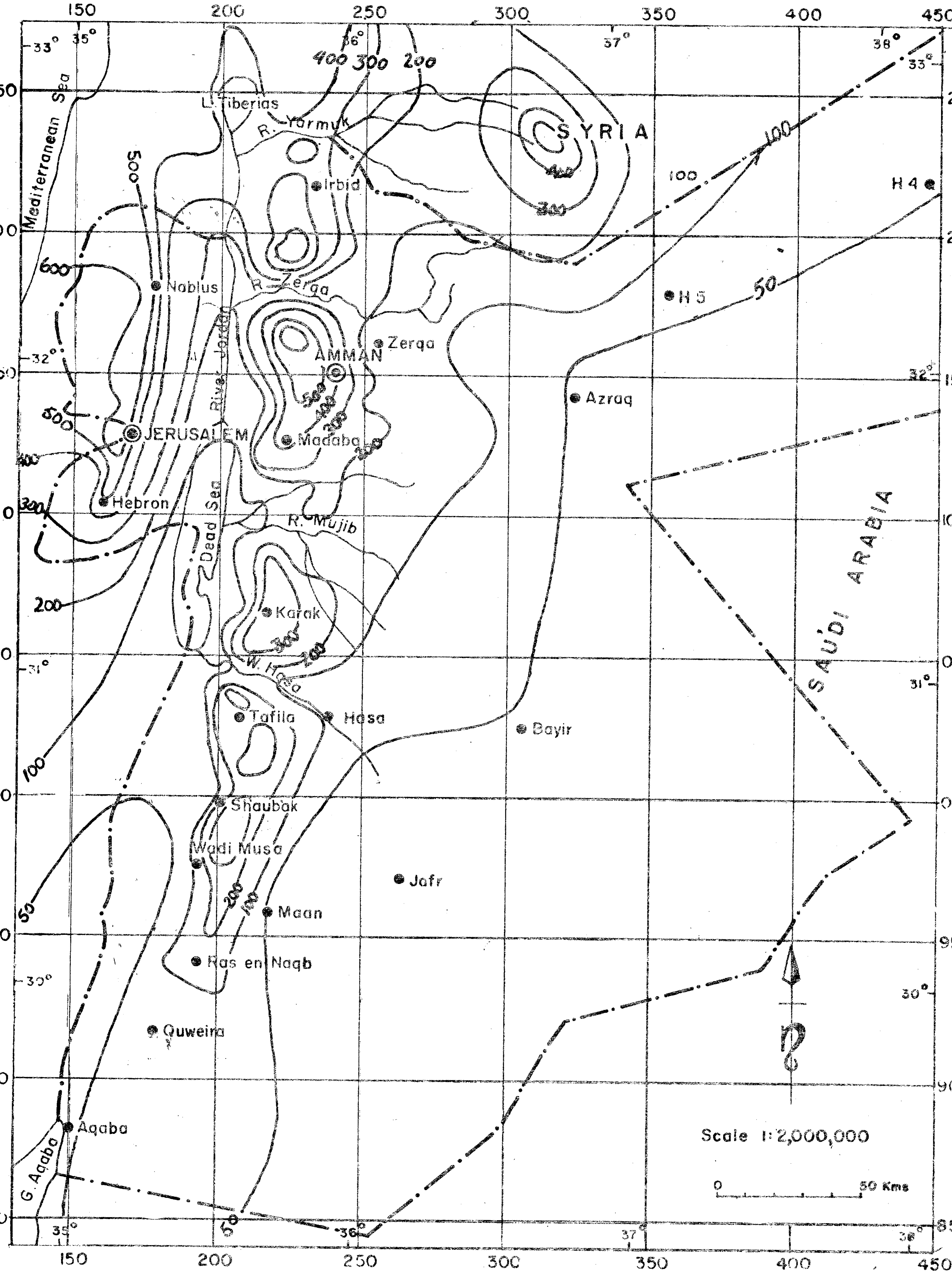
IV.4.1 Rainfall:

Rainfall in Jordan is produced by cold fronts which are associated with depressions generated by the eastern Mediterranean low pressure system. The depressions travel eastwards and their main track is through Turkey and Syria. The cold fronts bring moist, unstable air into Jordan and precipitation occurs when the air masses cross the mountain regions in the west and east banks. There are significant seasonal differences in rainfall. The rainy season occurs during October to April or early May and the greatest activity occurs from December to February of each year. Rainfall generally decreases gradually from north to south and rapidly from west to east, figure IV.2.

The highest rainfall zones correspond to the major mountain blocks of Jordan. The deeply incised wadis which separate these blocks are marked by narrow, east-west regions of lower rainfall. The highest mean annual rainfall which is exceeding 600 mm/a, is recorded in Nablus-Ramalla and Ajlum-Salt regions. The average rainfall decreases rapidly eastwards from the western highlands and westwards from eastern highlands into the Jordan Valley - Dead Sea - Wadi Araba depression where rainfall ranges from 50 mm in Wadi Araba to about 400 mm near Lake Tiberias. The 200 mm isohyet is approximately limiting the foothills of the mountain regions. In the eastern plateau area rainfall is generally below 100 mm/a. About 80 per cent of the country receives less than 200 mm of rainfall per annum. About 8000 MCM/annum of rain falls over both the East and West Banks of Jordan.

Rainfall data are periodically published by the Natural Resources Authority of Jordan in yearbooks. The index of the rainfall stations presents 290 different rainfall stations of which about 210 are still being operated by the Jordanian authorities concerned.

9/ Smith, R.L., UNESCO/WHO/IAHS "Utilizing Climatic Data to Appraise Potential Water Yields" Proceedings of the Madrid-Symposium, January 1973, Vol.2 pp. 253-264



MEAN ANNUAL RAINFALL (mm.) 1938—1967

IV.4.2 Evapotranspiration;

Since 1962 mean monthly figures on rainfall, cloudiness, wind speed, atmospheric pressure, temperature, humidity, sunshine hours, solar radiation, and evaporation have been published for about 30 evaporation stations in Jordan. The annual potential evaporation varies from 1984 mm in North Shuneh to 4323 mm in the south at Durrah station near Aqaba. About 70 per cent of the annual evaporation is recorded in the dry season from May to October. The variation between actual and average monthly evaporation is generally very small. The lowest monthly evaporations are recorded during December to February. Yearly potential free water surface evaporation at a number of stations and for a number of years is shown below[10].

Station-	1960	1961	1962	1963	1964	1965	1966
Amman	2171	2122	2217	1920	2042	2780	2055
Mafraq	2310	1952	2030	1953	-	-	-
Azraq	-	-	-	-	-	2281	2274
Ma'an	-	-	1945	1757	1779	-	-

IV.4.3. Stream Flow:

The drainage pattern is controlled by the major topographic features in Jordan. The general trend of this pattern is mainly in an east-west direction. Most of the stream flows are directed towards the Jordan Valley- Dead Sea - Wadi Araba depression, through deeply incised wadies and rivers disecting the West and the East Bank highlands. Shallow streams flow generally eastwards from the Eastern highlands towards the internal desertic basins and mudflats. In the West Bank highlands, deep wadis cut through and flow westwards to the Mediterranean sea.

10/ HKJ, NRA, Water Resources Division, Field Evaporation Records.

Table IV.3

Potential Streamflow in MCM/Year 11/

YEAR	AREA	Rainfall MCM	Runoff Coeff.		Estimated Streamflow		
			Storm %	Total %	Storm Runoff	Baseflow	Total
Dry	Eastern Jordan Valley Area	3186	3.8	12.8	123	284	407
Average		4140	6.1	14.7	250	357	607
Wet		5092	8.3	17.0	422	443	865
Dry	Dead Sea Basin	938	1.8	15.5	17	128	145
Average		1406	3.6	13.6	50	141	191
Wet		1874	5.4	13.8	101	157	258
Dry	Desert Basins	1381	0.3	1.7	4.7	18.6	23.3
Average		2068	1.4	2.4	29.2	20.1	49.3
Wet		2755	2.8	3.6	78.3	21.6	99.3
Dry	Total	5758	2.5	10.3	145.9	451.5	597 12/
Average		8065	4.2	10.9	338.6	539.7	878
Wet		10370	6.1	12.3	627.7	643.9	1272
	Western Jordan Valley Main Wadis	147	-	-	36.0		13/

11/ National Water Master Plan of Jordan, Vol. III, 1977 Annex III. A-3.6 p. 1

12/ Without Jordan River Flow from lake Tiberias and the west bank wadis

13/ Natural Resources Authority, WRD files.

- The Dead Sea Basin and Wadi Araba Basin water resources are affected by spring flows of poor quality water. However, the salt content is generally below the maximum permissible level according to the international drinking water standards except in the case of highly saline water of Zarqa Main springs.
- Indications of pollution from chemical and domestic effluents are recognized by the heavy trace elements contents in the River Zarqa water particularly during the dry seasons.

IV.5. Water Resources Areas[14/]

For better understanding of the water resources situation on a country wide scale, Jordan has been divided into fourteen areas as shown in Figure IV.2. The bounderies of these areas coincide, in general, with natural limits of the elements of the water resources systems.'

Jordan has been more dependent on groundwater particularly for domestic purposes and to a less extent for irrigation. Large surface water potentialities still exist for future developments. Indications of an increasing interest for surface water resources development are marked in the last 5 years National Development Plan of Jordan. In 1977 out of the estimated total water consumption (451 MCM) 10 per cent was used for domestic and industrial purposes while 90 per cent for irrigation. A brief description of the water resources situation is presented by the following:

14/ The discussion under this item is based on:

(a) Barber, W., HKJ, NRA. "An Outline for Water Planning in East Jordan 1975 pp. 1-41.

(b) HKJ, NRA "National Water Master Plan of Jordan" Vols. I-VII, 1977.

1. Hammad Area:

It comprises the part that belongs to Jordan territory of Hammad Basin which Jordan, Syria, Iraq and Saudi Arabia share. The area receives rainfall of less than 50 mm/a. Hydrogeological data is inadequate to estimate the available or potential water resources. Several wells were drilled in the area indicating a general depth to water of 150-200 m below ground level and of poor quality (more than 2000 ppm of TDS). The aquifer is Basalt on the west and carbonate rock of the upper cretaceous is on the eastern part of the area. No detailed study was carried out in the areas.

2. Azraq Basin:

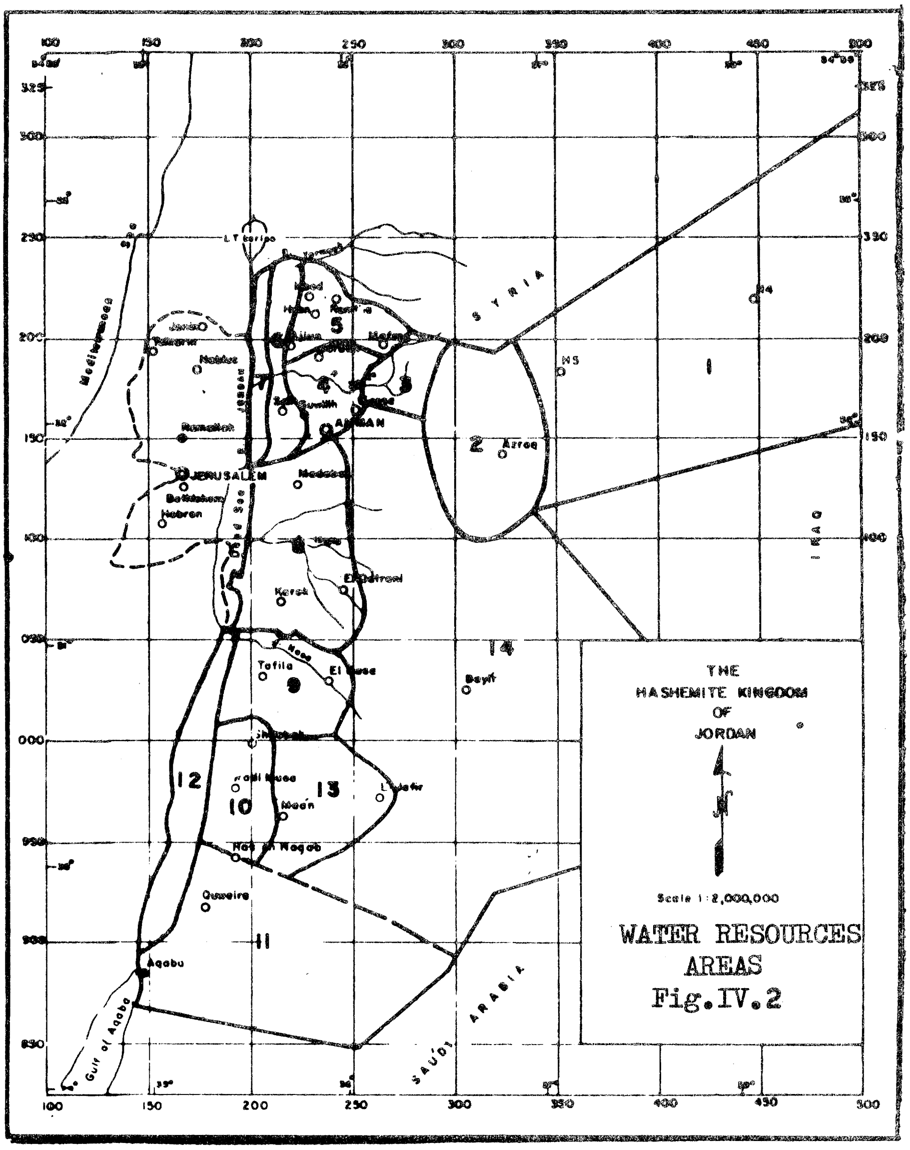
It is a closed depression, about 90 Km north east of Amman and has a surface catchment area of about 13000 Km^2 which is drained by several shallow streams converging radially towards the Azraq mudflat. Rainfall ranges from 50-200 mm/a. Evaporation is high (2000-2200 mm/a).

Several hydrogeologic investigations were carried out in the area including modelling. The outcomes were variable but most of the studies indicate that the area offers good potential of water resources if water utilization is well managed and administered. Groundwater recharge is estimated at 20-25 MCM/a. The estimated exploitable groundwater from the area is in the order of 10-15 MCM/a bearing in mind that the springs flow (Druze and Shishan) is about 14 MCM/a. Annual accumulated flash floods is estimated at 5 MCM/a which is mostly lost through evaporation or perculates downwards in the zone of poor water quality.

The aquifers occuring in the Azraq Basin are: unconfined Basaltic and carbonate formation of Tertiary age and a deep confined aquifer which belongs to upper cretaceous chert limestone and contains relatively poor quality and hot water.

3. Wadi Dhuleil Area:

It comprises the area about 45 Km north-east of Amman. Rainfall ranges from 100-200 mm/a. The mean annual surface water flow in the main wadi Dhuleil in the area is about 12.7 MCM measured at Sukhna Station in addition to the Sukhna Spring which discharges about 10 MCM/a.



WATER RESOURCES
AREAS
Fig.IV.2

Several private and public wells were drilled in the area (about 50 wells). The area was fully investigated and a mathematical model simulating the groundwater condition was established.

The hydrogeologic studies indicate that 10-12 MCM/a is the estimated annual groundwater recharge and the exploitable groundwater should not exceed 12 MCM/a. Overdraft conditions are recognised in the area through continuing water level decline and water quality deterioration. Hence a restriction on well drilling in the area was imposed since 1969.

The main aquifer occuring in the area is the Basalt and the underlying chert limestone of the upper cretaceous groundwater recharge is originating from the northern Jabal Druze area within the Syrian territory.

4. Amman-Zarqa Basin:

It comprises a surface catchment area of about 850 Km^2 and encompasses the most populated area in Jordan where Amman and Zarqa cities occur. Rainfall varies from 200 to 500 mm/a. Evaporation ranges from 2000-3000 mm/a. Wadi Amman which is the main wadi draining the area and contributing to Zarqa River, has an average annual baseflow of about 9.3 MCM measured at Sukhna. Annual mean flood flow is estimated at 10-15 MCM.

Several and detailed hydrogeologic investigations including modelling were carried out in the area. As in other basins the estimated water resources potentials are different. Two main aquifers occur in the area: The upper unconfined aquifer consisting of alluvium and the underlying chert limestone of the upper cretaceous. The other is a confined limestone aquifer and belongs to the Middle Cretaceous. The estimated groundwater recharges are 20 MCM and 5 MCM for the upper and the lower aquifers respectively. Overdraft conditions prevail in both aquifers and are recognised through water level and piezometric head decline. Water abstraction from both aquifers was estimated by VBB in 1976[15/] at 31 and 9 MCM for the upper and lower aquifer respectively, of which 12.0, 4.5 and 23.5 MCM are for irrigation, industry and domestic purposes respectively.

15/ VBB. Consultant Firm, Fawzi and Associations "Water Resources Study for Amman Water Supply" AWSA, November 1976.

It is worth mentioning here that a severe water shortage is being experienced in Amman-Zarqa area as the water demand is rapidly increasing particularly for domestic purposes, The total water demand in the area is expected to be 83 MCM and 165 MCM in 1985 and 2000 respectively (VBB 1976). The concerned Government Authorities are working hard to secure a feasible water resource from other areas in order to meet the increasing water demand. The resources that are being explored are: King Talal Dam, the Azraq Basin, Swaqa Qastal Well field (Area 8), Rumeil Dam (to be constructed) and the Yarmouk River diverted water into Jordan Valley area.

5. The Irbid Governorate Area

It emcompasses the area that extends eastwards of the Jordan Valley escarpment to Yarmouk River and Sama Sdud area in the north. It receives annual rainfall ranging from 300-400 mm. Evaporation is in the order of 2500-3000 mm/a.

The area is drained by a number of wadis that contribute to the baseflows of the River Yarmouk in the north and westwards into the Jordan Valley area. There are two main aquifers in the area: the shallow perched aquifer which occurs in a limited area in the very north eastern part and consists of chert-limestone unit of lower tertiary age; the other one is deeper, thicker and consists of chert-limestone of the Upper Cretaceous and provides lowyielding wells in most of the area except in Sama Sdud Area.

Depth to water level is generally deep and ranges from 150-300 m. Water quality is almost good (less than 1000 ppm of TDS). Detailed hydrogeologic investigations in the area are lacking. Preliminary studies were carried out based on the available scattered data. Annual recharge to groundwater is estimated at 110 MCM.

The Sama Sdud well field is the only promising area for groundwater development within this area. It is believed to offer annually about 10 MCM. The total annual groundwater abstraction from the Sama Sdud area is estimated at 6.5 MCM of which about 1.0 MCM in addition to what is being piped from Wadi Dhuleil (2.7 MCM) and Azraq (1.5 MCM) are utilized to provide Irbid area with domestic water supply.

6. Jordan Valley Escarpment:

It comprises the eastern escarpment flanking the Jordan Valley area from UM Qais in the north to Salt in the south. The area is drained by several wadies and springs into the Jordan Valley. The mean annual rainfall ranges from 300-600 mm. Only hydrogeological reconnaissance was conducted in this area. The primary aquifers occuring belong to the members of the Cretaceous carbonate rock units. The lower members are confined with piesometric heads at or close to ground-surface.

Depth to water level is variable relying on the local topography. Water quality is generally good to medium. Groundwater recharge is estimated at 50-60 MCM/a.

7. Jordan Valley Area:

The area encompasses the Jordan Valley floor from lake Tiberious to the Dead Sea.

Surface water resources of the Jordan Valley consist of the stream flow of the Jordan River and its eleven tributries (the east bank only) whose discharges are summarized in the table below:

	Annual Discharges MCM		
Name of Wadi	Mean Flood flow	Mean Base flow	Total
Yarmouk	250	200	450
Araba	2	34	36
Ziglab	2	11	13
Jurm	-	12	12
Yabis	0.5	4	4.5
Kufrinja	7	6	13
Rajib	1	3	4
Zerqa	34	54	88
Shueib	2	8	10
Kufrein	1.5	8	9.5
Hisban		5	5
Total	300.0	345	645.0

The mean annual rainfall on the valley floor ranges from 100 mm in the south to 400 mm in the north. Potential evaporation ranges from 2000-2500 mm/a.

The main aquifers of this area are the alluvial deposits in the valley floor and the underlying older carbonate rock units within the valley as well as in the foothills of the eastern escarpment. The recharge to these aquifers was estimated at 160 MCM/year of which only 50 MCM/year may be exploitable due to the overdraft conditions which were recognized, as from 1960's, by the continuing water level decline and water quality deterioration reaching up to 4000 ppm of TDS in some localities in the valley particularly in the southern portion of the area.

One of the major surface water projects in the valley is the East Ghor Canal which conveys about 120 MCM from Yarmouk river to irrigate 123,000 dunums. About 115 MCM are annually withdrawn from ground water and from the baseflow of the side wadis for irrigation.

The increasing dependency on surface water for irrigation will ultimately change the ground water extraction pattern and may result in solving the overdraft problems in the southern part of the valley.

8. Mujib Basin

The area covers the zone east of the Dead Sea from Madaba in the north to Karak in the south.

Rainfall ranges from 100-300 mm/a. Zarqa Ma'in, Mujib and Karak are the main wadis in the area. They have an estimated baseflow of about 70 MCM/a.

Reconnaissance hydrogeologic investigations were carried out in the area including digital modelling for some parts of the basin (Qatrana area). The estimated annual groundwater recharge is about 20-30 MCM. Depth to water ranges from 50-100 m below ground level. Water quality is generally good. Swaqa, Qatranch and Sultani well fields are the main areas of promissing groundwater potentials. The primary aquifer in the area belongs to carbonate rock units of the cretaceous age. Deep sandy aquifer (Kurnub-Disi Aquifer) is a possible contributor to the base flows of Mujib Wadi and spring flows, in accordance with the regional hydrogeological investigations carried out through the preparation of the National Water Master Plan 1977, (Vol IV, Figure IV. 1C).

A feasibility study has been conducted (1977) to divert about 40 MCM/a of Wadi Mugib baseflow to the Southern Ghors south of the Dead Sea. Another water tranference project, from Swaqa well field to Amman area, has recently been investigated to help in solving the water supply shortage of the Capital area.

9. Hasa Basin

The basin has a surface catchment area of about 2833 Km^2 and drained mainly by wadi Hasa which has an estimated baseflow of about 47.4 MCM/a measured at Ghor Safi Station near the southern end of the Dead Sea. Annual rainfall ranges from 100-300 mm. Most of the Hasa baseflow is being utilized in irrigation downstream.

The main aquifer of the area is the chert-limestone of the Upper cretaceous. The mean annual recharge is estimated at 20-30 MCM. The annual exploitable ground water ranges from 10-15 MCM, of good water quality. Depth to water level in the area ranges from 30-100 m with a general increase eastwards.

Most of the potential groundwater in the area is being utilized at the industrial demand of phosphate mining at El-Hasa, where the demand for water was 3.2 MCM in 1975 and expected to increase to 6.5 and 10 MCM in the years of 1985 and 2000 respectively.

Only reconnaissance hydrogeologic investigations were carried out in the area. More investigations may be beneficial to identify potential areas to meet the expandable phosphate mines water requirements.

10. The Shaubak-Ras en Naqb Area:

Surface water in the area is almost non-existant except in some major springs discharge westwards into the escarpment of Wadi Araba. Rainfall varies from 50-350 mm/a.

Groundwater occurs in the main aquifer which is the chert limestone unit of the upper cretaceous. Depth to water level ranges from 50-100 m. Water quality is good, less than 1000 ppm of TDS. Estimated annual recharge to groundwater is about 15-20 MCM and the possible exploitable groundwater volume is about 10 MCM/a. An analogue model was constructed to simulate the groundwater conditions in Wadi Arja zone of this area.

11. Aqaba-Disi Area:

The area comprises the zone that extends from Aqaba-Mudawara-Ras en Maqb. Mean annual rainfall ranges from few millimeters to 100 mm.

Surface water in this area does not exist except during the high rainy seasons which may result in sporadic flash floods in Wadi Yetum.

Detailed hydrogeologic investigations were conducted by NRA and others. Several digital models were constructed. The major aquifers in the areas are the valley fill deposits in Wadi Yetum and the deep Disi Group sandstone aquifer. Depth to water level is about 75 m in Disi area, 150 m in upper wadi Yetum and 20-90 m in lower wadi Yetum and Mudawara areas. Water quality is very good. (200-700 ppm of TDS). Recent studies indicate slight water quality deterioration at depth, up to 1500 ppm of TDS in some localities in Disi area.

Estimated groundwater recharge by different investigators in this area varies from less than 35 to about 70 MCM/a. Recent studies carried out in the area indicated that the safe yield of the Disi well field does not exceed 18 MCM/a. The estimated exploitable groundwater in Wadi Yetum area is about 2.4 MCM/a. Most of the potential groundwater resources of this area are committed for the socio-economic development of the Aqaba area and its surroundings. Hence a water transference project from Disi well field (65 Km north east of Aqaba port) is being executed.

12. Southern Ghor and Wadi Araba Area

The area is not developed. Surface water is limited to flash floods which occasionally occur in the main side wadis draining into the area from the eastern escarpment. The main wadis are Hasa, Khneizira, Feifa and Fidan. The estimated mean annual flood flow of Wadi Hasa is 47.4 MCM of which baseflow is 25 MCM/a. The other wadis total baseflows are estimated at 5.4 MCM/a.

Only hydrogeologic reconnaissance was conducted in the area by NRA Groundwater occurs mainly in the valley fill deposits. Water quality is fair to poor. The potential groundwater in the area is not identified. It occurs in the Southern Ghors with water level at or very close to the groundsurface (less than 30 meters). The depth to water level in Wadi Araba ranges from 20-80 meters. Exploratory drilling in the area indicates low-moderate well yields.

13. Jafr-Ma'an Area:

The area receives a mean annual rainfall of less than 50 mm. Surface water resources do not exist except the sporadic accumulated flood waters in Qa Jafer and the surface runoff which may occur in the main wadi Jurdana (0-7 MCM/a). Most of the accumulated flood water is lost by evaporation from the Qa area.

Detailed investigations in the area were not made. Groundwater occurs in the chert limestone units of the lower tertiary (Rijan) and the underlying upper-cretaceous unit. Recharge to groundwater is estimated at 6 MCM/a. Depth to water ranges from 15 to 30 meters. Water quality is good to fair local water quality deterioration occured in this area by the return flow of the excessive irrigation water. Hence the concerned government authorities are practicing piping water from distant well fields for irrigation.

14. The Eastern Desert Area:

The area receives scanty rainfall of less than 50 mm/a. No hydrogeologic investigations were conducted in the area. Hence the availability of water resources is unknown. Groundwater may occur in some localities in the area within the chert limestone aquifer of the upper cretaceous age. Depth to water level is about 150 m or more and increases towards the east. Water quality is fair, 1000 ppm and deteriorates eastwards.

IV.6 Storage Dams

The concerned government agencies have paid great attention since the 1960's to make use of the flood flows to cope with the increasing water requirements of the country's development projects. A great deal of investigations were carried out relating to storage dams and reservoirs. The majority of these studies were complementary of the overall socio-economic development plan of the Jordan Valley. The major storage dams which have been constructed in Jordan are King Talal, Ziqlab, Kufrein and Shueib Dams. Other studies are being undertaken to construct more dams of major importance to Jordan such as Maqarin, Wadi Arab and Mujib Dams.

Records on the operation of the existing resrvoirs are either not available or inconsistent, hence the actual and potential future operational conditions of these dams cannot be concluded. Annex 3 presents the existing and the future possible storage dams in Jordan as presented in the National Water Master Plan and NRA files.

IV.7 Conclusion

Extensive hydrological and hydrogeological investigations have been undertaken for most of the country since 1960. A national water master plan was recently drawn up in 1977. The plan aimed at a comprehensive understanding of the available and potential supplies and a better allocation of the country's water resources.

Jordan has been highly dependent on groundwater but recently surface water has formed an integral part of the country's water resources. Quaternary alluvium, Basalt, Mesozoic Carbonate rocks and Paleozoic sandstones are the major producing aquifers in Jordan. The estimated annual safe yield is about 220 MCM out of the expoitable stored groundwater which is estimated at 12000 MCM.

Good groundwater quality zones are recognized in the highlands foothills, in the extreme north from the Basaltic aquifer and in the extreme south from the sandstone aquifer. Poor water quality generally occurs in Jordan Valley - Wadi Araba Depression. Overdraft conditions were experienced in some localities particularly in Jordan Valley and the capital area. Indications of groundwater pollution were marked in the major urban areas.

About 8000 MCM/a of rain falls over the country, about 80 per cent of it receives rainfall of less than 200 mm/a. The estimated surface water flow in an average year is about 878 MCM of which about 50 MCM/a is being lost through evaporation in the desert areas. The practice of constructing dams to make use of the the flood waters was undertaken. About 60 MCM of surface water is being stored behind the existing dams. Plans to store about 220 MCM behind Maqarin, on the Yarmouk River, and Wadi Araba dams are being considered.

The distribution of water resources does not correspond with the areas of highest demand, particularly the densely populated urban areas. The capital and surroundings, Irbid and Aqaba areas are experiencing a severe water shortage relative to their demands. The Government agencies have accomplished great progress to overcome some of the country's water problems.

Bearing in mind the above remarks, it is desirable to consider the following in order to help in overcoming the water shortages in some localities of Jordan:

- To investigate the most economic and feasible ways and means for better allocation of the country's water resources considering priorities and graded purposes.
- To study the possibility of desalting the brackish groundwater which does occur on a considerable scale in Jordan Valley and at depth in the eastern plateau, through low cost methods, for domestic and industrial purposes.
- To investigate the possibility of utilizing the sporadic flood waters in the desertic areas through artificial groundwater recharge, diversion to other areas or locally in dry forming projects.
- To enhance projects where surface and groundwater resources may be utilized in an integrated manner like in Southern Ghors and Wadi Araba areas.
- There are opportunities for co-operation with Syria, Iraq and Saudi Arabia to evaluate and develop the shared aquifers which stretch beyond political boundaries in the north, east and south of the country.

V. THE STATE OF KUWAIT

Population: 1.1 million

Area : 17815 square kilometers

V.1 Geographical Environment

The State of Kuwait lies at the northwest corner of the Arabian Gulf between latitudes 28°30' and 30°5' north and longitudes 46°30' and 48°30' east. It is bounded on the north and northwest by Iraq and on the southwest and south by Saudi Arabia (Figure V.1). The Gulf coastline is 195 kilometers long.

V.1.1 Climate

The climate of Kuwait is characterized by extremely hot dry summers with average daily temperatures of 45° C with frequent sandstorms and mild to cool winters in which temperatures of -1° C occur, and low rainfall. The summer season lasts from June to September. The winter season is from December to February.

Evaporation is dominant over the whole year, and reaches 24.3 mm/day in July and August. The relative humidity is highest in December and January with average maxima of 85 per cent. Summer humidity is about 20-30 per cent.

The frequent winds from the northwest are cool in winter and spring and hot in summer. Southeasterly winds, usually hot and damp, spring up between July and October; hot and dry south winds prevail in spring and early summer.

Annual average precipitation is about 113.2 mm and exhibits great temporal and spatial variation from 30.3 to 242.4 mm as indicated by the records which show almost no rainfall occuring in June-September of any year during the observation period of (1958-1976)[1/].

V.1.2 Topography

The topography of Kuwait is generally flat or undulating with occasional low hills and shallow depressions. The ground surface elevations range from sea level to about 300 meters above sea level in the south-western corner of the State. Generally the land surface of Kuwait slopes northeastward at an average gradient of 0-002 and the topography is related to the regional tectonic structure of Kuwait.

---

1 TAHA, F.K., Kuwait Institute for Scientific Research, "Agriculture Development in Kuwait with Special Reference to Water Resources" UN/ECWA/FAO, E/ECWA/IAD/WG. 11/12, 1979, pp. 4-5.

According to Mitchell 1957 Kuwait and the Neutral Zone are situated on the Unstable shelf of the Arabian Shield. Only very gentle structures have been recognized and no dips exceeding 3° have been identified. The structures of Manageesh, Rawdatain, Umm Gudair, Ahmadi Ridge and Jal ez-Zor escarpment are the major elements identified in Kuwait.

V.3 Hydrogeology

Two main geological formations were known to contain usable groundwater in Kuwait. They are: Kuwait and Hasa Groups. The former comprises the Dibdibba, Fars and Ghar Formations. The other comprises the Dammam, Rus and Um er Radhuma Formations.

Table V.1 shows the main hydrogeological characteristics of the principal aquifers in Kuwait. The following discussions present briefly the water bearing characteristics of these aquifers based mainly on the information compiled from the unpublished reports available in the Water and Gas Department and the Water Resources Development Centre of the Ministry of Electricity and Water of Kuwait.

V.3.1 Aquifers

(a) Kuwait Group

The Kuwait group extends all over the State and varies in thickness from a few feet to about 700 feet (213 m). It is composed of cemented sand and gravel interbedded with silt, clay and limestone layers. The hydraulic characteristics vary considerably. Depth to water varies from close or at the surface along the coast to a few hundred feet in the south west of the State. Total dissolved solids in the water tapped in this group is generally less than 1000 ppm but reaches up to 50000 ppm in the northeast.

Local fresh groundwater surrounded by brackish water occurs but in limited quantities under the depressions of Al-Rawdatain, Um el-Aish, Hannabya and Um Niga areas. The Kuwait group comprises the following members:

TABLE V.1

Geologic Time Scale				Lithology	Water bearing Characteristics	Exploitation Area
Period	Epoch	Group	Formation			
QUATERNARY	Recent	Kuwait	Recent	Beach sand, eolian sand, valley fills and sabkha sediments.	High permeability, local fresh water	Coastal areas
	Pliestocene		Dibdibba	Sand and ground complex with sandstone and clays and silt (105 meters)	High permeability, local fresh water under valleys sand major depressions salinity increases at depth	Rawdatain, Um Al Aish Abdaly and other private wells.
TERTIARY	Pliocene		Fars	Calcareous sandstone with clays and gypsum about 105 meters	Low permeability. Low salinity at shallow depths with local fresh water under valleys and depressions	Field A and Wafra and other private wells.
	Miocene		Ghar	Quartzitic sandstone with gravel and some silt at bottom. Thickness (few meters to 275 meters)	Generally contain deep groundwater with low salinity.	
	Oligocene		Erosion and weathering activities			
	Eocene	Hasa	Dammam	Chert and siliceous chalky limestone. Dolomite with subordinates of anhydrite and clays (180-220m)	Medium permeability with low water salinity in south west Kuwait high salinity in north eastern Kuwait.	Sulaibiya, Abdaliya, and fields A,B, C and other scattered wells
			Rus	Limestone, with anhydrite (75-120m)	Saline water	
	Paleocene		Um er Radhuma	Limestone, dolomite with anhydrite	Saline water with H_2S Gas	
	Cretaceous and loder rocks			Limestone, dolomite and sandstone.	Saline water	

Source: S. Abu Sada, "Groundwater in Kuwait", 1976 (Arabic) PP 1-26

(i) Recent Deposits: It is composed of beach sands, carbonate rocks, detrital sediments and valley fills. Its thickness does not exceed a few meters and provides low-yielding wells but good quality shallow water within and along the coast.

(ii) Dibdiba Formation: It is composed of sand and gravels with subordinates of clays and silt, Its thickness may exceed 100 meters. It is characterized by high permeability but contains limited and local fresh groundwater. Water quality deteriorates laterally and vertically from about 500 ppm to more than 5000 ppm of total dissolved solids.

(iii) Fars Formation: It is composed of calcareous sand and gravels with subordinates of silt and limestones with gypsum. Thickness may reach up to 100 meters. Its permeability is low and contains water of low salinity and may contain limited fresh water when it occurs close to the surface such as in the southwest of Kuwait.

(iv) Ghar Formation: It is composed of quartzitic sand and gravel with some silt at its bottom. Its thickness may reach 275 meters. Groundwater contained in this formation is generally encountered at great depth and of fair quality.

(b) Hasa Group

It comprises mainly of carbonaceous rock units of marine origin. Damman formation is the most important member of this group as it provides most of the groundwater consumed in Kuwait. The other members (Rus and Um er Radhuma) are known to contain saline water and of low permeability.

The Damman formation lies directly below the Kuwait group and extends all over the State. It consists of karstified limestone beds fractured and fissured inter-bedded with clay layers. Its thickness ranges from 180-220 meters. It contains groundwater ranging from brackish in the southwest (2000-5000 ppm) to brine in the north east (5000-100000 ppm) water movement is from southwest to northeast at an estimated velocity of one foot/day. In the extreme southwest, it is a water-table aquifer while in other areas it is either a confined or semi-confined aquifer, like in Wafra area where the piezometric head is above the ground level, Locally the Kuwait Group and the Dammam aquifer are hydraulically connected but generally the piezometric head of the lower Dammam aquifer is higher than the water level within the Kuwait group aquifer.

V.3.2 Groundwater Area

Based on the hydrogeological survey carried out by the concerned Government Authorities, the area containing groundwater of less than 10000 ppm of total dissolved solids was identified as shown in figure V.1. Eleven primary well fields were also recognized. Tables V.2 and V.3 describe the main hydrogeological features of these well fields and their estimated capacities and the potential areas for groundwater exploitation.

Table V.2 2/

Potential Areas for Brackish and Ground Water Exploitation

Area No of Name	Estimated Yield MIGD	Estimated Salinity TDS	Life expectancy Years
I	35 - 40	3500-5000	More than 25
II	30	3500-6000	More than 25
Wafra	30 - 40	4500-6500	More than 25

2/ Source: Al-Saoud Al-Nassir, Ministry of Electricity and Water, water 1978, op. cit., E/ECWA/IAD/WG. 11/12. p. 15

TABLE V.3 [3]

Existing and Under Construction - Fresh and Brackish Ground Water Fields

Name of the field	Existing Yield MIGD [4]	Potential Yield MIGD [4]	Salinity TDS, ppm	Life Expectancy Years	Aquifer [5]	Number of wells [5]
Shagaya Project Field A, B, C	32	40	3000-4000	More than 50	Kuwait group and Dammam	60
Sulaibiya Field	15 - 20	20	4500-5500	More than 25	Dammam	133
Rawdatain and Um-Al Aish	1.5	4	(fresh) 700-1200	More than 20	Dibdibba	52
Abduliya	About 5	Unknown	About 4500	---	Dammam	14
Abdali-Um Nigga Farms	20 - 25	20 - 25	3000-7000	More than 15	Dibdibba	Approx. 110
Wafra Farms	20 - 25	30	4000-6000	More than 15	Kuwait group	Approx. 110
Shagaya Project Field D, E.	-	25	3000-4500	More than 50	Kuwait group and Dammam	54

3) After Al Saoud Al Nasir, 1978, Water Resources Development Centre, Ministry of Electricity and Water, P17

4) Million Imperial Gallons per day

5) After S. Abu Sada, Water and Gas Department, Ministry of Electricity and Water. 1976

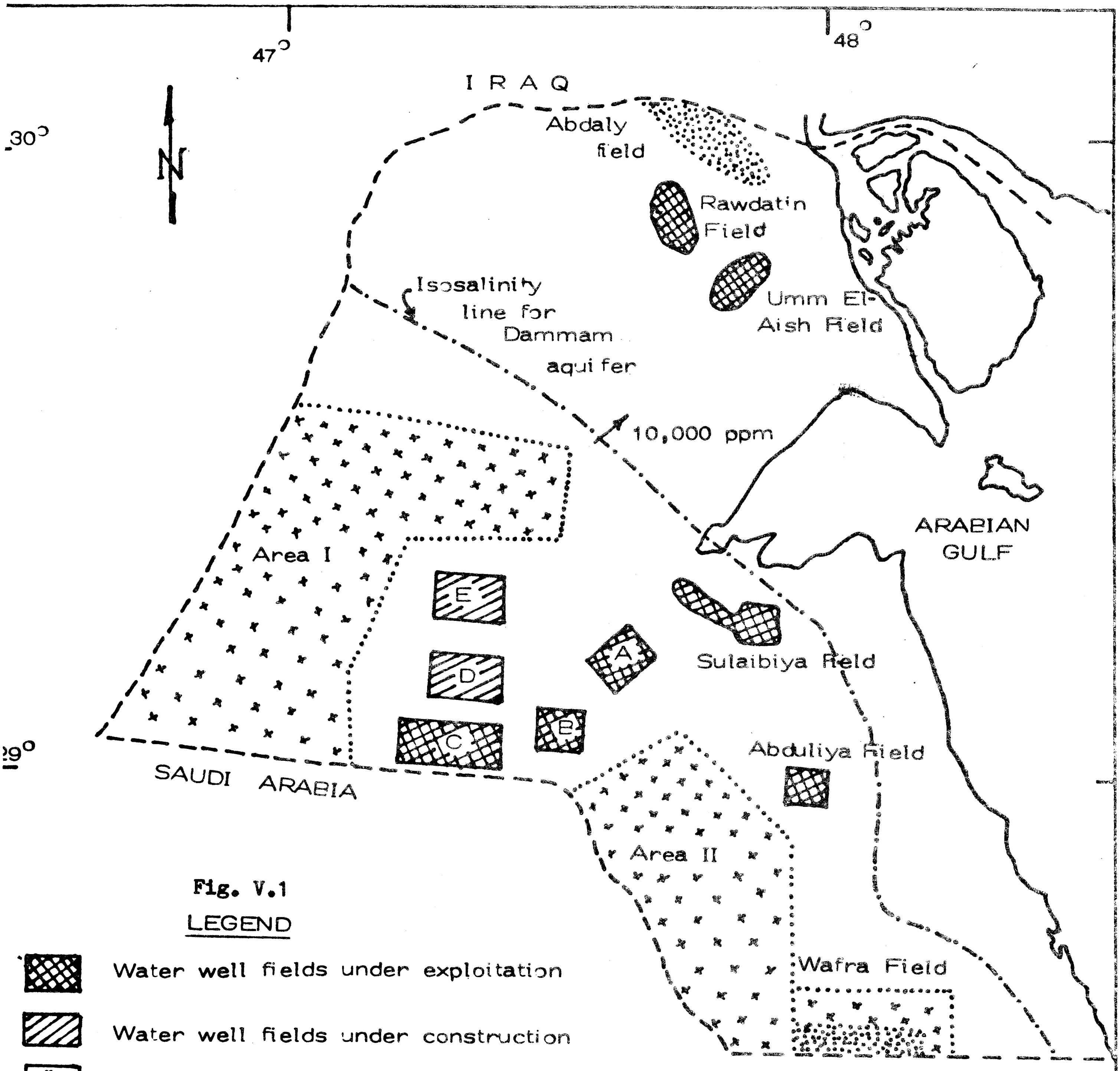


Fig. V.1

LEGEND

- Water well fields under exploitation
- Water well fields under construction
- Potential areas for ground water exploitation
- Private Farms areas where ground water is being exploited locally for irrigation.

Scale

0 10 20 30 40 50 Km

WATER WELL FIELDS AND AREAS OF ACTUAL AND POTENTIAL GROUND WATER EXPLOITATION

V.4 Surface Water Resources

The prevailing hydrometeorological conditions do not favour the existance of perennial surface water flows in the State. Accumulation of surface water runoffs often occurs in the major valleys and depressions during the rainy season extending from November to April of the year. The sustained waters are reported to last for several weeks. Annual rainfall of less than 3 inches to more than 13 inches has been recorded with as much as 5 inches falling in one month, and result in considerable surface runoffs. Only a small percentage of this runoff infiltrates into the groundwater due to high evaporation loss and due to the pressence of an impermeable (gatch) layer underlying the sandy deposits[6].

Artificial groundwater recharge projects were undertaken in Kuwait to utilize the accumulated surface runoffs in Rawdatain and Um Al-Aish areas. The project involved drilling of recharge pits so as to expose the Kuwait group or the Dammam aquifers to the accumulated surface water runoff. The outcomes of these recharge projects are unknown to the writer as the relevant information is lacking.

V.5 Desalination

Kuwait has turned to the sea for its fresh water supply since 1950, when a submerged tube distillation plant produced 100000 gallons per day. At present the State with its 22 distillation plants, all Multi Stage Flash type, and a total capacity of about 60 MIGD is considered as the world's leader in the production of fresh water from the sea.

There are three power and distillation plants in Kuwait namely: Shuwaikh, North and South Shuaiba Plants. The total capacity is about 62 MIGD.

6/ Al-Saoud, Al-Nassir, op. cit., pp. 21-22

To meet the presently increasing and the projected water demand of 220 MIGD by 1985; the Ministry of Electricity and Water (MEW) of Kuwait has plans to increase the fresh water production by building new desalination schemes. As part of Doha East Project 7 distillation units are under construction at a new site in Doha. The total capacity is estimated at 42 MIGD and the last unit is expected to be in operation by October 1979. Under the Doha West Project the MEW has plans to build distillation units with total capacity of 96 MIGD by the end of 1985[7/].

In the older distillation station at Shuwaikh additional distillation units are planned to be erected so as to produce 72 MIGD 1984. Rehabilitation of the old units will be undertaken too. Table V.4 indicates the existing and planned fresh water production by desalting sea water in Kuwait.

V.6 Treated Sewage Water

Another source of water is the treated sewage effluent in Kuwait. At present the existing sewage treatment plants produce around 8.8 MIGD while it is designed to treat 220 MIGD and will be expanded to accomodate 330 MIGD by 1985. The average salinity of the sewage effluent is about 2000 ppm of TDS most of the produced water is being used for agriculture mainly in Sulaibiyah area[8/].

7/ Ibid., pp. 6-14

8/ Ibid., pp. 23-25

TABLE V.4[9]

Existing and Planned Desalination Plants of Kuwait

Plant Design-ation	Supplier	Year of Commn.	No. of Units	Output each unit (MIGD)	Total Output (MIGD)
SHUWAIKH					
E1 E2	Weir-Westgarth	1960	2	1.0	2.0
F1 F2	" "	1965-66	2	1.0	2.0
G1 G2	Westinghouse	1968	2	2.0	4.0
New B1B2	IHI	1968	2	2.0	4.0
New A	IHI	1970	1	4.0	4.0
SHUAIBA NORTH					
A1 A2 A3	Weir-Westgarth	1965-66	3	1.0	3.0
B	Westinghouse	1968	1	2.0	2.0
C1 C2	IHI	1968	2	2.0	4.0
D	Alsthom	1971	1	5.0	5.0
SHUAIBA SOUTH					
A1A2A3A4	Alsthom	1971-72	4	5.0	20.0
A5 A6	IHI	1975	2	5.0	10.0
DOHA EAST					
A1 A2 A3	IHI	1978	3	6.0	18.0
A4A5A6A7	IHI	1979	4	6.0	24.0
SHUWAIKH	---	1983-84	-	---	72.0
DOHA WEST	---	1985	-	---	96.0

Note: Shuwaikh E1E2 and F1F2 will soon be scrapped to make way for the new Shuwaikh units.

9/ Al Saoud Al Nasir, Water Res. Dev. Center MEW. Water, 1978, p. 11.

V.7 Conclusion

Groundwater and deslated water are the major water resources of the country. The principal aquifers are: the Kuwait Group (Recent and Dibdibba Formations) and the Hasa group (Dammam formation) aquifers. Groundwater quality is generally fair and resources of less than 10000 ppm of TDS occur in the south western half of the country and deteriorate in a north-easterly direction. The potentiality of the existing groundwater fields is estimated at 93.5 MIGD (150 MCM/a) which may be doubled by developing the potential fields in Kuwait.

Surface water resource is practically nonexistent in Kuwait. Desalted water production out of brackish groundwater or sea water is the other major resource of the country. The present desalted water production is estimated at 62 MIGD and it is planned to produce 270 MIGD to satisfy the water demand of 220 MIGD by 1985.

Construction of desalination plants is costly; the cost would be reduced if the practice of recharging the aquifers artificially by utilizing the sporadic flood waters were enhanced, so that the plants would start with a better quality groundwater.

VI. THE LEBANESE REPUBLIC

Population: 3.2 million
Area : 10400 square kilometers

VI. 1 General

Lebanon is situated along the eastern seaboard of the Mediterranean between latitude 33°03' and 34°41' north and longitudes 35°06' and 36°05' east. Figure VI.1.

VI.1.1. Climate

Mediterranean climate prevails almost over the entire Lebanon. It is charactereised by: prevailing western winds blowing north-west during the rainy season, Mediterranean Sea influence and a dry summer and it is a function of the general topography of the country.

Annual rainfall ranges from 800-1000 mm along the coast and increases eastwards to more than 1500 mm/a in Sannine-Laqluq highlands, and 1000 mm/a over Hermon mountain. It goes down to 400 mm/a along the eastern boundary and in northern portion of Beka'a area where semi-continental climate occurs. Relative humidity is about 70 per cent as monthly average along the coast in winter and decreases to 55 per cent in summer[1/].

VI.1.2. Topography

Lebanon is generally of mountaineous topography. The principal physiographic structural units which dominate the country are: Two NNE-trending mountain ranges, the coastal Lebanon and the inland Anti-Lebanon, separated by the Beka'a structural depression[2/].

The coastal plain has a length of about 210 Km from Ras el Nakoura to Tripoli. It is a narrow plain ranging in width from 2-3 Km and characterised by the occurrence of several small heads and bays.

1/ Republique Libanaise "Atlas Climatique du Liban", Tome I Cahier I-B, 1977.

2/ Beydoun, A.R. "Observations on Geomorphology, Transportation and Distribution of Sediments in Western Lebanon and Its Continental Shelf and slope Regions", Marine Geology 21, 1976, p. 312.

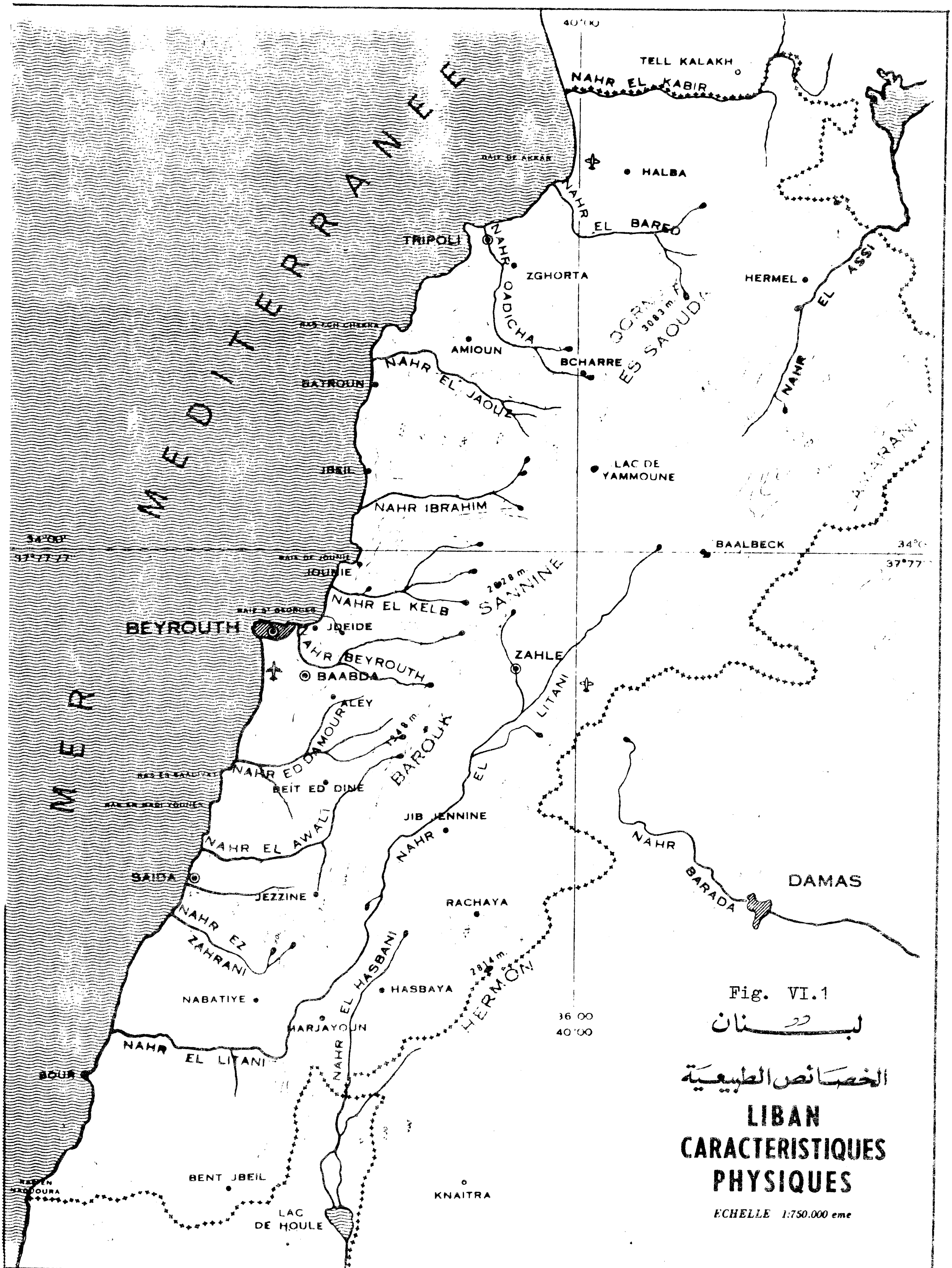


Fig. VI.1

لبنان

الخصائص الطبيعية

LIBAN
CARACTERISTIQUES
PHYSIQUES

ECHELLE 1:750.000 eme

The coastal Lebanon Mountain Range ~~extends~~ almost parallel to the sea coast and has a peak of 3083 m a.s.l. at Qornat el Saouda with an average elevation of about 2200 m. It slopes gradually westwards but abrupt cliff-like sloping towards the Beka'a area. Several wadis and rivers cut through the range and drain westwards to the sea. Some peaks of elevation exceeding 2500 m a.s.l. occur in the eastern slopes of this Lebanon range. In the northern part of the range there occur some intra mountain depression-like areas such as Akkar and Koura. To the south of Beirut the mountain range goes down gradually to an elevation of about 400-600 m a.s.l. near the Litani twist north of Marj-Ayoun.

The Eastern Mountain Range (Anti-Lebanon Range) forms the natural eastern boundary of Lebanon with Syria. The highest peak in the north (Tal'at Mousa) is 2629 m a.s.l.. Its average elevation is about 2000 m a.s.l. Moun Hermon comprises the southern portion of this range and has a peak of 2814 m a.s.l. It slopes steeply towards Hasbani River in the south.

The Beka'a Area lies in between the eastern and western mountain ranges. It forms a narrow in-land fertile plain, the width of which ranges from a few meters to 20 Km. Its average ground elevation is about 900 m a.s.l. and reaches up to 1100 m near the Ba'albeck area. It extends and widens north towards the Homs Lake in Syria, and terminates southwards in the hilly area of Jebal el Arabi (1508 m) and Bir el-Dahr (1221 m)[3].

VI.2. Geology

VI.2.1. Stratigraphy: Rock units exposed in Lebanon are predominantly sedimentary succession ranging in age from early Jurassic to recent and consist of a very high proportion of carbonate rocks mainly limestone and dolostone with lesser development of chalky marly limestones and marl. Developments of clastics including sandstone, siltstone, shale, mudstone and shaley marl,

---

3/ Receuil de Statistiques Libanaises No. 9, 1973, pp. 9-11.

occur in the early cretaceous succession up to and including the Albian, but these contain interbeds and intervals of carbonate rocks at the top. Local volcanic deposits, laterised to fine clastics occur within the Upper Jurassic series, the Basal Cretaceous series and the Aptian formation. Limited occurrences of Pliocene sandstone and shale and Quaternary alluvium and sand occur in the northern coastal areas. Quaternary deposits also occur in patches along the coast and within the Beka'a area. All other gelogical series and systems represented in Lebanon are carbonate in Lithology with the exception of Neogene conglomerates whose components, however, mainly consist of limestone. The Upper Eocene and Oligocene formations are absent as indicated by several investigators (Beydoun, Z.R. 1976).

Table VI.1 presents briefly the main lithostratigraphic rock units exposed or occuring at the subsurface in Lebanon[4/] [5/].

4/ Beydoun, Z.R. "The Levantine Countries: The Geology of Syria and Lebanon", The Ocean Basins and Margins, Vol. 4 - A, 1977.

5/ Beydoun, Z.R., Marine Geology 21, 1976, op. cit., p. 312.

TABLE VI.1

Lithostratigraphic Summary

Geological Age	Formation	Symbol	Thickness (m)	Lithology in Lebanon	Lithology in Syria (Maritime Region)	Thickness (m)
Pleistocene to Recent			-	Alluvium, sand and gravel with shore and river deposits	Alluvium, congl. marine marl and river deposits	-
Pliocene			360	Limestone, marl, sand with volcanics, mostly in Akkar	Clay, sandstone, limestone local congl. and volcanics	470
Miocene	Upper	m	800	Coarse clastics lacustrine gypsum and marl (chekka)	Limestone, clay marl, gyp. volcanics	40
	Middle		320	Limestone reefoid basal clastics	Clay marl, limestone, coarse fine clastics calcarious, clay limestone	170-225
	Lower	ml	80	Marly limestone (Beka'a)	limestone argillaceous and sandstone interbeds limestone clay marl interbeds	150-225
Oligocene	A b s e n t				Limestone & argillaceous limestone (Ghab only)	120
Eocene	Upper	A b s e n t			A b s e n t	
	Middle	e1	800	limestone, chert limestone	limestone argillaceous limestone	185
	Lower	e2	370	limestone marly limestone chert and marl	limestone marl chert	65
Paleocene			360	chert, marl chert	marl, clay marl, chalky marl	650
			-	limestone	marly chalk	30
Cretaceous Senonian	Chekka	C6	-	Chalky marly limestone	chalky limestone, marly limestone, congl. base ophiolites	30
				phosphorous, chalky limestone, cherty gluconitic.		-

TABLE VI.1 (Cont'd)

Geologic Age	Formation	Symbol	Thickness (m)	Lithology in Lebanon	Lithology in Syria	Thickness (m)
Turonian	Ghazir	C5	800	Limestone thinly bedded and marl interbeds	Marly limestone to limestone	1ᵯ
Cenomanian	Sannine	C4	800	limestone a) dolomitic limestone with chert modules b) Marl with geodes c) limestone to dolomitic limestone and Chert modules	limestone with marl local volcanics	400
Albian	Cordian Knemiceras Beds	C3	200	Sand, limestone with large Mulasca and marl interbeds and marly limestone form cliffs.	limestone argillaceous limestone and marl	
Aptian	Jezzine	C2b	90	Sand and argillaceous sandy limestone and massive limestone end with sand facies.	Shale limestone, rare sandstone and volcanics	35
	Gastropoda beds	C2a	120	with volcanics		
Neocomian	Basal Cretaceous	C1	300	Sandstone, deltiac with coal seams, sulpher and pyrite. It wedges northwards of Jezzine to few meters in thickness	Not recognized	-
Jurassic Portlandian	Salima	BJ7 J 7) J6a)	180	Volcanics limestone, marl and oolitic limestone limestone, karstified	Absent	

TABLE VI.1 (Cont'd)

Geologic Age	Formation	Symbol	Thickness (m)	Lithology in Lebanon non	Lithology in Syria (Maritime Region)	Thickness (m)
Kimmeridgian to Bajocian	Bhannes	BJ6b		Volcanics and marl		
	Bikfayya, Kesrouane	J4-J6	800-1000	limestone and dolomitic limestone	limestone	450
					limestone rare clay interbeds	150
				limestone, chert l.s.	dolimitic limestone and limestone	400
Lias	-	J1-J3	400	Unfossilleferous limestone and dolimitic limestone	Not exposed	
Triassic	Not Exposed				exotic blocks, Ophiolites-radiolarites.	

VI.2.2. Structure

There are three major geological structures predominating in the country and have direct control on rainfall distribution, occurrence and accumulation of surface and groundwater resources. These structures are: the Lebanon Coastal Mountains, the Anti-Lebanon range and the Central Beka'a grabin.

The structural patterns prevailing in the Lebanon mountain ranges are generally arched block uplifts with west dipping, locally strongly flexured, seaward flanks and truncated eastward flank bordering the rift valley system faults. The northern part of the Lebanon Range is a large horst-anticline with its east flank truncated by the major Yamouneh fault and the west flank exhibiting steep dips. The range plunges north into the Tripoli-Homs depression. A parallel but topographically lower structural trend separates the main uplift from the coast and is cut into offset segments by small east-west strike faults, with apparent horizontal movement to the west, one ahead of the other as one goes south. The southern part of the main uplift divides into parallel assymetric structures separated by a tight syncline wedged into a "V" shape formed by the NHE trending Yammouneh fault, the western boundary of the Beka'a Graben, and the N-S trending Roum fault extending into the western Jordan Valley boundary fault. The Yammouneh fault has throws varying from a few hundred meters in the north to about 3000 m near Machghara in the south. The southern part of the Lebanon range is a monocline with a gentle west dip.

The central Beka'a Graben forms the northern extension of the Dead Sea-Jordan Valley depression and extends northwards into the Ghab area in Syria and Kara-Su depression in Turkey. As mentioned earlier the Yammouneh fault forms the western boundary of the Beka'a Graben. The eastern boundary is another major fault extending east of Beka'a along Hermon Mountain and northwards into Syria. The width of Beka'a Graben varies from about 20 Km in the north to a few meters in the south. The Beka'a area such as the Jordan Valley area in Jordan, forms the main drain of the eastern and western aquifers occuring on the adjacent Lebanon and Anti-Lebanon mountain ranges.

VI.3. Hydrogeology

Annual precipitation in Lebanon ranges from about 1600 mm over the highlands to about 200 mm in the northern Beka'a depression. Snow always covers the higher altitudes during the period of December-April of the year. This snow cover is the major contributing source to groundwater recharge for the carbonate aquifers occuring in the mountain areas of Lebanon. Advanced karstification is very well developed over the predominating carbonate terrain of the high mountains giving a great potential for groundwater accumulation and results in issuing of many large spings[6/].

According to the computation made by the Ministry of Water and Electric resources the total annual precipitation over Lebanon in the form of rain and snowfall is about 9700 MCM; of this total about 4025 MCM is surface runoff, 600 MCM is groundwater recharge to aquifers and the remainder is lost by evapo-transpiration and by submarine seepage.

Countrywide hydrogeological investigations were carried out by UNDP and others[7/], in 1970. The available information on aquifer occurrence, characteristics and groundwater potentials are indadequate to evaluate the groundwater resources situation of the country. However, based on the available information it can be stated that there are two main aquifers in Lebanon, namely: Cenomanian-Turonian and Jurassic predominantly limestone aquifers.

VI.3.1. Aquifers

Cenomanian-Turonian Aquifer (c)

It consists of thin to well-bedded limestones and dolimitic limestones with thin marl intervals. It is the most important aquifer as it offers a large receptive surface area of about 4290 Km^2 subjected to high rain and snowfall zones within the coastal and eastern mountain ranges of Lebanon. The estimated thickness of the aquifer is 800-1000 meters. Karstification in this aquifer is very well developed giving rise to high well yields exceeding 50 l/s.

6/ Beydoun, Z.R., Marine Geology, 21, op. cit pp. 316, 317.

7/ Programme des Nations Unies pour le développement, New York, Rapport Technique, Liban, "Etude des Eaux Souterraines" 1970, pp. 185 + maps.

Jezzine Aquifer (c2b)

Is another aquifer known to exist in Central Lebanon and consists of limestone, sand and argillaceous sandy limestone.

Quaternary Aquifer (q)

It consists mainly of sea shore sand, alluvium and talus deposits. It occurs in a continuous manner along the flood plains of the major streams and rivers issuing from both the coastal and the eastern highlands. It also occurs in the Beka'a area and inthe Tripoli depression. The estimated cumulative surface area of the aquifer in the country is little over 1000 Km^2. It has a variable permeability and so its thickness which may reach up to 600 m in Beka'a area. It offers low to moderate well yields which range from less than 10 to 30 l/s.

More information about the hydrogeological conditions of the country will be made available through the discussion presented under item VI.6.

VI.3.2. Groundwater Quality

Groundwater in Lebanon is generally of good quality. It is fresh at the foothills on both slopes of the coastal and the eastern highlands. In Beka'a area, water quality is generally of less than 1000 ppm of T.D.S. At the coastal plains water quality deteriorates by the sea water encroachment due to local overpumping. Annex 4 indicates the chemical analysis of some spring water samples from the different aquifers in the country.

VI.4. Surface Water Resources[8/]

Although the dry period of no rainfall lasts for about five months of each year, Lebanon has a great potential of surface water resources. About 15 perennial rivers(Annex 4)occur in the country. Twelve of them issue from the western Lebanon mountain range and flow in relatively short courses to the Mediterranean sea. They are from north to south: El-Kebir, Ostouene, Arka, El-Bared, Abu Ali, El-Jaouz, Ibrahim, El-Kalb, Beirut, El-Damour, El-Awali and El-Zahrani. Other two rivers of longer courses flow inland in the Beka'a area: El-Asi River flows northwards to Homs Lake in Syria, and Litani River flows southwards and then westwards to the Sea: Hasbani River originates inthe south from mount Hermon and flows southwards to Lake Tibereous.

8/ Mainly after: Sharaf-Eddine, J. Ministry of Water and Electric Resources Lebanon "Water Situation in Lebanon" Open File Report, 1971, pp. 20 (Arabic).

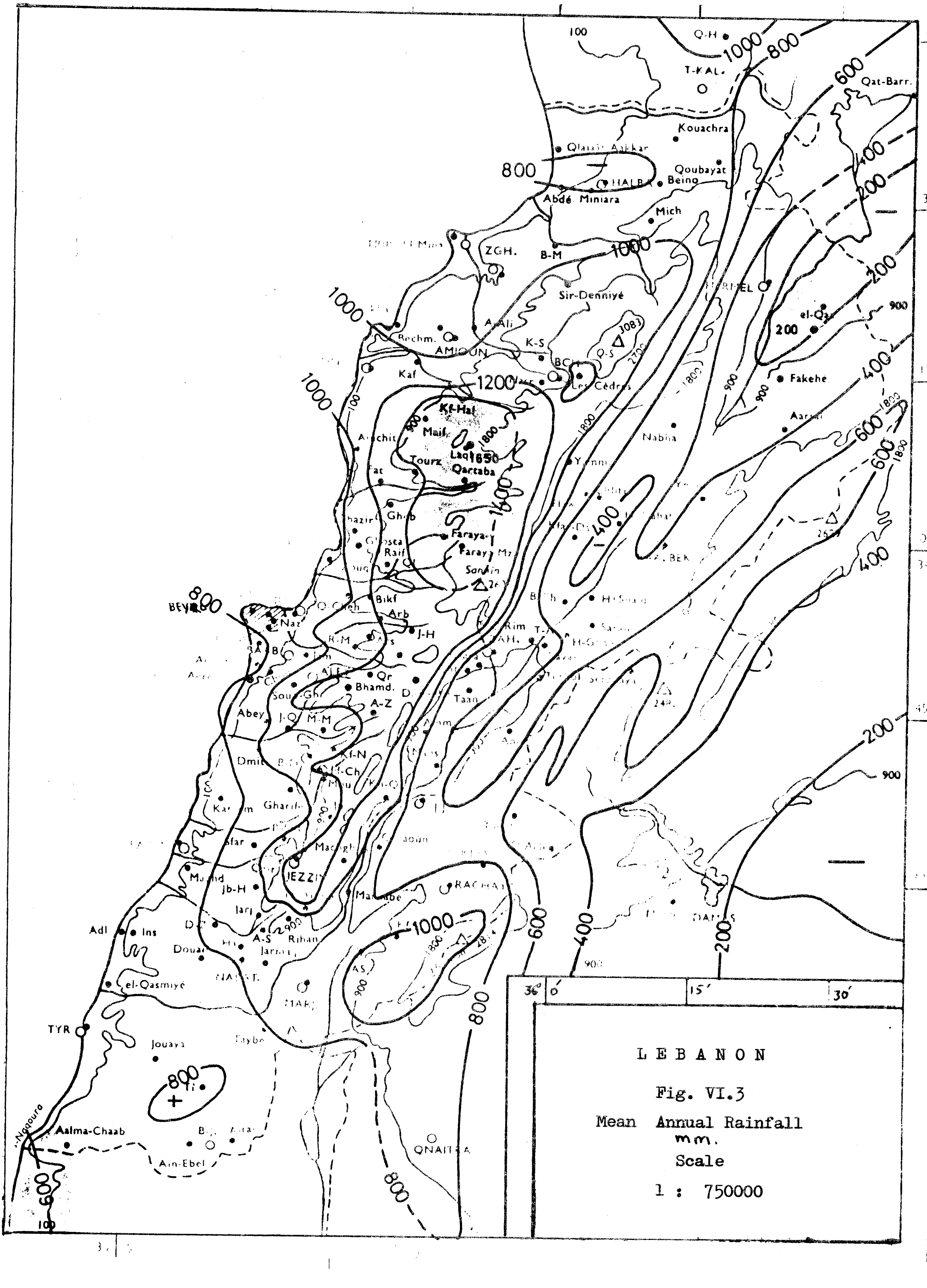
Rainfall and snowfall which are the sole source of the surface water flowage in Lebanon occur during October-April of each year, with maximum falls often occuring in February. Fig. VI.2 shows the rainfall distribution in an average year in Lebanon. The estimated total volume of rain and snowfall that the country receives annually is about 9700 MCM, of which the total estimated volume of the annual surface water flow in the above 15 rivers is about 4025 MCM (including the shared waters). Peak floods often occur in March and April particularly after snowmelt. Low flows which are mainly from groundwater storage, occur during the period from August-October.

Of the above total runoff figure, 2025 MCM flows to the Mediterranean principally along the above-mentioned perennial and semi-perennial streams and rivers. The flow in the upper Litani river is not included here as much of it contributes to the storage behind the Qaraoun Dam in the south Beka'a. About four fifths of the annual surface runoff takes place between December to May, while perennial or semi-perennial flow is maintained by springs during the dry summer and the early autumn, when much of the rainfall from October initially goes towards replenishing soil moisture deficiencies and the depleted groundwater table. Considerable floods often occur after intense rainfall.

Several hydrological investigations were carried out, by Lebanese Officials and others, in the major river basins of Lebanon, as early as 1947. These investigations were conducted for the purposes of domestic water supply, agriculture, and hydropower development projects.

Annex 5 shows the average annual and monthly surface water flows that occur in Lebanon. The annual surface water flow from the western slopes of the coastal mountains including lower Litani, springs water and small streams, is in the order of 2570 MCM of which about 95 MCM represents El-Kabir River water in Syrian territory. In the Beka'a area the total volume of surface water flow including the upper Litani and the major springs in the area is about 1305 MCM/a, of which 140 MCM/a of Hasbani River waters go into Palestine, 410 MCM/a of Al-Asi River waters flow towards Homs Lake in Syria and about 220 MCM is being stored in Qaraoun Lake[9/].

9/ *Ibid.*, Table 8.



LEBANON

Fig. VI.3

Mean Annual Rainfall mm.

Scale

1 : 750000

VI.5. Water Balance

As a result of the UNDP reconnaissance studies on the hydrogeology of Lebanon, preliminary estimates were made for the hydrologic balances in the various basins composing the country. These estimates were based on the available data relevent to: rainfall, surface runoff, soil moisture, rates of infiltration, evapotranspiration, pumpage, subsurface flow, and aquifer exposures and characteristics. The outcomes of these estimates are shown in annex 6 the summary of which follows:

Province	Surface Area Km^2	Rainfall mm	Rainfall mcm	Water Deficit* mcm	Infiltration mcm	Runoff mcm
Mediterranean	5500	1163	6500	3500	2000	1000
Interior	4700	710	3300	2000	1000	300
Total	10200		9800	5500	3000	1300

* Water deficit includes: subsurface flow, evapotranspiration, pumpage, interception, etc.

The above estimates of surface runoffs and downward infiltration to groundwater do not agree with the estimates made by the concerned officials of the Ministry of Water Resources and Electricity of Lebanon as shown in annex 6. The runoff estimates seem to be low and the rate of infiltration is high (30 per cent).

In accordance with the computation made by the Officials of the Ministry, the following water balance was deduced:

Rainfall and Snowfall mcm/a	Surface Water Flows			Total mcm/a	Groundwater replenishment	Total loss mcm/a (5+6-1)
	Area	In Leb.	Out of Leb.			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Western Slope	2473	95	2568		
	Beka'a					
	Al Asi	97	415	512		
	Up.Litani	641	-	641		
	Hasbani	13	140	153		
	Springs	47	-	47		
	Domestic Water	104	-	104		
9700	Grand Total	3375	650	4025	600	-5075

Hence about 5075 MCM/a is being lost by evapotranspiration and subsurface flow into the sea and the Hula depression. From the total surface runoff, 3375 MCM/a occured in Lebanese territory. This volume occurs as 2557 MCM during the rainy season (December-May) and 818 MCM during the low flows period (June-November).

During the high flows period, it was estimated that only about 480 MCM is utilized in the country, 60 MCM for domestic and industry, 200 MCM for irrigation and 220 MCM is stored in Qaraoun Lake. Hence about 2077 MCM (2557-480) is wasted through evapotranspiration, subsurface flow and runoff into the sea, in addition to what is being wasted during the low flows period as surface runoff into the sea mainly along the rivers of: Akkar plain, Ibrahim, Damour, Awali and Litani.

From what has preceeded, it can be concluded that there is great potential for water resources development in the country. The Ministry of Water and Electric Resources has proposed a country-wide plan to develop the water resources through:

	MCM
1. Artificial groundwater recharge in: Akkar Plain, Beirut Area, Barouk-Niha Area, Southern Coastal Plain and Beka'a	160
2. Utilization of Submarine Springs at Chekka Area	80
3. Possible dam construction at selective sites: Nahr El-Kabeer, Nahr Ostouene, Nahr Arka, Kurkuf, Qarhiya, I'al, Asfur, Jannah, Shabrouh, Nahr Awali, Nesfadon Litani at Khardala and in Beka'a Area	460
The total possible stored volume of surface water will be about 540 MCM. Only 85 per cent of this volume may be reliable.	
4. Groundwater Development particularly in Beka'a depression	400

The total estimated volume of water resources (surface and groundwater) which can be developed in the entire Lebanon is about 1100 MCM/a. This is in addition to about 690 MCM which is presently consumed, from the baseflows during the low flow period.

VI.6 Water Resources Areas

Based on the hydrogeological conditions and rainfall behaviour, Lebanon has been divided into four major water resources areas (zones).[10]

VI.6.1. The Northern Coastal Area (Zone A)

It comprises the western slopes of the Lebanon mountain range from the Syrian border in the north to Zahrani Basin in the south. The northern part of this area, to the north of Dahr el Baidar, is characterized by the highest annual rainfall and the thickest snow cover during the rainy season. The annual average rainfall over the entire area is about 1170 mm. The area to the south of Dahr el Baidar has less rainfall and snow cover and the predominant structural pattern also does not favour issuing of major springs such as those occuring in the northern part.

About 29 streams and rivers dissect the area and enter the Mediterranean with a high rate of flow and high water levels. Most of the water flowage in these rivers during the dry summer originates from the groundwater storage from within the Cenomainian Carbonate Aquifers which predominate in the area. The groundwater recharge to these aquifers is primarily from the snow cover and the rainfall that the northern portion receives annually, and being accumulated over the impermeable strata of the Albian-Aptian ages. Large springs issue from this aquifer, as mentioned earlier VI.4, and occur in the area such as the springs of Fnediq, Soukkar, Kadischa, Mar Sarkis, Akoura, Afka, El Asal, Laban, Khan Sannine Richmaya and Jezzine.

10/ Yordanov, Y.U., "Resources Hydrauliques du Liban par Images", 1973.

The area is faulted down by several traversal faults truncated to the East by the major NNE trending Yammouneh fault. This fault system favours the groundwater recharge and results in the great groundwater potential particularly in the permeable karstified layers of the Jurassic and Cretaceous carbonate rocks which occur in the entire zone. Groundwater flow in this zone is almost coincident with surface water flow towards the sea and reappear in the form of several small springs, about 450, along the coast. In Chekka area there are several submarine springs of which the estimated flow is about 80 MCM/a being wasted into the sea.

VI.6.2. The Southern Coastal Area (Zone B)

It comprises the southern hilly area of the Lebanon Range from Zahrani till the Lebanese Southern borders. The annual average rainfall is about 740 mm, and there is no snowfall in this zone.

Surface water flow occurs only in Litani River which originates from the Beka'a area (Zone D).

The hydrogeologic conditions in the area do not favour good accumulation of groundwater due to the occurrence of several faults that drain the potential groundwater storage towards the sea and/or to the Haula Graben in the east.

Local artesian groundwater bodies may occur along the coastal plain. Few low yielding springs also occur in the area.

VI.6.3. The Eastern Slopes of the Lebanon Mountain Range and Mount Hermon Area (Zone C)

The zone comprises the eastern slopes of the coastal mountain ranges, the Houla depression and the Hermon Mountain. It receives the highest rain that falls over internal Lebanon. The average annual rainfall is estimated at 1050 mm. The eastern boundery of the zone coincides with the isohyet 700 mm.

The zone is characterised by the existance of major faults that have direct control on the groundwater occurrence and movement. They are the faults of: Yammouneh, Rachaya, Hasbaya and Serghaya. The Yammouneh fault extends parallel to the eastern slopes of the western Lebanon Range. It acts as a barrier against the groundwater that flows eastwards from the Cenomanian-Turronian Aquifers occuring in the western Lebanon mountains, resulting in issuance of large springs, to the north of Zahle, such as Marj Chim, Jbab el Homor, Ain Ata, Yammouneh, and Bardouni. There are no springs to the east of Yammouneh fault except small ones issuing as a result of the traversal E-W faults.

To the south of Zahle, and along the same fault, there are some springs fed from the/groundwater storage in the Jurassic aquifers occuring in the Barouk-Niha highs. These springs are: Kab Elias, Ammik, Khreizat and Machghara. Ain Zerka which is fed from the limestone aquifer at Jabal ed Dine furnish the major contribution to Litani flow. The springs which are issuing from the Jurassic carbonate rocks at Hermon Mountain as a result of the existing fault systems are: Cheba'a and Hasbani.

In general, surface water resources of this zone occur in the form of spring flows. Most of the rainfall water is normally absorbed by the permeable formation (the soil and the underlying strata) and perculates downwards to the groundwater body. The potential groundwater reservoir is believed to be great. The estimated groundwater throughput accross the Houla depression is about 500 MCM/a.

VI.6.4. <u>The Beka'a and the Eastern Lebanon Mountain Range</u> (Zone D)

This is the area which receives the least volume of the annual rainfall in the country. It varies from 700 mm/a to 200 mm/a. The zone comprises the Geomorphologic depression between the eastern and the western Lebanon highlands and bordered from the west and the east by the Yammouneh and Sarghaya faults respectively.

An appreciable percentage of the rainfall volume and most of the snow cover over the eastern highlands are normally absorbed to recharge the groundwater body occuring in the Jurassic and Cenomanian aquifers which exist in the adjacent flanking highlands or within the Beka'a depression at depth.

Surface water resources are mainly represented by the major river flows of Al-Asi in the north and Litani in the south. Spring flows occur almost along the two major bordering faults and along the Litani course, such as: Saouda, Tell Hazzine, Ain Tal, Khessali, Atais, Aalaq, Safia, etc... The springs that occur at or to the east of Serghaya faults are: Nabi Hud, Nabi Ham, El-Qala'a, Bournaya, Delbe, Amechke, Maqsous, Lejouj, Chougour, Rayan, Sukhna, Nahla, Ainata, Labna, El Ain, Fakeh and Ain Ras Baalbeck.

Groundwater occurrence in the Zone D, is not well indentified or developed. There are some localities where shallow groundwater bodies are partially developed. Along Chtoura-Anjar Rd. a shallow pay zone (60-100 m depth) occurs. Two pay zones at less than 20 m depth, and about 90 m depth were recognized along Chtoura-Riyak and Ablah-Riyak Rds. In the viscinity of Baalbeck shallow groundwater (5-15 m) was encountered. The groundwater recharge to these shallow zones is mainly from the surface water runoffs along the streams and rivers that originate from the flanking eastern and western highlands bordering the Beka'a depression.

Nothing is known about the aquifers that may occur at depth in the Beka'a depression. It is believed that the groundwater recharge to these aquifers is highly appreciable and furnished through the several traversal fault systems that occur in both flanking eastern and western mountain ranges.

The occurrence of the major springs of Al-Asi and Ain Zerka and their regular hydrologic behaviour are positive indication of the existance of a great potential groundwater reservoir in the Beka'a depression. This reservoir is not yet well defined or developed.

VI.7 Conclusion

The total volume of rainfall that Lebanon receives annually is about 9700 MCM, of which about 5075 MCM is lost through evaporation, soil moisture, sub-surface flow into the sea and Hula depression, plant interception... etc. The surface runoff that occurs in Lebanese territory is estimated at 3375 MCM/annum. About 1100 MCM/annum of water resources (surface and groundwater) may be developed through executing water projects such as: artificial groundwater recharge, groundwater abstraction, storage structures and utilizing sub-marine spring water. This is in addition to about 690 MCM which is presently consumed from baseflows.

Groundwater in Lebanon is generally of good quality. The main producing aquifers are the Karstified Carbonate rocks which belong to Jurassic and Cretaceous geologic time scales. The potentiality of the groundwater resources in the country is unidentified and the resources are not well developed although it is believed to be highly appreciable particularly in Beka'a depression. The annual groundwater replenishment through direct rainfall and surface runoff is estimated at 600 MCM.

There is room for joint water development projects between Lebanon and Syria to exploit and manage the South Al Kabir river water and probably the Al-Asi river too.

Integrated use of surface and groundwater resources in Lebanon is essential to develop the resource and meet the year 2000 water demand of 1985 MCM/a. Development and applications of appropriate water regulations and legislations seem to be essential to conserve and administer the national water resources.

VII. SULTANATE OF OMAN

Population: 1.5 million[1/]

Area : About 212450 square kilometers

VII.1 Geographical Environment

The Sultanate of Oman occupies most of the south-eastern corner of the Arabian Peninsula. The country is bordered on the north, east and south by the Arabian Sea and on the west by the United Arab Emirates, Saudi Arabia and South Yemen, Figure VII.1.

Topographically, the country can be divided into:

- The Coastal Plain streching about 1700 Km from the Straits of Hormuz in the north to the frontier with South Yemen. The Batinah, coastal plain in the northern Oman and the Sallalah plain in Dhofar region are the most important parts of this plain.

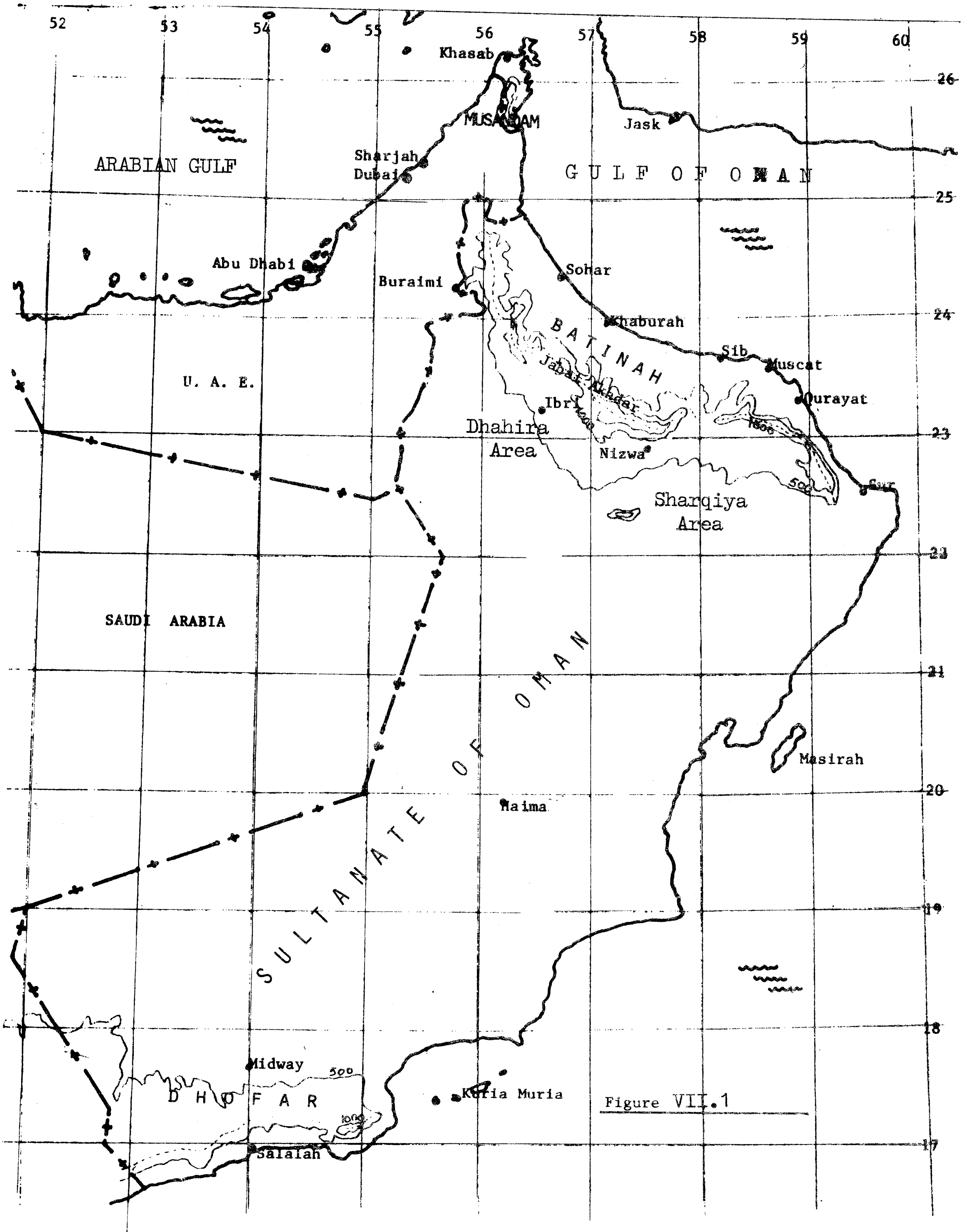
- The Omani Mountains: In northern Oman, the mountain range runs almost parallel to the Batinah Coastal Plain. It is locally known as Jabal Akhdar uplands which have peaks rising to over 3000 meters.

In Dhofar region, the main highs are locally known as: Jabal Al-Qamar, Jabal Al-Dara and Jabal Samhan.

- The Interior Plains: These are mainly: Dhahira plains in the north west; Sharqiya plains in the north east; and Nejd area in the Dhofar region.

The climate of Oman is generally hot and tropical. The climatic year in Oman can be divided into: winter months of November to April with a predominant airflow from the north-west, and summer months of June to September with a monsoon airflow from the south-west. May and October are months of transition between the winter and summer conditions.

1/ Middle East Review, 1978



52
53
54
55
56
57
58
59
60
26
25
24
23
22
21
20
19
18
17
Khasab
MUSANDAM
Jask
ARABIAN GULF
Sharjah
Dubai
GULF OF OMAN
Abu Dhabi
Buraimi
Sohar
Khaburah
BATINAH
Sib
Muscat
U. A. E.
Jabal Akhdar
Ibri
Qurayat
Dhahira
Area
Nizwa
Sur
500
Sharqiya
Area
SAUDI ARABIA
SULTANATE OF OMAN
Masirah
Haima
Midway
DHOFAR
Kuria Muria
Salalah
1000

Figure VII.1

Winter conditions arise from a general area of low pressure over the Indian Ocean extending over the low coastal areas of Oman. Troughs from the eastern Mediterranean migrate in a south-easterly direction. Orographic rain can result when these disturbances, usually led by a cold front, encounter the Jabal Akhdar or by moist air moving inland from the Gulf of Oman.

In summer the country is influenced by two main air streams: the north-easterlies over the Arabian Gulf and the south-west monsoon.

During the transition months between summer and winter, cyclonic storms originating over the Arabian Sea migrate westwards towards the Oman coast usually near Sallalah but occasionally as far as the Gulf of Oman.

Rainfall is highly variable from year to year and it is a function of topography and stormy in occurrence. Country wide rainfall data is insufficient to make a reliable description of the rainfall behaviour over the country. At Muscat the average annual rainfall from 24 years complete records is about 99 mm. At Sallala the average annual rainfall during the period 1942-1972 is about 108 mm.

VII.2 Geological Environment[2/]

VII.2.1 Stratigraphy

In northern Oman, the Omani mountains, constitute the core around which the present geological features and the more recent strata have been formed. In Dhofar region exploratory drilling in Jabel and Nejd areas have revealed the stratigraphic column from pre-cretaceous to Quaternary deposits.

The main stratigraphic sequences recognized in Oman and based on various studies carried out in the country can be described from bottom to top as follows:

- Basement Rocks comprising from granites, gneisses, partly metamorphosed siliclastic and carbonate sediments and meta-volcanics. It outcrops mainly in Jabal Akhdar.

2/ For more details see:

- Sir W. Halcrow and Partners "Survey and Investigations for land and Water Resources Development in Dhofar", 1975
- Renardet, Sauti, ICE "Water Resources in NE Oman" Interim Report and Hudrogeology Annex c, 1975
- Gibb, A. "Water Resources Survey of the Northern Oman, Final Report Vol. 1 Main Report", 1976
- Ilaco et Al, "Water Resources Survey of the Northern Oman", 1975

- Hajar-Super Group consists of up to 3000 m of thick to massive bedded limestone and dolomites with some thin, argillaceous, clayey carbonates. It is of mid Permian to late Cretaceous (Senonian) age.

- The Sumeini Group consisting of sedimentary sequences of Permo-Triassic limestone, dolomites sandstones and marls.

- The Hawasina Group it consists mainly of quartz sandstones, cherts, silicified limestones and shales. It is of Triassic to Upper Cretaceous (Cenomanian) age, and exotic blocks of white partly recrystallised limestones of Permian and Triassic age.

- The Sama'il Nappe Group It is thick sheet (about 3000 m) of basic and ultrabasic rocks mainly peridotites babbroes, diabase and spilitic lavas unconformably overlying the Hawasina Group and it is refered to as Ophiolites. Its age is uncertain but it is believed to be mid-to late-Cretaceous.

- Shallow Marine Deposits of Meastrichtian and early Tertiary age consisting of calcareous sandstone, marls, reef limestone, evaporites and conglomerates. It is locally known as Um er Rhaduma, Rus and Dammam formation. They overlie unconformably the older rock units.

- Alluvium and Recent Deposits. They are well developed along the main wadis and all along the Coastal Plains of Oman. They comprise gravels, sands, silt and conglomerates.

VII.2.2 Geological Structure

The predominant geological structure which occurs in northern Oman is characterised by the two major subdivisions of the mountain range which extents to over 700 Km along the north eastern margin of the Arabian Subcontinent. To the west of Wadi Sama'il the structure is dominated by the narrow anticline of the Jabal Akhdar - Jabal Nakhl range which forms part of the central Oman mountains, This anticline continues to the south east as far as Saih Hatat. The anticlinal axis are shifted to the north east resulting in the displacement of the Jabal Nakhl towards the coast and narrowing the coastal plain in the area to the east of Wadi Ma'awil. A basinal structure occurs to the south of the main anticlinal axis between Jabal Nakhl and the Saih Hatat. A synclinal structure plunges gently towards the south exists between these structures.

In Dhofar region, the trend of the north Hadramout Arch exists and extends across the northern Jabal Areas. Slight flexures also appear to be present on the northern flanks of the Arch. Dips to the north and south of the axis are generally low ($1-2^{\circ}$) although locally steeper folding 10° along similar axes is observed in the Hatab-Hahuf area. Normal faulting of the southern flanks of the Hadramout Arch occurs in the area. The Sallalah Plain is down faulted with respect to the northern plateau areas of the Jabal and Nejd.

VII.3 Hydrogeology

VII.3.1 Introduction

The following resume on the hydrogeology of the Sultanate of Oman is entirely based on the information and the conclusions of the extensive hydrogeologic studies carried out by several consulting engineering firms during the period 1972-1975. They are: Ilaco et Al, Sir A. Gibbs et Al, Renardet et Al and Sir W. Halcrow and Partners[3/].

None of the mentioned reports may be considered as definitive in terms of the availability of water resources. The water resources evaluation made by the consultants are mainly based on scarce and dispersed hydrogeologic data. They often had to rely on guess estimates of mean annual rainfall to derive values of recharge and runoffs.

VII.3.2 Principal Aquifers

Table VII.1 presents briefly the hydrogeologic characteristics of the main aquifers in Oman.

Hydrogeologically, rock units in Oman may be divided into three main groups:

(i) The alluvial plains including the coastal plains which contain the most important groundwater resources.

3/ In addition the following references are recommended to the reader
- Barber, W. "Water Resources of Oman" 1976 pp.10.
- Hearnshow, J. "A summary of Water Resources and Development Reports in Oman" 1976.
- Appelgren, B.G. UNDP/FAO Collating Mission, "A summary of Water Resources and Agricultural Development" 1976 pp 22.

Table: VII-1

General Stratigraphy and Hydrogeology in Oman

		Lithostratigraphy		Aquifer Potential
Quaternary	Holocene Pliestocene Pliocene	Terestial Deposits; conglomerate, sand and ground with clastics andeolian sand and silt		Main aquifer, good water quality in Batinah, Dhahir and Sallalah plain
Tertiary	Miocene	Marls and clays with evaporites		Aquiclude
	Oligocene	Marls, limestone and massive limestone		Fair
	Eocene up Eocene Mid Eocene Lower Paleocene	Dammam: marls limestone RUS: limestone, cherts gypsiferon Umer Radhuma:		Fair quantity and quality Good poternial in Dhofar
?	Uncertain Probably UP. Cretaceous	Semail Mappe; Basic and ultra basic rocks		Fair if fractured Good in Wadi Samail
Mesozoic	Uncertain	Hawasinah Group: Conglomerate Calcareous, Quartz s.s, L.s., Congl., Cherty L.s., Shales and radiolarites		Offer fair aquifer if fractured
	Cretaceous UP	Figu, Muti, and Qumayrah:	Shales and 1.s.	No potential
	Cretaceous Mid Cretaceous L.	Wasia) Hajar Super Group Kahmah)	Limestone 1.s. and shales	Fair to good
	Jurassic	Sahtan group	Shales and 1.s.	No potential
	Triassic	Mahil Formation	Dolomite	?
	Dermian	Saiq Formation	Dolomite	

(ii) The limestone mass with significant groundwater storage yielding springs at many places.

(iii) The impermeable crystalline basement complex at the mountaineous regions yielding most of the runoffs.

The main aquifers occuring in both northern Oman and Dhofar region can be described as given below:

1. The Alluvial aquifers

This is the most important aquifer which was the first to be exploited in Oman either by falaj systems, hand dug wells or tube wells. The aquifer consists of a succession of alluvial sediments generally non-consolidated to semi-consolidated by calcareous cementation. The amount and grading of the matrix material is also quite variable in the alluvium, ranging from clean gravels to clay bodies possessing smaller fractions of larger constituent particles. This variability in cementation and matrix condition makes the alluvium a very inhomogeneous aquifer .

The main occurence of this alluvial aquifer is along the coast of Oman in the Batinah and Sallalah plains, and in the main wadi channels which cut through the foothill areas towards the sea or the interior plains in Dhahira, Sharqia and Nejd and in the intra-mountain depressions. It varies in thickness from a few meters to more than 100 meters and decreases in average particle size moving from the Jebel to the coast.

Grounwater in this aquifer occurs essentially under unconfined conditions but occasionally under semi-confined ones. Depth to water level ranges from about 1m near the coast to over 50 meters in the Batinah Plain, and shallows again as the mountains are approached."

Groundwater quality is highly variable. It is generally good to fair throughout the year. Total dissolved solids (TDS) varies widely in space, vertically and horizontally and time. It is low during the flood season and high in summertime. The salinity increases towards the coast and the interior plains. Freshwater zones are encountered above saline water zone in a trough like groundwater basin with its axis at approximately 3 km inland from the coast. The depth of this zone ranges between 50-200 m.

../..

Groundwater salinity of about 1000 micromohms in the alluvial aquifer generally occurs within a zone of approximately 1 km width along the coast with some exceptional locations where high salinity occurs owing to salinization of groundwater by irrigation or sea water intrusion. Good quality water occurs along the main wadi courses and in the upper reaches of the wadi near the foothill areas.

There is little information available about transmissivities and storage coefficients of the alluvial aquifers in Oman. In general its permeability depends essentially on the coarseness of the deposits and for this reason the permeability decreases with increasing distance from the mountain regions either towards the coast or towards the desert in the interior.

2. Limestone Aquifers

It comprises mainly shallow-water limestone shales, marls and minor evaporites: They are:

(a) Dammam-Rus-Um er Radhuma formations of Meastrichtian - early tertiary geological age.

(b) Hajar Super Group of late Jurassic - early Cretaceous geological age.

The Dammam-Rus-Um er Radhuma formations act as a one single unconfined aquifer unit in Dhofar region Jebel areas, but restricted to the lower Um-er Radhuma acting as a confined artesian to semi-artesian aquifer under the impermeable Upper Um-er Radhuma strata particularly in the northern and eastern Nejd area. This aquifer extends over the whole of Dhofar with an area of outcrop in the south roughly defined by the limits of the Jebel and extending northwards at depth under increasingly impermeable overlying strata.

Groundwater quality in the Dammam - Um er Radhuma limestone aquifer is good at the Jabal area where the active recharge conditions occur. The quality deteriorates from about 500 ppm to 2000-4000 ppm associated with evaporitic deposits within the aquifer or the overlying strata in central Mejd areas in Dhofar region.

Little is known about the aquifer parameters or groundwater levels. The majority of recently drilled wells in Dhofar proved the occurrence of fair to good groundwater potential within the tertiary limestone aquifer and the estimated transmissivity derived from recent pumping tests was reported to range between 50-60 $m^3/d/m$.

The Hajar Super Group limestone aquifer is of particular importance as it comprises the main limestone and dolomites masses characterised by the existence of fractures, fissures and cavernous features, and exposed in the area where high rainfall occurs in northern Oman. These conditions favour good water infiltration and result in good possibilities for groundwater reservoirs. The main and large springs of northern Oman issue from these limestone masses and they maintain perennial flows in the upper reaches of the adjoining wadis whose water disappears further downstream in the alluvial deposits along the coast or in the interior plains.

3. Other minor aquifers recognized in Oman are:

Samail Nappe Group which comprises a thick sheet of basic and ultrabasic rocks of uncertain age (probably upper Cretaceous). Only small springs and seeps in the country are known to issue from this aquifer. It is generally poor aquifer but fair possibilities of groundwater potential may occur associated with faults, breccias and zones of jointing and fracturing.

The Hawasina Group aquifer consists of quartz sandstones, cherts, silicified limestone and shales. A few springs have been found to issue from this aquifer but it is generally impermeable and lacking any groundwater potential.

VII.3.3. Groundwater Regions in Oman

Based on the previous discussion and in accordance with the main aquifer occurrences in Oman, the country can be divided into the following main groundwater regions:

1. The Northern Coastal Region
2. The Interior region
3. The Mountain region
4. The Dhofar region.

1. The Northern Coastal Region

The coastal area north of Jebel Akhdar receives its principal rainfall from Mediterranean depressions brought in during the winter months.

The principal part of this region is known as the Batinah Coatal Plains.

Alluvial deposits are the main and predominate water bearing sediments in the area. The saturated thickness of the alluvial aquifer exceeds 100m in some places but it generally ranges between 30-40 m within an area of 5-15 km of the coast. The lower impermeable boundary of the aquifer is determined by thick units of conglomerates and clays or by the older rock units. Another hydraulic boundary is marked by the salt-fresh water interface which occurs at various depths dependent on the pumpage conditions and the quifer porosity.

The aquifer permeability is about 50m/day, the average hydraulic gradient ranges between 0.01 and 0.0004.

Field investigations proved that there are considerable water losses within and along the coastal plain as a result of: (1) high rate of evapotranspiration as indicated by the existence of the extensive wild vegetation and palm trees and sabkhas,(2) flood discharges (Table VII.2) to the sea across the Batinah.

Overdraft conditions are proved to exist in the Batinah plain particularly in the Sanail well field and the Rumais well field. This was indicated by the 4m water level decline in the Sanail well field and by the water quality deterioration in the Rumais well field.

Groundwater quality in the area improves from around 1000 ppm of total dissolved solids up to 1 km from the coast to less than 300 ppm between 2-7 km from the coast and even at larger depths.

Consultants indicated that with good water management by planned well spacings and artificial recharge projects, the volume of exploitable groundwater within the Batinah can be increased up to 50 per cent.4/

2. The Interior Region

The interior region is subject to the monsoon airflow from the south-west barred by the Jabel Akhdar and hence receives its main rainfall during the summer months.

4/ Appelgren B.G., UNDP/FAO, op.cit., p.7

Groundwater is found, in this region, in alluvium layers at 10 to 40 meters depth. The quality varies from 300 ppm at the foothills to over 2000 ppm of total dissolved solids. Deep groundwater in the underlying aquifers in the area tends to be saline.

Groundwater abstraction in this region is entirely carried out by the Falaj Systems, the traditional source of irrigation water in many Omani settlements.

In the southern part of the region a total falaj flow of 3000 l/s is available ; the main volume being produced by a few aflaj with reliable flows of more than 100 L/s. However, owing to the increased costs of labour, the falaj supply structures are now deteriorating due to lack of proper maintenance. Hence the falaj systems are declining in importance in the region.

Dhahira and Sharqiyah plains, Wadi Dayqah and Burayni Oasis are the most important areas in the region.

In Dhahira the exploitable groundwater is proven to be erratically distributed. Small scale developments can be envisaged in areas where soils are proven and prospecting shows the availability of water.

In Sharqiya plains, the alluvial plain of Wadi Batha extends from near Ibra to Bilad Bani Bu Ali a distance of about 120 km and 10 km wide. The stored water reserves were estimated at several billions cubic meters. About 60 MCM of water is being exploited in the area by falaj systems. The alluvial deposits in this plain exceed 100 m in thickness. Depth to water level varies from 15 to 40m and the water quality is fair to good.

In Wadi Dayqah the estimated mean annual discharge is about 360 L/sec with a range of 150-550 L/sec. during a dry year. This discharge rapidly disappear into the wadi alluvium and the underlying formations. The only groundwater abstraction is by the Al-Ghaf falaj which has an estimated discharge of 80 L/sec., leaving a groundwater balance of about 280 L/sec for possible development. It is estimated that water extraction of about 3 MCM/Annum could be utilized in the area.

The Burayni Oasis lies in the north-western corner of Oman near to and extending into the UAE frontier. Groundwater in the Burayni area is encountered in relatively thin deposits of course clastic materials overlying impermeable marl. Hydrogeological studies indicated overdraft conditions occuring in the Buraymi area in terms of water level decline (1.5-3 m in less than two years) and in water quality deterioration. Deep drilling in the area proved the existence of poor quality water bearing aquifers.

3. The Mountain Region

Groundwater resources of the mountain region are well developed in the narrow bottoms of deeply incised valleys which form natural line sinks for groundwater discharge from the hilld. Groundwaters either discharge naturally as springs or baseflows or by falaj systems. The region is entirely considered as the active recharging zone from which the groundwaters flow towards the Batinah Coastal, or the interior plains for the benefit of users on the lower reaches.

4. Dhofar Region

Sallalah Plain has a tropical hot climate and receives its main rainfall from the south-west monsoon during summer. Extremely intensive cyclonic storms occur in the area. The region is mountainous, except the sallalah coastal plain. Steep slopes to the south and gentle slopes towards the Nejd area are predominant.

Groundwater, the principal water resources of the region, occur in a sequence of carbonates and conglomerates. Recharge to groundwater occurs by underflow or springs flow issuring from the Jabal areas.

Estimates of the annual recharge to the plains is about 60 MCM while the actual water usage at present is about 15 MCM. The area north of Um Al-Ghawarif that could possibly yield up to 10 MCM of good quality water was proved to exist in the region. The recharge estimates of 125 MCM/annum[5/] seems to be over optimistic or non-realistic as it represents 25 per cent of the rainfall on the Jabal catchment area. Groundwater quality is generally poor except in the central part of the Sallalah plain. In the interior of Dhofar, the area is not reached by the monsoon and it receives rainfall of heavy erratic cyclonic storms. Little is known about the groundwater conditions in this area. It is believed to be underlain by a carbonate aquifer system of regional extent, under artesian conditions and of poor quality water.

5/ Sir W. Halcrow and Partners.

VII.4 <u>Surface Water Resources and Recharge</u>

As mentioned earlier, the mountain limestones, in northern Oman and in Dhofar, form the major watershed that separates the coastal plains from the interior plateau. In Northern Oman, the mountain region, rising to over 3000 m, is dissected by deeply incised valleys draining towards the coastal plains or to the interior plateau.

The mountain region in both; the northern Oman and Dhofar areas receive most of the precipitation that falls over the country and generates most of the surface runoff that contributes to groundwater recharge.

The scarcity of basic data on rainfall, runoff and aquifer parameters limits the reliability of the assessment of the country's water resources. The consultants have often used their own hydrogeological data relevant to rainfall, runoffs, evapotranspiration, infiltration and pumping test results which they have observed during the periods of their studies. Hence the total water resources figures estimated by the several investigators are considered to be as vague indicators for the availability of water resources of Oman.

It is worthwhile here to present a summary of the surface runoffs and recharge estimates which were produced by the investigators and appear to be rather conservative. The basic assumptions employed in the computations of these estimates were as follows:

Runoff from the limestone mass is about 10 per cent of the rainfall
Runoff from the impermeable mountain region is 20 per cent of rainfall
Runoff from the alluvial plains and replenishment of the alluvial aquifers is about 5 per cent of rainfall?

Recharge of the limestone aquifers is about 10 per cent of rainfall
100 mm mean annual rainfall for the zone 0-500 m a.s.l.
150 mm " " " " " " 500-1500 m a.s.l.
200 mm " " " " " " 1500-2000 m a.s.l.
250 mm " " " " " " 2000-3000 m a.s.l.

Based on the above-mentioned assumed data Table VII.2 was developed in which:

a stands for limestone rock outcrops area
b stands for the impermeable rock outcrops
and c stands for the alluvial formation area.

TABLE VII.2 - I NORTH EAST OMAN

Wadi Name	Catchment Area Km^2			Weighted average rainfall mm/a	Runoff + Recharge MCM/a
	a	b	c		
Dayqah	1000	1000	-	175	70.0
Mijlas	200	250	-	166	14.7
Bani Khalid	400	-	-	250	20.0
Al Batha	500	2500	3000	175	190.0
Fulayj	500	-	330	190	26.5
Amdan) Samad)	-	1250	1920	140	59.4
Aday) Mayh)	500	600	100	113	34.5
Harabis, Shab) Tiwi, Mangal) Hilm)	1400	-	-	250	70.0

Total Surface Runoff Volume is 485.0 MCM/annum

TABLE VII.2 (continued) II NORTH WEST OMAN - INTERIOR REGION

Buraymi (Border wadis	-	1720	1030	163	81.7
Muraykhat	-	250	)		
Sifa	-	290	)		
Thumayma	-	230	)1360	168.0	124.3
Datah	-	200	)		
Dank	-	1250	)		
Jufra	-	720	)		

Total Surface Runoff Volume is 206.0 MCM/annum

TABLE VII.2 (Cont'd) III. NORTH WEST OMAN - COASTAL REGION

Wadi Name	Catchment Area Km^2			Weighted average rain-fall mm/a	Runoff + Recharge MCM/a
	a	b	c		
Al-Hawasina	-	390	230	163	16.3
Bani Umar	-	270	220	155	11.8
Kanuf	-	280	120	170	11.7
Sarami	-	280	270	150	12.5
Shidah	-	170	190	124	6.1
Ahim	-	730	100	180	30.1
Sohar	-	570	310	132	18.6
Jizzi	-	740	250	174	30.9
Al-Gharbi	-	300	90	177	12.5
Fizh	-	250	40	186	10.3
Rajmi	-	270	70	179	12.0
Shinas	-	140	150	124	4.9
Hatta	-	560	220	172	23.4

Total Surface Runoff is 201.0 mcm/annum

IV. NORTH CENTRAL OMAN - INTERIOR REGION

Halfayn	60	260	100	214	16.3
Jahla	70	140	140	190	11.3
Al Abyad	100	540	400	192	34.1
Bahla	230	570	200	220	40.9
Sayfan	-	320	290	152	14.4
Al-Ayn	160	570	760	173	32.0
Al-Kabir	-	810	360	169	34.0

Total Surface Runoff is 183.0 mcm/annum

TABLE VII.2 - V NORTH-CENTRAL OMAN - COASTAL REGION

Wadi Name	Catchment Area (Km^2) a	b	c	Weighted average rain-fall mm/a	Runoff + Recharge MCM/a
Samail	160	1980	260	193	88.3
A Ajai	-	140	120	154	6.5
Rubkhab	50	370	100	186	17.9
Ma'will	60	470	200	177	22.6
Bani Kharus	220	580	250	187	35.2
Far	180	950	160	195	47.0
Al-Hawqayn	160	740	260	185	38.9
Al-Ulya	-	520	160	138	16.4
Mabrah	-	820	270	138	26.2

Total Suface Runoff is 299.0 mcm/annum

Table VII.2 indicates the estimated surface runoff volumes in the main wadis of the Northern Oman coastal plains and the interior plains only. In Dhofar region the surface water resources are almost non-existent as most of the precipitation over the region occurs during summer months when high rate of evaporation losses are prevailing.

VII.5 Water Resources Balance

Based on the previous presented table and considering the presently estimated water consumption, mainly for irrigation the following water resources balance can be deduced as shown in table VII.3 below:

TABLE VII.3

Region	Total water Resources mcm/a	Present Water Use mcm/a	Balance mcm/a
North Eastern (East of Wadi Samail)	485	127	358
North Western (West of Wadi Samail)	500	432	68
Interior	389	207	182
Dhofar	35	15	20
TOTAL	1409	781	628

Hence the water resources overall balance is estimated at 628 MCM/annum as a surplus over and above what is being consumed in the country. It has to be emphasized again that the above estimates of the available water resources are indicative and not definitive.

VII.6 Other Water Resources

Sea water desalination projects have been undertaken to provide domestic water supply for the capital (Muscat-Matrah) area. The existing desalination plant installed in the Ghubrah Power and Water Plant of a multistage flash type has a total estimated capacity of 6.64 MCM/a. An additional desalination plant with a total capacity of 8.4 MCM/a is being planned for to meet the future water supply requirements of the capital area.

VII.7 Conclusion

Local hydrogeological investigations were carried out in some parts of the country, namely the northern Oman and Dhofar areas. The scarcity of basic data on rainfall, runoff and aquifer parameters limits the reliability of the assessment of the country's water resources, hence the outcomes of these investigations are at best indicative.

Groundwater is the primary source of the country's water resources. The principal aquifers are: Quaternary alluvium and the Carbonate sequence of the Damman-Rus-Um er Radhuma and the Hajor Super Group. Four groundwater zones are known: The Batina' coast where groundwater of fair to good quality occurs in alluvium. However overdraft conditions prevail; the Interior where groundwater of 300-2000 ppm occurs mostly in alluvium and deteriorates at depth. Falaj Systems to extract groundwater are predominant in the area; the Mountainous where the groundwater is of good quality and well developed but not defined; and the Dhofar where the potential groundwater is not well developed or identified. Water quality is generally poor, and will deteriorate where overdraft conditions exist unless appropriate actions are taken, probably through more desalination.

The mountain region in northern Oman and Dhofar receives most of the country's precipitation and generates most of the annual surface runoff that contributes to the groundwater recharge. The total estimated volume of the surface runoff and groundwater recharge is about 1409 MCM/a. The present water consumption is estimated at 781 MCM/a. Hence the water resources overall balance is estimated at 628 MCM/a. About 15 MIGD of desalted water is presently produced to meet the domestic water supply of the capital and its surrounding areas.

A programme to establish a countrywide hydrometeorological network is highly required. Detailed hydrogeological investigations may be desirable to aim at better understanding of the country's water resources. Artificial groundwater recharge projects and dams construction, to make use of the appreciable potential floods which do occur in the Batinah, Dhahira and Sharqiya areas, are very beneficial particularly to lessen the rate of the growing overdraft conditions and flood hazards.

VIII. THE STATE OF QATAR

Area: 10600 square kilometers
Population :180000 - 200000 1/

VIII.1. General

The State of Qatar is an arid peninsula about 180 Km long and with a maximum width of about 85 Km. It lies between the latitudes 24°30' and 26°10' north and longitudes 50°45' and 51°40' east. The Qatar peninsula protrudes into the Arabian Gulf as an appendix to the Arabian Peninsula, Fig. VIII.1.

VIII.1.1. Topography

The Qatar Peninsula is of low to moderate relief with the highest elevation being 103 m a.s.l. About 850 almost circular type depressions of diameters ranging from 100 m to 2000-3000 m, are recognized in the landscapes of Qatar. These depressions give rise to a rolling terrain in northern Qatar. They are often crater-like of about 20 m deep in Southern Qatar.

Sabkhas and coastal saline flats or playas are known to exist along the coast of Qatar. Extensive sand dune field occurs in the Khor Al-Udied region of south east Qatar.

VIII.1.2. Climate

The Qatar climate is characterised by scanty rainfall, high temperature, hot dry summer and high relative humidity for the great part of the year. It varies from the coastal to the inland areas.

Maximum temperatures that exceed 42°C for a period of 45 days are recorded during July-August. The prevailing wind in the Qatar Peninsula is from the north-west. Evapotranspiration ranges from 2.5 mm/day in winter months to 11.5 mm/day during summer.

1/ Middle East Annual Review, 1978.

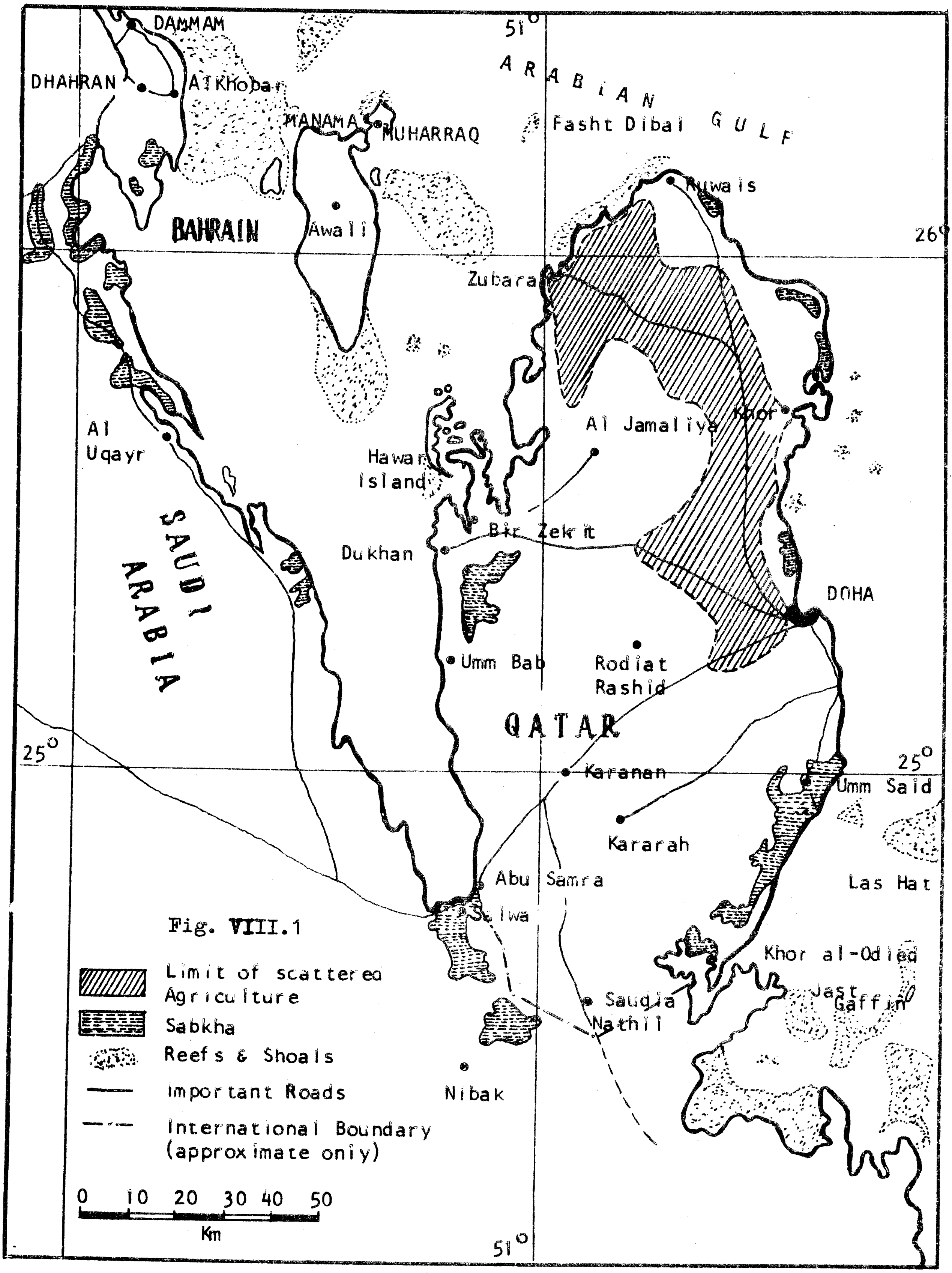

DAMMAM
DHAHRAN
Al Khobar
MANAMA
MUHARRAQ
BAHRAIN
Awali
ARABIAN GULF
Fasht Dibal
Ruwais
Zubara
Al Jamaliya
Khor
Hawar Island
Al Uqayr
SAUDI ARABIA
Bir Zekrit
Dukhan
DOHA
Umm Bab
Rodiat Rashid
QATAR
Karanah
Umm Said
Kararah
Abu Samra
Salwa
Las Hat
Khor al-Odied
Jast Gaffin
Saudia Nathil
Nibak
51°
26°
25°
Limit of scattered Agriculture
Sabkha
Reefs & Shoals
Important Roads
International Boundary (approximate only)
0 10 20 30 40 50
Km

Fig. VIII.1

Rainfall over Qatar is of Mediterranean type. In winter the peninsula lies in a region of warm subsiding air associated with the winter position of sub-tropical jet stream, giving rise to light to medium intensity rainfall and sometimes high intensity, winter rainfall may exceed 150 mm but it is more likely to be of the order of 75 mm. In general rainfall in Qatar is of a highly erratic nature, low intensity and of about 50 mm/annum.

VIII.2. Geology

VIII.2.1. Stratigraphy

The geological sequence in Qatar is composed of Tertiary limestones and dolomites with interbedded clays, marls and shales overlain in some places by the Quaternary and Recent deposits. The following description of the main stratigraphic units exposed or existing in the sub-surface, is based mainly on the previous investigations carried out in Qatar by Cavalier, 1970 of BRGM[2/] and others and presented in the preliminary Technical Report No. 1, "The Water Resources of Qatar and their Development", UNDP/FAO, 1977. pp. 22-39.

Table VIII.1 below shows the general description of the stratigraphic column occuring in Qatar as recognized by Cavalier, 1970.

2/ Bureau de Recherches Géologiques et Minières of France.

TABLE VIII.1

STRATIGRAPHY OF QATAR

A g e	Formation	Sub-Formation	Member	Thick-ness (m)	Lithology	Equivalent in Saudi Arabia	Thick-ness in S.A.
Miocene-Pliocene	Hofuf			?	Sandy marl and sandy limestone	Hofuf	95
Middle Miocene Lower Miocene	Dam	Upper Lower		50 30	Marl, shale Sub- Ordinate sandstone	Dam	91
Middle Eocene	Dammam	Upper	Abarug	10	Dolomitic lime-stone and Marl	Alat	
		Lower	Simsima	30	Dolimites and limestones	Khobar	35
			Alveoline	1	Limestone	Alveoline	
			Midra Shale	5	Shale and Marl	Saila and Midra	
			Fhaihil Limestone	1	Limestone		
Lower Eocene	Rus			28-44	Dolomites Limes-tone with thick bands of gypsum	Rus	56
Paleocene	Umm er Radhuma			300	Dolomites with bands of chert, marl and Clay	Umm er Radhuma	243

- Mesozoic Succession: It comprises: The Upper Jurrassic Carbonate rocks of the Arab Formation; and Cretaceous sequences which consists of up to 800 m of calcarenites, limestones, dolomites, sandstones and shales of Riyadh, Wasia and Aruma Formations which are known to be good aquifers in Saudi Arabia.

- Paleogene Succession: It includes:

  Um-er-Radhuma Formation dolomites with bands of chert, marl and clay (300 m thick) and of Paleocene - L. Eocene age;

  Rus Formation (L. Eocene) which crops out at 26 Km north-west of Doha and composed of dolomitic limestone, and limestone with thick bands of gypsum and anhydrite. Thickness range is 20-110 m;

  Dammam Formation which is composed of:

  Upper Dammam Abarug dolomitic limestone and marl. Simsima dolomite and limestone

  Lower Dammam Dukhan Alveoline limestone, Midra shales, Fhaihil limestones.

  The Upper Dammam formations outcrops over almost the entire Qatar Peninsula.

- Neogene Succession:

  The Neogene Succession comprises the marine limestones and clays of the Dam Formation (Middle Miocene) cropping out in the south-west of Qatar with thickness of about 80 m; and the continental gravels, sands, and conglomerates of the Hofuf formation (Upper Miocene or Mid-Pliocene).

- Quaternary Deposits

  It comprises: (1) The marine limestone, beach rocks, and beach gravels along the coastal margin of Qatar; (2) Gravels of continental origin in south central Qatar; (3) Depression fills of fine silts and clays of 1-2 meter thickness; (4) Sabkha and flat playas deposits consisting of fine silts and calcareous sand. The estimated area of the sabkhas in Qatar is about 701 Km^2 (Pike 1971); and (5) Aeolian Sands which occurs in the form of mobile thin sheets of different types of sand dunes mainly in the south-eastern corner of Qatar Peninsula.

VIII.2.2. Structure

The Qatar peninsula forms part of the Interior Platform of the Arabian Peninsula (Powers et al 1966) as mentioned in IX.2.2. page . This Platform is characterised by a thick accumulation of sedimentary rocks with low gentle undulations dipping ENE and a series of NS Trending folds and gentle arching.

A wide anticlinal structure exists in the Peninsula, with its axis trending NS coinciding with the center of the country. Other structures such as Dukhan anticline, Karanah, Sauda Nathi and Simsima domes also exist. Major faulting, fracturing and jointing have been recognized in the Peninsula and almost trending NE-SW and NNW-SSE. These structures give rise to high secondary permeability.

Collapse structures which were formed by the sub-surface solution activities in the gypsum and anhydrite beds of the Rus formation resulting in almost circular depressions (about 850) have been recognized in southern and northern Qatar.

VIII.3. Hydrogeology[3/]

VIII.3.1. Aquifers

Limestones and dolomites of the Rus and Dammam Formations form the principal aquifer system in Qatar. They outcrop over the entire peninsula and overly the older rock units which contain highly saline groundwater.

3/ For more details, refer to the Preliminary Report No. 1, The Water Resources of Qatar and Their Development, UNDP/FAO, 1977.

Secondary permeability is highly developed within the aquifer system (Rus and Dammam Formation). This is mainly attributed to the folding and sub-surface solution activities which result in collapse structures associated with fracturing of the rock units. These activities give rise to the karstification of the aquifer system and enhance its groundwater potentiality.

The areal extent of the aquifer in northern Qatar is influenced by sea water intrusion along the coastal areas, particularly along the eastern coast.

Depth to water level generally varies from close to ground surface along the coastal areas to about 80 meters below ground level at some locations in Southern Qatar. Free water table conditions generally prevail in the Peninsula, except in south-western Qatar where confining beds occur and provide artesian conditions. The deepest groundwater levels occur almost along the axis of the central arch of the Peninsula where water levels are up to 40 meters below ground surface in northern Qatar. In southern Qatar the water levels are in excess of 30 meters below ground surface. Groundwater level elevation ranges from 0-20 meters (a.s.l.). It is higher in the central Qatar and decreases radially. The FAO team, in collaboration with the Water Department of Qatar, has conducted several pumping tests of various durations and in different localities all over the peninsula. The interpreted pumping test data using various methods has indicated that aquifer transmissivity (T) ranges from 2 m^2/day to 580 m^2/day with values of 3600 and 4500 m^2/day obtained from Rodiat el Faras locality. This wide variation of (T) values is due to the variable degree of Karstification of the limestone-dolomite aquifer sequence. Annex 8 shows the range of (T), permeability (K) and well yields as determined from 37 wells mainly in northern Qatar. The storage coefficient (S) ranges from 0.1 to 0.7 per cent.

In comparing the transmissivity values obtained for the Qatar aquifer system with those obtained for the equivalent aquifer members in Saudi Arabia and Bahrain, a general decrease in (T) values from north to south along the adjacent Saudi Arabian Coast as in Qatar was recognized. (UNDP/FAO, Technical Report No. 1, 1977, p. 123).

VIII.3.2. Groundwater quality

Groundwater quality in Qatar is controlled by two major factors: sea water intrusion along the coastal margin and the upward leakage from the underlying connate saline water body in central Qatar. The composition of the host rock affects also the groundwater quality. In northern Qatar fresh groundwater with TDS ranging from 400 ppm to 2000 ppm is known to occur as floating lenses over brackish and saline groundwater often occurring in the Um-er-Radhuma formation.

Except for small isolated lenses of groundwater of 2000-3000 ppm, the groundwater quality in the southern area ranges from 3000 to 6000 ppm having been contaminated by the upward leakage of saline water. In the extreme south-west, at Abu Samra, free-flowing wells with TDS value of 3000 ppm have been encountered: Monitoring of the groundwater quality by FAO Technical Team in Qatar during the period October 1971 to October 1976 have indicated an overall increase of 22 per cent in TDS. This is due to the overdraft conditions experienced in Qatar and resulted in groundwater deterioration by sea water encroachement or upward leakage of brackish groundwater.

VIII.3.3. Groundwater Provinces

Based on groundwater occurrence, quality and aquifer characteristics, two distinct groundwater provinces have been recognized through the UNDP/FAO Hydro-Agricultural survey:

VIII.3.3.1. The Northern Groundwater Province which is the most important source of fresh and potable groundwater in Qatar. It comprises the northern half of the Peninsula starting from just south of Doha-Dukhan road. Groundwater occurs as freshwater floating lenses within the limestone-dolomite succession of Dammam-Rus formation overlying the brackish and saline water in the older rock units. The configuration of these lenses is not well defined and hence the freshwater volume in storage is not adequately estimated. However, the estimated fresh water stored in this province is about 2500 MCM. The estimated areal extent of the groundwater body having TDS of less than 2000 ppm is about 2180 Km^2 which is 20 per cent of Qatar area.

The fresh groundwater body in northern Qatar is currently undergoing water level decline and shrinking in its areal extent due to the prevailing overpumping conditions, which has been experienced in the province as early as 1966.

VIII.3.3.2. The Southern Groundwater Province

The southern groundwater province encompasses slightly more than half of the land area of Qatar and its hydrogeological conditions are considerably more complex than that of the northern province. Groundwater recharge is less, and no fresh groundwater bodies but brackish water occur throughout southern Qatar. Only limited development of the aquifer has been made. The water well field of Rawdat Rashid is the only major source of groundwater extraction.

In the south west of Qatar near Abu Samra post, fresh groundwater of artesian conditions has been encountered. The source of recharge to this area is believed to be from Saudi Arabia.

In general terms, groundwater in this province is of a deeper water level, poor quality and low aquifer permeability in addition to the upward leakage from deeper saline aquifers along the major strucutural lines occurring in the southern province.

VIII.3.4. Groundwater Recharge and Flow Pattern

The configuration of the equipotential lines describing the water level behaviour in the Peninsula indicates the general flow pattern of the groundwater movement in Qatar. It flows dominantly from the center of the Peninsula radially towards the sea, and coincides generally with the regional topographic trend. This situation reveals the existence of an active recharging zone in the central area of the northern Qatar. In southern Qatar the groundwater flow pattern is complex and affected by the prevailing geologic structures in the area, particularly the Dukhan anticline, the Karanah dome and the major collapse depressions.

Groundwater recharge in Qatar occurs through direct prolonged rainfall or indirectly through accumulated storm runoff collecting within the numerous depressions and hence by downward perculation through the depression deposits.

Recharge computations made by the UNDP/FAO project was based on the available rainfall records during the period 1971-1976. It was assumed that 2 per cent of rainfall that exceeds 10 mm/day recharges directly the aquifer system, and 35 per cent of that rainfall infiltrated through the depression soils. Soil moisture storage and water interception by the vegetal cover were also considered. Accordingly the following Table VIII.2 was obtained for groundwater recharge estimation:

Average recharge in Northern Qatar is about 16 per cent and the average recharge in Southern Qatar is about 14 per cent of the accumulated effective rainfall in excess of 10 mm/day.

Table VIII.2

Area	Mean Annual Recharge (MCM)	Maximum Annual Recharge (MCM)	Minimum Annual Recharge (MCM)	Equivalent % of effective rainfall in excess of 10 mm/day
Northern Qatar	17.6	5.5	26.3	16 %
Southern Qatar	14.2	3.3	30.1	14 %
Over the Peninsula	31.8	8.8	56.4	9 %
Over the Peninsula for long-term 18 years 1958-1976	30.0	7.0	73.0	-

VIII.4. Surface Water Resources

VIII.4.1. Rainfall

Rainfall water is the primary water resource all over the Peninsula. It occurs as winter storms covering the whole country during December-February with localized high intensity cells, and as late or early winter thunderstorms of localized high intensity.

Applying different statistical methodology, the investigators were able to describe the long-term rainfall characteristics over the Peninsula using the available rainfall records of Doha (18 years) and Bahrain (49 years). Accordingly it was deduced that:

	Bahrain	Doha
Maximum annual rainfall (mm)	186.1	190.7
Minimum annual rainfall (mm)	16.1	2.0
Mean annual rainfall (mm)	75.1	63.3

During the course of their study (1971-1976) the UNDP/FAO project, technical staff have observed rainfall records measured at 22 rain gauges throughout the country. A good deal of statistical analysis to delineate the rainfall behaviour over Qatar was presented in their technical report No. 1, 1977, (pp. 59-79). Based on the recently recorded rainfall data and those long-term records at Doha, countrywide estimates of groundwater recharge were made.

Table VIII.3 shows the observed significant storms that occured over Qatar during 1971-1977 period.

VIII.4.2. <u>Stream Flow</u>

Stream flow as such is non existent in Qatar as the prevailing hydrometeorological conditions do not favour the occurrence of perenial streams. Only sporadic surface runoffs may occur from the central areas of the Peninsula and flowing radially towards the coastal areas, Surface runoff also occurs in a localized manner towards the inland wide-spread depressions, as stated earlier. Le Grand Asoo, 1959 have estimated that between 10-15 per cent of rainfall, when this was in excess of 12 mm, reached the depressions as runoff. Two other estimates were made for surface runoff from thunderstorms over some localities in Qatar. They were 26 per cent of a storm amounting to 67.6 mm in 1972 and at 18 per cent of rainfall over Karaneh, south central Qatar in 1975. However all the runoff obsevations proved that it relies on catchment area size and shape, rainfall amount, duration and distribution and soil moisture storage. It often occurs after 8-10 mm of rainfall provided that soil moisture has been satisfied.

Table VIII.4

Significant Storms Qatar
1971 - 1977

Season	Date	Maximum Fall	Average Total Storm	Storm Area km^2	Mean Seasonal Rainfall
1971/72	17.3.72	25.0	10.0	8027	
	19.4.72	68.0	30.0	3850	38.0
1972/73	2.1.73	24.0	10.0	11360	30.8
1973/74	13.2.74	53.0	18.0	3425	
	18.2.74	36.5	10.0	8520	
	31.3.74	46.5	25.0	11360	49.9
1974/75	10.12.74	40.0	20.0	6500	
	29.1.75	73.0	35.0	11360	
	2.2.75	36.6	15.0	9500	
	10.2.75	18.0	11.0	8710	56.0
1975/76	1.2.76	23.2	15.6	8760	
	10.2.76	29.0	21.4	9890	
	23/24.2.76	37.0	22.2	6320	
	21.3.76	30.0	18.0	4200	
	23/24.3.76	37.8	17.0	8600	
	5.4.76	38.0	20.0	5900	133.5
1976/77	12.10.76	22.0	18.0	3400	
	8.11.77	27.6	14.0	3800	
	2.1.77	41.0	16.8	11360	
	4/6.1.77	42.6	15.4	11360	
	24/25.2.77	56.0	23.0	5070	

The table above shows two types of rainfall storms: (1) Wide spread winter storms covering an area ranging between 400 - 8000 km^2 and 2 - 5 days duration; (2) Thunderstorms of high intensity occur in early or late winter period covering an area of up to 4000 km^2 and less than 2 hours duration.

Table III.1

River Basin	Total catchment Area km^2	Subtotal Catchment Area in	km^2	% of total	Contributing Catchment Area in	km^2	% of sub-total	% of total
Tigris	471606	Iraq	253000	53.6	Iraq	83237	33	17.6
		Turkey	57614	12.2	Turkey	57614	100	12.2
		Syria	834	0.2	Syria	834	100	0.2
		Iran	160158	34.0	Iran	130158	813	27.6
Euphrates	444000	Iraq	177000	40	Iraq	-	0.0	0.0
		Turkey	125000	28	Turkey	125000	100	28.0
		Syria	76000	17	Syria	76000	100	17.0
		Saudi Arabia	66000	15	Saudi Arabia	-	0.0	0.0
TOTAL	915606		915606	100		472843		51.6

Approximately 70 per cent of the surface water available reaches Iraq from neighbouring countries through the two major rivers the Tigris and Euphrates. The remaining 30 per cent is contributed by the northern tributaries of the Tigris which rise also outside the country. Flow is generally sustained through snow melt in the mountaineous regions providing continuous flow conditions throughout the year.

Generally, the water resources of Iraq are estimated at 106 km^3/a. About 80 km^3/a of this total volume flows through the Tigris and Euphrates Rivers before entering their delta in the lower Mesopotamian plains in the vicinity of Baghdad. The remaining 26 km^3/a is brought into the cuntry from other sources south of the Capital. These waters may not be considered of good value as they pass through saline courses and marshes, locally known as Hors.

Considering a probability of 90 per cent and an estimated volume of water loss through evaporation of about 10 MCM/a the safe yield of the available surface water is estimated at 67500 MCM/a.

There follows a brief description of the main river basins that contribute to the surface water resources of the country7/.

7/ Ibid. pp. 8-15.

Groundwater Province	Recharge MCM/annum	Net Water Extraction Agriculture MCM/a	Municipal MCM/a	Outflow MCM/a	Depletion or Increment to storage MCM/a
Northern Qatar	17.6	34.4	4.51	6.25	- 27.7
Southern Qatar	14.2	9.04	0.12	3.75	+ 1.3
Total	31.8	43.44	4.63	10.0	- 26.4

The table shows that the net groundwater extraction from northern Qatar is exceeding the annual recharge and hence overdraft conditions are prevailing. In southern Qatar the water extraction is almost in equilibrium with the annual recharge. However, general overdraft conditions are occuring all over the Peninsula with an annual net deficit of 26 MCM.

VIII.6. Desalination

Desalinated sea water is the primary source of providing potable water for the domestic and industrial needs of Qatar. Desalination activities were undertaken in Qatar since 1954 when the first desalting station of 60000 mgpd was established. Additional stations were established in 1962, 1974 and 1977 up to a total capacity of 7.5 mgpd at Ras Abu Aboud station and 16.0 mgpd (two phases 2x8) at Ras Abu Fintas. By the end of 1978 the total capacity of Ras Abu Fintas station is supposed to produce 24 mgpd. Desalted sea water is produced having a TDS of about 100 ppm; then it is blended with groundwater.

VIII.7. Conclusion

As in the other Gulf states, groundwater and desalted water are the major components of the country's water resources. Limestones - dolomites sequence of the Rus and Dammam formations are the principal aquifers in Qatar. In the northern half of the Peninsula, fresh and potable groundwater lenses overlying brackish groundwater occur. The estimated usable groundwater in storage is about 2500 MCM. In the southern half of Qatar deeper water level, poor water quality and low aquifer permeability occur throughout the area.

Overdraft conditions prevail and the net water balance is estimated at -26.4 MCM/a over entire Qatar resulting in water level decline and quality deterioration. Average annual groundwater recharge is estimated at 30 MCM.

Streamflow as such is non-existent. Only sporadic floods may occur from the central areas of the Peninsula and flow towards the coastal areas.

Desalted water is the primary source to provide water for domestic supply. About 31.5 MIGD is the present production.

Appreciable hydrogeologic and hydrologic investigations were carried out in Qatar by the concerned government agencies in co-operation with UNDP/FAO experts. These studies may be considered as a preliminary phase towards more detailed investigations.

Continuous monitoring of the groundwater levels and quality modifications is highly required. Investigating the possibility of utilising the sporadic flood waters may be beneficial. A methematical model to simulate the hydrogeologic conditions of the Peninsula may be desirable to arrive at the optimum and wise groundwater withdrawal on a long-term basis. But the growth of demand will essentially have to be met by increased desalination.

IX. THE KINGDOM OF SAUDI ARABIA

Population: 8.6 million
Area : ± 2.15 million square kilometer 1/

IX.1 Geographical environment

Saudi Arabia occupies about four-fifths of the Arabian Peninsula. It is bordered on the north east by the State of Kuwait, the Arabian Gulf and the United Arab Emirates ; on the east by the Sultanate of Oman ; on the south by the Yemen Arab Republic and Democratic Yemen. The Red Sea and the Gulf of Aqaba are on the west. Jordan and Iraq are on the north (Fig.IX,1).

Saudi Arabia is characterized by a hot climate subject for the great part of the year to northerly winds moving from the eastern mediterranean towards the Arabian Gulf, and the rest of the country is effected by the monsoon wind from the Indian Ocean. Humidity is generally low except along the coastal areas, where it reaches over 90 per cent. The average annual temperature is about 35°C in summer and 25°C in winter in the coastal area, from 21 - 16°C in the mountainous area and more than 25°C in the desert area, but there are wide variations. The inland temperature range from below zero at night to a maximum of 50°C during the day time in summer. In the northern part of Saudi Arabia temperature are high in summer, the hotest month is July while in the south-east region, the hotest month is June and the coldest is January. 2/

Rainfall in Saudi Arabia is generally scanty, unpredictable and irregular. It varies in intensity and duration from year to year. Long periods may pass with no rainfall, except the south west area. When rainfall occurs, it is very local and sometimes very intense and results in sporadic floods that cause great damage and erosion of wadi beds and terraces. The average annual rainfall generally ranges from 25 mm to about 100 mm. The total rainfall volume that the Kingdom receives annually is estimated at 126.8 bcm which is equivalent to 56.2 per cent of the total rainfall over the Arabian Peninsula 3/.

1/ The World Bank, World Development Report, August, 1978 pp.(76-77).

2/ El-Khatib, A.B., Ministry of Agriculture and Water, Saudi Arabia, "Seven Green Spikes", 1974,p.5.

3/ Arab League, Food Security in the Arab States, Part 1,January 1980 (Arabic).

In the north western regions of Saudi Arabia, rainfall varies from 30 mm to 75 mm per annum while it ranges from 50 mm to about 100 mm in the north eastern part. In central areas, particularly the Riyadh region, rainfall decreases from north to south and from west to east and its annual average ranges from 85 mm to 110 mm. In the Hijaz mountains and Asir regions, rainfall conditions are continental in winter and monsoonal in summer. It is well distributed throughout the year with peaks in spring and autumn. Its annual average is about 250 mm along the Red Sea coast south of Jeddah. It decreases to the north towards Aqaba[4/]. Fig. IX-1 indicates the main types of rainfall conditions over Saudi Arabia. They are:

1) Mediterranen type of winter rainfall
2) Monsoonal rainfall
3) Monsoonal and orographic rainfall

The potential evaporation in Saudi Arabia is reported to be in the range of 1500 mm to 3000 mm per annum[5/].

IX.2 Geological Environment

IX.2.1. Stratigraphy

Two main rock outcrops were recognized in Saudi Arabia. They are: (1) the extensive outcrops of the crystalline Pre-cambrian Basement Complex (the Arabian Shield) which covers about one-third of the country. (2) The remaining two-thirds of Saudi Arabia is underlain by sedimentary formations, (the Arabian Shelf) consisting of the geological time scale from the Cambrian to the Recent.

Basalt outcrops of upper Cretaceous to Tertiary exist in the extreme south-west of the Hijaz Plateau. Other Basalt outcrops of late Tertiary to Quaternary occur over the entire western part of the Arabian Shield. The total area covered by basalts in Saudi Arabia is about 95000 km^2 [6/].

4/ Seven Green Spikes, op. cit. pp. 5, 6.

5/ Burdon, D.J. and G. Otkun, "Hydrological Control of Development in Saudi Arabia", Inter Geological Cong. Vol. 12, 1968, p. 147.

6/ Seven Green Spikes, op.cit. p.46.

The Arabian Shield area on the north, east and south-east is mantled and surrounded by series of sedimentary rocks dipping gently off the Basement compl... as shown on fig. IX-2. The total estimated thickness of the stratigraphic column of sedimentary sequences is about 5500 meters. It can be summarized on hydrogeological point of view as follws[7/]:

Age	Lithology	Approx. thickness (m)
Teriatary - Up. Cretaceous	Carbonates; some shale-marl	800
Middle Cretaceous	Sandstones; other elastics	450
Lower Cretaceous Jurassic	Carbonates; rare sulphates	1350
Triassic	Sandstones; rare carbonates	750
Permian	Carbonates; some shale	150
Pre-Permian	Sandstones; shale-carbonates	2000

Sandstones of the Nubian facies are the first to cover the Arabian shield with a thickness ranging from a few meters in the areas 200 km west of Riyadh to more than 1000 meters in the Tabouk area. Its thickness increases northwards away from the Shield. Ordovician and Silurian are also dominantly sandstones but they vary in facies with some shaly horizons.

Carbonates, limestones and dolomites start with the upper Paleozoic and keeps mainly this lithologic charcters up to Middle cretaceous. The upper Triassic formation is sandy and shaly continental facies. The upper cretaceous and tertiary formations are dominantly limestone, dolomites and shales.

7/ After Burdon, D.J. and G. Otkun, op. cit., p. 146.

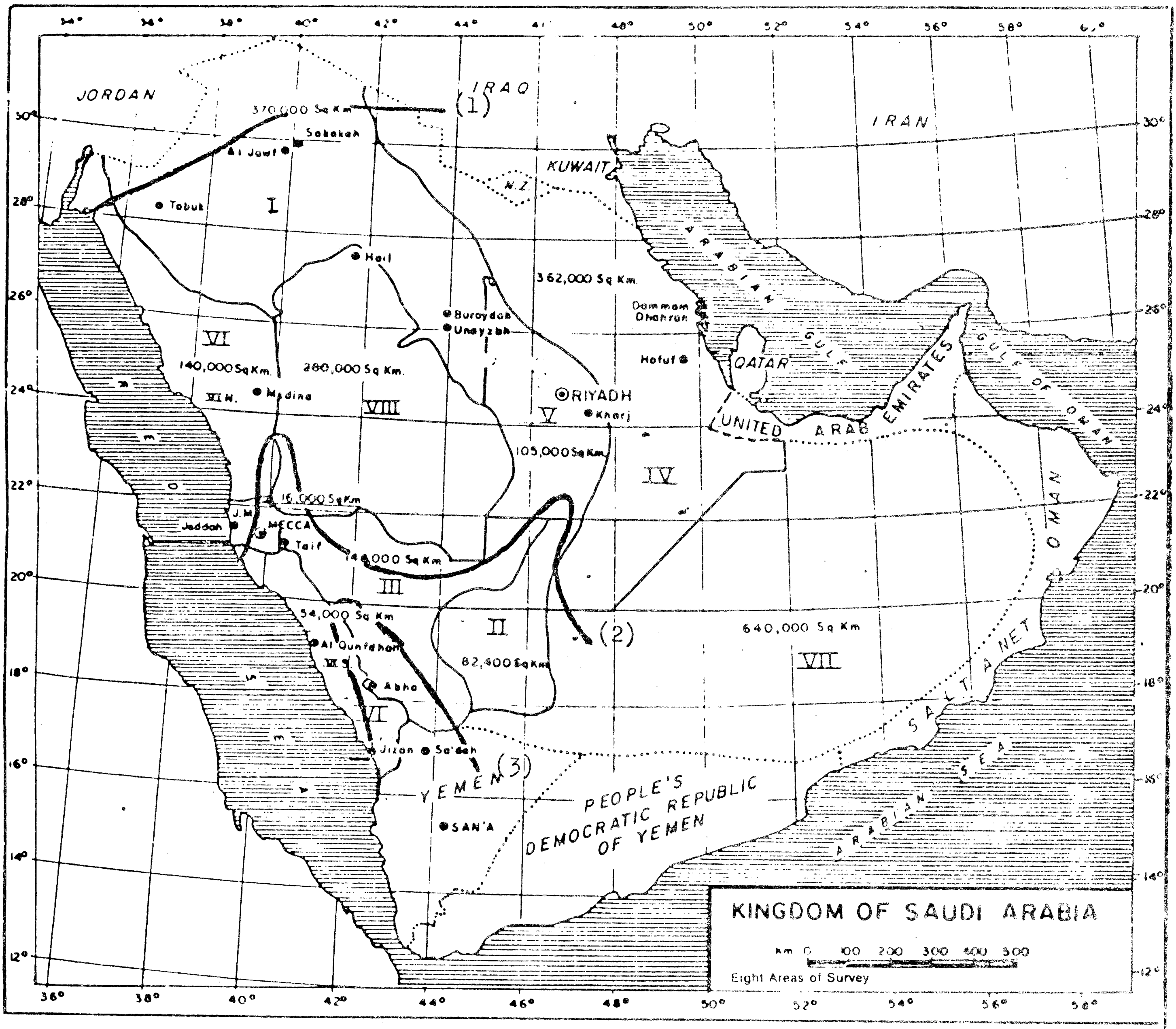


Figure IX.1
Location Map Showing:

a) Hydrogeological Areas
b) Precipitation Trends (After D. Burdon & Co. Otkun, 1968)

(1) Southern limit of Mediterranean-Type Rainfall
(2) Northern Limit of Diminishing Monsoonal Rainfall
(3) Limit of Strong Monsoonal and Orographic Rainfall

The thickness of the sedementary sequences varies from few meters at the contact of the basement complex and increases rapidly but not regularly as one goes away from the shield. Facies tend to change from dominantly clastic and terrestrial on the west to carbonates of marine origin on the east. A summary of the stratigraphic sequences of the Arabian Shelf is shown in table IX.1.

IX.2.2 Geologic Structure

Saudi Arabia lies within a comparatively stable structural zone, charcterized by regular gentle dips and absence of folding and thrusting. Two major geologic structural features are recognized: the Arabian Shield on the west and the Arabian Shelf, where most of the sediments were deposited, on the east. The latter includes the Interior Platform and Basins occupied by thick sediments within which gentle folding and doming occur.

The Arabian Shield forms the almost straight 2000 km long eastern shore of the Red Sea and the 1500 km long northern shore of the Arabian Sea and extends inland for about 700 km to form the great Najd area towards Riyadh and to form the 300 km wide plateau in the Yemen Arab Republic. It has three main componenets[8]:

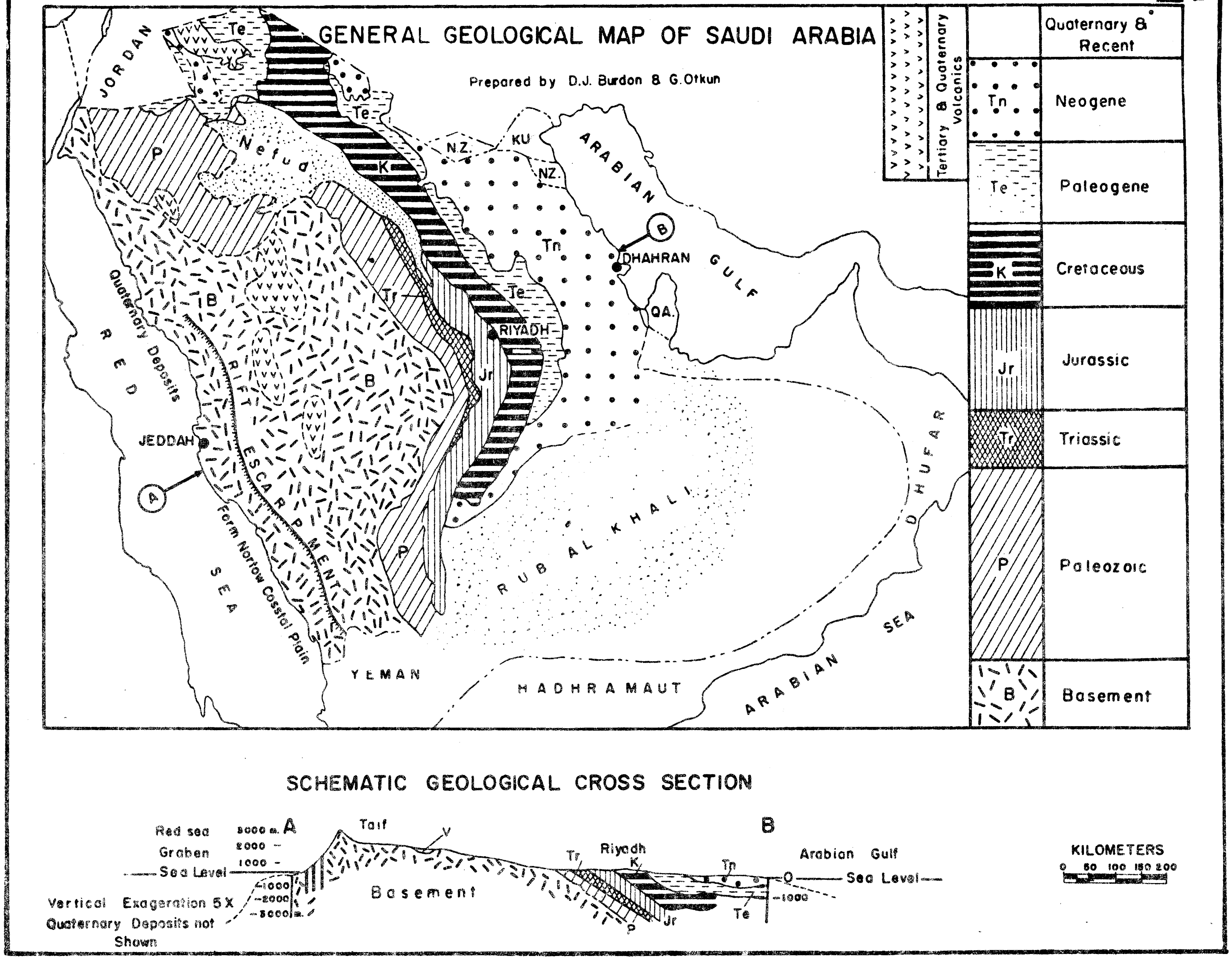
1) The western Arabian Shield forming Central Najd, Hijaz and Asir regions
2) The Yemen Aden Plateau
3) The Southern Arabian Shield along the Arabian sea coast

The Arabian Shelf encompasses three main regions:

- The Interior Homocline which resulted in a wide synclinarium in the north in Wadi Sirhan, in a broad anticlinarium in Hail and Central Arches and in a gentle synclinarium in the Rub Al-Khali.
- The Interior Platform caused by horstype block movements on the very east and along the Arabian Gulf. Qatar, Bahrain and Kuwait belong to this Platform.
- The Basins which are: the Rub-Al-Khali, the northern Arabian Gulf, the Dibdibba and the Wadi-Sirhan-Turaif basins.

8/ Seven Green Spikes, op. cit., p. 4.

Figure _ IX .2*



* Source:Groundwater Potential of Karst Aquifers in Saudi Arabia, D. Burdon & G. Otkun

IX.3 Groundwater Resources[9/]

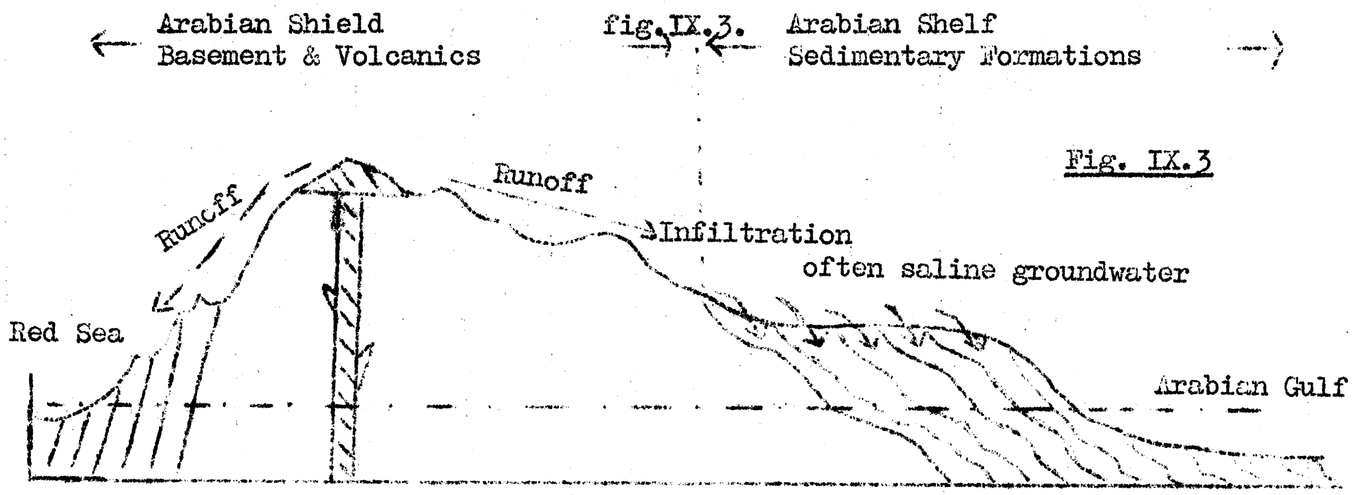
IX.3.1 Introduction

In 1964, the Ministry of Agriculture and Water of Saudi Arabia signed an agreement with the Food and Agriculture Organization (FAO) for supervising a country-wide hydro-agricultural studies to be carried out by selected international consultant firms. Based on the main hydrogeologic and geomorphologic features, the country was divided into eight areas for the purpose of these studies (Fig. IX.1). They are:

Area No.	Name	Area Thousand km^2	Description
I	Great Nufud Sedementary Basin	370	It comprises the Northern part of Saudi Arabia and encompassess: Wadi Sirhan, Qasim, Jawf depression, Skaka and Tabuk areas.
II	South Central Saudi Arabia	82	It comprises the Southern Tuwayq mountains, Aflaj and Wadi Dawasir till Wadi Tathlith.
III	Eastern Asir	122	It extends from North of Taif to Najran
IV	Eastern Province	369	It comprises the North eastern, the Eastern Saudi Arabia
V	Riyadh Region	105	It comprises the northern part of Aflaj, Al-Kharji till Sdair in the north.
VI	Red Sea Coast	210	It extends from Aqaba Gulf till Jizan. It is known as Hijaz and Tenama. It encompasses Wadi Jizan, Jeddah, Mecca and Taif.
VII	Rub Al-Khali	640	It is the south eastern empty region
VIII	Arabian Shield	80	It encompasses the Central Najd area.

9/ The information embodied under this item is mainly after:
- Seven Green Spikes, op. cit., pp. 3-110
- Otkun, G., Ministry of Agriculture and Water, Saudi Arabia, "Outlines of Groundwater Resources of Saudi Arabia", Openfile Report, October 1968, pp. 12 and maps.
- Burdon, D. and G. Otkun "Groundwater Potential of Karst Aquifers in Saudi Arabia" International Association of Hyd. Cong. of Istanbul, 1967, pp. 12.

As mentioned in the previous discussions, two-third of Saudi Arabia is underlain by the sedimentary formations of the Arabian Shelf. They are mostly composed of: sandstones, limestones, shales, marls and alluvium and these are the main sources of groundwater of the country. The major hydrogeological components of Saudi Arabia can be presented schematically on fig. IX.3.



In the West the Basement Complex and the Volcanics are essentially impermeable ; useful groundwater may occur in the alluvial fill and in small amounts below the coastal plain of the Red Sea (Area VI) in Tehama.

The principal aquifers in Saudi Arabia occur within the sedimentary formations to the east of the Arabian Shield. The geologic structures described previously and predominant in the Arabian Shelf area have resulted in the occurance of major confined and even artesian groundwater basins particularly in the areas II, IV and V.

Table IX.1 summarizes the main characteristics of the principal water bearing formations of Saudi Arabia prepared by Messrs.Burdon, D.J. and G. Otkun, 1968 with slight modifications based on the outcomes of the various investigations carried out in the country.

TABLE IX.1

GENERALIZED HYDROGEOLOGIC SECTION OF SAUDI ARABIA*

AGE				Formation	Generalized lithologic description	Thickness (type or reference section)	Aquifer Characteristics
CENOZOIC	Quaternary and tertiary			Surficial deposits & basalts	Gravel, Sand, Silt and Basalt		Produce variable quantity and quality of water depending upon recharge by rainfall, Basalt yields little water in western Saudi Arabia
CENOZOIC	Tertiary	Meocene and Pliocene		Kharj	Limestone, lacustrine Limestone, gypsum	28 M	Generally called Neogene aquifer. Irregular occurrences of water. Artesian and non-artesian conditions. Prolific aquifer in the
CENOZOIC	Tertiary	Meocene and Pliocene		Hofuf	Sandy marl, and sandy Limestone	95 M	
CENOZOIC	Tertiary	Meocene and Pliocene		Dam	Marl, Shale, Subordinate Sandstone	91 M	areas of Hufuf, Wadi Miyah and some others
CENOZOIC	Tertiary	Meocene and Pliocene		Hadrukh	Calcareous, Silty Sandstone	84 M	in Eastern Province
CENOZOIC	Tertiary	Eocene	Lutetian	Dammam	Limestone, Dolomite	35 M	Produces moderate amount of water with artesian and non-artesian conditions.
CENOZOIC	Tertiary	Eocene	Yprersian	Rus	Marl, Chalky limestone	56 M	
CENOZOIC	Tertiary	Paleocene	Thanetian Montian	Umm er Radhuma	Limestone, dolomitic Limestone	243 M	One of the most prolific aquifer of the kingdom with high transmissibility varying between 500,000 and 3 million gpd/ft
MESOZOIC	Cretaceous		Maestrochtian Campanian	Aruma	Limestone	142 M	Yields little water of low quality
MESOZOIC	Cretaceous		Turonian Cenomanian	Wasia (Sakaka sandstone northwest Arabian)	Sandstone, Subordinate Shale	42-500 M	Low productive or even dry near outcrop, very high productive artesian and non-artesian conditions in Eastern Province. Hydraulically interconnected with Riyadh near outcrops.
MESOZOIC	Cretaceous		Aptian Barremian	Biyadh	Sandstone Subordinate Shale	425-600	Moderately productive sandstone aquifer, hydraulically interconnected with wasia near outcrop
MESOZOIC	Cretaceous		Hauterivian	Buwaib	Biogenic calcarenite & calcarenite limestone	180 M	
MESOZOIC	Cretaceous		Volanginian	Yamama	Biogenic	46 M	

MESOZOIC (Contn'd)	Jurassic	Berriasian	Sulaiy	Chalkyaphanitic limestone	17C M	
		Tithonian	Hith	Anhydrite	90 M	Yields always mineralized water.
		Kimmeridgian	Arab	Calcarenite, Calcarenite 8, aphanitic limestone	124 M	Yields little amount of water, mostly mineralized. Irregular occurrence of water.
			Jubaila	Aphanitic limestone	$\pm$118 M	Similar to Arab Formation above.
		Oxfordian	Hanifa	Aphanitic limestone	113 M	
			Tuwaiq	Aphanitic limestone	203 M	
		Callovian	Dhruma	Aphanitic limestone Sandstone South of 22^{o}N, and North of 26^{o}N	375 M	Produces moderate amount of water north of 26^{o}N and south of 22^{o}N where it is generally represented by sandstone. South of 22^{o} hydraulically connected with Minjur.
		Bathonian				
		Bajocian				
		Toarcian	Marrat	Shale and aphanitic limestone	103 M	Yields little water fair to poor quality
	Triassic	Upper	Minjur	Sandstone, Shale	315 M	Generally highly productive sandstone aquifer with flowing and non-flowing artesian conditions.
		Middle	Jilh	Aphanitic limestone Sandstone and Shale	$\pm$326 M	Mostly hydraulically interconnected with Minjur, produces low quality water
		Lower	Sudair	Red 8, Green shale	116 M	
PALEOZOIC	Permian	Upper	Khuff, Faw	Limestone and Shale Sandstone South of 21^{o}N	171 M	Moderately productive limestone aquifer, mostly mineralized water.
		Lower	Wajed	Sandstone Precambrian Basement Complex	$\pm$950 M Calculated	Highly productive sandstone aquifer, with flowing and non-flowing artesian conditions.
		Undated				
	Devonian	Lower	Jauf	Limestone, shale 8, sandstone	299 M	Productive generally in al Jouf area.
	Ordovician & Silurian		Tabuk	Sandstone and shale	1072 M	Productive sandstone aquifer with flowing and non-flowing artesian conditions.
			Saq (Umm Sahm (Ram (Quweira (Siq	Sandstone	300-600	One of the most productive sandstone aquifers of Saudi Arabia, with flowing and non-flowing artesian conditions.
	Cambrian					

* After G. Otkum (hydrogeology)
R.W. Powers and Lif Ramirez (stratigraphy)

XI.3.2 Principal Aquifers

In the following, the principal aquifers characteristics will be discussed briefly in an ascending order.

IX.3.2.1 Saq Sandstone Aquifer

It is of Cambrian age and is a homogeneous sandstone composed principally of medium to coarse grained sand particles that are only loosely cemented. It may be well sorted in particle size but sometimes contains subordinates fine to very fine-grained materials. It outcrops in the area 450 km west of Riyadh (area V) and extends for 1200 km and covering an area of 65,000 km^2. Recent drilling in the formation proved that its thickness exceeds 1000 m in the north-west of Saudi Arabia.

The Saq aquifer is well developed in Qasim, Asyeh and Tabuk (areas I, II and V) where several hundred wells have been drilled and found to be of artesian conditions. Wells encountered in the Saq aquifer generally ranges from 1000 - 2000 meters or even more, like in Turabah well (2250 m deep). Well yields from this aquifer are generally high ranging from 15-22 l/second and maybe more than 100 l/s.

Groundwater quality in the Saq aquifer is generally good and ranges from 500 ppm to less than 1500 ppm of total dissolved solids. Exploratory drilling in the formation proved the existence of poorer quality in the lower Saq. The average aquifer transmissivity is reported to be in the order of $2.7 \times 10^{-2} - 4 \times 10^{-4} m^2/s$ in Qasim and $3.8 \times 10^{-2} - 9 \times 10^{-3} m^2/s$ in Tabuk area.

IX.3.2.2 Tabuk Sandstone Aquifer

It is of ordovician age and its outcrop covers an area of 17,000 km^2 and is well developed in the Tabuk area in Qasim and north western Saudi Arabia (Area I). It is composed mainly of several sandstone units interbeded with shale beds. This lithostratigraphic configuration resulted in three water bearing horizons within the Tabuk formation but in some areas, they are hydraulically interconnected and in some localities not all represented. Blue-grey shale layers separate the Tabuk aquifer from the underlain Saq but occasionally both aquifers are interconnected.

The Tabuk aquifer yields good quality water, sometimes under sufficient head to flow. Generally, the Tabuk sandstones are not as permeable as the Saq sandstones and wells encountered in the Tabuk aquifer are of lower yields. Several hundred wells were drilled in this formation in Tabuk and Qasim areas. It was proved that lower Tabuk is the best layer of this aquifer. Aquifer transmissivities are ranging from $1x10^{-4}$- $5x10^{-5}m^2/s$ for the lower Tabuk and less than $1.6x10^{-3}$-$1.2x10^{-4}m^2/s$ for the Middle Tabuk. The aquifer parameters of the Upper Tabuk vary greatly and are not reliable.

IX.3.2.3 Wajid Sandstone Aquifer

It is composed of sandstone of lower permian age. Others consider its age as cambrian and equivalent to Saq Formation in the Southern part of Saudi Arabia. It crops out in the southern central part of the country and extends for 300 km towards south of Wadi Ad Dawasir and its width is not more than 100 km. The eastern boundary is unknown but it is believed to be found under Rub-Al-Khali. In some places it is composed of reddish friable sandstone with thin layers of white and variocolored clay. Wajid outcrops occur mainly in southern Saudi Arabia in the vicinity of Wadi Dawasir (Area II) and covers an area of about 53,000 km^2. The extent and thickness of the Wajid aquifer is unknown due to lack of data, but generally it is around 400-430 m[10/] and increases to the south (around 1000 m)[11/].

Hydrogeologic conditions of Wajid aquifer are: (1) Unconfined conditions covering an area of about 20,000 km^2 in the outcrop areas ; (2) Confined conditions in an area of 33,000 km^2. Reported artesian pressure ranging from 0.5 atmosphere to 9.1 atmospheres. Water quality ranges from 700 - 1000 mg/l and it reaches to 3000 mg/l in the irrigated area.

The vertical boundaries of the aquifer are determined by the crystalline basement complex at bottom and the shale or clay beds of overlying Faw or Khuff formations. Faw is found overlying wajid in the south while Khuff overlies it at the north.

The reported hydrogeologic characteristics of the Wajid aquifer can be summarized as follows:

Groundwater recharge (MCM)	Groundwater stored (MCM)	Thickness m	Water Quality ppm	Water temp. °C	Transmissivity m^2/s
114/year	proven $3x10^5$ MCM	400-1000	450-950	29-54	$5.7x10^{-4}$-$2.1x10^{-2} m^2/s$

Wadi Dawasir and Wadi Faw baseflows in area II is almost from the ground-water that outflows from Wajid aquifers as natural discharge.

10/ Seven Green Spikes, op.cit.,p.53

11/ Unpublished files of the Ministry of Agriculture and Water, Saudi Arabia.

IX.3.2.4 Minjur and Minjur-Dhruma Aquifers:

The Minjur is Upper Triassic where Dhruma is Lower Jurassic. The Minjur is actually in hydraulic continuity with Jilh and Marrat in Central and Southern Saudi Arabia and also towards the south the Dhruma passes laterally into a sandstone facies and forms part of the same aquifer complex.

The aquifer is formed of friable sandstones with shales interbedded. The results of the hydrogeologic investigations indicate that about 65 per cent of the aquifer strata are permeable.

It is the most important aquifer in the areas II and V as Minjur is the main water supply source for the capital city of Riyadh. As in Wajid aquifer, unconfined and artesian conditions occur in this aquifer. The unconfined part of the aquifer occurs as a narrow belt elongated north-south in the outcrops of the Minjur-Dhruma formation, west of the Tuwayq Mountains escarpments (area II). Its width ranges 20-30 km on areal extent of about 6500 km^2. The artesian conditions exist in an area of about 41,000 km^2 of the area II and in the Plains of Al-Kharj and Aflaj of the area V.

The vertical aquifer boundaries are determined by the underlain shales of the Jilh formation and by the impermeable basal strata of the overlying Tuwayq limestones.

The groundwater recharge to this aquifer is limited because the formation outcrops have limited extension as it forms the lower part of the Tuwayq mountains escarpment. This situation does not favour direct or indirect recharge. Recharge to the aquifer may occur from the Quaternary alluvium to the north of Wadi Dawasir flanking the Tuwayq escarpment to the west, as the bedrock of this alluvium belongs to Minjur sandstones. The complex nature of the water recharge to this aquifer and the absence of sufficient data could not lead to reasonable estimations of groundwater recharge.

Natural groundwater discharge from the Minjur-Dhruma aquifer occurs in the Quaternary alluvium of Wadi Dawasir.

Water bearing characteristics of the Minjur-Dhruma aquifer can be summarized as follows:

Groundwater stored(MCM)	Thickness (m)	Water quality (ppm)	Depth of wells(m)	Depth to water level (m)	Transmissivity thousand (gpd/ft)
460,000	Unknown	400-5000	1200-1500	60-100	12-100

Productivity of this aquifer is not as promising as that of the Wajid aquifer. Water mining at an annual extraction rate of 30-50 MCM is possible.

IX.3.2.5. Biyadh - Wasia - Aruma Aquifer

This complex is of creteceous age and composed mainly of unconsolidated quartzitic coarse to gravely sand and rarely sandstone interbedded with thin shale, and clay-limestone layers. The estimated total thickness is about 1200m and diminishes towards the west. The aquifer occurrences are mainly in the areas I,II,IV and V.

The vertical boundaries of the aquifer are marked by the impermeable limestone clay strata of the underlying Buwaib formation. The upper boundery is determined by (15-30m) of thin clay beds which may act as an aquiclude separating the overlying Umm er-Radhuma aquifer.

Although the aquifer is composed of three members: Biyadh sandstone, Wasia sandstone and Aruma limestones, they are considered as one singly hydraulic unit particularly in the areas II, IV and V. This is because of the intercalations of clay, shale and occasional dolomite and limestone which do not form an effective aquiclude.

Groundwater recharge to the aquifer is mainly from the run-off from the Tuwayq mountains and from the underflow in the Quaternary alluvium (about 5 MCM/year). According to ARAMCO studies, groundwater recharge to Wasia aquifer was estimated at 75 billion gallons/year (284 MCM/a). Recent studies by SOGRIAH have indicated the water recharge as 5 billion gallons/year (about 19 MCM/a).

Unconfined and artesian conditions are present in this aquifer. Groundwater quality is excellent to good 300-900 ppm. It deteriorates eastwards reaching 6000 ppm and more than 200,000 ppm (brine) near the Kuwait border. Transmissivity obtained from pump test data ranges from about 30,000 gpd/ft to about 100,000 gpd/ft.

In some areas especially in area V, the great depth to water in this aquifer (around 730 m), renders its development very expensive.

Recent estimation of recharge (BAAD and WRDD 1979) is as follows:

Area I : 11 MCM
Area V : 119 MCM
Area II : 288 MCM

IX.3.2.6. Umm er Radhuma Aquifer

It crops out for a distance of 1200 km from Iraq and Jordan border to south Wadi Dawsir in an arch-shape with width ranges from 50-120km. Dahna sands covers most of the outcrop north of Wadi Sahba.

The aquifer is composed mainly of dense cream coloured skeletal and dolomitic limestones and subordinates of marls and clays with thin intercalations of calcarenite and siliceous layers. It is the most important aquifer of the tertiary and the most reliable source of water for domestic and agricultural use in Saudi Arabia especially throughout the Eastern Province (area IV).

The aquifer thickness varies appreciably depending upon localities (300-50m). However, thickness increase towards east and from north to south.

Aquifer conditions vary from water table in some drilled wells of Haradh Project (Faisal settlement) to flowing artesian conditions in Wadi Miyah well which yielded 2000 gpm with artesian head of 7 atmospheres. Exploratory drilling in the aquifer proved that lower Umm er Radhuma represented a less fractured limestone and does not produce as much as the Upper Umm er Radhuma.

Groundwater recharge to the aquifer is questionable: leaky artesian conditions in the underlying Biyadh Wasia-Aruma aquifer lead to natural discharge into the Umm er Radhuma aquifer. Using mathematical models, G.D.C.(1980) calculated the recharge as 2405 MCM/year of which 1898MCM/year by rainfall. 4 MCM/year from run-off and the rest from leakage from other aquifers.

Groundwater quality in the aquifer increases from less than 1000 ppm to over 6000 ppm from west to east in area IV, with the existence of a tongue of good quality water as far as Damman area. Maximum reported salinity is 55,000 ppm at Ras Tanura.

The aquifer transmissivity is variable. However, it ranges from $6x10^{-1}$- $4x10^{-5} m^2/s$. Proven reserve is $16x10^3$MCM. Extraction from the aquifer is estimated as 150 MCM/year, but Umm er Radhuma contributes water to Al-Hasa springs whose amount is not known exactly.

IX.3.2.7. Damman Aquifer

The Damman formation is dominantly composed of limestone throughout its thickness in northeast Saudi Arabia. Subordinates of marl and clay occur in the lower part. It is Middle Eocene of marine origin. Maximum thickness is 51 m. It is divided into five members in the Eastern Province, area IV: Three members composed of clay and marl with limestone intercalations. The other members, the Khubar (dolomites and limestones) and the Alat (dolomitic limestone and dolomites) form the main pay members and occur in the upper part of the aquifer.

More than 1000 wells exist mostly under artesian conditions in the Alat and Khubar members. The average transmissivity of the Khobar member is between $0.9x10^{-1}$- $5,7x10^{-6}m^2/s$, while it is less in the Alat member, between $2.9x10^{-1}$-$2.6x10^{-5}m^2/s$. Groundwater quality is controlled by the geologic structure and the associated lithological changes of the aquifer and varies between 1500 to 2000 ppm and deteriorates rapidly towards south and east where it reaches more than 5000ppm.

IX.3.2.8 Quaternary Aquifers

The Quaternary alluvial deposits are associated with the various drainage systems which have extremely variable catchment areas and carry unconfined groundwater of variable quantity and quality whenever they occur in Saudi Arabia.

In south-west Saudi Arabia (area II) there are two major alluvial deposits originating from (a) Crystalline Arabian Shield ; (b) Eastern backslopes of the Tuwayq Mountain escarpments. Recharge to these deposits are from direct runoff infiltration or by the underflow from the deeper aquifers. Water quality is variable (790-24,000 ppm). Stored water is around 15 billion cubic meters.

In area III, groundwater occurs in alluvial deposits in the existing intermountain valleys, the Plateau Oasis, the Habawnal alluvial plain and Wadi Nijran. Several thousand hand-dug wells exist in the aquifer and yield fair to good water in quantity and quality. Estimated annual discharge is 313 MCM, and water quality ranges between 600-1500 ppm and rarely exceeds 6000 ppm.

In eastern Saudi Arabia, the overall regional potential of the Quaternary alluvial aquifer is limited and of poor quality.

In the Riyadh Region, the Quaternary alluvial aquifers are in most widespread use and they supply 75 per cent of all the Oasis of the area but do not hold very much groundwater.

Along the Red Sea coast, there are two major quaternary alluvial occurrances: the valley fill alluvium and the coastal aquifers. Groundwater of fair to good quality and considerable volume of water, about 163 MCM was encountered.

Quaternary in the basement complex area has the following :

- average annual run-off:	1755 MCM
- average annual recharge:	740 MCM
- storage:	65350.MCM

These figures are conservative (after BAAC and WRDD, 1979).

Quaternary in the sedimentary area has the following :

- average annual run-off: more than 270 MCM
- average annual recharge: more than 330 MCM
- storage: 19800 MCM
- extraction: 173 MCM

These figures are conservative (after BAAC and WRDD, 1979).

Annex 9 presents the hydrogeologic data recorded from some selected wells drilled in the eight areas.

IX.3.3. Groundwater Recharge

The subject of the groundwater recharge to the Arabian Shelf aquifers was debated by many investigators. It was believed that the available groundwater resources, particularly in the deep aquifers in Saudi Arabia, are fossil water. This was attributed to the general arid to semi-arid conditions prevailing in the Arabian Peninsula, the poor groundwater quality encountered at depth and the outcomes of the C-14 radioisotope analysis. The latter indicated that the groundwater ages in Saudi Arabia main aquifers range from 20-25 thousand years (Tatcher, Rubin, Brown 1961)[12].

Recent hydrochemical and hydrogeological investigations proved that the groundwater resources in the Arabian Shelf can be recharged to an extent by direct recharge from rainfall and/or the resultant surface runoffs along the major wadis and streams and from interchangeable leakage. The groundwater recharge occurs through direct infiltration into the shallow alluvial aquifers to the deeper carbonate and sandstone aquifers or directly in the areas where these aquifers crop-out (Fig.IX.3 page 187). This recharge mechanism was proved by the general trend of the groundwater movement and the groundwater salinity distribution which increases in north-eastern and eastern directions away from the major water divide that coincides almost with the crest of the western Arabian shield. The major springs which exist in the inland: Qatif and Has'a Oases and the submarine springs along the Arabian Gulf coast are other indicators of the general groundwater movement in the Arabian Shelf. Along the Red Sea Coast, area VI, groundwater moves away from the Arabian Shield area into the Quaternary alluvium in the Tehama and Hijaz coastal plains.

Recharge in Saudi Arabia, takes place through the following :

- Infiltration of rainfall through outcrops
- Infiltration of run-off through wadis crossing outcrops
- Underflow from alluvial deposits into the underlying aquifers
- Natural underflow from aquifer to aquifer
- Leakage from layer to layer due to bad well construction
- Infiltration of surplus irrigated water into the soil

12/ Arab League, Food Security in the Arab States, Part I, January 1980 (Arabic).

IX.4 Surface Water Resources

As mentioned before, rainfall in Saudi Arabia is very low and unpredictable and the resulting runoff is irregular and storage of surface water is almost negligible. There are no perennial streamflows in the proper sense. Floods occur but they are localised and the water flows for a few kilometers and then disappears into the valley fills and other fractured rocks which may sustain these floods. Investigations have shown that runoff is generally subject to wide variations in both quantity and quality.

In the Great Mufud Basin (Area I), high intensity storms often occur and result in runoffs over a great part of the area. Estimates of these floods duration, distribution, frequency and amount were not made due to unreliable and inadequate data.

In south west Saudi Arabia (Area II), the most important runoff generating areas lie in the median rainfall belt (between 200-300 mm), away from the mountain region. Najran discharges observations showed that Wadi Bishah, Wadi Ranyah and Wadi Turabah are the most important catchments in the area in terms of total discharge. In the sedimentary and desert areas to the east of the Arabian Shield area, runoff appears to be localised and of infrequent occurrence.

In the Asir Highlands where comparatively high rainfall, coupled with relatively impervious underlying geologic formations and steep gradients, result in considerable volume of surface runoff.

Some perennial flows occur in the higher regions but rarely reach the Red Sea.

ITALCONSULT who carried out the hydro-agricultural survey of some parts of Saudi Arabia, estimated the runoffs from the main catchments in south-west Saudi Arabia (Area III) as follows:

Name of Basin	Catchment Area (Km^2)	Runoff (MCM)
Turabah-Khurnah	15,475	35
Ranyah	11,950	30
Bishah	35,780	70
Tathlith	29,782	45
Idemah	6,475)	
Habawnah	7,275)	75
	TOTAL	255

It is estimated that all run-off of the country is about 2025 MCM/year and of which 1265 MCM/year runs in the Red Sea coastal wadis and makes 62% of all run-off while Najran, Bishah, Tathlith, Ranya and Turaba which drain inland makes 24% of all run-off (BAAC and WADD,1979).

In eastern Saudi Arabia, area IV, evidence of surface water runoff is almost non-existent. This is because of the arid to desert prevailing climate all over the area where mean annual winter rainfall rarely reaches 100 mm. The existence of Qatif and Hassa oasis and flowing springs correspond closely with areas receiving seasonal and high intensity rainfall.

There are no perennial streams in the Riyadh Region (Area V). Records indicated a mean annual rainfall of 85 to 110 mm over the area. Heavy showers usually accompanied by considerable runoff particularly from the steep slopes of the Tuwayq mountains, and Marrat and Aruma formations. SOGREAH have estimated the total runoff in the region of Riyadh as follows:

Runoff from:	MCM
Tuwayq mountains	200
Marrat formation	15
Aruma formation	70
Other formations	15
Total:	300

Along the Red Sea Coast, rainfall over the mountains'regions is stormy and results in floods, generally sudden and of a short nature. The main wadis in this area are: Biyash, Yiba and Hali which have runoff estimates of around 100 MCM/year, and Khulab, Itwad, Qanunah, Ahsihah, Shaqah, Al-Shaniya and Al-Lith which have runoff between 50-100 MCM/year. According to SOGREAH, the total runoff for all the wadis in the Red Sea coastal area is estimated at 1610 MCM/year. Peak floods have been estimated at 10,000 m^3/sec. for Wadi Biyash and Hali, and in the others about 4000-5000 m^3/sec.,but generally do not last more than a few hours or a few days, and disappear before reaching the sea.

IX.5 Dams

Due to low precipitation in Saudi Arabia, the Ministry of Agriculture and Water has paid great attention to make use of every drop of water all over the country by constructing a number of dams of various kinds wherever possible. The objective of these dams are mainly to provide:

- Drinking water supply and for livestock purposes
- Flood controls and soil conservation
- Irrigation facilities
- Artificial groundwater recharge.

Annex 10 presents the dams which have been constructed in Saudi Arabia and their main characteristics. Up till 1979, 47 dams were constructed with a total storage capacity of 224 MCM.

In recent publications of the Arab League on "Food Security in the Arab States", January 1980, (Arabic), estimates for the annual groundwater recharge and the available and potential water resources in Saudi Arabia were presented as follows:

	Rounded mcm/annum			
Area No.	Surface runoff	Groundwater recharge	Exploited water	Available stored water
I	-	220	211	30,000
II	-	155	47	115,000
III	273	316	313	4,257
IV	Nil	slight	675	shallow water
V	350	220	268	1,862,000
VI	1,610	?	245	-
VII				
VIII	Unknown	?	?	?
Total	2,233	911	1,758	2,011,257?

IX.6 Other Water Resources

The limited water resources of Saudi Arabia could not meet the increasing water requirements due to the rapid socio-economic development which the country has experienced in recent years. This situation led the Ministry of Agriculture and Water to explore additional water resources to meet the country's water requirements.

In 1965 an ambitious sea water desalination programme was embarked upon in Saudi Arabia and is rapidly becoming a well proven and developed technology in Saudi Arabia. The multi-stage flash process is being employed to produce distilled water and electricity from a single fuel source.

. . . In the Second 5-Year Development Plan, which began in 1975, desalination of sea water is planned to cover the major water needs of both the existing cities and the new urban, industrial, agricultural centres along the Red Sea and the Arabian Gulf coasts. It is also planned to meet the demands of selected locations away from the coasts. By the end of the Plan in 1980 the production of fresh water by the proposed desalination plants will exceed 300 millions gallons a day. Other plans are being undertaken to interconnect the desalination plants within the Eastern and Western Regions so as to achieve maximum flexibility in meeting emergencies and efficiency in periodic maintenance. Presently 11 plants on the Red Sea coast and 4 on the Arabian Gulf produce about 1.5 MCM/day.

By the mid 1980's further projects in this line will be implemented to reach the capacity of fresh water production of about 148 MCM/annum 13/.

Treated sewage water is another source as there are treatment plants in some cities and plans for establishing more in the new future. The estimated treated sewage water in 1980 was 113 MCM/annum and the forecasted production in 1990 and 2000 will be 397 and 694 MCM/annum respectively. In Riyadh, a project is underway to supply nearby farms with 200,000 m^3/d and 20,000 m^3/d to industry.

Annex 11 summarizes the current and projected fresh water production by desalination in Saudi Arabia.

IX.7 Conclusion

The country receives scanty, unpredictable and irregular rainfall which ranges from 25-120 mm/annum and reaches up to 300 mm/annum over the south/west region. Groundwater and desalinated water are the major components of the country's water resources and treated sewage water will contribute in future.

A good deal of preliminary hydrogeologic and hydrologic investigations were carried out in most of the country. Unidentified groundwater resources occur mainly within the Arabian Shelf and in the Tihama areas. The principal aquifers are: Sandstones of the Saq, Tabuk, Wajid, Minjur-Druma and Biyadh-Wasia Formations;

13/ Arab League, Food Security in the Arab States, Part 1, January 1980, (Arabic).

Carbonate rocks of the Aruma, Umm er Radhuma, Damman and Neogene Formations ; and the Quaternary alluvium. Groundwater quality is generally moderate to fair. It deteriorates in radial directions away from the central Najd areas. In general, good groundwater quality occurs at the peripheries of the Arabian Shield and in the upper reaches of the major wadis in the country.

Surface water resources are very limited. There are no perennial streamflows in the proper sense. Floods occur but they are local and flow for a few kilometers and then disappear into the valley fills and fractured rocks. Investigations have shown that runoff is generally subject to wide variations in both quantity and quality. Estimates of surface floods which occur in Saudi Arabia are about 2,165 MCM/annum as computed by the different investigators. The estimated storage capacity of the existing water structures is about 100 MCM and it is planned to activate constructing dams and reservoirs to secure additional storage capacity of 140 MCM.

Desalted water is the other major water resource. The estimated production capacity of the existing plants is about 300 MIGD. It is planned to raise the production to 502 MIGD by 1983.

In general, water resources data varies in quantity and quality all over the Kingdom. They are mostly scanty, dispersed and short-term observations.

Considering the predominating geological structures, the Kingdom comprises the major recharging zones to most of the aquifers occuring in the neighbouring countries. Development of and managing these aquifers in co-operation with the concerned member States are highly beneficial. Such aquifers are: The Paleogene chert-limestone and the Paleozoic deep sandstones aquifers shared with Jordan.

- The Tertiary aquifers (Damman and Umm er Radhuma) aquifers shared with the Gulf States.

- Rub Al-Khali Basin aquifers shared with UAE, Oman and both Yemens.

The establishment of a country wide hydrometeorological network and data recording should be continued and are believed to be beneficial towards updating and better understanding of the country's water resources. Hydrochemical investigations should be undertaken to keep track with water quality modifications in the major well fields like in the Riyadh Basin. The use of sporadic floods in the Tihama region may be beneficial to recharge the alluvial aquifer artificially so as to alleviate overdraft conditions.

Nevertheless, the expected increase in water demand will have to be met largely by developing presently underdeveloped groundwater resources, future desalination plants and treated sewage works. These should be put in hand in good time.

X. THE SYRIAN ARAB REPUBLIC

Area: 185000 square kilometers
Population: 7.7 million

X.1. General

The Syrian Arab Republic lies along the Eastern Mediterranean coast between the longitudes 36° and 42° east and the latitudes 32° and 37° north. Turkey, Iraq, Jordan and Lebanon bound the country from the north, east, south and west respectively. Fig. X.1.

X.1.1. Topography

Syria can be divided into five major topographical units 1/:

The Coastal Strip: which extends from the Turkish boundary with Syria in the north till Nahr el Kabeer mouth in the south forming a total coastline distance of about 170 Km. It is a narrow plain running along the Mediterranean coast and the western slopes of the coastal mountain range. It has a variable width and dissected by several streams and rivers issuing from the adjacent highlands entering the sea.

The Coastal Mountains: they are composed of two parallel ranges separated by the Ghab depression. The western range extends parallel to the Mediterranean coast and composed of three main mountains: Amanus (1800 m), Akr'a (1700 m), and Alaouite (1500 m). The eastern highlands which extends parallel to the western mountain range and consists of the following heights from north to south: Akrad (1200 m), Sam'aan (870 m), Harim (800 m), Zawiya (880 m), and the Anti-Lebanon range which has the maximum elevation in Syria, 2800 m at Hermon Mountain.

The Dislocated Plains: they form the northern segment of the main Red sea - Dead sea - Jordan Valley - Beka'a Rift valley system which is part of the African Graben, within Syrian territory. They separate the eastern and the coastal mountain ranges and consists of Al-Ghab, Al-Rouj and Al-Omq plains.

1/ Safadi, C. "Water Resources of the Syrian Arab Republic" Ministry of Public Works and Hydraulic Resources, 1979 (Arabic) p. 3,4

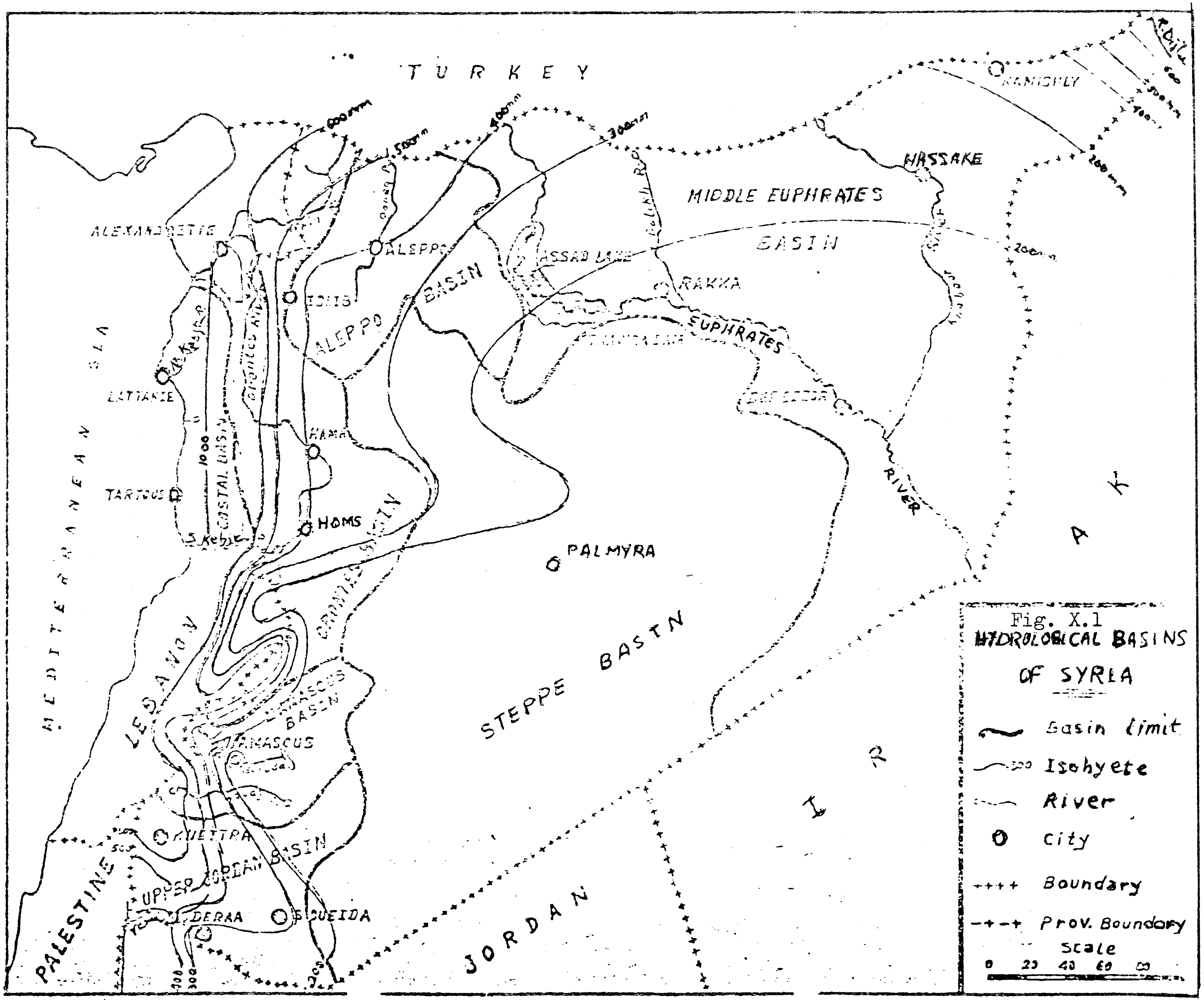


Fig. X.1
HYDROLOGICAL BASINS OF SYRIA

The Inland Mountains: they occur at different localities in eastern and southern Syria. They are composed of: volcanic highlands at Golan (1200 m) and Jabal Arab (1800 m) and the highlands of: Tadmur Range (1400 m) Bala'as (1390 m), Bushra (850 m) and Abdul Aziz Mountain (920 m) in Al-Jazira northern Syria.

The Inland Plains and Plateau: which comprises Al-Jazira, Badiat Al-Sham Desertic region and Damascus, Homs, Hama, Aleppo and Huran plains.

X.1.2. Climate

The climate of Syria belongs to the hot temperate zone of the Mediterranean Climate which is generally characterised by a rainy winter and a hot dry summer and two transitional seasons: the spring and the autumn. The general topography of Syria has a great influence on the prevailing climatic conditions and rainfall distribution. Four main climatic zones are recognised in Syria: the coastal zone which is characterised by heavy rainfall in winter and a moderate temperature in summer. The interior zone is characterised by a rainy winter and a hot and dry summer. The daily difference between the maximum and the minimum temperature during summer is high and subject to large fluctuations. The mountaineous zone is characterised by high rainfall which may exceed 1000 m, per annum particularly over the altitudes of 1000 m and above. In summer time the climate is generally moderate and the differences in the daily temperature is low. The desertic zone receives the least rainfall which does not exceed 100 mm/a in winter and during summer the climate is hot and dry.

In general the daily differences between the maximum and minimum temperatures are high in most of the country. It reaches 23°C in the Interior and Desertic zones and about 13°C in the mountaineous and coastal zones. December and January are the coldest months of the year while July and August are the hotest. The temperature frequently falls below 0°C in winter but rarely below -10°C. In summer it may rise up to 48°C[2/].

2/ Syria, Statistical Yearbook of Syria, 1978, pp. 40-41.

Snow fall occurs over all altitudes exceeding 1500 m, and may occur over altitudes ranging from 800-1500 m,a.s.l. Rainfall as shown on (Fig.X.1) varies from 500-1000 mm/a over the coastal and mountainous zones. It decreases gradually towards the Interior and Desertic zones from 500-50 mm/a. Relative humidity varies from 20-50 per cent in the Interior, 70-80 per cent along the coast in summertimes. In winter it ranges from 60-80 per cent in the Interior and from 60-70 per cent along the coast[3/].

X.2. Geology

From the geological point of view, Syria and Lebanon have almost the same conditions particularly the maritime regions of both countries.

X.2.1. Stratigraphy

There are three main groups of rocks which occur at the surface or exist in the sub-surface of Syria. Table X.1.

The Sedimentary Rocks occur in a great part of the country and comprises the following lithostratigraphic units (Fig.X.2)[4/].

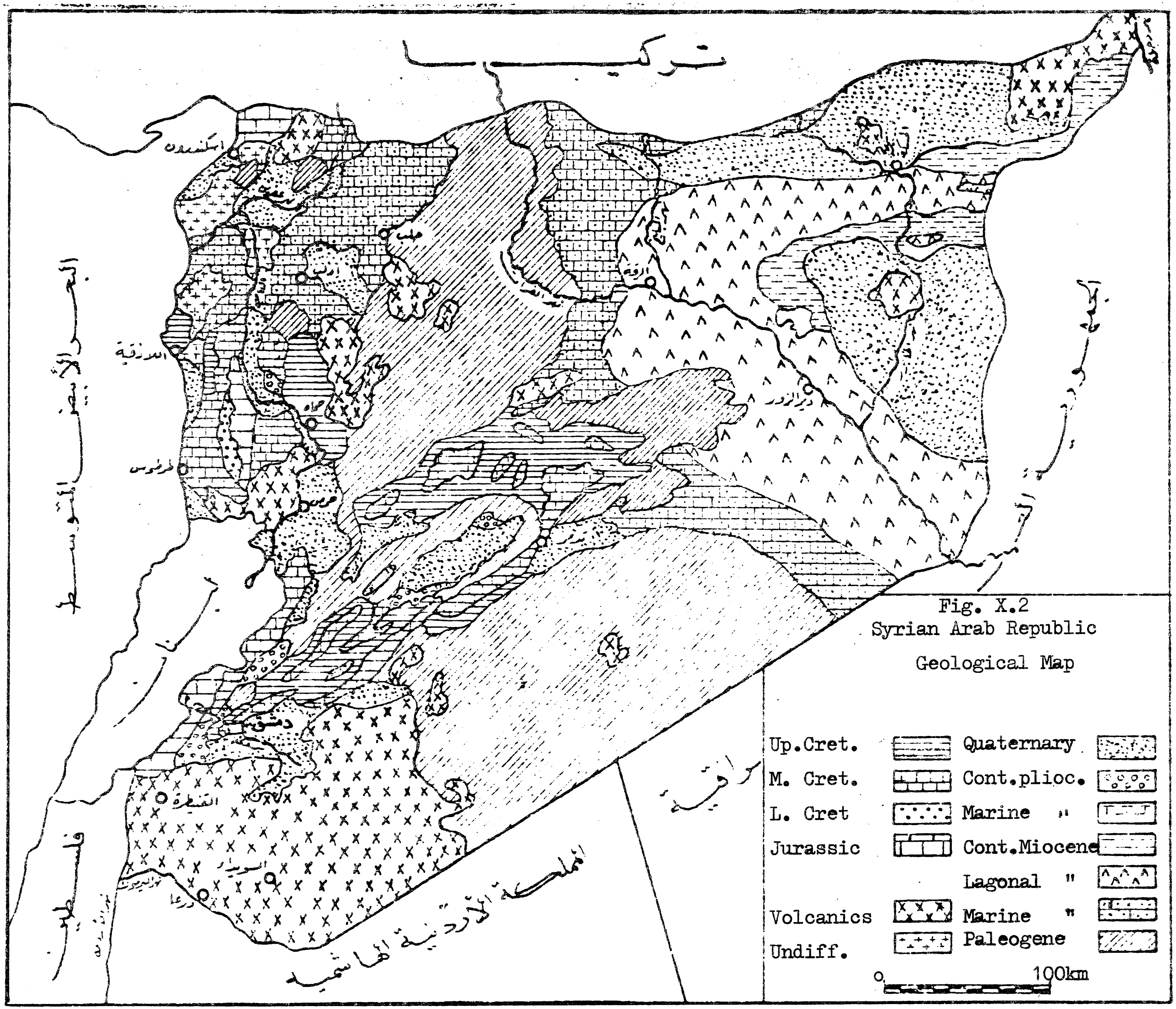
- Jurassic and middle cretaceous dolomites and limestones
- Upper cretaceous and Paleocene marls, chalky marls and chert.
- Paleogene and marine Miocene limestones and chalky limestones.
- Lagoonal Miocene evaporites.
- Pliocene conglomerates, sand, marls and lacustrine formations.
- Quaternary conglomerates, alluvium and lacustrine formations.

The volcanic rocks occur mainly in the North east in the Jezzira area. They are composed of basic and ultrabasic basaltic flows, volcanic ash and tuff.

The Green Rocks, which occur mainly to the north of Lattaquia along the north western coastal region of Syria. They are composed mainly of ophiolite series and associated radiolarites and other igneous and sedimentary rocks.

3/ Ibid. p. 42

4/ Safadi, C., Op.Cit.,pp.8-9.



مقتبس عن الخارطة الجيولوجية لسوريا ولبنان، دوبرتريه ١٩٦٢

م. بشي . صفدي ١٩٧٢-١٩٧٤

Table X.1[5/]

Lithostratigraphic Sequence in Syria

Era	Period		System	Average thickness (m)	Lithology
CENOZOIC	Quaternary		Recent	Variable	Alluvium, river deposits, marine marl
			Old	250	Conglomerate, marl, marine limestone
	Tertiary	Neogene	Contl.Pliocene	300	Conglomerate, sandstone, marine marl
			Marine Pliocene	200	Limestone, marl, sandstone
			(U.Fars)Contl. Miocene	200	shale, sandy shale, silt
			(L.Fars)Transitional Miocene	450	gypsum, anhydrite marl
			Marine Miocene	500	Argillaceous limestone, chalky marl, sandstone
		Neomilitic Paleogene	Oligocene	150	limestone, argillaceous limestone, sandstone
			Eocene	600	limestone, chalky limestone, chalky marl
			Paleocene	200	chalky marl, marl limestone, marl, chert
MESOZOIC	Cretaceous		U. Cretaceous	800	chalky marl, marl, marly limestone, chert
			M. Cretaceous	700	limestone dolomite, marly limestone
			L. Cretaceous	200	sandstone, limestone, shale
	Jurassic		U. Jurassic	300	marl, shale, limestone
			M. Jurassic	1600 ?	limestone, dolomite marl, anhydrite
			L. Jurassic	150	sandstone, limestone, anhydrite
	Triassic		Triassic	?	clastic blocks, ophiolites, radiolites

5/ Safadi, C. "Outlook for Investment in Groundwater for Irrigation in the Syrian Arab Republic" 1976.

X.2.2. Geologic Structure

The structural pattern of the maritime region of Syria is generally arched block uplifts with west dipping, locally strongly flexured, seaward flanks and truncated eastward flanks bordering the major rift faults. The magnitude of these faults is variable. Local compressional strucutres are present but they are associated with small scale strike slip faults. Structural horsts, bending, gravity sliding with vertical tectonics dominate and normal steep to overturned faults, also occur. In general the prevailing geological structures in the Alaouite Range is less complex and less diverse than that of the Lebanon Range (para. VI.2.2 page 134)[6/].

The other major structure in the area is the Ghab Massyaf Geologic Graben which forms the northern extension of the Rift Valley System, which comprises the Red Sea-Dead Sea-Jordan Valley-Beka'a Depression. It forms a low-land area parallel and to the east of the coastal mountains (Alaouite Range) separating the eastern arched blocked Zawiya mountain and the Kurd Dagh uplifts in the north.

In the inland areas, the geological structure is generally simple and not complex and reflects the general topography of eastern Syria. The only complex structure occurs in the folded and step faulted Tadmur Range and the Daw Basin.

X.3. Hydrogeology

X.3.1. Introduction

The Ministry of Public Works and Hydraulic Resources with its various water departments; the Ministry of the Euphrates Dam and the Ministry of Housing and Utilities with its Domestic Water Supply Department are the main institutions that are administering the water resources exploration, development and management in Syria. Several hydrogeological investigations were carried out, as early as the 1940's, by various individuals and consulting firms as well as by Syrian Officials. The main source of information presented under this chapter and the others coming after is from the Ministry of Public Works and Hydraulic Resources published and unpublished reports.

6/ Beydoun, Z.R. "The Levantine Countries: the Geology of Syria and Lebanon" The Ocean Basins and Margins, Vol. 4-A 1977, pp. 319-350.

X.3.2. Aquifers[7]

The following is a brief description of the main aquifers occuring in Syria, in an ascending order.

(i) Jurassic Limestone and Dolomites

It is karstic carbonate rock aquifer occuring mainly in the coastal highlands and the Anti-Lebanon Range. It forms one of the important aquifers in Syria. The major springs that issue from the aquifer are: Banyas (1700 L/s) from Hermon Mountain, Barada (3500 L/s), the eastern slopes of Alaouite Range springs such as El-Barid (1300 L/s) and Na'our Spring (650 L/s), and Sinn spring which forms the Sinn River Headwaters (10500 L/s).

The quality of the encountered groundwater from this aquifer is in the order of 360-380 ppm of T.D.S.

(ii) Lower Cretaceous Sandstone

It consists of sandstone layers with intervals of limestones and shales. Low-yielding springs issue from this aquifer particularly in Kafroun area of the Alaouite Range and Sarghya area north west of Damascus. The yield ranges from few liters/second to little over 10 L/s. Groundwater quality is generally good and the T.D.S. ranges from 200-400 ppm.

(iii) Middle Cretaceous limestone and Dolomites

The areal extent of this aquifer is large. It occurs in the coastal and the internal highlands and in some plains. It forms good aquifer of local importance as some of the major springs in Syria are fed by this aquifer.

- Fasraya, north of Damascus (250 L/s)
- Tannur, near Homs (1200 L/s)
- Sakhinah, south of Homs (450 L/s)
- Tell-Ayon between Hama and Ghab plain (5500 L/s)
- Banyas, south of Lattaqyiah (1500 L/s)
- Nabaa Al-Fija (7000 L/s)

7/ Safadi, C., "Water Resources of Syria", Op. Cit., pp.11-23.

- Group of springs occur to the east of Ghab plain and have a total flow of about (9000 L/s)
- Himma, south west of Syria at Yarmouk River (800 L/s). It is believed that the spring is also fed by the lower Jurassic Aquifer, to which the high temperature is attributed.
- Grounwater quality ranges from 420-600 ppm in both the spring and well waters.

(iv) Upper Cretaceous-Paleocene Chert and Chalky Marl

It consists of alternating beds of chert, marl and chalky marl with local limestone layers. The pay zone within this aquifer is the chert layers when they are thick. Generally, the aquifer is fair to low-yielding and water quality is fair too (700-4000 ppm of T.D.S.) and has a high water temperature (up to 35°C).

(v) Paleogene and Marine Miocene Limestone

The aquifer is variable in its productivity due to the lithofacies changes which predominate in it. It occurs mainly in Aleppo basin, Tadmur Range, Anti-Lebanon Range and south east of the Badiat As Sham. Karstification is fair to moderate in this aquifer as indicated by the issuance of some major springs from it, such as:

Ras el Ain which feeds Khabour River (40000 L/s), Arous spring which feeds Bleikh River (6000 L/s), Ura spring in Rouj Plain west of Idlib (2500 L/s), Healan (250 L/s). Qarena (150 L/s) and Maneen spring in Damascus area (400 L/s).

Groundwater quality ranges from 360-665 ppm of T.D.S. for both the spring and well waters.

(vi) Miocene Gypsum, Anhydrite and Sandstone

Marine Plyocene limestone aquifers: They are different aquifers. The first Miocene aquifer occurs in Al-Jazira and the last Paleocene one occurs within the coastal plain. They are of limited importance, low productivity and fair water quality (1000-4000 ppm) for the Miocene formations and better quality (about 500 ppm) in the Paleocene limestone coastal aquifer which may suffer from quality deterioration by sea-water encroachment.

(vii) Conglomerate and Marine limestone

It belongs to Pliocene-Quaternary age, and occurs mainly in the areas of Damascus, Homs, Jazira and central Badiyat. Free water table conditions predominate in the aquifer. Permeablility is variable as well as the productivity which is generally low. Groundwater quality is fair (1250-1500 ppm). Groundwater recharge is directly from rainfall or from other adjacent water bearing formations. The aquifer is locally utilized by means of wells and fuggarat (Aflajs). Small springs issue from this aquifer with yields not exceeding a few liters/second.

(viii) Volcanic Rocks Aquifer

The main occurrence of this aquifer is in the upper Jordan Valley basin south of Syria. It is of two variaties the pyroclastic volcanics which occur in the uplifted blocks and the basaltic aquifer which occurs in the inland plains. The former generally forms a low yielding aquifer due to low and variable permeability and feeds small springs. The other has higher permeability and feeds some of the major springs in southern Syria as: Mzeirib (1500 L/s), Zizon (750 L/s), Sakhineh (500 L/s), Ashari, Ghazoly, Bandak (900 L/s), Sheikh Maskyn springs (400 L/s), Dhakar (75 L/s), Sayada (900 L/s), Burjiyat, Fajir and Juleibina (550 L/s).

Groundwater quality is generally less than 500 ppm of T.D.S.

X.3.3 Groundwater Conditions

From what has preceeded it can be concluded that karstified carbonate rock units form the most productive aquifers in Syria as well as in Lebanon. They are most productive in zones where high tectonic activities, such as faults, folds, fractures and other geological structural patterns have occured. The major springs in the country issue from these rock units such as: Ras el-Ain, Sinn, Barada, Figeh, Tell Oyoun, Banias, Ghab springs, el Barid, Tannour.

The internal low-land dislocated plains formed by the major geological structure: the Rift Valley System; namely Ghab-Massyaf Garben constitute a big drain to the aquifers that occur in the eastern and western flanking uplifted blocks. This results in the following estimated spring flows:

- The group of springs at Omuk plain with average flow 6000 L/s
- The group of springs issue at Rouj plain with average flow 2500 L/s
- The group of springs at eastern Ghab plain with average flow 9000 L/s
- Tell Oyoun spring at eastern Ghab plain with average flow 5500 L/s
- Banias spring at Upper Jordan Valley Basin 1700 L/s
- Springs at Houla Depression 1500 L/s
- Hima springs at Yarmouk River 800 L/s

The total average spring flow along these dislocated plains is estimated at 27000 L/s or about 850 MCM/a.

In the southern coastal plain, good potential groundwater occurs in the Middle Cretaceous limestone, but it contributes mostly to the sea as sub-surface flow, the same conditions occur in the Lebanese coastal plain particularly in the Chekka area. In the northern coastal plain, the groundwater potential is low as a result of the predominating low permeable formations in the area. Groundwater of fair quantity and quality may be encountered within the alluvial deposits along the flood plains of streams and rivers issuing from the coastal mountains and crossing the coastal strip.

Detailed hydrochemical investigations covering the whole country were carried out by different individuals. The outcomes of these studies indicate that water quality is a function of rainfall distribution, geological structure, groundwater movement and rock types. In general groundwater of 1000 ppm of T.D.S. and less may be encountered throughout western Syria. As one goes eastwards, water quality deteriorates to more than 5000 ppm of T.D.S. sulphate water in the northeast, the middle Euphrates Basin; and chloride water in south eastern part of Steppe Basin (Daw, Tadmur and Tunif areas).

X.4. Surface water resources

X.4.1. Rainfall

Fig. X.1 shows the rainfall distribution in an average year over the country. General remarks on rainfall and snowfall behaviour are stated earlier under item X.1.2 page . The estimated volume of rainfall that Syria receives annually is about 45000 MCM[8/], with a country-wide annual average of 243 mm. About half of the country (the eastern desert) receives rainfall of less than 100 mm/a

8/ Ibid.

X.4.2. Evaporation

Data on evapotranspiration is lacking. However, approximate average annual evaporation was computed, so as to estimate the water balances for each hydrologic basin (Fig.X.1). These estimates as presented in the paper "Water Resources of the Syrian Arab Republic" by G. Safadi 1974 were as follows:

Basin	mm/annum	Basin	mm/annum
Damascus	1800	Aleppo	1600
Upper Jordan	1700	Middle Euphrates	2500
Al-Asi	1400	Steppe (Badiat)	2200
Coastal area	900		

X.4.3. Stream flows

The drainage pattern is controlled by the major topographic features in Syria. Most of the streams and rivers flowing in north western Syria are directed towards the Sea and to the Al-Asi River. In north eastern Syria, the Euphrates River is the main base level for most of the drainage pattern in the area. Likewise, in the south eastern part of the country, the Yarmouk and Jordan River are the reference points. Shallow streams and wadis flow generally eastwards from the eastern highlands towards the inland depressions and plains.

Accordingly, streams and rivers in Syria belong to three main categories:

1. The Coastal Streams and Rivers which originate at the coastal highlands and enter the Mediterranean Sea. Three main rivers belong to this category, namely North El-Kabir, Sinn and South El-Kabir rivers. In addition, there are several non-perennial streams cut through the coastal highlands and terminate in the sea across the coast.

2. The In-Land Rivers which originate at the eastern slopes of the coastal highlands and at the inland mountain ranges and flow across the country's plains and plateau towards the sea. They are:

- Al-Asi River and its tributaries (Afrin river and other non-perennial streams) which enter the Mediterranean Sea.
- Middle Euphrates Basin in Syria where it is composed of Euphrates, Khabour, Balikh and Sajour rivers in addition to the non-perennial streams. Euphrates river enters the Arabian Gulf across Iraq.
- Upper Jordan River Basin in which the Yarmouk and Banyas Rivers in addition to the other non-perennial streams contribute to the Jordan River which enters the Dead Sea in Jordan, and

3. Finally the In-Land Streams and Wadis. They originate from the eastern slopes of the Anti-Lebanon Range and at the Inland mountains and flow across the country where they terminate in the inland depressions and plains. They are:

- Barada and A'waj rivers in Damascus Basin
- Queiq and Al-Dahab rivers in Aleppo Basin
- Non-perennial streams and wadis in the eastern desertic areas.

Table X.2 states the main rivers that occur in the Syrian Arab Republic. The average, minimum and maximum flow rates are listed. More information on the surface water conditions will be made available later, through the forthcoming discussion on the hydrologic basins of the country (item X.6).

Table X.2 9/

Length of Rivers within the Syrian Arab Republic and their Flow Rates (1977)

Rivers	Flow Rate: Minimum flow m^3/sec.	Flow Rate: Maximum flow m^3/sec.	Flow Rate: Average m^3/sec.	Length (Kms): Within Syrian Territory	Length (Kms): Total	Average annual discharge MCM
Euphrates	529.0	2885.0	1042.0	602	2330	26800 MCM at Al Thawra
Al-Khabour & Tris.	18.0	200.0	43.0	405	405	1500
Jaghjagh	-	-	-	100	124	-
Al-Balikh	-	-	-	110	110	150
Sajour	0.8	60.8	4.2	48	108	140 at Dadat
Orontes & Tris.	18.5	252.0	51.1	325	571	1500
Afrin & Tris.	0.6	92.0	8.0	85	149	250
Queiq	0.8	8.2	1.7	110	126	75
Al-Kabir Al-Shamali	0.5	14.3	4.9	56	80	250
Sinn	1.0	22.8	12.4	6	6	400
Barada	2.7	23.9	8.8	71	71	300 at Al Hama
A'waj	0.4	12.7	2.5	66	66	70 at Um Al Sharatit
Al-Yarmouk			-	47	57	425 at Al Muqarana
Al-Kabir Al-Janubi	1.3	164.0	11.3	50	50	250
Banyas	1.0	3.2	1.4	1	1	80
Sybarani	0.3	5.5	1.2	15	15	-
				Total		32190

9/ Statistical Yearbook, Syrian Arab Republic, 1978.

X.5. Dams and storage reservoirs

The concerned government authorities had paid great attention as early as the 1950's to making use of the flood waters in the rivers and some non-perennial streams. A great deal of hydrologic and hydrogeologic invetigations were carried out related to storage dams and reservoirs in different localities in Syria, for various objectives. The major storage dams which have been constructed in Syria are: Euphrates, Al-Rastan, Mouhardeh, Taldo and other smaller dams. Other studies are being undertaken by the General Administration of Major Projects Department to construct more dams of major importance in Syria such as: Barada, A'waj, Maqarin (co-project with Jordan at River Yarmouk), Al-Asi Afrin, N. Al-Kabir, S. Al-Kabir (co-project with Lebanon) and Khabour dams. Annex 13 presents the characteristics of the existing main dams in Syria as presented in the statistical yearbook of 1978. In addition there are about 55 small dams constructed in Syria to make use of the flood waters for irrigation, domestic or livestock purposes. The expected stored water behind these structures, is estimated at 148 MCM/annum.

X.6. Water resources areas

For the purpose of a country-wide water resources assessment, Syria has been divided into seven main hydrologic basins as shown in fig. X.1. The boundaries of these basins coincide, in general, with the natural limits of the elements of the water shed areas. Most of the following information is based mainly on the data presented in the paper "Outlook for Investment in Groundwater for Irrigation in Syria" by C. Safadi 1976.

A brief description of the water resources situation in each basin is shown on table X.3 and the following discussion:

1. Damascus Basin

Surface water resources comprises:

- Barada River with average annual discharge	300 MCM
- A'waj River with average annual discharge	70 MCM
- Springs flow of estimated discharge	50 MCM
- Three small storage dams of estimated capacity	4.35 MCM

Future plans to construct two additional dams are being undertaken. Groundwater Resources are of good potential and occur in Jurassic, cretaceous and paleogene limestones; pliocene and Quaternary conglomerates alluviums and lacustrine limestones and volcanics. About 8000 wells exist in Damascus basin with total estimated groundwater abstraction of 250 MCM.

2. Upper Jordan Basin

Surface Water Resources comprises:

- Lweizani with average annual discharge	45 MCM
- Banyas with average annual discharge	80 MCM
- Yarmouk with average annual discharge shared with Jordan and Palestine	425 MCM
- Spring flows of estimated annual discharge	75 MCM
- Several small dams of total capacity	25 MCM

Studies are in progress to construct a large dam at Maqarin-Yarmouk shared with Jordan.

Groundwater Resources

These occur in fair to good quantity and good quality. The main aquifers are Basalt, and Cretaceous limestones and chert. A good (but unknown) number of wells were drilled in the area.

3. Al-Asi Basin (orontes Basin)

Surface Water Resources comprises:

- Al-Asi river of average discharge	1500 MCM/a
- Afrin river of average discharge	250 MCM/a
- Springs flow of estimated annual discharge	75 MCM
- Homs Lake	195 MCM
- Raston Dam	225 MCM
- Mouhardeh	50 MCM
- Small dams of total capacity	26 MCM

TABLE X.3

Basin Name	Area Km^2	Ave. Annual Rainfall mm	Ave. Annual Rainfall mcm	Ave. Annual evaporation mm	Estimated Volume (Mcm) Overflow springs & Fig. (1)	Underflow (2)	Surface Runoff (3)	Total (1+2+3)
1. Damascus	6850	182	1250	1800	350	200	150	700
2. Upper Jordan	9300	263	3450	1700	350	50	500	900
3. Al-Asi	16900	372	6350	1400	1000	200	800	2000
4. Coastal	5100	950	4850	900	675	275	950	1900
5. Aleppo	12250	276	3400	1600	100	325	300	725
6. Middle Euphrate*	64100	278	17850	2000	1600	400	500	2500
7. Steppe	70500	125	8850	2200	25	175	400	600
Grand total	185000	243	45000	1950	4100	1625	3600	9325

* In addition to the average annual Euphrates River flow at Tabaka: which is equal to 26000 mcm/a.

Groundwater Resources

Good groundwater potential occurs in the area between Hama and Shughur Bridge. The main aquifers: Jurassic, Cretaceous and Paleogene limestone; Pliocene and Quaternary conglomerates. Alluviums and lacustrine limestones; chalky marls and chert.

4. Coastal Basin

Surface Water Resources comprises:

- Sinn River with average annual discharge 400 MCM
- N. Al-Kabir River with average annual discharge 250 MCM
- S. Al Kabir River with average annual discharge 250 MCM
- Non perennial streams of unknown discharge
- Springs flow of estimated total annual discharge 18 MCM
- Small dams with estimated total capacity of 20 MCM

Groundwater Resources

Good groundwater potential occurs in the southern coastal plain, but it is being wasted as sub-surface flow into the sea. The main aquifers in the area belong to most of the known aquifers in Syria.

5. Aleppo Basin

Surface Water Resources

- Queiq River with average annual discharge 75 MCM
- Al-Dhahab River with average annual discharge 20 MCM
- Small dams of estimated total capacity 20 MCM

Groundwater Resources

Fair groundwater potential occur in the area. Some local shallow aquifers of good potential occur in the northern part of the basin. The aquifers belong to Paleogene and Miocene limestone and chalky limestone; chalky marls and chert; Quaternary alluvium. An unknown number of wells exist in the area.

6. Middle Euphrates Basin

Surface Water Resources comprises:

- Euphrates River of annual discharge	26000 MCM
- Khabour River of annual discharge	1500 MCM
- Balikh River of annual discharge	150 MCM
- Sajour River of annual discharge	90 MCM
- Tabaka Dam of estimated capacity	11.9 Km^3
- Small dams of total estimated capacity	33 MCM

Groundwater Resources

Fair groundwater potential (quantity and quality) occurs in the basin. The main producing aquifers belong to: Paleogene and Miocene limestone; Quaternary alluvium.

7. Steppe Basin

Surface Water Resources

- There are no perennial streams in the area
- Some springs like Ras el Ain and Zanoubya
- Small dams mainly for liverstock purposes of estimated capactiy 19 MCM

Groundwater Resources

Low groundwater potential occur in general except in some localities such as Daw sub-basin. The main aquifers belong to Jurassic, Cretaceous and Miocene limestone, chalky marls and chert; Pliocene and Quaternary conglomerates, sands and alluvium.

X.7. Conclusion

In conclusion the country relies almost equally on surface water as on groundwater for its national water resources. Large surface water resources are available in Syria, notably the rivers Euphrates, Khabur, Al-Assi, Sinn, Balikh, A'waj and Barada, in addition to the major storage dams which have been constructed on these rivers in order to regulate flood flows, and for power production. The estimated volume of the annual river and spring flows is about 33.7 Km^3 including the annual river flows of the Yarmouk (425 MCM) and the Euphrates (26 Km^3). The estimated storage capacity of the main dams constructed is at 12.5 Km^3.

Having regard to the limited distribution of the surface water resources in Syria, the concerned Government agencies have considered the development of the country's groundwater resources to satisfy their water demand. Large groundwater resources occur in Syria but still of unknown quantity and not totally well developed in some areas; yet over-developed conditions have already reached in four out of the seven hydrologic basins composing the country. The major aquifers that occur in Syria are: Jurassic - Cretaceous Carbonate Rock Aquifers, Paleogene Marine Miocene Limestone Aquifers and the Volcanic Rocks Aquifer.

A national water master plan should be drawn so as to utilize the country's water resources in an integrated manner. This plan should involve detailed hydrologic and hydrogeologic investigations on a countrywide scale so as to determine the optimum safe yield of the potential groundwater resources, to make use of all possible flood waters as presently planned and for better allocation and most economic use of water resources for various sectors.

Opportunities for cooperative actions undertaken by Syria, Jordan and Iraq to carry out joint hydrogeological investigations to evaluate and develop the shared aquifers, do exist. Mutual co-operation between Syria and Iraq for the development and management of the shared Euphrates River Basin, would be highly beneficial.

XI. UNITED ARAB EMIRATES

Area: Approximately 77,600 square kilometers
Population: about 652,936 based on 1976 Census[1/]

XI.1 General

The United Arab Emirates (UAE) lies in the south-eastern corner of the Arabian Peninsula to the North of Oman and Rub Al-Khali Desert. It lies approximately between the lat. 22°30 - 22° north and long. 51°- 56°30' east. It is bordered on the west by the Arabian Gulf and on the east by the Gulf of Oman, (Fig. XI.1).

Politically the country is composed of the Emirates of: Abu-Dhabi (67,350 km^2), Ajman (250 km^2), Dubai (3,900 km^2), Fujairah (1,150 km^2), Ras el-Khaimah (1,700 km^2), Sharjah (2,600 km^2), and Umm-el-Qaiwan (750 km^2)[2/].

The United Arab Emirates climate belong to the hot-arid desertic climate. Rainfall is generally meagre and shows extreme variability in space and time. The rainy season occurs in the winter months between November and April and in intense erratic storms of short duration. The mean annual rainfall varies from less than 50 mm to little more than 250 mm over the mountain region.

Daily temperatures are generally high and reach a maximum of 44°C. Relative humidity is low except along the coast and the potential evaporation is generally high[3/].

Topographically the country can be divided into: the mountainous region on the east, the Batinah coastal plain, the central and southern sand dune area, and the western coastal plain along the Arabian Gulf.

XI.2 Geology

The mountain ranges which run south from the Musandam Péninsula are basically Tertiary folded mountains with an extremely complex and unidentified structure.

1/ El-Mohaylam, M.I., Ministry of Electricity and Water, UAE "Water Resources" pp. 1-17 and Figures.

2/ UN/FAO PAG Mission, Arar, A., D. Burdon and A. Pecrot, "Technical Notes on Land and Water Resources of the UAE in Relation to Agriculture Uses "pp. 53-70, 1973.

3/ El Mohaylam, M.I., op. cit, pp. 6 and 7.

Rock units from Palaeozoic to Upper Cretaceous outcrop in the mountain region of UAE. They show great affinity to those rock units exposed and existing in the subsurface of the Omani mountains (Table XI.1). These rock units belong to: (1) the Hawasina Group ; with conglomerate at base, then calcareous shales ; with a succession of limestone conglomerates, cherty limestones, shales and radiolites of probably mixed ages. (2) The Semail Nappe, comprising of serpentinized periodites, gabbros, basic dykes and intrusives. After these rocks units, Paleocene and Eocene rocks were deposited (Umm er Rhaduma, Rus and Damman formations). After an erosional unconformity, these units were followed by marine Oligocene deposits. At this stage, the main folding and uplifting structures took place. In the north of the UAE, there was a repeated inthrusting which brought a great thickness of about 3,500 meters of Triassic-Jurassic-Lower Cretaceous limestones to overlie the Hawasina/Semail Nappe rock units4/.

Since then the rock exposures have been subjected to major erosion activity ; this has continued over long periods, as the mountains have continued to move upwards and rejuvenate the drainage. In this way, the great outwash gravel plains have been formed, as well as the thick layers of conglomerates which fill many of the drainage channels and form the alluvial fans where the wadis depouch from within the mountains onto their piedmont plains on the east and west of the mountain areas.

XI.3 Hydrogeology

XI.3.1 Introduction

The following discussion is based mainly on the findings and conclusions of the previous hydrogeologic investigations carried out in the country by: Parsons (1963), Sir W. Halcrow (1966-1968), Sir A. Gibb (1968-1970) and D. Carr and W. Barber (1976). In addition to the gathered hydrogeologic information during the ECWA mission by direct communications with the concerned Government officials.

Most of the previous studies have concluded that groundwater is and will remain the major natural water resources within the UAE, and that resources of good water quality are limited.

4/ United Nations, FAO, PAG Mission, op.cit., p.63.

Hydrogeologically and for the purpose of the water resources investigations, the United Arab Emirates was divided into nine major zones (Fig. XI.1) as determined by Sir. W. Halcrow in the course of their investigations. They are:

(i) Central Mountains. Extending south from the Dibba fault line and forming the watershed which separates the drainage systems to the Gulf of Oman and to the Arabian Gulf. The region receives the highest precipitation that falls over the country.

(ii) The Limestone Mountains. Extending north from the Dibba fault line into the Musandam Peninsula of the Sultanate of Oman. Wadis Bih, Negeb and Ausaq drain westwards to Jiri Plain.

(iii) Batinah Coastal Plain. The plain lies between the Central mountains and the Gulf of Oman. It is the extension of the Batinah plain of Oman. The wadis in the plain flow eastwards.

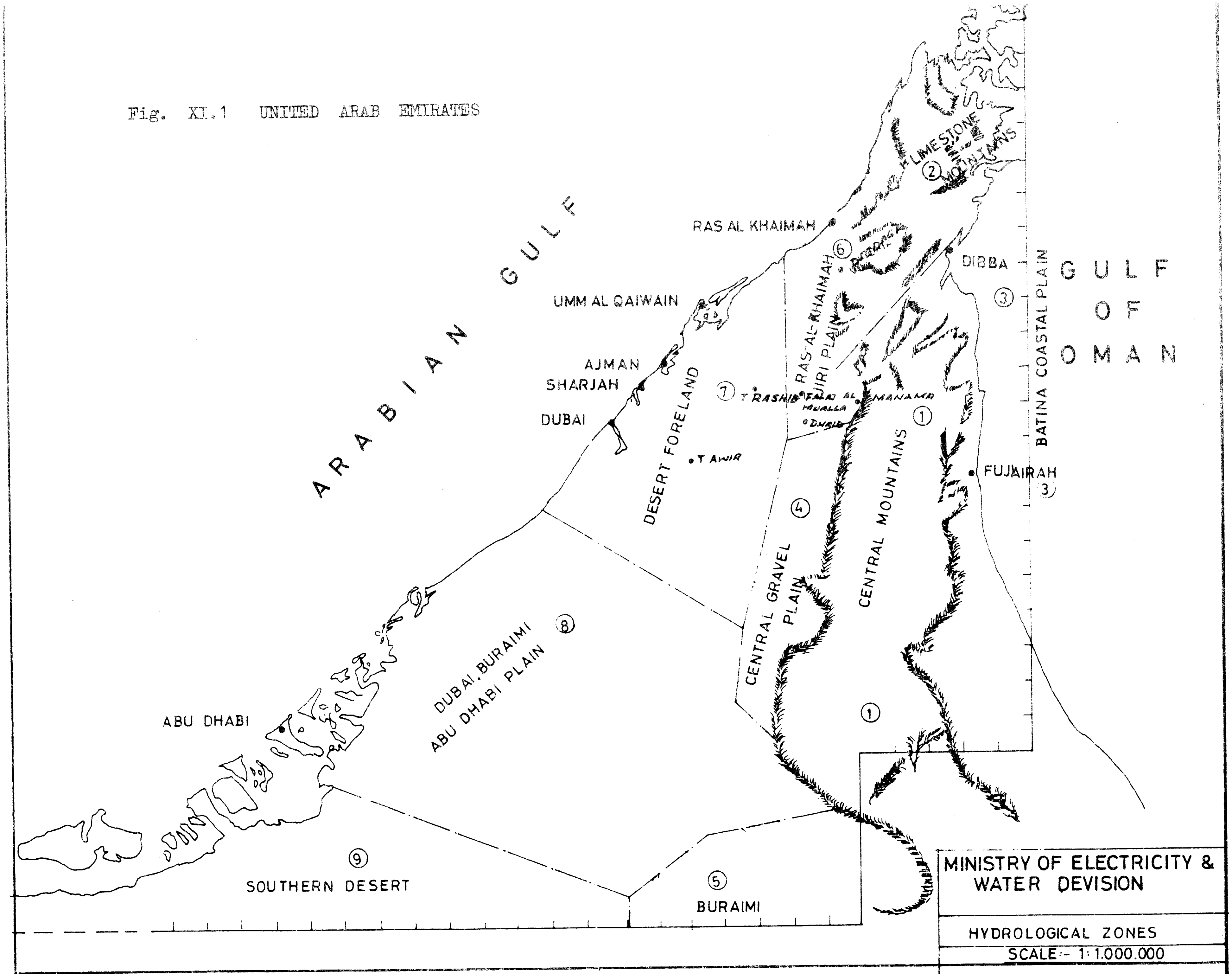
(iv) Central Gravel Plain. It lies mainly between the Central Mountains and the western hilly area where Jabal Faiyah, Jabal Aqabat and Jabal Buhats exist. The plain is covered with alluvial deposits of increasing fineness towards the west. It extends from the opposite Dibba Gap to Wadi Maiha.

(v) Buraymi Oasis. It comprises the Oasis proper and the Jawa Plain to the west. The Oasis lies in a region where the foothill folds west of the Central Mountains have been subjected to differential erosion giving chances for possible surface and groundwater occurrences.

(vi) Ras Al-Khaimah - Jiri Plain. It occurs between the limestone mountains and the Arabian Gulf and extends north from opposite the Dibba Gap to where the mountains reach the sea coast in high cliffs.

(vii) Central Desert Foreland. This is the hinter land of the Dubai Umm el-Qaiwain coasts with sand dunes through which some major wadis flow towards the sea draining the surface runoff from the Central Gravel Plain. In this region, the coast-line comprises sabkhas, lagoons and tidal flat areas.

Fig. XI.1 UNITED ARAB EMIRATES



(viii) Dubai-Buraymi-Abu-Dhabi Plain. It is mainly a sand dune area of increasing size and decreasing vegetation.

(ix) Southern Desert. It comprises of sand dunes inland and major sabkhas along the coast westwards from the Abu-Dhabi mainland.

XI.3.2 Groundwater Resources

Table XI.1 describes briefly the areal stratigraphy and the hydrogeologic characteristics prevailing in the different zones of the United Arab Emirates.

There are three main aquifer systems which constitute the groundwater resources of the country. They are: (1) the shallow alluvial aquifer underlying the central gravel plain and desert foreland; (2) the Batinah Coastal Plain Aquifer; (3) the Deep Carborate Aquifer[5/].

1. The Alluvial Aquifer System

All the investigations indicated the importance of this aquifer system in the United Arab Emirates. It is composed of an extensive terrestial deposits of boulders, cobbles, pebbles, gravels and sand of Quaternary Age. The productive zone within the aquifer system is restricted almost to the course alluvium for reasons of both water quality and aquifer permeability, which is generally high with exceptional zones of cemented gravel which do occur.

The saturated thickness of the productive zone rarely exceeds 10 meters in the Central Gravel plains (zone iv). Aquifer sections increase below the Jiri plain (zone vi) and northwestwards towards the coast. Along the coast the saturation zone extends upwards into the overlying sand dune sediments.

The course alluvium is hydraulically connected with the underlying mudstone evaporitic sediments which contains poor quality water. The areal distribution of water quality within the aquifer system is a function of recharge mechanism and the aquifer transmissivity distribution, i.e. it is of good quality in the upper reaches of the main wadis. The quality deteriorates westwards towards the coast.

5/ Barber, W. and D.P. Carr "Preliminary Appraisal of Water Resources", Phase I, United Arab Emirates, 1976, p. 31.

TABLE XI.1

SCHEMATIC STRATIGRAPHICAL -
HYDROGEOLOGICAL DATA

Zone / Formation	West Coast (W – E)	Desert (W – E)	Djebel Faiyah / Djebel Hafit	Gravel Plain (W – E)	Mountain (W – E)	Batina Coast (W – E)
Quaternary	≤ 60m Sand, silt evaporites (gypsum, halite, anhydrite)	~60m 20to40m gravel, sand conglomerate mudstone Water quality, Saline fresh	*	20-40m 0m gravel, sand conglomerate mudstone	fill of valleys (gravel, sand	Sand, gravel
Miocene-Oligocene	Marl, limestone dolomite, evaporites very	idem saline	idem artesian	idem water	-	-
Eocene	?	≥ 250m marls, limestone water quality locally Saline fresh ? high Yield	Dj. Hafit 250m marls, limestone Yield Unknown	marls, limestone groundwater?	-	-
Upper Cretaceous	? ?	(limestone) marl in general aquiclude	Dj. Hafit limestone marl, Dj. Faiyah limestone marl groundwater?	marl, limestone caliche aquiclude on top, aquiclude below	Maestricht limestone Semail ++ local groundwater Hawasina+ local groundwater variable salinity	Hawasina+
Lower Cretaceous to Jurassic	Sand marl limestone, marl dolomite groundwater?	idem	idem	idem	South and North of Dibba line limestone locally: marls, dolomites local groundwater	Like east coast
Triassic to Permian	dolomite anhydrite boulder beds, marl, limestones groundwater?	idem	idem		North and south of Dibba line limestone dolomite cretaceous on top water holding and water yielding	

\+ Hawasina formation: Metamorphites, Radiolarites, limestone. marl, shale, Conglomerate, serpentinitic sills, volcanites.
++ Semail formation: Serpentinite, serpentinized ultrabasic rocks, Gabbro.

Source; El Mohaylam Ismail, Water Resources, UAE, 1976.

The reservoir capacity of the aquifer system is reported to be considerable. Surface runoff from the western slopes of the mountains is the main contributing source to the groundwater recharge. Halcrow has estimated that the total amount of groundwater in storage in these alluvial gravels is about 5,280 MCM (Halcrow 1969, p. 89). Carr and Barber, estimated the annual groundwater recharge to the aquifer system through a 170 km long recharge front extending from the vicinity of Al-Ain Oasis to Ras Al-Khaima, at about 100 MCM (Carr and Barber, 1976, p. 33). This is based on similarity with other catchment areas of available long runoff records in Southern Arabia.

Based on the annual water consumption for various sectors and the estimated evaporation losses on the coastal sabkas (about 60 MCM/annum), Carr and Barber have roughly estimated the current gross balance of the alluvial aquifer system between Al-Ain and Ras Al-Khaima at -124 MCM/annum (Carr and Barber, 1976, p. 34). This indicates that overdraft conditions are currently occuring in the aquifer system, although the figure mentioned above is only indicative and not definitive and is proved by the rapid local head declines, the overdraft conditions in the Al-Ain Oasis as well as the overall water quality deterioration. However, as mentioned earlier, the volume of good quality water stored within the aquifer system is considerable, hence mining of groundwater from this aquifer is possible provided that careful water abstraction is well undertaken.

2. The Batinah Coastal Plain Aquifer

It is also alluvial aquifer comprising the alluvial deposits which form an almost continuous littoral strip extending from Musandam Peninsula to the Omani frontier along the Batinah. The aquifer is composed of alluvial fan materials consisting of coarse sand, gravels and boulders, ending up with fine grained sabkha deposits in some localities along the Gulf of Oman coast.

Recharge to the aquifer is mainly from the surface runoff from the wadis adjoining the western mountains and draining eastwards towards the Batinah coast. Underflow from the mountain valleys to the fans does not form significant recharge to the aquifer system. Many of the floods cross the alluvial fans and discharge to the sea. Well yields from this alluvial aquifer are high (Carr and Barber).

Depth to water level is shallow but water levels are only a few meters above sea level. No estimates were made for the total water resources balance in this area, but the total renewable resources is reported to be adequate for future development. Water quality is generally fair but deteriorates eastwards.

3. The Deep Carbonate Aquifer System

The aquifer system is composed of thick carbonate rock sequences underlying the region to the west of the Oman mountains extending to the area of Al-Dhafrah in southern Abu-Dhabi. Groundwater movement in the aquifer is westwards away from the recharge zone over the Oman mountains. The aquifer is drained naturally at the Sabkhas in the Al Uriq al Mutaridah region where the Liwa Oasis occurs.

The aquifer is under artesian conditions with a hydraulic head at or near the surface in Al-Ain or desert foreland areas. It is unconfined in the area along the Omani frontier south of Al-Ain.

Groundwater quality encountered in this aquifer is generally poor (about 10,000 ppm) and decreases at depth to about 4,000 ppm (Carr and Barber, p. 36). Better quality water (1000-1500 ppm) was encountered from the shallow wells tapping this aquifer at Liwa Oasis, Al-Asab and Habshan areas.

It is believed that this aquifer system offers a major water resource in the area between Liwa Oasis and the coast.

Owing to the lack of the hydrogeological information on the aquifer system within the United Arab Emirates, no estimates were made for the storativity and the groundwater recharge to the aquifer.

XI.4 Surface Water Resources

Most of the precipitation in the United Arab Emirates falls over the mountain region (zones i and ii). It is characterized by erratic, short duration and intense rainfall. This may give rise to floods of varying sizes resulting in considerable damages.

Surface water runoff records are inadequate to give rise to a reliable assessment of surface water resources of the country. Peak flows were estimated by the investigators using the slope area method with a Manning's roughness coefficient of 0.03 for all the main wadis in the country. Flood volumes were estimated using these peak flows and guesstimates of flow duration. Hence most of the surface runoff estimates are subject to large errors and should be considered as indicative estimates.

Table XI.4 shows the estimated peak flows and the probable flood volumes flowing in the main wadis of the UAE.

Table XI.2 6/

The probable volume of the streamflow in some Wadis in UAE

Flood discharge measured at	Peak flow m^3/s	Probable Duration (hr)	Probable flood volume MCM
*Wadi Qar (near Jabal Faiyah)	42.5	20	1.500
Wadi Ham (near Bithna)	29.4	2	0.105
Wadi Siji (near Siji)	50.5	4	0.360
*Wadi Lamhah (near Falaj al-Mu'lla)	87.4	20	3.140
Wadi Lamhah (near T. Qaran)	54.7	12	1.180
Wadi Bih (near Burayrat)	190.5	54	17.440
Wadi Bih (near Al-Fulayyah)	58.4	15	1.580
*Wadi Semaini (below T. Bahuth)	76.5	20	2.760

* Flows assessed by Survey of trash marks.

Flows measured by antographic recorders.

6/ El Mohaylam M. Ismail, Water Resources, UAE, 1976.

For the purpose of making use of flood waters in the country, studies have indicated that there are no sites suitable for major surface water storage projects. Potential reservoir sites are small, steep and costly if constructed. Moreover flood waters are reported to be highly charged with suspended sediments and the useful life storage of reservoirs would be very short. Also the dependable annual yield of surface storage reservoirs would be small due to the extreme intra-annual variability of runoff (Carr and Barber, 1976, p. 29).

Flood retention structures such as spreading dikes and spate breakers, for the objective of groundwater recharge would be beneficial.

XI.5 Water Resources Balance

In his report, Halcrow, 1969, table 37, p. 100, has presented a tentative water resources balance for the United Arab Emirates based on rainfall, runoff groundwater recharge and water abstraction. The table is very rough as most of the basic data employed in the water resources balance computations were not adequate. The investigator ended up with estimated groundwater abstraction from storage (mining) at about 203 MCM/annum, and the total estimated stored water in the alluvial aquifer at about 5,280 MCM. Much of this estimated water storage may not be recoverable due to technical, economical and water quality factors; but still this figure indicates that by proper and wise groundwater withdrawal the country can be considered almost on the safe side from the availability of the water resources point of view, in particular when other non-conventional water resources should be undertaken.

XI.6 Other Water Resources

Bearing in mind the limited and diminishing fresh groundwater resources, the United Arab Emirates concerned authorities have undertaken the establishment of desalination plants to provide fresh water supply for domestic purposes. The existing and planned desalinated projects are:

Name	Source of water	Capacity	Method
Ras Al-Khaimah	Brackish groundwater	1.5 mg/d	Reverse Osmosis
Jabal Ali (Dubai)	Sea water	5 mg/d	Multi flash type
Abu-Dhabi	Sea water	?	Multi flash type
Sharjah	Sea water	?	Multi flash type

In addition to sea water desalting projects, treated sewage effluent is presently being discharged to the sea from both the Dubai and Abu-Dhabi treatment plants. The reported capacity of the Dubai treatment plant is about 3-4 mg/d of which only 0.5 mg/d is being consumed for public gardens' irrigation.

XI.7 Conclusion

In conclusion, groundwater is and will remain the major natural water resource within the United Arab Emirates, but resources of good quality are limited. The main producing aquifers are: (1) the alluvial aquifer system which has about 10 m saturated thickness. The quality of the contained groundwater is good in the upper reaches of the main wadies and deteriorates westwards near the coast. (2) the Batinah Coast Aquifer which is also alluvium and occurs to the east of the Omani mountains. The total renewable resources is reported to be adequate for future development, water quality is generally fair and deteriorates eastwards. (3) the Carbonate Artesian aquifer that occurs at depth to the west of Omani mountains where the aquifer is recharged. It is drained naturally at the in-land Sabkhas. Water quantity is unidentified and quality is fair but improves at depth.

Groundwater in storage in the alluvial aquifer is estimated at 5,280 mcm. The annual groundwater recharge to the aquifer is about 100 mcm.

Surface water resources are almost non-existant in the United Arab Emirates. Short duration and intense rainfall may occur over the Omani mountains resulting in floods of variable sizes and causing severe damage. Surface water runoff records are inadequate to give rise to a reliable assessment of the resource, but the main object of any works should probably be to avoid the damage caused by unregulated floods.

Desalted water and treated sewage effluent are presently being produced in the United Arab Emirates. The former is for domestic purposes, the other is for irrigating the public gardens. With the growth of population and of all kinds of demand, these unconventional sources will probably need to be expanded.

Nevertheless, detailed hydrogeologic investigations covering the country, seem to be desirable to determine a realistic safeyield of the potential groundwater so as to arrive at a proper and wise groundwater withdrawal and usage in conjunction with non-conventional water resources production.

XII. YEMEN ARAB REPUBLIC

Area : 195,000 km^2 1/
Population: 6 million

XII.1 Geographical Environment

The Yemen Arab Republic is situated in the southwestern corner of the Arabian Peninsula, approximately between the latitudes 12° 40' and 17° 30' north and between the longitudes 42° 40' and 46°00 east. Fig. XII.1.

XII.1.1 Topography

Most of the Yemen Arab Republic (Y.A.R.) is mountainous with several heights over 3000 meters a.s.l.; the highest being 3760 meters which is also the highest peak in the Arabian Peninsula.

Based on climatological and topographic characteristics the country can be divided into several physiographical units 2/.

1. The Maritime coastal plain of Tihama

It covers an area extending 440 km along the Red Sea coast and with an approximate altitude of up to 400 m. and an average width of about 45 km. The plain is flat to rolling terrain intersected by almost east west running wide and shallow wadis which during the rainfall can carry enormous floods from the western mountain slopes towards the Red Sea.

2. The foothills and middle height western mountain slope

They comprise the area between 400 m and 2000 m altitudes. They are the most rugged part of Y.A.R. where wadis have cut deep canyons with sometimes almost vertical or very steep slopes. The area is characterized by high rainfall.

1/ The World Bank, United Nations World Development Report, August, 1978 (pp. 76, 77).

2/ Matheus, H.J. and A.M. Badr "Country Paper on the Groundwater of Y.A.R.", 1978 pp. 47 (open file report).

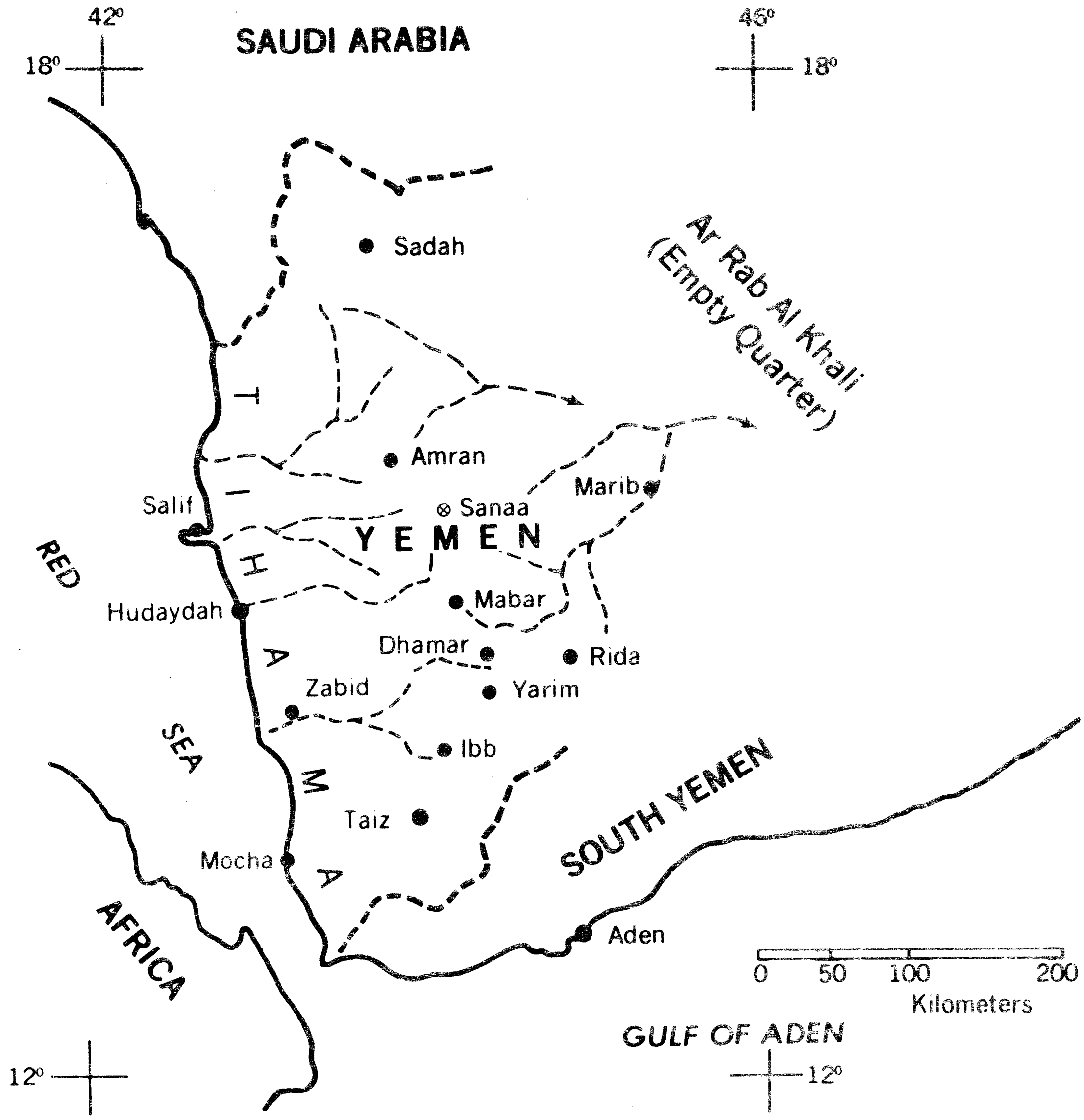


Fig.XII.1 Map of Yemen.

3. The central highlands

They comprise the upper parts of the central mountain range with altitudes varying from 2000 m to 3000 m with peaks often exceeding 3500 m. This area is much less rugged than the western slopes. The eastern slopes are gentle and terminate in the interior region of the high plateau. Rainfall in this area is less than the western slopes area.

4. The interior undulating plateau (Mountain Plains)

They are intermountain plains, almost flat varying in altitudes from 2200 m to 2700 m (a.s.l.). The cities of Sana'a, Mabar, Dhamar and Yarim are in this region. The area is mostly covered with lava flows overlain by alluvial deposits which vary in thickness from zero to several hundred meters. The drainage system in this area is mostly eastwards.

5. The eastern mountain slopes

They comprise the largest part of Y.A.R. They are almost flat desert areas with rare rainfall. It ranges in altitude from about 2000 to 1000 m (a.s.l.). Drainage is due east towards Rub Al-Khali desert.

XII.1.2 Climate

The Yemen Arab Republic has considerable variability in climate ranging from the hot and humid coastal plain bordering the Red Sea to the cool highlands with relatively low humidity and, towards the east, to the hot and dry eastern desert area bordering the Great Arabian Desert (Rub Al-Khali). Three basic climates as well as rainfall regions may be distinguished in Y.A.R.: Western maritime, Southern maritime and inland continental regions 3/.

Precipitation is scanty over most of the country. Most of the rainfall is absorbed in upstream reaches of the wadis.

Mean annual rainfall which related to monsoon system ranges from less than 100 mm along the Red Sea to as much as 1000 mm near Ibb. To the east of the mountains, rainfall is low and not defined. It is estimated, in the mountain regions, at about 400 mm/year. Most of the rainfall occurs in spring and summer. Storm totals are usually not large; though the rainfalls may be intense but of short duration.

3/ ITALCONSULT, Water Supply for Sana'a and Hodeida, Sana'a Basin, Report on Groundwater Studies, Vol. 1, 1973 pp.

Daily range in temperature in the Sana'a intermountain plain is from about zero to 20°C in winter and from 27°C to 30°C in summer. In the Tihama, summer temperatures reach greater than 37°C but seldom exceed 40°C. Winter minimum is rarely below 20°C.

Countrywide potential evapotranspiration is not well defined. Measurements have been made in some selected stations in Sana'a, Taiz and Hodeida cities for the years 1976 and 1977 and found to be as follows:

	Sana'a	Taiz	Hodeida
1976 :	1,549.6	2,477.9 (11 months)	2,523 (8 months)
1977 :	1,438.9 (for 10 months)	1,160.6 (8 months)	1,705.6 (9 months)

(Source Meteorological Dept. Sana'a)

XII.2 Geological environment

XII.2.1 Stratigraphy

In regional terms the stratigraphy of the Yemen Arab Republic shows great affinity to the rest of the Arabian Peninsula. The stratigraphic sequences outcroping or present in the subsurface in Y.A.R. ranges from Precambrian to Quaternary of the geological time scale. Investigators have indicated the absence of Triassic to Silurian geologic ages. Based on the available literature, the stratigraphy of the Y.A.R. can be divided into:4/

1. The basement complex of the Precambrian age is widely distributed in the south and north-eastern parts of the country, especially east of Radah and around Sadah in the north. It also outcrops in the foothills and in the midland belt. The formation forms a general north south folding.

2. Wajid sandstone which mostly consists of a well sorted cross bedded quartizitic sandstone with conglomerate. It is of Ordovician age and overlies the Precambrian formations.

4/ Mateus, H.J. and A.M. Badr, op. cit. pp. 21, 22.

3. Kohlan series. It is of Jurassic geologic time scale consisting of shale, sandstone and conglomerates. The Series occur at the foothills and midland areas. It overlies directly the Basement Complex.

4. Amran series. It is of upper Jurassic age and is widely distributed on the highlands of Sada-Jabal Musawar-Amran and Mareb regions. It is mainly limestone, marl and shale.

5. Tawilah group and Majd-Zir series. It consists of coarse cross-bedded sandstones with lenses of conglomerates and gravels and shale. Its outcrops occur mainly in the highlands of the midland area. It is of cretaceous to Paleocene age.

6. Yemen volcanics. It is composed of bedded AlKali flows and pyroclastic rocks including basalts and varicolored tuffs. It covers an extensive area south of Sana'a. It is of tertiry to quaternary age.

7. Recent alluvium and eclien deposits. They are composed of silt, clay, sand and alluvial valley fills with Loess deposits in the mountain plains.

XII.2.2 Geologic structure

The structural style of the Yemen Plateau is typically tensive. The vertical movements of the plateau itself are generally of minor magnitude compared with those which occured along the escarpments which face the Red Sea Rift Valley system on the west. The major effect of the tectonic movements is that they opened passages for the rise of magma which led to the formation of extensive volcanic extrusions in Yemen.

The Jurassic and Cretaceous strata have been subjected to gentle folding everywhere in Yemen. The volcanic province forms an uplifted horst and most faults and structural alignments are parallel to the Red Sea Rift. The Tihama is down-faulted several thousand meters with respect to the rest of the Country along an axis roughly coincident with the position of the present mountain front.

XII.3 Groundwater resources

XII.3.1 Introduction

The National Water and Sewerage Authority, the Department of Rural Water Supply of the Ministry of Public Works and Municipalities; together with the Irrigation Department of the Ministry of Agriculture of Y.A.R., are the main authorities which are actively involved in hydrogeologic and hydrologic activities in the Country.

Several hydrogeologic investigations were carried out in the Y.A.R. by many consulting firms under the auspices of WHO particularly in the areas of: Sana'a Basin, Hodeida and Taiz. USAID had a hydrogeologic team settled in Yemen to undertake furhter steps in the countrywide hydrogeologic investigations and to initiate exploratory drilling programmes. Several reports were published on the subject, but unfortunately most of them were not accessible to the writer.

Detailed information on the hydrogeologic characteristics of the main water bearing formation in Y.A.R., is very limited. Accordingly the following presentation of the hydrogeologic characteristics of the various rock units are based mainly on general principles and the lithostratigraphic features of the rock units concerned.

Based on the available hydrogeologic investigations, the principle aquifers in the Y.A.R. are:

- Tihama Plain Alluvial Aquifer
- Kholan Series
- Tawilah and Mejd-Zer Series
- Yemen Volcanics
- Quaternary alluvium and Quaternary Volcanics

Summary of the hydrogeologic characteristics of the Y.A.R. aquifers and aquicludes are shown on table XII.1 after Sir William Halcrow and Partners, 1977 with slight modifications based on recent studies.

Table: XII.1

Hydrogeological Characteristics of Rock Units in YAR

Formation	Age	Thickness	Lithology	Hydrogeology
Tihama Plain Alluvials	Quaternary	0-600 m	Alluvium, conglomerate, silt sand and gravel. Thickens towards the coast	Good to excellent unconfined aquifer, good quality
Upper catchment alluvials	Quaternary	variable up to 500m	Alluvium, coarse boulders congl. to clay	Good to excellent unconfined aquifer, good quality
Quaternary volcanics	Quaternary	Variable	Basaltic lava interbedded with fluviatile and lacustrine sediments	Fair to good, unconfined
Yemen Volcanics	Tertiary-cretaceous	variable upto 1200m	Laves, aglomerates, tuffs interbedded with alluvium	Fair to good, unconfined
Tawilah Series	Cretaceous	± 400 m	Sandstone with conglomerates	Good, satisfactory water quality, unconfined
Amran Series	Jurassic	? 350 m	Limestones, rocks, Shales	Aquiclude or poor aquifer
Khalan Series	Jurassic	100-500m	Sandstone and conglomerates	Good semiconfined to confined but poor quality
Precambrian	Precambrian	?	Crystalline metamorphic and intrusive rocks	Aquifuge

XII.3.2 Tihama plain alluvial aquifer

The alluvial deposits of the Tihama coastal plain may be considered as one single aquifer approximately 500 km long and varying from 10-50 km in width. This aquifer receives its groundwater recharge from the Yemen Plateau via a number of wadis running across its surface and by subsurface flow at the mountain front.

Fig. XII.2 shows a diagramatic cross-section of the alluvium of the Tihama Plain. The thickness of the aquifer increases rapidly westwards away from the mountain front. ITALCONSULT confirmed by geoelectric survey a rapid increase in depth of alluvial cover to over 500 m within 10 km of the mountain front.

The aquifer is composed mainly of cemented to uncemented boulders, pebbles, gravels and sands. Grain size generally decreases westwards away from the mountains front. It is expected that the Tihama alluvial aquifer is underlain, after 200 m depth, by Tertiary or pre-Tertiary sedimentary volcanic rocks.

The average regional transmissivity (T) of this aquifer was estimated at 1,700 m^2/day (ITALCONSULT) or 2,500 m^2/day (Sir William Halcrow and Partners). Storage coefficient (S) for the aquifer was estimated by the Institute of Geological Science of London (IGS), at 10^{-1} to 10^{-2}. The estimated currently available groundwater reserves are about 1.9 MCM/year/km width of aquifer.

Groundwater quality in the Tihama aquifer is fair to good. Water quality deteriorates laterally as one goes away from the mountain front, and vertically at depth. Good quality water is generally associated with wadi flows and flood irrigated areas within the Plain. Large scale extraction of groundwater from the Tihama aquifer within the zone 20-40 km from the coast might result in serious water quality deterioration by sea water encroachment.

IDEALISED HYDROGEOLOGICAL CROSS SECTION OF THE TIHAMA AREA

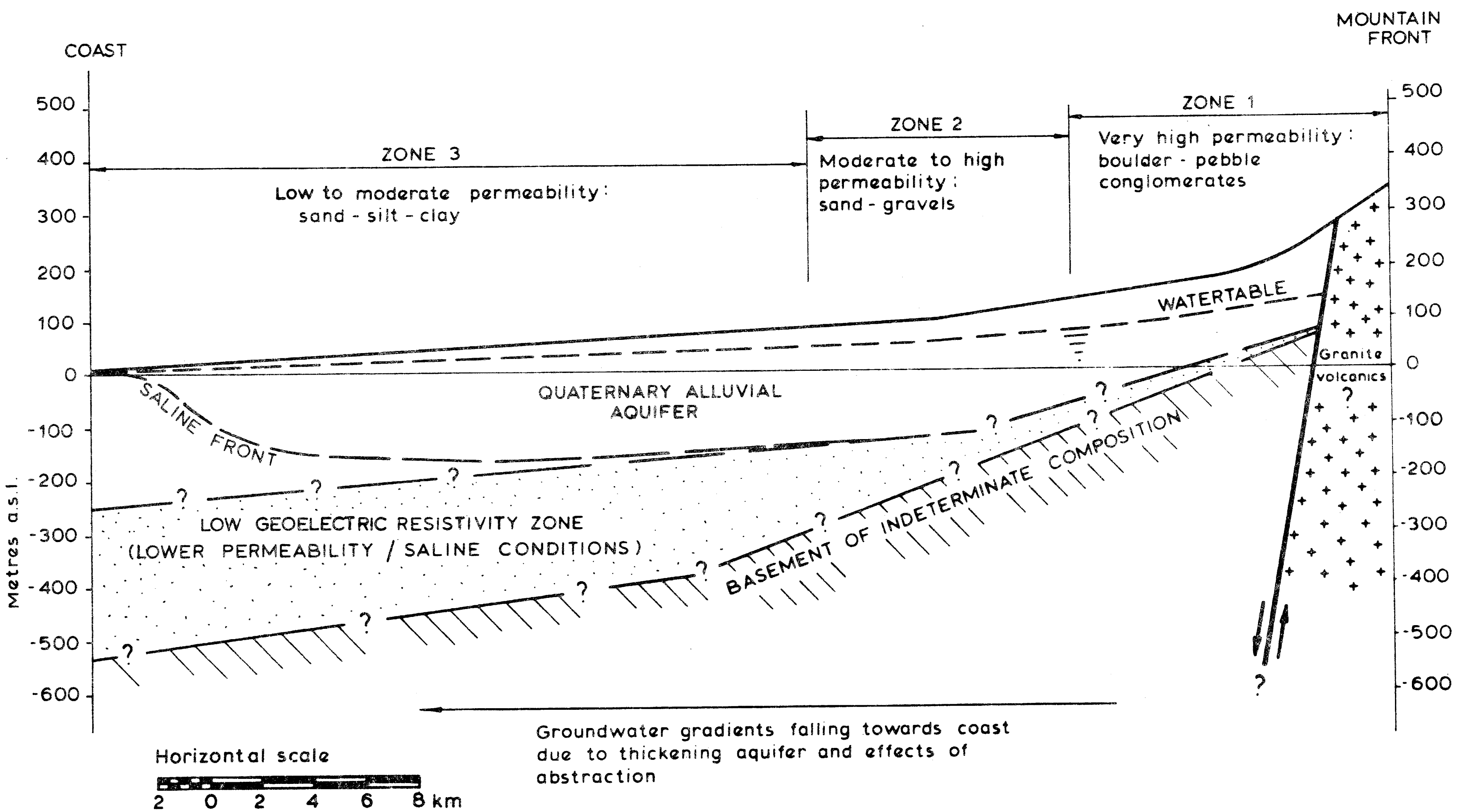


FIG. XII.2

Sir William Halcrow & Partners, MARCH 1977

XII.3.3 <u>Kholan Series Aquifer</u>

The aquifer is composed of a series of white and violet cross bedded sandstones with several thin layers of conglomerate. Its thickness ranges between 100 m to more than 500 m. These rocks represent an important aquifer in the interior areas of the Y.A.R. and it is expected to possess good aquifer potential.

Aquifer parameters are not well defined and water quality is uncertain, but generally it is encountered at great depths.

XII.3.4 <u>Tawilah and Mejd-Zir Aquifer</u>

The aquifer is composed of coarse grained sandstones with conglomeratic layers totaling about 400 meters in thickness. Its potential is good particularly the lower 300 m of its thickness and characterized by a well developed fracture system which results in good permeability.

The aquifer areal extension coincides roughly with the outcrops of the Tawilah formation in the north and north east; to the west it is bounded by the Red Sea excarpment; to the east by the escarpment facing the eastern desert. The southern boundary is not defined. The vertical boundary of the aquifer is marked by the Cretaceous-Jurassic shales at the bottom while the upper limit is marked by the overlying Tertiary basalts or Quaternary basalts and/or sedimentaries.

Depth to water level is primarily a function of topographic elevation and generally varies from 25 to 100 meters.

Aquifer parameters are not well defined. Numerous hand dug wells are known to penetrate the aquifer in many areas like in the catchment areas of Kharid, Bana, Rasyan Siham and Surdud. Well yields are variable.

Several low yielding springs of the water table type are fed by the aquifer. Large springs are reported to be fed by this aquifer along the Red Sea Rift escarpment.

XII.3.5 Yemen Volcanics Aquifer

A large part of Y.A.R. is covered by an extensive thick layer of volcanic rock predominantly lavas with alternating tuffs and agglomerates. The series is intruded by basaltic rocks in the form of dykes, sills and localiths. The maximum thickness is about 1200 meters or more.

The hydrogeology of the aquifer is complex and highly variable. Due to the very large area of the aquifer outcrops and the expected high to very high permeabilities, its storage capacity and water quality are expected to be good.

The water bearing characteristics are governed by the fracturing of the rock. The aquifer is likely to possess very variable but locally extremely good aquifer properties. Depth to water level is variable depending on the topography. Generally the water table tends to follow the overall topographic character. Groundwater quality is uncertain.

XII.3.6 Quaternary Volcanic Aquifer

Its outcrops are mostly basaltic flows in the extreme north-east corner of the Y.A.R. The areal extent of the aquifer is estimated at about 1000 km^2. It is composed predominantly of lava flows reaching in thickness several hundred meters. No sufficient information is available on the groundwater potential of the aquifer.

XII.3.7 Quaternary Valley Fill

It is composed of alluvium varying from coarse boulder conglomerates through gravel, sand, silts and clays which are deposited in the floors of most of the upper catchment wadis in the mountain regions. Aquifer parameters are variable and not well defined. The aquifer potential and water quality are likely to be good.

Thickness of the aquifer is variable and ranges from a few meters to over 300 m. Water table conditions predominate, Semi-artesian conditions may occasionally occur.

The Quaternary alluvial aquifer is one of the most exploited aquifers at the present time and is being tapped by a large number of wells all over the Yemen Plateau. The aquifer permeability is a function of the fine materials percentage within the alluvial sediments.

XII.4 Groundwater Flow Systems and Recharge

Groundwater movement within the main aquifers of the Y.A.R. is complex. The overall behaviour of the groundwater flows, based on general principles, can be detected and it is very similar to the system sketched in Fig. IX.3 which represents the groundwater movement within the Arabian shelf in Saudi Arabia.

Fig. XII.2 represents a diagramatic flow system of groundwater within the Tihama Plain.

In the mountain regions and based on the previous discussions, two distinct main aquifer systems separated by the Amran limestone-shale series are likely to be present regardless of the complications introduced by the geologic structures within the area. In general terms the groundwater flow system and recharge to these aquifers are through direct infiltration from rainfall and runoffs through the wadi floors in most of the Y.A.R. mountain area where permeable rocks, (Quaternary alluvia and volcanics, Yemen Volcanics, Tawilah and Kholan Sandstone series) are outcropping. A pronounced groundwater mound occurs within the mountain area exhibiting a potential distribution pattern which is a subdued reflection of the rainfall isohyetal map of the Y.A.R. Fig. XII.3. Groundwater flow from this mound will be radially outwards from the centre of maximum rainfall in the Ibb area. Accordingly it can be stated that a general groundwater divide occurs close and parallel or even roughly coincid s with the summit axis of the mountain area running from Ibb in the south to Sodah on the north. Flow of groundwater will occur eastwards towards the interior and to the Rub Al-Khali area, and westwards towards the Tihama and the Red Sea.

The assessment of the annual groundwater recharge in the mountain area is unknown. ITALCONSULT suggested a very conservative figure of 3 per cent of annual rainfall that is being recharged annually to the mountain region aquifers.

XII.5 Overdraft Conditions

Groundwater over exploitation in many areas of the Y.A.R. has been experienced during recent years, particularly in the urban areas and in areas where intensive irrigation is being practiced.

Recent investigations indicated a general water level decline in Sana'a Basin. The rate of this decline was estimated at an average of 1.85 m/year with a minimum of 0.52 m/year and a maximum of 3.75 m/year depending on the extent of water pumpage. This rate of decline is expected to reach 5 m/year or more if over pumpage conditions continued. Water quality deterioration due to overdraft conditions were also experienced recently in Sana'a Basin but not defined.

The area of Taiz, Mabar, Dhamar and others will have the same overdraft conditions within the forthcoming 10 years as already the annual water extraction is exceedingthe estimated annual groundwater recharge.

XII.6 Surface Water Resources

XII.6.1 Rainfall

Yemen Arab Republic has an arid climate although in many areas the annual precipitation exceeds 400 mm. Mean annual rainfall as high as 1000 mm occurs over small areas near Ibb Fig. XII.3. Generally rainfall which is mostly related to the Monsoon system ranges from about 400 mm in most of the mountain areas to as little as 100 mm east and west of the mountains. Annual rainfall is highly variable from year to year as can be detected from fig. XII.4 for Sana'a area (after ITALCONSULT and others).

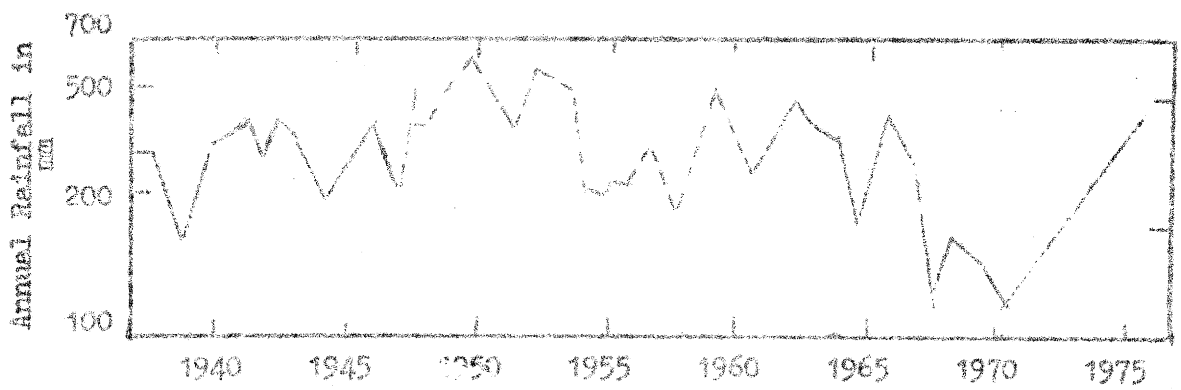


Fig. XII.4

MEAN ANNUAL RAINFALL IN YEMEN ARAB REPUBLIC

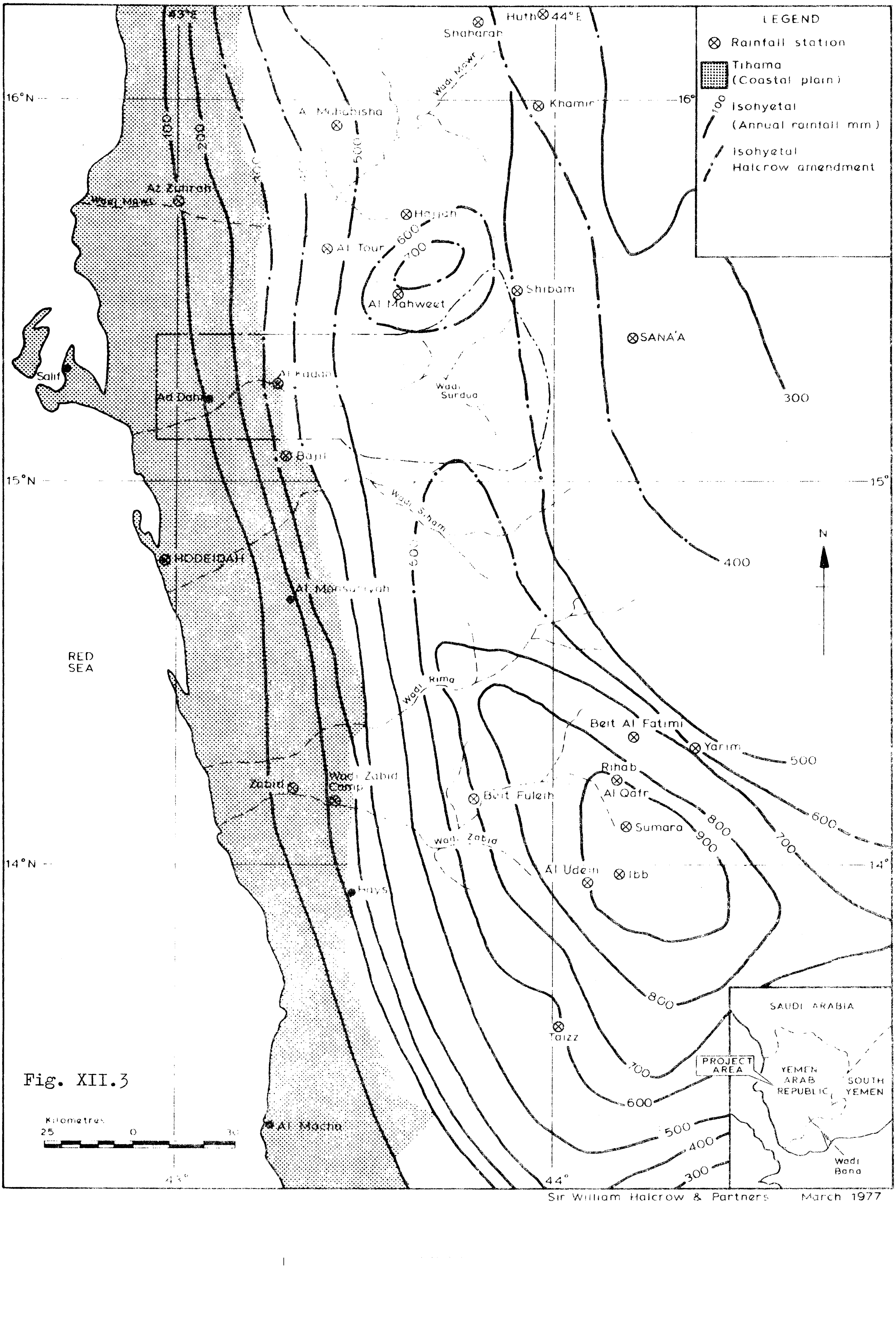


Fig. XII.3

Sana'a has appreciable rainfall mainly in spring and midsummer; June is usually a dry month. In Taiz a rainy season of seven consecutive months usually occurs.

Notable daily rainfall at Sana'a from 1963-1970 was used for frequency analysis by ITALCONSULT. It was concluded that daily rainfall greater than 30 mm occured with an average frequency of twice a year; greater than 35 mm, once a year; greater than 40 mm, once in two years and greater than 60 mm, once in ten years.

Rainfall in Y.A.R. usually occurs as short storms falling in a limited areal extent. This character can be demonstrated by the measurements of four raingauges operated by the US Geological Survey situated at Amran Valley on an almost straight west-east line over about 35 km.

Table XII. 2 shows the annual rainfall observed during 1970-1975 from some selective stations in Y.A.R.

Table XII.2
Annual rainfall (mm) measured at some station in YAR

Station	Years					
	1970	1971	1972	1973	1974	1975
Ibb	1040	1118	1331	1151	1500	2205
Al Udein	644	398	387	464	409	1107
Sumara	830	1230	1460	479	321	866
Rihab	446	696	737	461	497	469
Yarim	368	677	454	396	374	350
Beit al Fatomi	308	396	282	119	-	-
Fuleihi	624	539	285	230	-	-
W. Zabid Camp	379	245	226	314	546	437
W. Zabid Town	133	121	106	92	208	193

XII.6.2 Stream Flows

Perennial stream flows in the Y.A.R. are practically nonexistent. Some perennial springs and small wadis exist and issue, from the aquifers exposed at the Western and Eastern escarpments of the mountains area. The discharges of these springs and small wadis are totally consumed for irrigating in the small areas along the wadis concerned. Warm to hot water springs, sometimes of poor quality, occur at several places throughout the country.

The drainage pattern in the Y.A.R. is determined by the watershed dividing line running over the peaks of the central mountain range. The main wadis draining the western slopes to the Red Sea and those draining the inter-mountain plains and the eastern slopes, are listed below:

Draining to Red Sea	Draining to Rub Al-Khali
Wadi Hairan	Wadi Al-Ard
Wadi Mawr	Wadi Marwan
Wadi Surdud	Wadi Atfayn
Wadi Siham	Wadi Hishwash
Wadi Rima	Wadi Khablu
Wadi Zabid	Wadi Al Jauf
Wadi Rasyan	Wadi Rugwan
Wadi Al Ghali	Wadi Marib

Other wadis run towards the south and discharge into the Gulf of Aden. They are the Wadis of: Ghoban, Bana, Tibban and As Shar.

Most of the above-mentioned wadis are ephemeral because of the short rainfall events, the high evapotranspiration rate and the stream channel modification by the extensive terraces to provide water storage.

The most important wadis in the Y.A.R. run towards the Red Sea like: Wadis Zabid, Rima, Siham Surdud and Mawr. Some of them have perennial flows in their upper reaches but rapidly disappear in the highly porous alluvium of the Tihama Coastal Plain. Wadi Jauf the largest catchment area (9,500 km^2) discharges into the eastern desert.

No adequate hydrological information about most of the Y.A.R. main wadis is available. Several qualitative investigations have been carried out in about 30 catchment areas in Yemen. Continuous records of stream flow in the country are reported to be available for wadi Zabid (since 1960), Wadi Mawr (since 1973) and Wadi Rima (since 1975).

Mean annual flows and flood peak frequency characteristics of a few wadis in Yemen have been estimated from records on wadi Jizan (Saudi Arabia) and on records of some wadis in the People's Democratic Republic of Yemen.

Monthly and annual discharges of most of the main wadis are highly variable. This can be indicated by the discharge measurements carried out over six years at different places on the wadi Zabid.

Table XII.5 5/

Year	Zabid at Kolah (MCM)	Zabid at Ma'ah (MCM)	Remarks
1970	11.7	67.7	The difference between the two values is an indicator of water lost by recharging the alluvial aquifer of Tihama and by off-take irrigation
1971	125.3	91.3	
1972	124.0	94.2	
1973	120.1	80.3	
1974	145.9	111.8	
1975	230.4	184.0	

Monthly totals measured at the same above stations and at Wadi Mawr are shown on table XII.6 below.

5/ Tipton and Kalmbach, Inc., Engineers, Wadi Zabid Groundwater Potential. Report to Tehama Development Authority, Y.A.R., 1974.

Table XII.6

1975	Zabid at Kolah (MCM)	Zabid at Ma'ah (MCM)	Mawr (MCM)
January	2.4	0.1	3.9
February	2.2	0.4	3.5
March	3.2	1.5	6.3
April	8.5	7.0	46.7
May	5.0	2.9	11.7
June	10.2	7.4	15.0
July	35.3	29.1	17.8
August	83.5	72.1	43.1
September	49.5	41.1	25.6
October	17.0	13.5	9.6
November	7.7	5.5	6.0
December	5.9	3.4	4.0

The quality of surface water resources in Y.A.R. is generally good and suitable for irrigation. It ranges from less than 1000 ppm to over 4000 ppm such as in Wadi Jawf and Wadi Siham.

XII.7 Other Water Resources

Desalination plants to produce fresh water supply have been established in only three places in Yemen along the Red Sea coast. The capacities are limited as the communities which have to be supplied with fresh water are small.

XII.8 Conclusion

Groundwater forms the major water resource of the Y.A.R. It is of unknown quantity and fair to moderate quality. The principal aquifers are: Quaternary alluvia and volcanics, Yemen volcanics, Tawilah and Kholan sandstone series. Its main occurrences are in the Tihama coastal and the intermountain plains. The estimated groundwater throughput across the Tihama plain is 1.4 mcm/year/km width of the alluvial aquifer. A groundwater recharching zone occurs within the mountain areas which receives the highest annual rainfall reaching up to 1000 mm/annum near Ibb. Groundwater overdraft conditions were recognized by quality deterioration as in Tihama plain and/or water level declines as in Sana'a Basin and other urban areas.

No perennial streams occur in Y.A.R. Most of the major wadies are ephemeral and have variable discharges. Some of them have perennial flows in their upper reaches. There are some springs issuing from the mountain areas draining the exposed aquifers. It is believed that the Y.A.R. does have a good potential of surface water resources.

The available hydrological and hydrogeological data are inadequate to evaluate and assess the water resources of the Y.A.R. Most of the investigations carried out were based on scanty and not of long duration water records. Hence they are probably misleading or merely indicative.

In order to identify the country's water resources in quantity and quality wise, an assessment programme should be initiated as early as possible. The programme should involve all the natural elements and parameters that govern the availability of water resources. A countrywide hydrometeorological network is required and must be considered as a priority project.

Mutual co-operation between the two Yemens seems to be beneficial to evaluate and develop the water resources of the shared major water shed areas such as the wadies of Tiban, Bana and Beihan.

ANNEXES

Annex 1

A-I

83 (VII): Establishment of the Regional Water Resources Council

The Economic Commission for Western Asia

Recalling the recommendation to establish a Regional Water Resources Council adopted at its First Regional Water Meeting held at Baghdad,

Further recalling the resolutions and recommendations of the United Nations Water Conference, which constitute the Mar del Plata Action Plan, as well as Economic and Social Council resolutions 2115 (LXIII) and 2121 (LXIII), which called upon the regional commission to expand their activities in the field of water resources,

Further recalling Commission resolution 39 (IV) concerning regional co-operation in the field of water resources development, and the resolution adopted at its Second Regional Water Meeting held at Riyadh,

Noting that the United Nations Water Conference requested the regional commissions "to play a central role in the promotion of intergovernmental co-operation" in the respective regions, as a follow-up to the Mar del Plata Action Plan, and specially recommended in its resolution VIII that they should, inter alia, "assign specific responsibility on water to an existing intergovernmental committee within the regional commission, or, if necessary, create a new one and establish or strengthen, as appropriate, the secretariat units of the commissions dealing with water, which would serve as the secretariat of the intergovernmental committee referred to",

Bearing in mind that the General Assembly, in its resolution 32/197, on the restructuring of the economic and social sectors of the United Nations system, recommend that "the regional commission should exercise team leadership and responsibility for co-ordination and co-operation at the regional level",

Recognizing the important role of water in the over-all socio-economic development of the region and the urgent need for accelerated progress in the development of this vital natural resource, Having considered the report on the establishment of the Regional Water Resources Council (E/ECWA/96) and, in particular, appendix 15 (the report on the Commission's meeting at Damascus on 17 and 18 September 1979), which provided for the proposed terms of reference of the Water Resources Council to be amended so as to replace its executive functions by co-ordinating functions, in order to avoid duplication of the work of organizations already active in the area of water resources,

Noting with satisfaction the implementation of the tasks referred to in the resolution of the Second Regional Water Meeting held at Riyadh,

1. Decides:

(a) That the Regional Water Council shall be established;

(b) That the competence of that Council shall be restricted exclusively to the co-ordination of the efforts of the regional organizations and bodies active in the field of water resources in the region and to the conduct of activities that complement the work of these organizations;

(c) That the Council's co-ordination efforts shall be discharged through the compilation of information concerning the organizations active in the region and the discussion of that information at its periodic meetings;

(d) That the Council shall meet once a year, the exact date to be agreed upon between the secretariat and the member States, and that this meeting shall be held at least four months prior to the date of the regular session of the Commission;

2. Requests the Executive Secretary,

(a) To assess the financial implications of the present resolution and to explore with the member States, regional and international funding agencies, other countries and development institutions the possibility of raising and securing the necessary funds that will enable the secretariat of the Commission to provide adequate secretarial support to the Council;

(b) To report to the Commission at its eighth regular session on the progress achieved regarding the establishment of the Council, and in particular on the implementation of the tasks mentioned above.

8th meeting
23 April 1980

Annex 2

B III. 1

YEARLY DISCHARGES OF TIGRIS RIVER AND ITS TRIBUTARIES
IN (MILLIARD CUBIC METERS)

* WATER YEAR	TIGRIS RIVER	TRIBUARIES OF TIGRIS RIVER					
	AT MOSUL	GREATER ZAB AT ESKI KELEK	KHAZIR AT MANGUBA	LESSER ZAB AT GOMA ZERDALA	ADHAIN AT NARRIWS	DIYALA AT DISCH.SITE	TOTAL DISCHARGES OF TIGRIS RIVER & ITS TRIBUTARIES
1932-1933	12,20	10,80	0,70	7,03	0.70	5.51	36,94
1934	12,60	9,300	0,70	6,47	1,-	5,09	35.16
1935	16,30	9,50	0,70	4,95	0,80	2,33	34,98
1936	17,60	10,90	0,70	6,07	0,90	5,48	41,65
1937	15,50	14,20	0,70	7,87	0,50	4,75	43,52
1938	23,10	12,30	0,70	8,83	0,60	7,82	53,35
1939	22,10	13,30	0,70	8,99	0,70	8,59	54,38
1940	24,20	15,60	0,70	9,88	0,70	7,74	58,82
1941	26,20	15,50	0,70	8,12	0,40	5,98	56,90
1942	22,30	14,90	0,70	7,61	0,20	4,96	50,67
1943	27,80	12,80	0,70	6,02	0,30	6,49	54,11
1944	17.80	13,70	0,72	4,62	0,20	3,24	40,28
1945	16,60	11,60	0,83	5,72	0,72	5,01	40,48
1946	25,20	19,70	1,42	10,60	1,83	9,57	68,32
1947	15,20	11,40	0,81	4,87	0,18	3,23	35,69
1948	25,30	14,00	0,71	4,34	0,28	2,66	47,29
1949	19,50	16,30	1,15	9,42	1,06	7,99	55,42
1950	19,70	15,70	1,60	11,00	1,20	8,00	57,20
1951	14,60	8,80	0,44	3,69	0,22	3,42	31,17
1952	24,80	16,00	0,89	9,09	0,21	4,61	55,60
1953	24,50	14,80	1,14	8,99	1,65	6,38	57,46
1954	34,50	19,90	1,75	15,10	0,99	9,72	79,96
1955	13,90	8,70	0,47	4,24	0,21	3,61	31,13
1956	22,40	14,60	0,67	8,04	0,27	5,20	51,27
1957	23,00	13,30	0,75	9,45	1,60	8,99	57,09
1958	18,20	9,300	0,50	4,41	0,38	5,23	38,02
1959	13,20	9,60	0,50	3,02	0,40	5,50	32,22
1960	15,50	9,10	0,40	3,72	0,20	2,50	31,42
1961	12,00	8,70	0,70	5,37	0,90	5,00	32,67
1962	18,80	8,90	0,8	5,23	0,50	2,40	36,63

CONT.

Annex 2 (CONT'D)

B XII. 1

* WATER YEAR	TIGRIS RIVER	TRIBUTARIES OF TIGRIS RIVER					
	AT MOSUL	GREATER ZAB AT ESKI KELEK	KHAZIR AT MANGUBA	LESSER ZAB AT GOMA ZERDALA	ADHAIN AT NARRIWS	DIYALA AT DISCH.SITE	TOTAL DISCHARGES OF TIGRIS RIVER & ITS TRIBUTARIES
1963	38,30	22,10	1,50	5,52	0,90	5,30	73,62
1964	24,20	18,00	1,10	7,63	0,30	4,70	55,93
1965	19,50	10,10	0,80	7,56	0,51	3,82	42,29
1966	24,20	15,20	0,80	5,90	0,45	3,79	50,35
1967	31,60	16,00	1,10	4,81	0,37	3,83	57,71
1968	39,20	17,30	1,40	6,23	0,80	5,58	70,51
1969	45,90	24,20	2,83	17,01	1,85	14,27	106,03
1970	17,70	10,23	0,98	9,56	0,62	7,29	46,38
1971	18,75	11,79	1,20	6,73	0,75	5,20	44,42
1972	23,43	10,33	1,27	6,36	1,49	10,74	53,64
1973	11,95	11,89	0,46	7,60	0,57	5,18	37,65
Mean Yearly 1974	17,03	11,82	1,10	10,10	2,17	10,91	53.13
Discharge 1975	15,70	9,37	0,40	6,83	1,02	5,49	38,81 milliard
1933- 1972	22,84	13,20	0,88	7,04	0,65	5,53	50,02 cubic
1933- 1975							49,54 meters

* Water year starts from the first of October of a year to the end of September of the next year

Annex 2 (CONT'D)

B III.1

YEARLY DISCHARGES OF EUPHRATES RIVER
IN (MILLIARD CUBIC METERS)

WATER YEAR	YEARLY DISCHARGE MILLIARD M^3	WATER YEAR	YEARLY DISCHARGE MILLIARD M^3
1924 - 1925	19,10	1951	21,10
1926	31,10	1952	31,40
1927	18,90	1953	34,60
1928	20,90	1954	39,10
1929	32,70	1955	23,40
1930	12,50	1956	27,70
1931	25,90	1957	27,60
1932	18,40	1958	24,00
1933	15,60	1959	20,50
1934	18,30	1960	30,40
1935	28,00	1961	16,10
1936	36,20	1962	24,30
1937	25,80	1963	42,10
1938	35,70	1964	25,50
1939	29.60	1965	27,00
1940	35,50	1966	36,40
1941	37,50	1967	44,90
1942	30,60	1968	53,00
1943	35,30	1969	64,00
1944	33,20	1970	28,00
1945	27,60	1971	30,41
1946	32,00	1972	30,42
1947	26,20	1973	15,43
1948	35,80	1974	9,00
1949	23,20	1975	9,42
1950	24,90		

Mean Yearly Discharge through the years 1925-1973 is 29,14 milliard m^3
" " " " " " 1925-1975 is 28,36 " "

Note: Water year starts from the first of October of a year to the end of September of the next year.

Annex 3

B. IV.1

EXISTING RESERVOIRS AND STORAGE DAMS / FLOOD RETENTION BASINS*
1975/76

Name of Reservoir/ Dam	Location/ Region	Source of Water Supply	Storage Capacity MCM 2)	Objectives 1)	Remarks
Sama Sudud	Mafraq	Local Wadis	1.7	I; D	Effective Yields unconfirmed
Ghadeer Abyad	Mafraq	Local Wadis	0.7	I	Effective Yields unconfirmed
Um Jimal	Mafraq	Local Wadis	1.8	I; D	Effective Yields unconfirmed
Hawatda	Mafraq	Local Wadis	0.7	I	Effective Yields unconfirmed
Al-Lahafi	Dhuleil Area	Local Wadis	0.7	I; G	Effective Yields unconfirmed
Qatrana	Qatrana Area	Local Wadis	4.2	G; D; (I)	Effective Yields unconfirmed
Sultana	Sultana Area	Local Wadis	1.2	G; D; (I)	Effective Yields unconfirmed
Ziqlab	Wadi Ziqlab	Wadi Ziqlab	4.3	I	Jordan Valley Scheme
Shueib	Wadi Shueib	Wadi Shueib	2.3	(I)	Excessive Seepage; Limited Storage Effect
Kafrein	Wadi Kafrein	Wadi Kafrein	4.8	I	Jordan Valley Scheme
King Talal	Zarqa River	Zarqa River	48	I; (D)	Jordan Valley Scheme + Amman Water Supply

* Source: National Water Master Plan of Jordan, Vol. III, 1977.

B. IV.1 (Cont'd)

RESERVOIRS PROPOSED/UNDER STUDY*
1975/76

Name of Reservoir/ Dam	Location/ Region	Source of Water Supply	Storage Capacity MCM 2)	Objectives 1)	Remarks
Maqarin	Yarmouk River	Yarmouk River	(200)	I; D; H	Under Scope of Jordan Valley Project, Stage II
Wadi Arab	Wadi Arab	Wadi Arab	(20)	(I)	Tentative For Jordan Valley Project
Tannur + Ruweihi	Wadi Hasa Wadi Hasa	Wadi Hasa Wadi Hasa	(14) (2.5)	(I) (F) Flood Storage	Tentative Under Southern Ghors/Mujib Scheme Economy not confirmed
Rumeil	Wadi Wala	Wadi Wala	(30-75)	(I) (D) Flood Storage	Studies under Mujib Scheme; Domestic Supply
Nukheila	Upper Wadi Mujib	Wadi Mujib + Upper Tribut. (Wadi Nukheila)	(5 - 6)	(I)	Tentative Under Mujib Scheme; Economy not confirmed
Wadi Abyad	Wadi Abyad	Wadi Abyad	(12)	(G); (I)	
Swaqa	Wadi Swaqa	Wadi Swaqa	(2.8)	(G); (I)	
Al-A'keb	Wadi A'keb North Badia	Wadi A'keb	(1.4)	(G); (I)	
Wadi Sir	Wadi Sir Town	Wadi Sir/	(2-3)	(D)	Affecting Inflow to Kufrein Reservoir
Abdoun	Upstream Amman	Wadi Abdoun	?	(G); (D)	(Tentative Suggestion)
Dhuleil	Near Subkhna	Wadi Dhuleil	(18.5)	Flood Storage	Affecting Inflow to King Talal Reservoir (Prelim. Study)
Yabis	Wadi Yabis	Wadi Yabis	(2.8)		
Jurum	Wadi Jurum	Wadi Jurum		(H)	Only In Connection With Hydro-Power Scheme Presently under Study (AWSS)

* National Water Master Plan of Jordan, Vol. III, 1977

Annex 4

B. VI.1*

Chemical Analyses of Groundwater in Mediterranean Province Basin

Groundwater Area	Age	Area Name	Cations (Meq)			Anions (Meq)					T.D.S.	Hardness
			Ca	Mg	Na+K	Cl	SO_4	CO_3	HCO_3	NO_3		
Karstified	Jurassic	Ayoun	3.5	2.5	0.9	0.5	0.6	-	5.7	0.1	386	30
		Kesrouan	1.6	1.4	0.2	0.5	0.4	0.1	2.2	-	151	15
		Barouk-Niha	2.4	0.3	0.3	0.4	-	-	2.6	-	157	135
	Cenomani-an	Mount Lebanon Pachine	2.5	1.1	0.3	0.6	0.1	-	3.2	-	198	18
		South Lebanon Ras El Ain	4.5	1.7	0.8	1.0	0.1	-	5.9	-	374	31
		Hadath Hazmiye	5.9	2.6	0.1	2.0	0.9	-	5.7	-	472	42
	Eocene	South Lebanon Nabatiye Doubbe	3.8	1.7	1.2	1.0	0.3	0.2	5.2	-	358	27
	Mioceme	Koura Tripoli	5.4	0.6	1.3	2.0	0.7	0.1	4.5	-	632	30
Permeable Areas	Cenoma-nian	Mount Lebanon Sannine	2.4	0.9	0.4	0.4	0.8	-	2.5	-	180	167
	Quater-	Akkar	3.0	2.2	1.5	1.2	0.1	0.2	5.2	-	340	28
		Choueifate	4.8	3.5	3.6	6.8	2.3	-	2.8	-	792	375
		South Coast	4.8	3.1	1.1	2.0	1.8	0.1	5.1	-	414	345

* Etudes des Eaux Souterraines - UNDP 1970

Annex 4 (Cont'd)

B. VI.1*

Chemical Analyses of Groundwater in the Interior Province Basins

Goundwater Area	Age	Area Name	Cations (Meq)			Anions (Meq)					T.D.S.	Hardness
			CA	Mg	NA+K	Cl	SO_4	CO_3	HCO_3	NO_3		
Karstified Area	Jurassic	Parouk*Niha	3.5	0.9	0.4	0.5	0.3	0.1	3.8	0.1	266	22
		Jdita	3.5	0.9	0.4	0.5	0.3	0.1	3.8	0.1	266	22
		Hermon	2.5	1.4	0.3	0.4	0.5	-	3.3	-	214	19.5
		North-East of Serghaya	2.8	1.1	0.4	0.6	0.2	0.1	3.3	0.1	227	19.5
	Cennomanian	Mount Lebanon	2.2	0.8	0.1	0.3	-	-	2.8	-	160	15
		Anti-Lebanon	2.8	1.1	0.4	0.6	0.2	0.1	3.3	0.1	227	19.5
		Bekaa South Karaoun Tel ed Deir	3.4	1.1	0.5	0.7	0.2	0.1	4.0	-	251	22.5
	Eocene	Bekaa South Marjayoun Anjar	3.2	0.9	0.6	0.7	0.3	0.1	3.4	0.2	346	20.5
		Bekaa East-Terbol Ras Baalbeck	4.2	1.3	0.5	0.6	0.6	0.1	4.5	0.2	364	27.5
		Bekaa West Zahle Chmistar	3.0	0.4	0.2	0.6	0.1	0.2	2.7	-	164	17.0
Permeable Area	Quaternary	Bekaa El Marj Hermel	4.1	1.8	0.8	0.9	0.6	0.1	4.8	0.3	450	29.5
		Bekaa (plain)	8.5	4.1	4.7	6.3	5.1	0.1	5.0	0.8	1318	63

* Etudes des Eaux Souterraines - UNDP 1970

Annex 5

B.VI.2

Average Annual and Monthly Surface Water Flows

a) Mediterranean Province

River	Monthly Flows (MCM)												Av. Ann. flow MCM
	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	
Al-Jabeer	25,52	35,62	33,87	29.69	16,18	10,61	7,26	6,71	5,84	4,70	6,21	7,87	190,01
Ostouene	5,80	10,46	9,71	9,77	7,43	5,43	3,50	3,30	3,00	2,50	2,16	2,05	65.11
Akka	5,84	16,80	11,57	6,06	5,93	3,86	2,54	2,44	2,38	2,10	2,70	2,74	64,96
El-Bared	18,21	27,97	25,57	39,30	39,49	38,60	28,00	20,00	15,00	15,00	7,91	6,92	287,97
Abu-Ali	19,73	31,06	29,54	39,05	40,09	40,62	23,00	12,00	9,00	6,00	5,67	6,64	262,40
Al-Jawz	8,19	9,34	8,94	16,55	15,01	9,07	2,24	1,41	1,03	0,97	1,22	1,70	75,67
Ibrahim	29,10	50,40	42,90	74,00	108,00	109,00	45,00	21,00	10,00	7,50	6,00	5,00	507,90
El-Kelb	16,08	30,50	36,80	48,60	41,00	25,70	16,00	10,50	8,00	7,00	6,50	6,88	252,56
Antelias	1,34	2,68	2,25	2,14	2,08	2,01	1,30	1,07	0,80	0,52	0,80	0,78	17,77
Beirut	6,94	20,20	24,30	24,80	14,37	4,39	1,37	0,80	0,62	0,26	0,67	2,64	101,36
Damour	37,10	87,60	57,60	24,50	19,30	12,73	5,56	3,35	2,33	1,76	2,52	2,15	256,50
Al-Awali	26,00	48,90	63,50	36,30	19,35	12,80	10,10	13,40	15,40	12,74	13,30	12,56	284,35
Saitaniq	0,91	3,56	2,96	1,72	1,42	0,37	0,23	0,05	0,03	0,02	0,03	0,11	11,31
Zahrani	4,36	8,10	8,20	5,75	3,92	1,86	1,27	1,03	0,87	0,80	0,97	1,56	38,59
River or Spring Lower Litani	5,10	3,22	18,75	28,80	18,10	30,40	11,34	4,21	3,91	1,92	2,04	2,04	129,83
Ras El Ain	2,28	2,93	2,02	2,86	2,54	2,50	2,33	2,28	2,09	1,97	1,96	2,30	28,06
TOTAL	212,30	389,34	378,48	389,89	354,21	309,95	161,00	103,55	80.30	65,76	60,66	63,94	2568.64

Annex 5 (cont'd)

B.VI.2

Average Annual and Monthly Surface Water flows

b) Internal Province

River	Monthly Flows MCM												Average Annual flow MCM
	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	
Al-Asi	31,20	32,60	32,10	44,05	52,60	55,74	54,16	53,06	45,98	40,05	37,04	33,88	512,46 (1)
Upper Litani	41,50	14,70	115,90	105,70	84,00	56,40	32,40	35,30	22,10	21,60	24,30	27,40	641,30 (2)
Al-Hasbani	7,39	15,72	27,36	26,85	21,00	13,02	9,39	7,91	6,83	5,04	4,28	6,60	151,39 (3)
TOTAL	80,09	133,02	175,36	176,60	157,60	125,16	95,95	86,27	74,91	66,69	65,62	67,88	1305.15 (4)

1- 410 million goes to Syria

2- 220 million m^3 **is** stored in Qaraoun Lake

3- 140 million m^3 goes to Palestine

4- 550 million m^3 goes to Syria & Palestine

Annex 6

B.VI.3

Hydraulic Balance Sheets - Mediterranean Province

Zone	Age	Area Name	Surface Area (km^2)	Rainfall (mm)	Rainfall ($10^6 m^3$)	Water Deficit (mm)	Water Deficit ($10^6 m^3$)	Infiltration (mm)	Infiltration ($10^6 m^3$)	Runoff (mm)	Runoff ($10^6 m^3$)	T (m
Karstified Areas	Jurassic	Ayoun-Harf el-Mkass	135	1400	190	630	85	603	81	167	23	7
		Kasrouane	450	1450	650	700	315	625	280	135	55	7
		Barouk-Niha	90	1660	150	700	63	680	62	280	25	9
		Jisr el Qadi	17	1200	2,2	600	1,1	356	0,6	244	0,5	6
		Total (rounding)	690	1430	990	670	465	590	425	170	103	7
	Cretaceous Cenaman Turonien	Rachine-Chekka	700	1400	980	640	450	570	400	190	130	7
		Batroun-Jounieh	360	1100	400	550	200	485	175	65	24	5
		High plateaus of Lebanon	150	1650	250	725	110	810	120	115	20	9
		Hadath-Hazmieh	10	880	8,8	585	5,85	185	1,85	110	1,1	29
		South-Lebanon	910	850	770	450	400	340	315	60	55	40
		Chouf-Jezzine	130,5	1400	183	700	92	560	73	140	18	70
		Total (Rounding)	2260	1150	2600	560	1250	487	1100	103	250	59
	Miocene	North-Lebanon	103	950	100	531	55	333	34	86	9	41
	Eocene	South-Lebanon	540	800	430	480	257	225	120	95	53	32
Permeable Areas	Quaternary	Mountainous areas	100	1650	165	740	75	410	40	500	50	91
		Coastal areas	375	900	335	630	235	135	50	180	50	27
		Total (rounding)	475	1060	500	655	310	195	90	210	100	40
Low Permeable areas	Infra-cretaceous	Mountainous areas	248	1650	410	740	185	165	40	745	185	910
	Albien Aptien	Mountainous areas	453	1650	750	875	400	250	110	527	240	940
		Total (rounding)	700	1650	1150	829	585	220	150	610	425	829
	Miocene	Jabal Terbol	66	1000	66	500	33	200	13,2	300	20	500
Impervious	Senonian	In the province	298	700	210	600	180	Negligible		100	31	105
	Pliocene	North-Lebanon	73	9000	66	720	55	Negligible		180	13	180
	Miocene Pliocene Quaternary	In the province	300	850	256	680	204	Negligible		170	50	170
Mediterranean Province:		grand total (rounding)	5500	1163	6500	628	3500	360	2000	175	1000	535

Annex 6 (cont'd)

B.VI.3

Hydraulic Balance Sheets - Interior Province Basin

Zone	Age	Area Name	Surface Area (km)	Rainfall (mm)	Rainfall ($10^6 m^3$)	Water Deficit (mm)	Water Deficit ($10^6 m^3$)	Infiltration (mm)	Infiltration ($10^6 m^3$)	Runoff (mm)	Runoff ($10^6 m^3$)	Total outflow (mm)	Total outflow ($10^6 m^3$)
Karstified Areas	Jurassic	Barouk-Niha	160	1300	210	708	110	520	83	82	12	602	100
		Jdita	8	1300	10,4	700	5,6	515	4	85	0,7	600	4,7
		Hermon	420	890	370	490	205	350	145	50	20	400	165
		North-East of Serghaya	10	500	5,0	275	3	200	2,0	25	0,2	225	2,2
	Cretaceous (Cenomani-Turonian)	Lebanon, from Jdita to the Syrian border	960	1070	1025	596	571,0	440	420,0	34	34,0	474	454,0
		Anti-Lebanon from the Wazzani source to the north frontier	1115	600	670	340	380	222	250	38	40	260	290,0
	Eocene	South of the Bekaa (Karaoun-Telled Deir)	60	1000	58,0	634	37,8	345	20,0	21	1	366	21
		South of the Bekaa (Marjayoun - Anjar)	245	790	195,0	419	103,0	355	88	16	4	371	92,0
		East of the Bekaa (Terbol-Ras Baalbek)	52	440	23	256	13	169	9	15	1	184	10
		West of the Bekaa (Zahle-Chmistar)	17	600	10,5	350	6	230	4	20	0,5	250	4,5
Permeable Areas	Neogene, Quaternary	El Marj Bekaa Hermel	1260	450	560,0	360	450	21	23	69	87	90	110
Dry Areas	Cretaceous inferior to Neogene	Bekaa (in general)	393	510	200	260	102	Negligible		250	98	250	98
Interior Province: grand total (rounded)			4700	710	3300	425	2000	220	1000	65	300	285	1300

Annex 7

B.VII.1*

Estimates of Surface Runoff Volumes

For the Remaining Omani Wadis

WADI NAME	Total Area (Km^2)	Weighted Average Rainfall	Total Average Runoff (Mcm)
Wadi Bani Battash	188	200	40
Wadi Dhigda	105	175	61.3
Wadi Aqbiyah	622	165	72.5
Wadi Taww	310	167	72.5
Wadi Mistal	1010	215	85
Wadi Bani Ghafir	878	232	81.3
Wadi Hajr	371	200	40
Wadi Haylaln	702	193	71.3
Wadi Huthal	600	200	40
Wadi Doqal	540	200	76.3
Wadi Shafan	424	207	76.3
Wadi Al-Hilti	910	193	76.3
Wadi Khabiyat	662	180	67.5
Wadi Zabin	385	192	62.5
Wadi Bld	175	150	30
Wadi Dawr	475	207	71.3
Wadi Hulu	254	211	71.3
Wadi Ham	387	200	40
Wadi Fujayrah	330	225	45
Wadi Dadnah	333	225	45
Wadi Al-Fay	306	225	45
Wadi Dhabb Shansi	236	250	45
Wadi Limah	140	250	50
Wadi Aghda	595	200	40
Wadi Ibra	189	225	45
Wadi Khafifah	394	225	45
Wadi Bani Habib	789	227	90
Wadi Al-Habyat	369	275	55
		SUB-TOTAL	1645.4

* Source: Water Resources Council - Field Data on Surface Runoff in Oman

Annex 7 (Cont'd)

BVII.1

WADI NAME	Total Area (Km^2)	Weighted Average Rainfall	Total Average Runoff (Mcm)
Wadi Khawir	243	250	50
Wadi Lusayl	1726	247	110
Wadi Maqniyat	785	250	50
Wadi Al-Arid	289	225	45
Wadi Bijalah	207	225	45
Wadi Yanqul	663	250	50
Wadi Al-Khubayb	206	225	45
Wadi Shukayyah	205	250	50
Wadi Mudabbah	60	225	45
Wadi Jawwal	558	225	45
Wadi Al-Musaydirah	319	225	45
Wadi Sharm	478	250	50
Wadi Sumayni	298	225	45
Wadi Ausaq	400	225	45
Wadi Nagab	112	250	50
Wadi Shan	475	250	50
		TOTAL	2515.4

Annex 8

B.VIII.1

Permeability (K) Values Determined[1/]

for Selected Wells

Well No	Total Depth (m)	Saturated Thickness (m)	Discharge (m^3/day)	Specific Capacity m^2/day	Transmissibility (m^2/day)	Permeabi[lity] K m/d
A6	7.5	5.1	1702	554.6	480	94.7
A9	61.0	50.5	1058	361.1	290	5.7
A10	61.0	48.6	1020	449.3	370	7.6
A12	6.5	2.4	605	195.2	140	58.3
A13	61.0	51.5	1020	453.3	380	7.4
A30	11.0	5.6	605	125.3	82	14.6
B3	6.0	1.7	294	452.3	380	217.1
B5	17.0	3.8	363	226.9	170	44.7
B6	69.5	51.1	536	62.7	37	0.7
B7	61.0	46.7	341	140.3	95	2.0
B9	61.0	46.5	484	164.1	118	2.5
B10	61.0	39.0	622	116.9	75	1.9
B12	61.0	34.0	492	578.8	500	14.7
B14	61.0	28.6	518	1151.1	1100	38.5
B15	31.0	47.8	156	195.0	140	2.9
B17	55.8	40.8	389	54.0	31	0.7
B18	61.0	36.5	778	818.9	750	20.5
B21	61.0	45.3	415	49.4	27	0.6
B22	56.7	37.3	66	50.8	27	0.7
B23	35.3	14.4	66	12.2		
B24	61.0	41.4	950	730.8	150	15.7
B25	61.0	38.3	449	4490.0	3070	78.2
B26	61.0	24.9	52	34.6	19	0.8
B27	61.0	29.6	458	848.1	800	27.0
B28	61.0	34.7	747	230.0	170	4.9

Annex 8 (Cont'd)

Well No	Total Depth (m)	Saturated Thickness (m)	Discharge (m^3/day)	Specific Capacity m^2/day	Transmissibility (m^2/day)	Permeability K m/d	
B30	61.0	33.0	52	34.6	18	0.6	
B31a	61.0	28.5	747	43.1	24	0.8	
B32b	61.0	31.8	605	484.0	405	12.7	*
B33	61.0	41.6	492	820.0	760	18.3	
B34b	61.0	18.7	907	208.5	150	8.0	*
B35	61.0	33.1	569	307.6	240	7.2	
B36	61.0	20.3	613	88.1	55	2.7	*
B39	61.0	33.7	302	40.0	27	0.6	*
B43	61.0	5	622	368.0	300	5.4	*
C1	27.5	12.5	112	400.0	310	24.8	
C4	48.2	8.7	225	95.7	60	6.88	*
C6a	58.0	2.0	225	26.0	12	6.1	*

* Wells sited within major fracture zones

Average K for fracture wells = 38.44 m/d
" " " other wells = 12.20 m/d

1/ Source "Preliminary Report No.1, "The Water Resources of Qatar and their Development" UNDP/FAO 1977.

Annex 9

B.IX.1

(1) Showing Water Bearing Formations and Wells drilled in the mentioned locations which belong to Area I.

Location	Aquifer	Geological Age	Lithology	Thick- ness (m)	Well Na- me & No.	Depth (m)	Yield gpm	Water Quali- ty (ppm)	Temp. C°	Static Water le- vel (m)	Specif Capaci gpd/m
Al-Qassem	Saq	Cambrian	Sandstone & Sand	300 650	1-Q 88	650	500	700	40	+ 2	50
Al-Fuwailk Ain Ben	Saq	"	"	300	1-Q 107	200	200	700	30	70	25
Faheed	Saq	"	"	500	1-Q 12	1500	1000	650	45	+100	100
Tabuk	Tabuk	Ordovician Devonian	Sandstone Shale	250	1-T 24	250	250	650	28	+ 13	25
Al-Assafia	Tabuk	"	"	650	1-T 10	1000	150	650	35	25	2
Sakaka	Sakaka	Upper Cretaceous	Sandstone Shale	150		150	150	700	25	25	15
Al-Jauf	Jauf	Devonian	Limestone	150		150	200	500	28	+ 3	20
Ar ar	Aba ruath	Carbonife- rous	Limestone	70	1-NW 44	1400	400	650	42	+ 1	40

Annex 9 (cont'd)

B.IX.1

ıg Water Bearing Formations and Wells drilled in
ıed locations which belong to the Areas II and V.

Arabian Shield

Location

:thology	Thick-ness (m)	Well Name & No.	Depth (m)	Yield gpm	Water quality (ppm)	Temp. C°	Static Water level (m)	Specific Capacity gpd/m
;one, sand ıter-bedded ıth shale	315	Salboukh 14	1760	1000	1270	64,5	118	38,68
tone, sand ıter-ədded with ıale		Boueeb 7	1983	955	1536	68	115	26,93
tone, sand	160	DIWSU	1318,5	1200	490	54,7	± 95	
tone, sand	377	DIT 8	799,5	1618	810	47,7	+ 57	
tone, sand nd shale		2W9	220	258	7,8	35	13,4	13,5
tone, sand nd shale		5R 143 Nsah 12	220	950	390	29	72	137,7

Annex 9 (cont'd)

B.IX.1

(4) Showing Water Bearing Formation and Wells drilled in the mentioned Locations belonging to the Areas III, VI and VIII

Aquifer	Geological Age	Lithology	Thickness (m)	Well Name & No.	Depth (m)	Yield gpm	Water Quality (ppm)	Temp. C°	Static Water level (m)	Specific Capacity
Quaternary Alluvium	Quaternary	Gravels Sands fine sediments gilt	23	6-G-53	55,50	264	864	34,4	19,19	59,19
		—	6	6-G-52	50,50	206,9	768	37,1	23,68	26,05
		—	12	6-G-44	52	272,3	320	30,7	11,40	38,20
		—	15	3-N-13	34,5	228,9	320	24	2	25,18
		—	12	3-N-8	32,40	308	320	27,7	2,60	358

Annex 9 (cont'd)

B.IX.1

(3) Showing Water Bearing Formations and Wells drilled in the mentioned Locations which belong to the Areas IV and VII

Location	Aquifer	Geological Age	Lithology	Thick-ness	Well Name & No.	Depth (m)	Yield gpm	Water quality (ppm)	Temp. C°	Static Water level (m)	Specific Capacity gpd/m
Al-Hofouf	Neogene	Miocene	Limestone sand	100	Ministrys' wells in Abu Ghuneimu mountains	100	2000	1200	35	15	400
Al-Hofouf	Khobar	Pliocene	Sandstone & Silty stone	70	Al-mansoura	250	320	1300	30	18	44
Al-Dammam	Khobar	Pliocene	Sand & Silty stone	40	Al-Dammam	115	550 flowing	1500	30	flowing	
Al-Kateef	Khobar	Pliocene	Sand & Silty stone	50	Al-Kateef	150	800 flowing	1500	30	flowing	
Hafr Al Baten	Wasia	Cretaceous shale	Sandstone with some shale	100	No 4NI63 Al-Kaisouma						
Shroura	Wajid	Cambrian	Sandstone	100	Shoura Well	1150	560	800	42	87,50	40,14

Annex 10

BIX.2

List of Dams Constructed and their Characteristics*

Name	Catchment Area (Km^2)	Type	Storage Capacity (m3)	Length (m)	Height (m)	Location	Purpose
Hanifa		Concrete	1.3 million	390	9.5	Riyadh	
Laban		Rockfill	2.0 "	500	12.0	Riyadh	Recharge
Nammar		"	1.5 "	400	8.0	Riyadh	Recharge
Diriyah		Concrete	3.0 "	380	9.5	Al Diriyah	Recharge
Hair		Concrete	3.8 "	400	14.0	Riyadh	Recharge
Safar	54	Earth	300000	325	4.0	Riyadh	Rech. Aquifer
Hriqua	19	"	80000	190	6.0	Riyadh	"
Ghbeirah	21	"	90000	170	6.0	"	"
Jalajil		"	1.75 million	630	11.6	Sdair	Storage & Rec
Melham	20	Concrete	200000	100	4.0	Sdair	Storage & Rec
Hreimlah	350	Earth	1.5 million	1250	6.0	Sdair	Diversion
Majma'a	100	Rockfill	1.2 million	360	8.0	Sdair	Flood control recharge
Thadiq		Earth	2.0 million	850	7.0	Sdair	
Rawdah		"	3.0 million	554	14.0	Sdair	
Ghat		"	1.0 million	250	11.0	Sdair	
Khalah		Concrete	200000	60	7.0	Baha	
Jozan	1100	Concrete	71.0 million	316	41.6	Jizan	Flood control irrigation
Sa'ab		Earth	500000	290	10.0	Taif	
Abha	58.5	Concrete	2.4 million	350	33.0	Asir	Water supply
Bathan	20	Concrete	800000	266	12.5	Madinah	Rech. & Contr
Akramah		Rockfill	400000	300	8.0	Taif	
Shaqra'a		Rockfill	200000	90	10.0	Shaqra'a	
Marid		Earth	1.3 million	500	7.0	Asyah	Flood control
Ananyah		Earth		180	8.0	Qasim	Recharge and Diversion
Al Ainyyah		Masonry	1.0 million	400	5.0	Riyadh	Recharge and Storage

* Seven Green Spikes and Dams in Saudi Arabia (Arabic), Ministry of Agriculture and Water.

Annex 10 (Cont'd)

BIX.2

List of Dams to be Constructed or Under Construction

Name	Location	Type	Length (m)	Height (m)	Storing capacity (m^3)
Okda Dam	Hai'l	Earth	100	7	100,000
Salf Dam	Hai'l	Earth	230	6	150,000
Okoom Rabegh	Rabegh	Earth	800	6	Diversion Dam
Murat Dam	Murat	Earth	110	12	400,000
Rura'a Dam	Al-Madina	Earth	450	15	2,000,000
Rumma Dam	Al-Kaseem	Concrete	700	7	1,500,000
Al-Ghab Dam	Al-Madina	Earth	650	11	1,000,000
Hajla Dam	Aseer	Rockfill	110	12	1,000,000
Safrat Dam	Sadeer	Rockfill	490	13	1,000,000
Sroom Dam	Aseer	Concrete	75	13	1,000,000
Najran Dam	Najran	Concrete	250	60	85,000,000
Shuara'a Dam	Al-Dawami	Concrete	95	11	1,000,000
Lia Dam	Al-Tai'f	Rockfill	190	45	10,000,000
Turba Dam	Al-Tai'f	Concrete	380	21	20,000,000
Al-Hanabej	Al-Dawami	Earth	700	7	3,500,000
Kadoose Dam	Salboukh	Earth	520	7	700,000
Al-Akoul Dam	Al-Madina	Concrete	450	11	7,000,000
Houta Dam	Houta				
Bani Tameem	Bani Tameem	Earth	770	13	3,500,000
Samnan Dam	Al-Zulfi	Rockfill	150	21	1,500,000
Al-Ghayl Dam	Al-Aflaj	Concrete	126	11,5	2,500,000
Al-Sharaye' Dam	Al-Madina	Earth	500	8,5	88,000
Thama Dam	Babilkarn	Concrete	145	15	325,000
Surat Obeida Dam	Aseer	Rockfill	170	22	1,500,000

Annex 11

B.IX.3

Summary of Current Operation and Projects for Fresh Water production and Power by desalination in Saudi Arabia*

Region	Project: Name of Desalination Plant	Project: Phase	Capacity: Water Thousand (gpd)	Capacity: Power Mega-watts	Type of Fuel	Estimated Date of Operation	Region benefitting from Project
CENTRAL WESTERN	Jeddah	1	5000	50	Heavy Oil	Oper.since 1970	Jeddah & Surroundings
		2	10000	100	"	1977	" "
		3	20000	200	"	1980	" "
		4	50000	500		1983	" "
	Yanbu'	1	5000	50	Heavy Oil	1979	Yenbu' & Surroundings
	Medina	1	20000	200		1980	Medina and its surroundings
		2	40000	400		1984	
	Rabigh	1	240	-	Heavy Oil	1977	Rabigh and surroundings
NORTH WESTERN	Umm Lujj	1	120	-	Heavy Oil	Since 1975	Umm Lujj & surroundings
		2	1000	10		1982	
	Al-Wajh	1	60	-	Heavy Oil	Since 1969	Al-Wajh & surroundings
		2	120	-		1977	
		3	15000	150		1983	"
	Duba	1	60	-	Heavy Oil	Oper.since 1969	Duba town
		2	120	-	"	1977	Duba & surroundings
		3	5000	50		1979	Duba & industrial area
	Haql	1	120	-	Heavy Oil	1977	Haql town
		2	1500	15		1979	Haql & surroundings

* Saline Water Conversion Corporation Projects in Saudi Arabia (booklet).

Annex 11 (cont'd)

B.IX.3

Region	Project: Name of De-salination Plant	Project: Phase	Capacity: Water Thousand (gpd)	Capacity: Power Mega-watts	Type of Fuel	Estimated Date of Operation	Region Benefitting from Project
South Western	Al-Lith	1	120	-	Heavy Oil	1979	Al-Lith & surroundings
	Al-Qunfudhah	1	1000	-		1980	Al-Qunfudhah & surroundings
	Farasan	1	60	-	Heavy Oil	1979	Island of Farasan
EASTERN	Al-Khobar	1	7500	-	Natural Gas	Since 1974	Al-Khobar, Dammam, Qatif Saihat, Salwa
		2	50000	500	" "	1980	Most of the Eastern Region
		3	40000	400	" "	1982	The rest of the Region
	Jubail	1	2500	25	Natural Gas	1978	Jubail town
		2	20000	200	" "	1980	Jubail & Industrial Area
		3	30000	300	" "	1982	Jubail & Industrial Area
	Al-Khafja	1	120	-	Natural Gas	Since 1974	Al-Khafja & Al-Zurgani
		2	5000	50	" "	1980	Al-Khafja & surroundings
		3	25000	250	" "	1983	"
	Al-Uqair	1	25000	250	Natural Gas	1983	Al-Uqair & Industrial Area
CENTRAL	Al-Kharj	1	150	-		1980	Al-Kharj

Annex 12

B.X.1

Average Flow Rates of Main Springs

Period of records (1971-77)

Area	Spring Name	Average Flow L/s
Damascus	Al Figah (Ain Mne'en (Al-Haroush (Beit-Jen	6757 326 583
Dara'a	(Mzeireeb (Zeyoun (Al-Sakhneh	921 1328 427
Homs	(Ain Al-Tannour (Ain Al-Sakhneh	1169 341
Hama	(Safaafeh (Ain al-Ma'our & Al-Hajar (Ain al-fawwar (Ain Al-Bared (Abou Kbaiss (Ain Kalat & Al-Madeek (Al-Shari'a & Ain Al-Taka (Ain Joudeh (Naouret Shatha	6016 638 (for 1971 only) 593 1454.4 670 1527 4119.4 536 (for 1971 only) 368
Idleb	Yanabi Oura	1494.4
Aleppo	Ain Batman	389
Lattakiah	(Banias (Al-Surit & Harisoune	1492 1449

Annex 12 (cont'd)

B.X.1

FLOW RATES OF MAIN SPRINGS (Not mentioned in previous table) (1977)

Location & name of spring	Flow L/sec.	Location & name of spring	Flow L/sec.
Midanki	*1830	Damascus	
Sheeb	431		
Kutma	63	Barada	3330
		Ain Al-Khadra	150
Homs:			
		Ain Al-Irk	104
		Al-Naboue	168
		Sarda	170
Al-Haroun	180	Ouyoun Kalaya	234
Al-Sakhneh 2	120	Fasraya	159
		Deir-Al-Asaafir	247
Al-Samak (Kaseer)	401	Ras-Al-Ain (Ye'four)	314
		Ras-Al-Ain (Katana)	166
Hama		Saba (Irneh)	120
		Al-Bardeh (Irneh)	193
Byran	42	Al-Malha (Irneh)	125
Khan-Halaweh	53		
Tahoun Halaweh	*120		
Al-Wraideh	100		
Al-Kanieh	...	Al-Nabek	103
Al-Zahab	*160	Al-Karineh	186
Al-Dawar	74	Manbege	685
Al-Khateeb	200	Al-Kuteifeh	40
Al-Jrass	114	Shakhab	54
Al-Tayeb	* 50	Aleppo:	
Al-Jarab	71		
Al-Houra	...		
		Basouta	170
Mashta Mahfoud	* 61	Abou Kalkal	49

* 1967 figures Since 1977 figures are not available.

Annex 12 (cont'd)

B.X.1

FLOW RATES OF MAIN SPRINGS 1977

Location & name of spring	Flow L/sec.	Location & name of spring	Flow L/sec.
Dar'a:		Hama (cont'd):	
Al-Basal	46	Na'ouret Jourin	623
		Al-Difleh	...
Al-Bandak	143		
Al-Gazouli	235		
Al-Asha'ari	246	Al-Sous	...
Al-Ajami	230	Hailan	154
		Al-Samaneh	380
		Klaidin	35
		Al-Nasriyeh	250
Ain-Zakar	76	Al-Amikiyeh	53
Um Al-Dananir	131	Al-Kwaiz	730
Al-Suraiya	74	Al-Kharbaneh	41
		Al-Hawash	160
Quneitra:		Kastoun	200
Al-Fawar	...		
Al-Lowaizani	...		
Sa'ar	...		
Al-Burjiyat	...		
Al-Sayadeh	....	Sheezer	
Jleybeneh Kabireh	...		
Al-Balsam (Himeh)	...		
Al-Reeh & Makla (Himeh)	...		
Al-Himeh Al-Bardeh	...		
Al-Dub	...		
Nukheileh	...		
Al-Dardara	...		
Al-Fajera	...		
Al-Balou'	...		

1967 figures since 1977 figures are not available

Annex 13

B.X.2*

MAIN DAMS 1977

Name of dam	Location	Storage percentage %	Length M.	Maximum height M.	Surface area of basin (1000 M^3)	Storage capacity (1000 M^3)
a) Grand dams						
1-Euphrates	Al-Tabka	63	88000	40	625000	11600000
b) Medium dams						
1-AlRastan	Al-Rastan	80	446	69	19000	225000
2-Mouhardeh	North of Mouhardeh	100	230	52	4500	50000
3-Taldo	South of Taldo	100	1860	22	1570	15500
c) Surface dams						
1-Richeh	Damascus	-	190	6	1322	1750
2-Al-Dumair	Duma	9	425	16	650	2150
3-Al-Kalamoun	Al-Nabek	-	610	15	420	1630
4-Al-Ktaifeh	Al-Ktaifeh	-	160	18	79	502
5-Wadi Alkarn	Al-Zabadani	52	154	15	311	1700
6-Al-Ain	Salkhad	62	435	5	250	580
7-Dar'a	East of Dar'a	7	208	35	1365	15000
8-Um Jloud	Aleppo	3	432	14	462	3500
9-Al-Shahba	Aleppo	40	216	6	5000	12000
10-Maskanah	Homs	-	-	-	-	960
11-Al-Mohnaieh	Homs	38	306	9	185	600
12-Al-Talil	Homs	74	355	14	207	1000
13-Khirbet Al-Hamam	Homs	85	214	15	185	1250
14-Al-Kariatain	Homs	-	360	13	1400	5000
15-Al-Shandakieh	Homs	-	262	12	262	1250
16-Al-Marba'	Homs	-	420	10	1158	3200
17-Al-Wadi Al-Kabeer	Homs	-	212	10	200	515
18-Jbab Shakra	Homs	-	184	14	249	975
19-Sraiheen	Hama	9	194	19	176	1000
20-AlKafat	Hama	-	380	14	320	1500
21-Al-Lattamneh	Hama	-	157	11	215	650
22-Al-Ilbawi	Hama	12	521	13	300	1400
23-Abou Faiad	Hama	-	138	11	354	1100
24-Wadi Al-Azeeb	Hama	38	198	12	212	930
25-Beit Al-Kasir	Lattakia	-	254	18	166	737
26-Burmana	Lattakia	74	234	20	196	1365
27-Al-Wa'ar	Deir-ezzor	-	214	13	805	3345
28-Karima	Al-Hasakeh	2	255	11	800	1900
29-Abou Al-Kahf	Al-Raakka	1	194	9	390	620

* Statistical Year-Book, Syrian Arab Republic 1978

BIBLIOGRAPHY

1. Abd El-Al, Ebrahim. "Un Type Achevé de Torrent Cotier, Le Nahr Ibrahim". 1947.
2. Abd El-Al, Ebrahim. "Le Litani", Etude Hydrolique, Beyrouth, 1948.
3. Abu Sa'ada, S. "Ground Water in Kuwait" 1976, Arabic. (unpublished).
4. Akra, A. and Inglessis C.J. Republic of Lebanon, Council for Development and Reconstruction. "Potable Water Resources" March 1978.
5. ALECSO/UNESCO press: - National Science and Technology Policies in the Arab States, 1976. ISBN 92-3-001387-0.
6. Al-Saoud Al-Nasir, "Water Resources Development Centre". Ministry of Electricity and Water, Kuwait. (unpublished).
7. Ali Jaber Alawi, Engineer. A brief report on "Geology of Yemen Arab Republic and Exploration activities". Arabic, no date.
8. The ADAR Corporation. "Determination of Requirements for Resources Survey Programme". Yemen (YAR and PDRY), 1976.
9. The ADAR Corporation. "Integrated Resources Survey Programme, Wadi Beihan Region" (PDRY, YAR) Yemen. 1976. Part II.
10. Arab League. "Food Security in the Arab States". Part I, January 1980, Arabic.
11. Badri, M. Mahdi, Sh. and Khawar, G. "Water Resources and Water Balance in Iraq" 1976, Arabic. Submitted to ECWA 2nd regional meeting. pp. 28
12. Bahrain. Ministry of Works, Power and Water. "Policy on Water Distribution, Blended Supplies and Capital Investment Requirements". January 1979.
13. Bahrain. "Water Resources Situation in Bahrain". Memorandum No. 6, 1979, Arabic. p.6 and Figures.
14. Bahrain. Water Supply Directorate, Ministry of Works, Power and Water. "Water Supply to Villages", A Review, 1979.
15. Bahrain. Statistical Abstract of Bahrain, 1974.
16. Barber, W. "An Outline for Water Planning in East Jordan", Natural Resources Authority, Hashemite Kingdom of Jordan, August 28, 1975. pp. 41
17. Barber, W. and Carr., D.P. "Preliminary Appraisal of Water Resources, Phase I, UAE". 1976. pp. 46.
18. Bender, F. "Geology of Jordan", 1974.
19. Beydoun, Z.R. "The Levantine Countries: The Geology of Syria and Lebanon". The Ocean Basins and Margins, Vol. 4-A. 1977. pp. 319-350.

20. Beydoun, Z.R. "Observations on Geomorphology, Transportation, and Distribution of Sediments in Western Lebanon and its Continental Shelf and Slope Regions" January, 1976.

21. Bonifica. "Socio-Economic Development Plan for the Ram - Queira - Aqaba Area: First Stage: Hydrogeology, Wells Completion and Evaluation Report. Hashemite Kingdom of Jordan". 1975.

22. Bonificia. "Digital Model of the Qa Disi Aquifer of Southern Jordan". Hashemite Kingdom of Jordan, 1975.

23. Buckley, D.K. Shedlock, S.L. "Results of a Borehole Logging Investigation in the Qa Disi Area, Southern Jordan. Report No. WD/OS/77/8. Institute of Geological Sciences. 1977.

24. Burdon, D.J. "Handbook of the Geology of Jordan". Hashemite Kingdom of Jordan, Amman, 1959.

25. Burdon, D.J. and Otkun, G. "Hydrological Control of Development in Saudi Arabia" 1968.

26. Burdon, D.J. and Otkun, G. "Ground Water Potential of Karst Aquifers in Saudi Arabia" 1968.

27. Chow-Ven Te. "Handbook of Applied Hydrology" 1964.

28. Fannoun, A. Ministry of Irrigation, Iraq. "Irrigation Development and Water". (unpublished). No date.

29. Gibb, Sir Alex and Partners. "Water Resources of Abu Dhabi". 1970.

30. Gibb, Sir Alex and Partners. "Water Resources of Northern Oman". Final Report Vol. I. Main Report, June 1976.

31. Gischler, Christian. "Water Resources in the Arab Middle East and North Africa" 1979.

32. Halcrow, Sir William. "Water Resources of the Trucial States" 1969.

33. Halcrow, Sir William. "Wadi Surdud Development". Preliminary Report, Vol. I, Summary. Report to Ministry of Agriculture, Yemen Arab Republic, 1977.

34. Halcrow, Sir William. "Wadi Surdud Development". Preliminary Report, Vol. II, Main Report. Report to Ministry of Agriculture, Yemen Arab Republic, 1977.

35. Hashemite Kingdom of Jordan, "National Water Master Plan of Jordan" Vol. I - VII 1977.

36. Hashemite Kingdom of Jordan. Natural Resources Authority Pamphlets. No date.

37. Hashemite Kingdom of Jordan. Natural Resources Authority, "Ground Water Exploration Programme in Wadi Araba". (no date).

38. Hashemite Kingdom of Jordan. Natural Resources Authority Working Paper on "Irrigation Development in East Jordan", 1974.

39. Hashemite Kingdom of Jordan. Natural Resources Authority, "Mujib and Southern Gors Irrigation project". 1979.

40. Hashemite Kingdom of Jordan. Jordan Valley Commission, "North East Ghor Irrigation and Rural Development Project". 1973.

41. Hashemite Kingdom of Jordan. Papers presented at Jordan's National Water Symposium, held in Amman, 19-22 March, 1978.

42. Hashemite Kingdom of Jordan. Natural Resources Authority. "Aqaba Water Supply" prepared by Howart Humphreys and Sons, July 1977.

43. Hirzalla, B. and Joudeh, O. "Proposals for Artificial Ground Water Recharge in the Keramah - Rameh Area". Water Resources Division, Natural Resources Authority, Jordan. October 3, 1972 (unpublished).

44. Hirzalla, B. Proposal for "Groundwater Exploration and Development in the East Ghor Area" 1974.

45. Hirzalla, B. "Wadi Araba Development: Water Resources". Water Resources Division, Natural Resources Authority, Jordan 1974.

46. Hirzalla, B. "Ground Water Resources of the Jordan Valley" 1973.

47. Italconsult, "Water and Agriculture Studies in Bahrain" Final Report, Vol. I, 1971

48. Italconsult, PDRY. "Soil and Water Utilization and Conservation in the Wadi Tuban Watershed Area". Hydrological Report, Vols. I and II. DP/PDY/71/508/IAGL. September 1975.

49. International Geological Congress. Vol. 12, pp. 145-153. 1978.

50. Iraq: "Rural Water Supply Development Plan". Vol. II, Part I; by: Ward, Ashcroft and Parkman. UNDP/WHO IRQ/71/527 May 1974.

51. Iraq: "Rural Water Supply Programme". Vols. I - III. UNDP/WHO/EM/IRQ/PIP/002. November 1976.

52. Iraq: Minsitry of Irrigation. "Irrigation in Iraq". Baghdad. 1977.

53. Iraq: Ministry of Irrigation. Country Report to ECWA Second Regional Water Meeting, pp. 1-19, 1978/79 (Arabic)

54. Iraq: Country Report for the Regional preparatory Water Meeting of ECWA, 1976.

55. Iraq: Annual Abstract of Statistics Government of Iraq, 1972.

56. Ismail, El-Mohaylam, M. "Water Resources, UAE". 1976.

57. Jattal, A.E. and Harhash, I. "Ground Water Resources and their exploitation" presented to the second regional water meeting, ECWA. January 1979.

58. Johnson, Edward, E. Inc. "Ground Water and Wells" 1966.

59. Klimacki, K. United Nations Office of Technical Co-operation "Rural Development in Valley Hedramut and Northern areas of PDRY" Yemen, 1973.

60. Kuwait. Ministry of Public Works, Agriculture Department "Protected Vegetable Production in Kuwait", FAO pamphlet (no date).

61. Kuwait. Government pamphlets on "Power and Water Distillation plants at Shuwaikh, North and South Shuaiba" (no date).

62. Kuwait. Ministry of Commerce and Industry. "Explanation text to the Synoptic Geological Map of Kuwait", completed by Geological Survey of Austria, 1978.

63. Lebanon. "Recueil de Statistiques Libanaises", No. 9, 1973.

64. Linsley, Jr. R.K. Kohler, M.A. Paulaus, J,L.H. "Hydrology for Engineers" 1958.

65. LLoyd, J.W. Investigation of the Sandstone Aquifers of East Jordan, The Hydrogeology of the Southern Desert of Jordan. UNDP/FAO Technical Report. LA:SF/JOR 9, No. 1, 1969.

66. Macdonald, Sir M. and Partners. "East Bank Jordan Water Resources". Vol. 2-6, 1965.

67. Matheus, M. Bergman, H.J. and Abdullah Abdul Malek Badr. Country paper on "Ground Water for the Yemen Arab Republic", no date. (unpublished).

68. Murty, Y.S. WHO. "Rain Water and Drainage and Water Pollution, Municipality of Baghdad", 1976.

69. Oman. Oman Statistical Abstract, 1976-77.

70. Oman. Unpublished Information from the Water Resources Council (no date).

71. Oman. "Water in Oman" presented for distribution at the United Nations Water Conference, Mar del Plata, Argentina, 1977.

72. Parker, D.A. "Investigation to the Sandstone Aquifers of East Jordan: The Hydrogeology of the Mesozoic-Cainozoic Aquifers of the Western Highlands and Plateau of East Jordan," 1969.

73. People's Democratic Republic of Yemen. Board of Petroleum and Minerals, Department of Geology and Mineral Exploration. A brief report on "Geology and Mineralization in People's Democratic Republic of Yemen", no date.

74. Raikes, R.L. and Partners. "Simulation Study for a Water Use Strategy for the Qa Disi - Upper Wadi Yutm Sandstone Aquifer System. Evaluation of Alternative Water Resources", Rome. S.R.L. 1975. Rev. 1976.

75. Remote Sensing Center, Cairo - Feasability Study of a Proposed Transnational Project "Management of the Major Regional Aquifers in North East Africa and the Arabian Peninsula", August 1976.

76. Safadi. C. "Water Resources of the Syrian Arab Republic". Ministry of Public Works and Hydraulic Resources. 1979. Arabic.

77. Safadi, C. "Outlook for Investment in Ground-Water for Irrigation in the Syrian Arab Republic". 1976.

78. Saudi Arabia. Ministry of Agriculture and Water, "Seven Green Spikes". a booklet, 1974.

79. Saudi Arabia: Pamphlets of the Ministry of Agriculture and Water (unpublished, no date).

80. Sharaf-Eddine, Jaafar. "Water Situation in Lebanon". Ministry of Water and Electric Resources, 1971 (Arabic). pp. 20.

81. Syria. Report of the Committee for "Development and Exploitation of Barada River". June 1979.

82. Syria. Statistical Yearbook of Syria, 1978.

83. Taha, Faisal, C. "Agricultural Development in Kuwait with Special Reference to Water Resources". E/ECWA/IAD/WG-11/12.

84. Todd, D.K. Ph.D. "Ground Water Hydrology". 1963.

85. United Nations: "Special Agricultural Projects". Bahrain. AG: DP/BAH/74/005-UNDP/FAO, 1977.

86. United Nations: "Development and Use of Ground Water Resources of East Jordan". UNDP/FAO. AGL: SF/JOR 71/525 June 1974.

87. United Nations: "Planning and Development of Water Resources in Iraq". E/WNF - 70/AD 204, 1976.

88. United Nations, FAO PAG Mission, Arar, A. D.J. Burdon, A. Pecrot. "Technical Notes on Land and Water resources of The U.A.E. in relation to agricultural uses", 1973, pp. 53-70.

89. United Nations: "Living Conditions in Kuwait". UNDP/ADM/POST/KW/REV.3, 1977.

90. United Nations: "Rainfall Map of Lebanon - Hydro-Agricultural Development of South Lebanon". AE 106, UNDP/FAO, March 1973.

91. United Nations: Programme des Nations Unies pour le Developpement, New York. "Rapport Technique, Liban, Etude des Eaux Souterraines". 1973.

92. United Nations: FAO/UNDP Collating Mission to Sultanate of Oman, 1975-76.

93. United Nations: "The Water Resources of Qatar and their Development". Integrated Water and Land Use Project, Technical Report No. 9, UNDP/FAO

94. United Nations: "Stratigraphic Correlation between Sedimentary Basins of the ESCAP Region". Proceedings of the Regioral Special Working Group Meetings, Vols. III and IV, pp. 162-179. 1973 and 1975. ST/ESCAP/17.

95. United Nations: Report of the United Nations Water Conference, Mar del Plata, 14-25 March 1977. E/CONF.70/29.

96. United Nations: "Design of Water Resources Projects with Inadequate Data" Proceedings of the Madrid Symposium. UNESCO. WMO. IAHS, Vols. I and II. 1974.

97. United Nations: Economic Commission for Europe: "Long-Term Planning of Water Management" Proceedings of the Seminar on Long-Term Planning of Water Management, Zlatni Piasatzi (Bulgaria) 17-22 May 1976. Vols. I - III. ECE/WATER/15.

98. United Nations. Department of Economic and Social Affairs. Natural Resources, Water Series No. 4. "Ground Water in the Western Hemisphere" 1976. ST/ESA/35.

99. United Nations. Natural Resources, Water Series No. 1. "Management of International Water Resources: Institutional and Legal Aspects". 1975. ST/ESA/5.

100. United Nations. Department of Economic and Social Affairs. Natural Resources, Water Series No. 5 "Guidelines for Flood Loss Prevention and Management in Developing Countries" 1976. ST/ESA/45.

101. United Nations. World Meteorological Organization. Operational Hydrology, Report No. 12. "Applications of Remote Sensing to Hydrology" WMO. No. 513. 1979.

102. UAE: Statistical Yearbook, 1974, Ministry of Agriculture and Fisheries. (Arabic).

103. UAE. Ministry of Agriculture and Fishery Resources, Report on "Water Resources in UAE". Presented to the Second Regional Water Meeting. 1978/79.

104. UAE. Ministry of Electricity and Water, Water Division. "Water Resources", June 1976, by Dr. El Mohaylam, M. Ismail.

105. United States: Department of Interior, Bureau of Reclamation, Denver, Colorado. "Water Resources Investigation for the Nahr Abou Ali Basin". July 1958.

106. United States: Department of Interior, Bureau of Reclamation, Denver, Colorado. "Water Resources Investigation of the Nahr Ostouene, Nahr Aka, Nahr El-Bared, Nahr Abou Ali, Nahr Ibrahim, Nahr Kelb, Nahr Beirut" September 1958.

107. United States: Department of Interior. Geological Survey, Project Report. "Yemen Arab Republic, Investigations Data from Geological Investigations of the YAR 1976". 1976.

108. United States: Agency for International Development, Department of State. "Report on Water Resources Sector Study in the YAR". Project No. 298-0035. August 1977.

109. United States: Agency for International Development in Co-operation with YAR - US Geological Survey. "Brief Investigation of the Surface Water Hydrology of YAR". Open file report 77-150. 1977.

110. United States: Department of Interior. Geological Survey Water Supply paper. "Stream - Gaging Procedure. A Manual Describing Methods and Practices of the Geological Survey". 1962.

111. United States: Department of Interior. Geological Survey. "Theory of Aquifer Tests". Ground-Water Hydraulics. 1962.

112. United States: Department of Interior. Geological Survey Water-Supply 887 "Methods for Determining Permeability of Water-Bearing Materials, with Special Reference to Discharge-Well Methods". 1942.

113. VBB. Consulting, Fawzi and Assoc. "Water Resources Study of Amman Water Supply" AWSA, Amman, November 1976.

114. The Water Research Association, England. Proceedings of the Artificial Ground-Water Recharge Conference 21-24 September 1970. Vols. I and II.

115. Watson. J.D. and D.M. "Bahrain Sewerage Project". Vol. I, Master plan 1975.

116. The World Bank. World Development Report, PP. 76-77. August 1978.

117. Yemen Arab Republic: Ministry of Agriculture. "Water Supply for Sana'a and Hodeida. Sana'a Basin" Ground Water Studies (Vols. I and II). 1973.

118. Yemen Arab Republic. Ministry of Agriculture. "Development of Wadi Bana, Stage I". Preliminary Report, 1977

119. Yemen Arab Republic: Ministry of Agriculture. "Development of Wadi Rasyan, Stage I". Preliminary Report, 1977.

120. Yemen Arab Republic: Ministry of Agriculture. "Development of Wadi Bana and Wadi Rasyan. Stage I". Appendices to Preliminary Report, Soil and Classification Maps. 1977.

121. Yemen Arab Republic: Ministry of Agriculture. "Development of Wadi Jawf, Stage I". Preliminary Report. 1977.

122. Yemen Arab Republic: Ministry of Agriculture. Development of Wadi Al-Kharid. Stage I". Appendices to preliminary report. 1977.

123. Yemen Arab Republic: Ministry of Agriculture. "Irrigation and Agriculture Development in Wadi Rima, Volume I". 1977.

124. Yemen Arab Republic: Board of Petroleum and Minerals. "Five Year Plan for Geological Survey and Mineral Exploration in YAR" (Arabic).

125. Yemen Arab Republic: "Summary of Hydrology in Yemen". Paper presented to Second Regional Water Meeting of ECWA, January 1979.

126. Yemen Arab Republic: "Land Evaluation and Classification from Landsat". Imagery in the YAR (Map) 1975.

127. Yordanov, Y.U. "Apercu Succinct sur le Hydrogeologique du Liban", 1962.

128. Yordanov, Y.U. "Ressources Hydrauliques du Liban par Images". 1973.