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GROUNDWATER PROTECTION IN THE ARAB REGION

Prepared by the Working Group

Kamal F. Saad, Convenor (Egypt)
Jean Khouri (ACSAD)
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IHP

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PREFACE

No doubt Water is becoming the "issue" in the Arab countries with their truly and highly publicized water scarcity and potentials for conflicts. The updated 1993 report on the Water Security of the Arab World has estimated the total renewable water resources in these countries to be in the order of 352 billion m^3/year, of which 12% is groundwater. However, if one excludes the surface water from the internationally shared rivers (i.e., the Nile, Euphrates, etc.) with their known potential problems and considers the claimed 20,000 billion m^3 of nonrenewable aquifers, groundwater would certainly become the most important source of water in the region. It is a pity, however, that many cautions and worries are increasingly being voiced on the dangers that surround these valuable resources. The main elements of these worries are related to depletion of resources as a result of over abstraction and quality deterioration brought by many modes of contamination. The quality aspects are increasingly becoming important all over the world and prediction of pollution progress and protection of groundwater are becoming priority topics of research and applications. Besides the pollution from point and non-point sources such as agriculture, industries and domestic wastes, appreciable consideration are given nowadays to saline water intrusion in coastal and multilayered aquifers. These are becoming acute problems in the Arab World, threatening the availability of these vital resources and consequently the future survival of the human life in many parts of this region. It is hence becoming a very urgent responsibility of all concerned to protect these precious, but unfortunately extremely vulnerable, resources and manage them in a sustainable manner as a must for survival.

ROSTAS/ACSAD thought that they could play a modest role in that direction by launching a joint project, on "Groundwater Protection", that will act as a catalyst to promote wider and effective regional and international efforts in this field. This initiative is in line with the current UNESCO's IHP-IV and forthcoming IHP-V programmes. The main implementation tools of this project were a four-man working group and an expert meeting that was held in the period 18-20 October 1994 in Damascus. The working group has prepared a combined report that was discussed during the expert meeting which produced a coherent state-of-art document and a list of high priority topics and themes that can be followed up in the immediate and medium term plans of the concerned agencies. This publication is a reviewed version of the above document. Great appreciation and thanks are due to the four-man working group who provided the technical material and its convenor who patiently and professionally edited the manuscript. The expert meeting in Damascus has added a lot to the material and format of the document and hence great appreciation must be extended to all of the experts who attended that meeting. Before sending the document for printing it was carefully reviewed by Prof. A/Wahab Amer of Cairo University and Mr. Tarek Ezzat, a colleague at ROSTAS, for technical and typographical mistakes, respectively. Their well appreciated contribution has added very much to the correctness of the text.

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INTRODUCTION

Groundwater constitutes an important and rather vital natural water resource to all Arab countries, besides it is considered the only and sole natural water resource to the majority of these countries. Therefore, exploitation of the groundwater reservoirs and water bearing formations, wherever these are found, is considered an essential and a must operation for any socioeconomic development, particularly in these Arab countries where aridity and semi-aridity prevail almost all through their geographical boundaries. Although there are alternatives for the provision of water resources, such as; surface water in rivers and water channels, surface water in drainage basins and catchment areas, reuse of agricultural and sewage water and desalination of sea and brackish water, yet the groundwater remains of pivoted importance to most of the Arab countries.

In quantitative terms, the up-to-date assessment of the groundwater availability in the Arab region indicates that the average annual natural replenishment of the groundwater reservoirs is of the order of approximately 40 billion m^3, where as the estimate of the total surface flow in rivers, replenished annually from the local rainfall within the frontiers of the Arab countries, is in the average of approximately 150 billion m^3. Thus, the groundwater represents approximately 21 percent of the total available water resources annually replenished within the Arab countries. Moreover, estimates of the groundwater storage in the various extensive and deep seated aquifers indicate huge volumes of groundwater which can be made available for economic exploitation.

In the light of the above, and in view of the fact that the surface water, flowing in perennial streams and rivers, is restricted to a few number of the Arab countries, whereas groundwater is available underneath most of the Arab region, this latter water resource renders worth consideration towards wise conservation and protection enabling sound environmental exploitation and safe economic utilization. Through these measures, the prevailing gap between available water resources and actual needs for various purposes can be adequately reduced, and water security targets in the Arab region can be reasonably realized both in time and space.

As things stand now, the groundwater in the Arab region is continuously threatened by unwise management which will ultimately lead to serious deterioration of this valuable water resource both in quantity and in quality. If such behavior continues in the same trend, unavoidable risks, health hazards and soil destruction will lead to harmful impacts, while rendering this water source out of any value for economic and safe utilization.

In order to avoid and/or mitigate the harmful impacts of the continuous deterioration of the groundwater, in both quantity and quality, that prevail in the Arab region, the UNESCO Regional Office of Science and Technology for the Arab States (UNESCO/Rostas), in collaboration with the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD), is launching a Regional Project on "Groundwater Protection in the Arab Region", for which the present State-of-the-Art Report represents its First Phase. This will be followed by the preparation of a Follow-up Project Document which will comprise some crucial problems and constraints that currently confront adequate protection of groundwater. Such project, which represents the Second Phase of the

Regional Project, will be financed and implemented by extra-budgetary funding.

OBJECTIVES

i) Developmental Objectives

The main developmental (long-term) objectives of this project are:

a) To contribute to rational development and management of groundwater resources leading ultimately to sustainable socioeconomic development;

b) to promote national, subregional and regional cooperation in groundwater training, studies, development and management;

c) to develop networks between training and research institutes in Arab States and leading similar institutes in advanced countries;

d) to enhance the participation of Arab Groundwater Specialists in the working groups of UNESCO (IHP) and the technical divisions of specialized professional NGOs (IAHR, IAHS, etc.); and

e) to enlarge the working group to cover focal points in all Arab States to work as a technical hand for the IHP committees.

ii) Immediate Objectives

a) creation of a coherent regional working group in groundwater;

b) publication of a regional state of the art report, identifying priorities and outlining realistic line of action;

c) preparation of a project document for an extra-budgetary funding proposal;

d) utilization of the members of the WG as focal points where UNESCO outputs (publications) queries could be disseminated in an effective way and feedback could be obtained;

e) serve as basic resource data for the training workshop planned to be held in 1995.

SCOPE OF WORK

The present work pertaining to groundwater protection, which meanwhile constitutes the First Phase of a further comprehensive study, will focus on identifying the state-of-the-art of groundwater situation in the Arab region. This implies exploring and exploiting groundwater basins with reference to the basic concepts, actions and impacts of the prevailing forms of the groundwater deterioration. Part I presents a general overlook of groundwater availability and utilization in the Arab region including the groundwater basins and their quantitative and qualitative aspects. Part II covers the basic concepts of prevailing groundwater deterioration problems in respect to depletion, contamination, and deterioration due to climatic changes. Part III is concerned with the state-of-the-art of groundwater deterioration in the Arab region based on four subregions, namely, the Arabian Peninsula (Saudi Arabia, Kuwait, Bahrain, Qatar, U.A. Emirates, Oman, and Yemen), the Mashrek (Iraq, Syria, Jordan, Lebanon and Palestine), the Nile Valley (Egypt, Sudan, Somalia and Djibouti), and the Maghreb (Morocco, Algeria, Tunisia, Libya and Mauritania). Adequate methods for groundwater protection are described in part IV. The final part contains conclusions of the overall aforementioned study and presents some specific recommendations, in form of sub-projects, for future actions.

PART I

GROUNDWATER AVAILABILITY AND UTILIZATION IN THE ARAB REGION

I.1 Major Groundwater Basins in the Arab Region

I.1.1 Definition, Continuity and Limits

An aquifer is a geologic formation, a group of formations, or a part of a formation that yields water to wells and springs. A reservoir is a natural or artificial place, while a basin is a natural geologic structure. Both reservoir and basin are receptacle for fluid, capable for storing and supplying that fluid. A group of interconnected aquifers is called a groundwater reservoir or a groundwater basin. Implied in the definition of a groundwater reservoir or basin, there are three phases of operation: the addition of water or recharge, the static retention or storage; and the diversion of water or discharge.

Any groundwater basin or reservoir has one or more natural recharge and natural discharge areas. Artificial or induced recharge, and artificial discharge or withdrawal of groundwater, imply disruption in the reservoir or basin equilibrium. True static retention of the groundwater does not exist in any reservoir or basin. Accordingly any ground water basin in nature, attains a state of dynamic equilibrium. However, the motion may be so slow as to be imperceptible, particularly in case where artificial recharge or discharge is out of operation, a case which is meanwhile rarely sustained in nature. On the other hand, change of rates of natural recharge, i.e., rate of precipitation, can disrupt the equilibrium, and consequently the motion can be perceived.

There can be no doubt, that each of the formations that constitute a groundwater reservoir or basin is connected above, below or laterally with one another. However, in cases where adjacent formations are neither porous, nor fractured, stored water in the particular groundwater basins may be restricted to individual isolated basins.

In the light of the above, the motion of ground water from a group of aquifers belonging to a specific age of geologic formation, to another group of aquifer of different geologic age, constitutes a normal operation. Such motion of groundwater provides thus a relatively continuous hydraulic system, where groundwater can move vertically or horizontally in any direction irrespective of any political boundaries between countries. Also, in view of the vast areal extent of the reservoirs and the diversity of aquifers in the Arab region, it may be difficult to precisely identify all probable natural resources responsible for recharging the aquifers.

However, the importance of groundwater in the Arab region should not be evaluated in terms of quantity only. Other characteristics of groundwater such as quality are equally important. Its widespread occurrence and ready accessibility with simple technology are among several advantages of utilizing this resource for domestic, industrial and agricultural purposes. Lack or scarcity of surface water in arid and semi-arid regions increases further its value for socioeconomic development of these regions.

I.1.2 Hydrogeologic Groups in the Arab Region

The groundwater basins in the Arab region can be subdivided into six distinctive hydrogeologic groups (UNESCO/ACSAD, edit, Khouri & Drouby 1988), which are:

i- Precambrian crystalline rocks.

ii- Tertiary and quaternary volcanic rocks.

iii- Primary continental sandy rocks.

iv- Secondary continental sandy rocks.

v- Secondary and tertiary carbonate rocks.

vi- Tertiary and quaternary alluvium rocks.

The geology and extent of the main aquifers of the hydrogeologic groups can be illustrated in Figs. (I.1a) and (I.1b) respectively. Some hydrogeologic characteristics of the major groundwater formations and their locations appear in Table (I.1).

The main features of these six hydrogeologic groups can be summarized as follows:

i- The groups located in the North and Middle regions of Africa are hydraulically separated from those in the Arabian peninsula and East Mediterranean because of the presence of the Red Sea graben.

ii. The basement complex outcropping at both sides of the Red Sea act as main recharge areas, particularly at the southern portion of the Arabian shield and the African horn, due mainly to excessive precipitation, which meanwhile gives favorable recharge potentiality to adjacent and underlying formations.

iii. The vertical hydraulic interconnection between the successive formations in some particular groups permits feeding the overlying formations, which act thus as natural discharge areas to the underlying formation outcropping at localities of favorable natural recharge.

iv. The natural recharge areas of the hydrogeologic groups differ from one another according to their locations, extensions, exposures on the surface, and to their interconnection, vertically or horizontally, with other groups and formations.

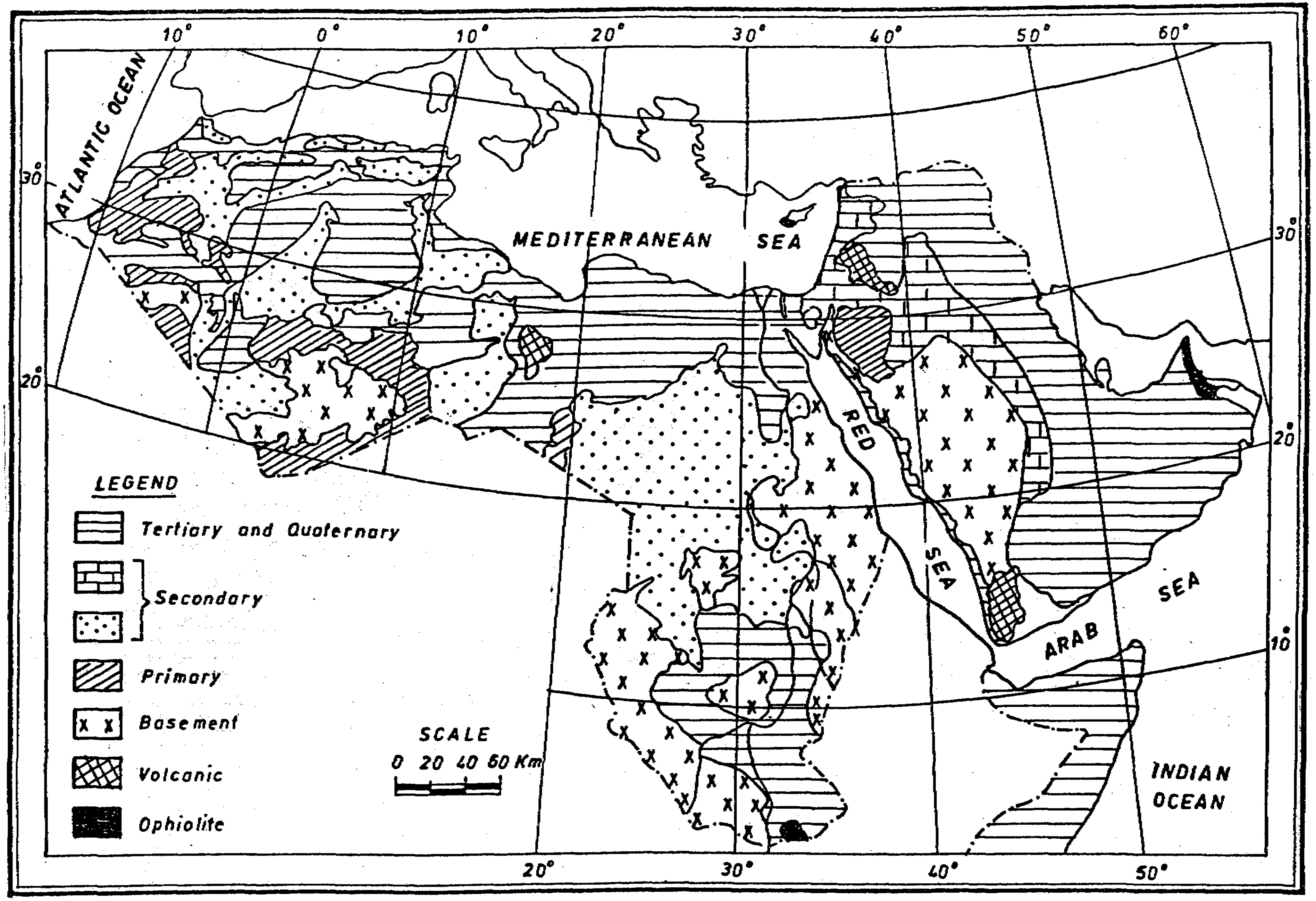
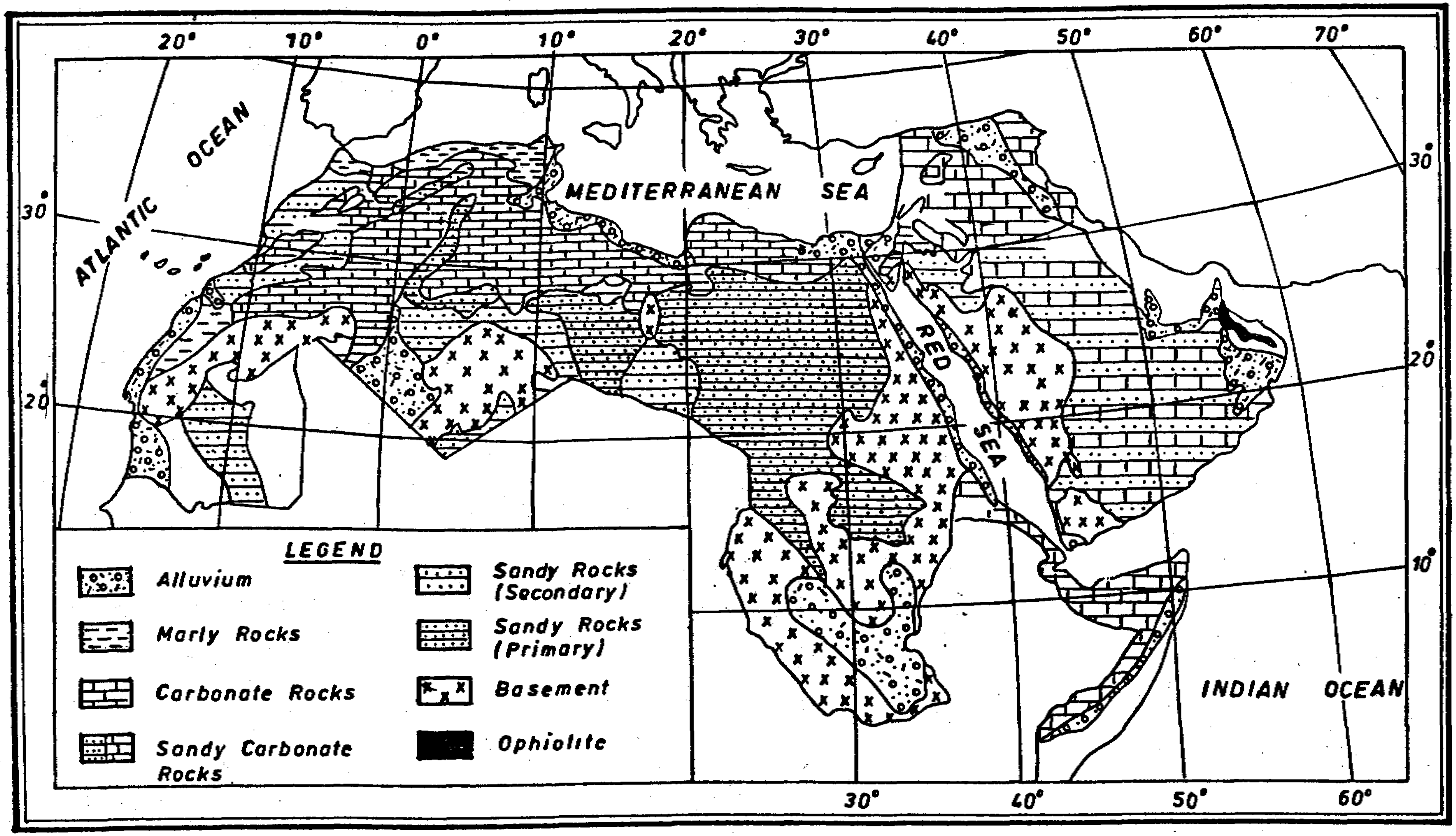


Fig.(I.1.a) GEOLOGIC MAP OF THE ARAB REGION



(FIGURE I.1.b) Aquifers rock groups of the Arab Region.

Table (I.1). The Hydrogeologic Groups in the Arab Region

Hydrogeologic Groups	Hydrogeologic Characteristics	Main Aquifers	Location of Aquifers
Permian Crystalline Rocks	Fissured Rocks, Low Productivity and Storage	Rocks of Arabian and African Basement	Yemen, Morocco, Sudan, Somalia, Algeria, S.A.
Tertiary & Quartenary Volcanic Rocks	Fissured Basalt, Limited Producti-vity and Storage	Paleogene & Neogene	East Region Arab Peninsula, Syria, Yemen, Jordan
Primary Continental Sandy Rocks	Continental Sand, Heterogeneous, Limited Productivity, over-Exploited	Saq, Tabuk, Wagid	East Arab Peninsula, North Africa, Middle Region
Secondary Continental Sandy Rocks	Sandstone Rocks of Various Texture, Poorly Recharged but possess Huge Fossil Reserve	Continental Intercalary and Terminal, Nubian Aquifer	Arab Peninsula, North Africa, Middle Region
Secondary & Tertiary Carbonate Rocks	Calcareous of Various Texture, Limited and Heterogeneous extension, High Discharge through Springs	Um Rudma, Damman, Cenom, Teron, Eocene	Syria, Lebanon, Jordan, Palestine
Tertiary & Quartenary Alluvial Rocks	Neogene & Quaternary Deposits, Poorly Cemented Widely Extended of Great Importance in the Arab Region	Sedimentary & Transported Rocks and Alluvium	River Delta of Nile, Tigris, Euphrates, Plains and Intermountain

v. The importance of the hydrogeologic groups for economic exploitation, to the relevant countries, is merely relative. Limited potentialities of some formations may represent high importance and top priority for exploitation in countries void of other diversified or alternative water resources, while other countries pledged by high groundwater potentialities may consider these of secondary importance, perhaps due to the presence of other water resources, or due to inappropriate geographic location of these basins for economic exploitation.

I.1.3 The Groundwater Basins of the Hydrogeologic Groups

The hydrogeologic map produced by UNESCO and ACSAD in 1988 (2 sheets of scale 1:5 million) depicts some 27 groundwater basins, covering the entire Arab region, including 137 hydrogeologic units. These units are classified geographically to five distinctive regions as follows: (Fig. I.2)

i- The Arabian peninsula region.

ii- The Eastern Arabian region.

iii- The Nile Valley region.

iv- The Atlas region

v- The Great Desert region.

The state of knowledge on the occurrence, quantity and quality of groundwater resources has reached an advanced stage in most Arab countries. A large number of aquifers has been recognized and their potential for development assessed. Aquifers, however are oftenly hydraulically interconnected with major aquifer systems. Large sedimentary basins underlain by such regional aquifer systems occupy vast basins reaching in

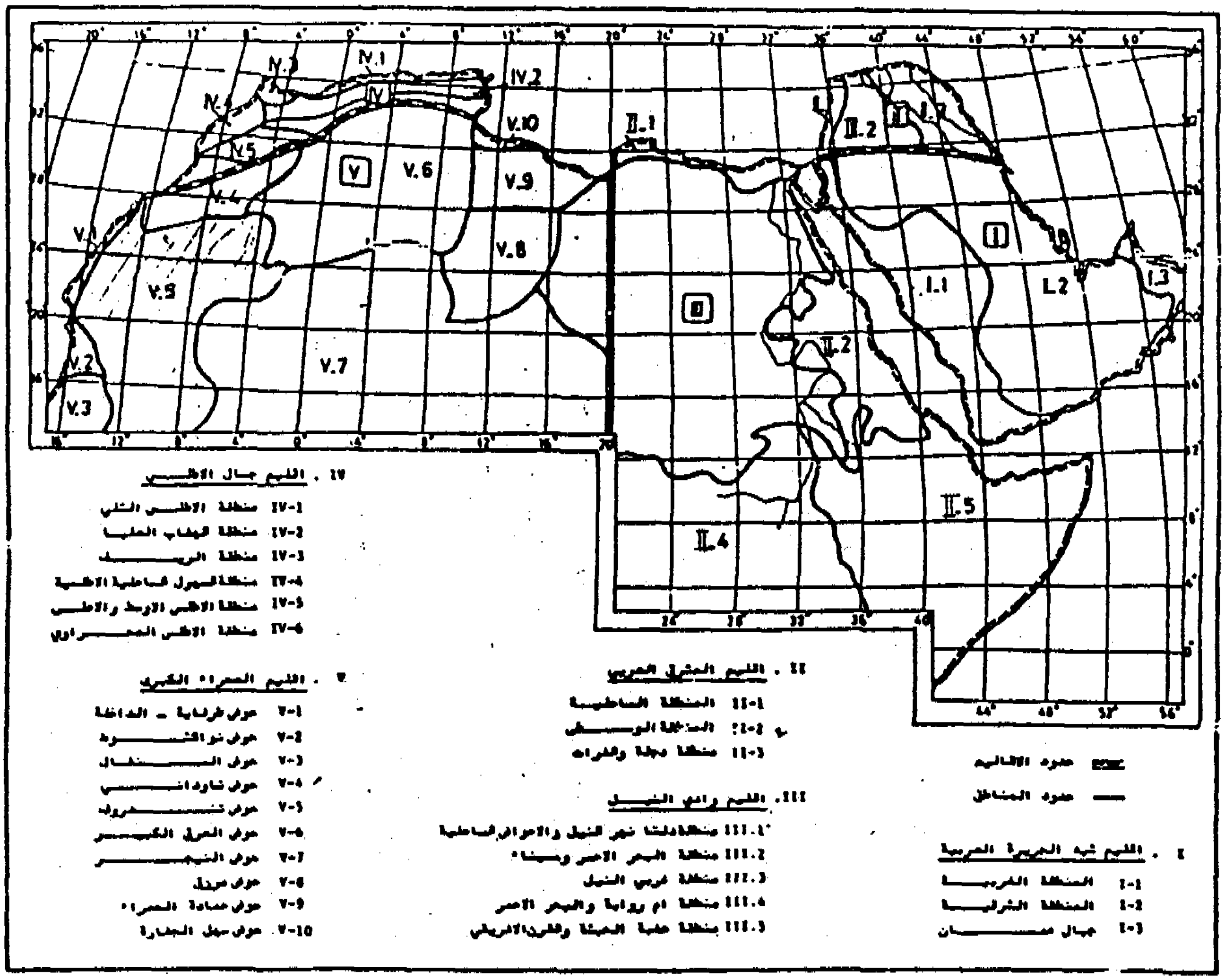


Fig.(I.2)-Hydrogeologic Basins in the Arab Region

I. Arabian Peninsula Region: (1.Western basin, 2.Eastern basin, 3.Oman mountains)
II. Eastern Arabian Region: (1.Coastal basin, 2.Middle basin, 3.Tigris & Ephrates basin)
III. Nile Valley Region: (1.Nile Delta & Coastal basin, 2.Red Sea &Sinai basin, 3.Western Nile basin, 4.Umm Rawaba & Red Sea basin, 5.Etheopian Plateau & African Horn basin)
IV. Atlas Region: (1.Telly Atlas basin, 2.Upper Plteau basin, 3.Reef basin, 4.Atlas Coastal Plain basin, 5.Upper & Middle Atlas basin, 6.Desert Atlas basin)
V. Great Desert Region: (1.Tarfaya-Dakhla basin, 2.Noakchot basin, 3.Senegal basin, 4.Taoudeni basin, 5.Tendouf basin, 6.Great Erg basin, 7.Niger basin, 8.Marzak basin, 9.Hamada Red basin, 10.Jifara Plain basin)

North Africa 2 million square kilometers. The following "great" basins could be recognized (Khouri & Drouby, 1990; Margat & Saad, 1984).

A. The Asian Part of the Arab Region: Mashrek and Arabian Peninsula

1. East Mediterranean rift basin
2. Jezira basin
3. Syrian steppe basin
4. Arabian Gulf basin
5. Tihama Alluvial (Wadi) basin
6. Oman Mountain Alluvial (Wadi) basins
7. Yemen Alluvial basins.

B. The African Part of the Arab Region

1. The Nubian Sandstone basin
2. The Fezzan basin
3. The North Sahara basin
4. The Atlas Intermontane basins
5. The South Sudan (Oum Rouwaba) fluvial basin
6. The Somalia coastal basin

The hydrogeology of these basins are described in several regional publication by ACSAD (1990), and UNESCO-ACSAD-IIHEE (1988), UN (1973), ESCWA (1992), SSO (1992) and other organizations, and need not be reviewed, in this report. However, an overview which emphasizes hydrogeological characteristics and natural attributes of the shared groundwater basins that influence the sensitivity of the system to human or natural impacts, need to be highlighted, in order to assess their vulnerability and possible response to human caused stress.

I.1.4 Shared Groundwater Basins

There exist some eight major groundwater basins which are shared between Arab countries, either due to their lateral extension or due to vertical or horizontal hydraulic interconnection. These basins are:

i. East Mediterranean Basin: The basin covers an area of about 48000 km² and extends across Syria, Lebanon, Jordan and Palestine. The main water bearing formations consist of fissured and Karstic rocks. The main recharge areas are the East Mediterranean Highs where considerable heavy precipitation prevails on quite extensive catchment area of high drainage density. The natural discharge areas of the basin are represented by springs of good quality water, feeding the rivers of El-Assi, and Al-Litani.

ii. Horan and Arabian Mountain Basin: The basin covers an area of about 15000 km² and extends across Syria, Jordan and Saudi Arabia. The main aquifers consist mainly of fractured basalt. The Golan Highs represent its main recharge area. The natural discharge areas of the basin are located at El-Yarmouk basin, and the natural spring of Mesirib, Azraq and Al-Hemma.

iii. East Arabian Peninsula Basin: The basin covers a fairly extensive area of about 1.6 million km² including Saudi Arabia, Bahrain, Emirates, Kuwait, Qatar, Yemen, Syria and Iraq. The main aquifers are composed of continental sandy formations, and carbonate rocks. The former are represented by the Saq, Tabuk, Al-Wasi, Al-Manjour and Al-Biyad aquifers, and the latter are represented by Um-Al-Rudma, Al-Damman and the Neogene water bearing formations. The natural recharge areas are restricted to the outcropping rocks of these formations where modest to limited precipitation prevails, while the natural discharge areas are poorly defined. The groundwater flow in general is toward the east and north directions. Some aquifers of this basin are presently over exploited.

iv. Great Erg Basin: The basin covers an area of about 600,000 km^2 extending across Tunisia, and Algeria. The main water bearing formations are composed of continental sandstones known as Continental Intercalary and Continental Terminal. The basin is characterized by huge water storage believed to be of fossil origin, however actual considerable rainfall prevails only on the western Erg and the Atlas Mountain. The natural discharge areas are represented by depressions and low lands, where evaporation processes are in excess, and through a number of natural springs.

v. Tandouf Basin: The basin covers an area of approximately 600,000 km^2 in Morocco and Mauritania. The water bearing formations are composed of sandy and calcareous rocks of limited recharge from local rainfall.

vi. Upper Gezira Basin: The basin covers an area of about 100,000 km^2 extending across Syria, Turkey and Iraq. The main aquifers are represented by the Eocene Carbonate rocks and the alluvial plains. The Zagros mountains represent the main recharge area of the basin, and the groundwater is naturally discharged through springs (Ras-El-Ain) and through feeding some rivers, e.g., Al Khabor. The basin is believed to be intensively exploited.

vii. Nubian Sandstone Basin: The basin is known to be one of the largest basins in the Arab region as it covers approximately 2 million km^2 extending across Egypt, Libya, Sudan, and Chad. The main water bearing formations are represented by continental sandstone with sand, silt and conglomerate successions. The groundwater in the basin is believed to be of fossil origin, however limited recharge is likely to arrive from precipitation falling on the formation outcropping in Chad, Sudan and Ethiopia.

viii. Taoudeni Basin: The basin is of limited areal extent of about 20,000 km^2 covering eastern Mauritania and northern Mali. The water bearing formations are mainly continental sandstone which are naturally fed by the Niger River during its passage through the formations. The discharge areas are poorly defined, however the basin is in contact with other adjacent aquifers which may be responsible for maintaining the basin hydraulic equilibrium.

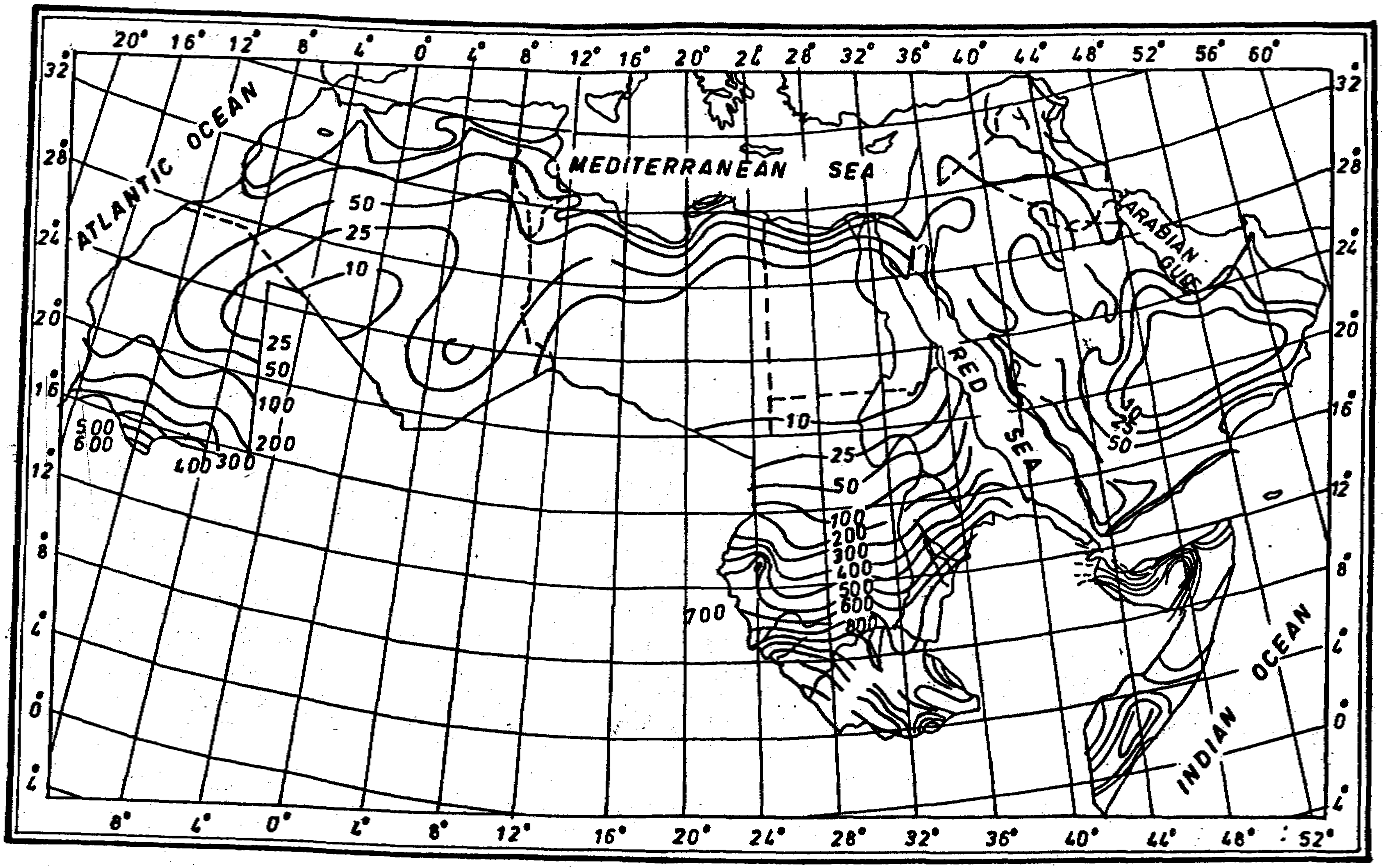
I.2 Quantitative Aspects

I.2.1 Natural Recharge Sources for the Groundwater Basins

The groundwater basins in the Arab region have diversified sources responsible for naturally recharging their water bearing formations and aquifers. These sources are represented in the following:

i. Rainfall: The rainfall reaches its maximum rates at the most northern and southern limits of the Arab region, where they range between 1500 to 2000 mm/year to the north of Lebanon, Morocco and about 1800 mm/year at southern Sudan. The rainfall diminishes toward the interior of the region to reach less than 100 mm/year at the desert region in both Africa and Arabian peninsula. Therefore, considerable amounts of recharge from precipitation are mainly restricted to the most northern and southern belts of the Arab region, whereas the precipitation prevailing at the rest of the region is considered of minor importance to feeding of the aquifers. Figure I.3 shows the distribution of rainfall in the Arab region.

ii. Seepage from large rivers and tributaries: The length of the water courses of the large rivers and their tributaries in the Arab region reaches approximately 34000 km represented in some 75 main rivers and tributaries. The main rivers are: the Nile (White, El Soubat, Blue and Atbara), Tigris, Euphrates and Jordan (Yarmouk, Banias and Hasbani). The catchment areas of these rivers and tributaries exceed 6 million km^2, with an average annual recharge of about 400 billion m^3.



(FIGURE 1.3) Map of annual rainfall in the Arab Region.

iii. Lateral and Vertical Seepage: The hydraulic conductivity and interconnection between various water bearing formations of the groundwater basins permit continuous movement from one aquifer to another in lateral and vertical directions. Such movement of groundwater takes place at both directions alike; from and to the Arab region.

iv. Downward Infiltration from the Irrigated Lands: The total cultivated lands under permanent irrigation in the Arab region is approximately 12 million hectares. These, in addition to the extensive irrigation system of canals and drains, allow for continuous feeding of the underlying water bearing formations.

v. Fresh Water Lakes and Artificial Reservoirs: There are numerous natural lakes in the Arab region, however the majority of these are in contact with seas, or act as outlets to drainage of irrigated lands. Few fresh water lakes in the region, subjected to fresh water replenishment from precipitation, may permit additional recharge to aquifers in contact. Also, some artificial lakes, represented by man-made reservoirs of various types of dams act as point feeding sources to adjacent aquifers.

I.2.2 Natural Discharge Areas of the Groundwater Basins

The natural outlets of the ground water in the various basins in the region, that are responsible for maintaining the hydraulic equilibrium of these basins are numerous and diversified. The most important of these are:

i. Coastal Areas in contact with Seas and Oceans: The Arab region is characterized by its long contact track with seas (Mediterranean, Red, Arabian Gulf and Arabian Sea), and oceans (Atlantic and Indian), which border the region from north, east and west, as well as at the interior. The total length of the contact line of the various water bearing formations with the shore lines reaches about 25000 km. These contact lines act as main natural discharge areas of groundwater basins in the region.

ii. Internal Lakes and Depressions: There exist a number of internal lakes, and depressions in the region which act as natural outlets to adjacent groundwater basins and aquifers, where groundwater move towards them and are lost by evaporation.

iii. Natural Springs: There is a large number of natural springs in the region which act as natural outlets of a number of water bearing formations. These springs are considered meanwhile as natural water resources that can be used directly or may naturally feed intermittent or perennial rivers and streams.

iv. Lateral and Vertical Leakage: Although these processes are considered natural discharge areas of water bearing formations, they also act as recharging sources to others. The process itself, whether discharging or recharging, is a normal action for maintaining the hydraulic equilibrium of any groundwater basin.

I.2.3 Estimates of Natural Recharge and Utilization of Groundwater

Although natural recharge and discharge areas of groundwater basins can be adequately identified, estimates of natural recharges and discharges can neither be easily evaluated nor accurately assessed. This may be due to the fact of extreme complexity of both hydrogeologic and hydrologic boundary conditions governing each particular groundwater basin. These coupled with natural interference and hydraulic interconnection between individual basins and their encountered water bearing formations, precise, or even satisfactory groundwater assessment is rendered thus a difficult task. Also, other types of induced water resources of undesirable quality, e.g., saline water intrusion, and contaminated or polluted surface water, preclude achieving appropriate groundwater evaluation. In addition to the above-mentioned complexity of boundary value problem, seasonal fluctuations of both rates of precipitation and water levels in surface water channels and rivers play important roles in the assessment operation.

Accordingly, and in due consideration for the need to acquire knowledge about the range of natural recharge of the groundwater basins, each country has endeavoured to approach estimates and average values of the availability of their water resources, which are inevitable components for any sustainable economic planning and development. Meanwhile, these estimates and accordingly the magnitude of the available amounts of the groundwater, do not properly differentiate between various qualities of groundwater, whether fresh, brackish, saline or polluted.

Table I.2 gives average estimates of annual recharge of the groundwater basins in each country, as well as the magnitude of possible storage, and the amount of groundwater utilized for various purposes (Saad, 1993). It should be understood, however, that the bases used for estimating these amounts differ from one country to another, and that these estimates may not necessarily include all the groundwater basins or water bearing formations in the particular country.

The total average annual groundwater recharge in the Arab region can be estimated as 39.54 billion m³, while the amount of groundwater used for various purposes is about 26.09 billion m³/year, which represents about 66 percent of the total recharge. The figures appearing in Table I.2 in regarding recharge and utilization do not account neither for the source of recharge, whether seepage from rivers or infiltration from precipitation or others, nor to the quality of the utilized groundwater. It is evident however, that some countries exploit groundwater from limited or non-rechargeable basins, while others exceed the rates of recharge. Both actions would lead to undesirable impacts as depletion and contamination of the groundwater basin. Also, the amounts of the stored groundwater are only indicative, as these do not include all basins in the Arab countries, but only for those which their hydrogeologic boundaries and extensions are so far known. However, some groundwater basins in the region contain huge reserves of water which can be safely and economically exploited with appropriate planning and management.

I.2.4 General Features of the Shared Groundwater Basins

The shared groundwater basins in the Arab region are of great importance due mainly to their considerable large areal extent across several countries. Some of these basins are known to have regular annual recharge, while others are of limited or non-recharge source. In regards to the recharge aspect, these basins can be grouped into three distinct categories, these are:

Table I.2. Estimates of Groundwater Recharge and Utilization in the Arab Region

Country	Area 1000 km³	Rainfall (10^9 m³/y)	Groundwater Recharge (10^9 m³/y)	Groundwater Storage (10^9 m³/y)	Groundwater Utilization (10^9 m³/y)
Mauritania	1030.7	157.2	0.75	400	*2.0
Morocco	710.9	150.0	10.00	200	3.0
Algeria	2381.7	192.5	4.20	1500	2.0
Tunisia	164.0	35.0	1.00	1700	1.53
Libya	1759.7	49.0	0.80	4000	1.72
Egypt	1001.4	15.0	**0.40	6500	3.43
Sudan	2505.8	1094.4	***7.80	4900	0.77
Somalia	637.7	190.6	3.30	-	0.02
Djibouti	22.0	4.0	0.05	-	0.02
Palestine	27.0	8.0	0.74	-	0.22
Lebanon	10.4	9.2	0.60	12	0.24
Jordan	90.0	8.5	0.41	-	0.51
Syria	185.2	46.0	****2.00	-	****3.50
Iraq	435.0	70.0	2.00	-	1.50
Kuwait	17.8	2.4	0.16	-	0.37
Saudi Arabia	2240.0	126.8	2.34	354	3.00
Bahrain	0.7	0.5	0.01	-	0.22
Qatar	11.4	0.8	0.06	2.5	0.10
UA Emirates	77.7	2.4	0.10	5.3	0.28
Oman	300.0	15.0	0.56	-	0.41
Yemen	550.0	67.2	1.40	-	1.25
Total	14158.9	2244.3	39.54	-	26.09

Source: Saad, 1993 - ACSAD

* Surface and groundwater

** From rainfall only

*** From Nile only

**** Excluding springs

i. Basins of considerable recharge from local precipitation on their outcropping rocks, e.g., Eastern Mediterranean, Horan, Gebal El Arab, and Gezira basins. In these basins, the rates of recharge differ in both space and time, which are reflected accordingly on the water levels at the lower reaches of these basins. However, these basins are widely exploited by the sharing countries.

ii. Basins of limited local precipitation, but of considerable seepage inflow from adjacent aquifers which are hydraulically connected with them. Important among these is the East Arabian Peninsula groundwater basin which is extensively exploited, particularly in the Arabian Gulf countries. Other basins, e.g., Taoudini and Tandouf are still not adequately identified, as these are located at remote desert areas which may require thus large investments for appropriate hydrogeologic investigations.

iii. Basins of limited, or perhaps non-recharging sources, e.g., the Nubian Sandstone and the Great Egr basins in the North Western African Desert. These basins are poorly exploited except in Tunisia and most recently in Libya and Egypt.

I.3 Qualitative Aspects

Fresh water is a vital resource for agriculture, industry, and for human existence itself. Water quality is a term which expresses the suitability of water to sustain various usages. Any particular usage requires certain physical and chemical specifications of the water, e.g., limits of concentration of toxic substances for domestic purposes. Water quality is normally defined by a range of variables which limit its mode of utilization. In the Arab Region, the groundwater quality is a major issue, due to the fact that the majority of the groundwater basins are located in arid or semi-arid environments, which reflects accordingly specific characteristics in respect to scarcity of water resources, irregularity of aquifer replenishment, and inadequacy of water quality. Moreover, the intensive exploitation of the groundwater in most of the Arab countries has led to adverse impacts on this resource, both quantitatively and qualitatively. Consequently, the groundwater quality is considered the decisive factor for any further development in many aquifers, particularly in those having limited extension.

I.3.1 Groundwater Salinity in the Arab Region

It has been demonstrated that the climatic conditions that prevail in the Arab Region (climate change, aridity, drought, and desertification) have direct influence on the groundwater quality. These severe climatic conditions preclude regular and adequate replenishment of the various aquifers under exploitation with the current rates of discharge. In addition to this, the presence of evaporites, and marine, lagoonal, and lacustrine deposits in the water bearing formations have also direct natural influence on the quality of the groundwater. Therefore the salinity of the groundwater can be either natural or induced.

(i) Natural Groundwater Salinity

The salinity of the groundwater can be classified in the following three categories:

- Fresh water with salinity less than 1 g/l.
- Slightly saline to Brackish water with salinity from 1 to 3 g/l.
- Saline water with salinity more than 3 g/l.

Fig. (I.4) shows the distribution of groundwater, in the Arab Region, with respect to its natural salinity. Fresh water is generally localized in areas of high precipitation. These areas are located along the Mediterranean sea coast , the Atlas mountain in Morocco and Algeria, the mountainous areas in west northern Jordan and Northern Iraq. Fresh water occurs also in large sedimentary basins, such as the Nubian sandstone basin, which is shared between Egypt, Sudan, Libya and Chad.

In the Arabian Peninsula, the groundwater salinity, in general, exceeds 1 g/l. The Dammam and Umm Raduma, which are considered the most potential aquifers in the Peninsula, have salinity ranging between 2.5 and 5 g/l, but increases in Kuwait, Qatar, and Bahrain.

In Syria, the salinity is generally higher than 1 g/l at the interior areas, and reaches 5 g/l in some localities, such as the Jezirah area. This latter high salinity is due to the presence of evaporites (gypsum).

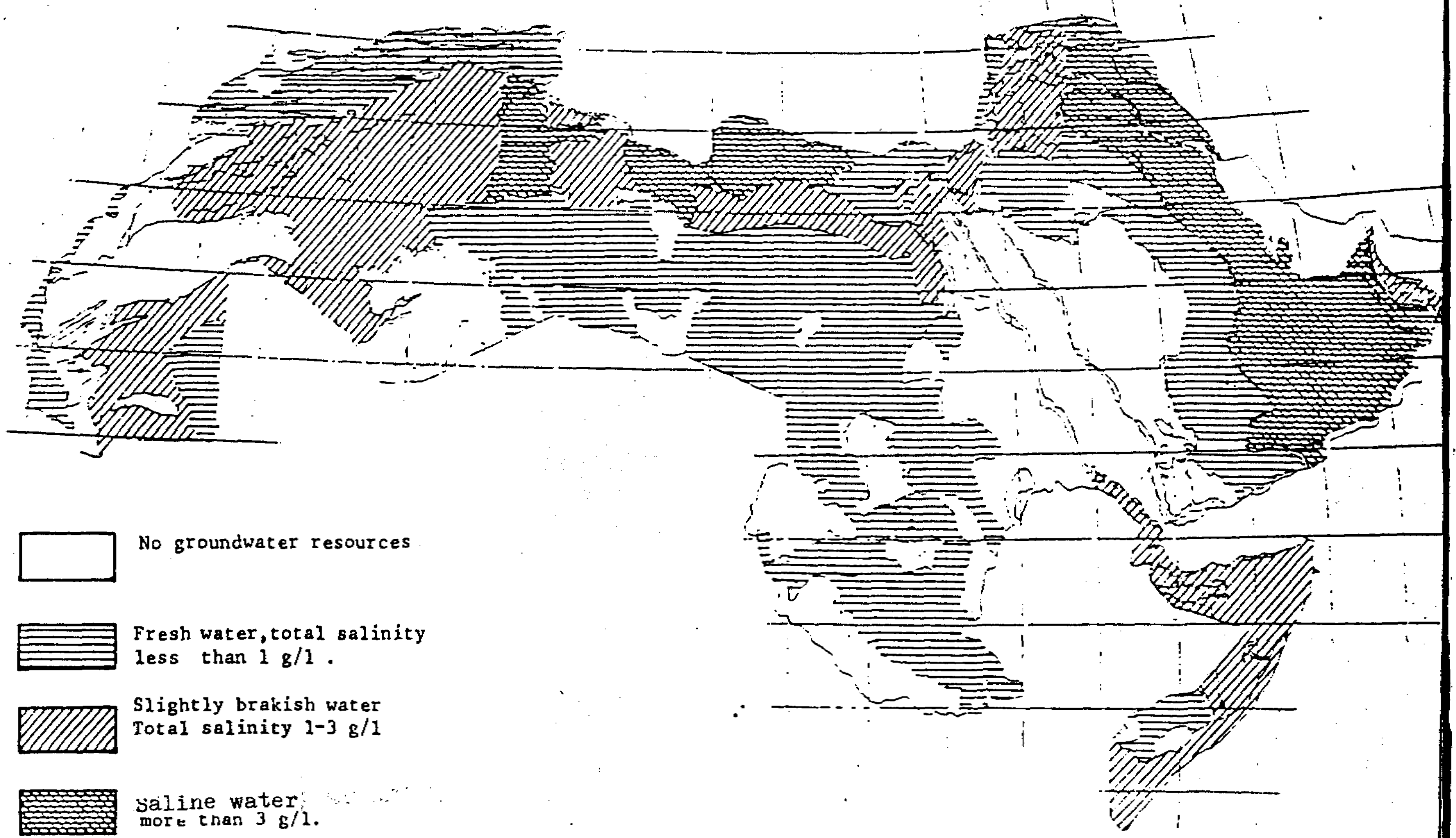
In Iraq, fresh water prevails in the north, but the salinity increases toward the central and southern zones, due to the presence of evaporites.

In Lebanon, fresh water prevails mostly all over the entire country due to high rates of precipitation.

In Egypt, the seepage from the Nile River, its branches, and irrigation network enhances the formation of fresh water in the Delta, the Nile Valley and their adjacent areas. To the north of Qattara depression, the groundwater is generally brackish to saline. In the Eastern Desert and Sinai, the salinity ranges between 2 and 5 g/l.

In Sudan, the groundwater salinity is in general less than 1g/l.

In Libya, fresh water is localized in Nubian aquifer, e.g., Kufra, Sarrir, and Murzok basins. Also, fresh water is found at Jebal Al-Akhdar at the north-eastern part of the country. Apart from these localities, brackish to saline water prevail in the country, e.g. Djefarah and Bengazi plains.



(Fig.I.4)-Ground Water Salinity in the Arab Region

In Tunisia, fresh groundwater is rarely found. The salinity of the deep aquifer at southern Tunisia is about 2.5 g/l, and reaches 4 to 8 g/l in the Jerba plain. In the northern and central zones, the groundwater salinity in the clayey formation exceeds 1.5 g/l, whereas it is less than 1 g/l in limestone aquifer.

In Algeria, with the exception of the deep aquifers in the south, fresh groundwater generally prevails in the country.

In Morocco, fresh groundwater is found in the north, but the salinity increases towards the south, e.g., Sakiya, El Hamra and Wadi el Dahab, where it varies from 2 to 8 g/l.

In Mauritania, brackish to saline groundwater generally prevail.

(ii) Induced Groundwater Salinity

Induced salinity of the groundwater is normally a result of overabstraction. Increase in salinity may be temporary due to seasonal fluctuation of climatic conditions, or permanent due to continued exploitation of groundwater at rates exceeding the normal recharge. Both actions may lead to salt water intrusion in coastal areas. Numerous examples of this phenomenon are found in all the Arab countries.

Also, overabstraction from an aquifer may lead to leakage of saline water from adjacent aquifers of higher salinity, e.g., the Russ formation in the Arabian Peninsula which contains highly saline water, damages the Dammam formation which is overexploited.

Return flow from irrigated lands may also cause increased salinity to the groundwater, as in the case of the Nile Delta, and Tigris and Euphrates valley.

I.3.2 Chemical and Biological Contamination of Groundwater

The agricultural, industrial, and domestic activities are all responsible for the deterioration of the groundwater quality both chemically and biologically. There are numerous examples in the Arab Region, particularly in urban areas. Damascus basin is a striking example, where the basin is charged from infiltration of surface water of the Barada river in which sewage waste water represents more than 40% of its base flow.

PART II

BASIC CONCEPTS OF GROUNDWATER DETERIORATION PROBLEMS

II.1 Forms of Groundwater Deterioration

Deterioration of groundwater basins may take one or both of the following forms:

i. Depletion of groundwater in regards to permissible exploitable discharge and/or water levels.

ii. Contamination of ground water either chemically, biologically or by radioactive contaminations.

Both forms of groundwater deterioration would ultimately render the basin out of any standard acceptable measures for safe and economic development. These forms however are normal, direct or indirect, impacts of inaccurate assessment of groundwater availability, inadequate planning for development of the basin, or due to inappropriate management of groundwater and lack of quantity and quality control.

The activities generating groundwater deterioration are numerous and diversified. Some of these activities would lead to depletion, while others are responsible for contaminating the groundwater bearing formations as follows:

i. The agricultural expansion and the continuous need for establishing irrigation projects based on groundwater may represent the main activity causing depletion and exhaustion of the aquifers. The agricultural activities are also responsible for contaminating the groundwater due to excessive nitrates derived from applied fertilizers and pesticides, and solid and liquid wastes of livestock feaces and urine, as well as due to drainage from farms, buildings and yards and silage.

ii. Industrial activities are evidently the main reason for contaminating both groundwater and surface water. The type of contamination of groundwater varies with the source of pollutant and ranging from cyanide wastes of metallurgical operations, through sulfite-rich paper and pulp manufacturing wastes, mercury rich materials from electrical industry, to solid residues from the petrochemical industries, the mining operations, and gas and oil production. However, the need for water (not necessarily groundwater) for industrial activities is considered extremely modest, as compared to the agricultural needs. Therefore, industrial activities cannot be considered as main cause for measurable depletion of groundwater, but mainly for contamination.

iii. The domestic and commercial activities are also considered among the main causes for contaminating the groundwater, with limited effect on depletion. The generated pollution from such activities is principally due to high concentration of sulfate, chloride and ammonia. Leachates from domestic and commercial activity wastes may be serious contaminants to groundwater by virtue of their dissolved constituents and high biological oxygen demand which may produce anoxic conditions in both saturated aquifers and unsaturated zones subject to direct infiltration from rainfall. On the other hand, the need for groundwater, particularly in localities void of adequate surface water resources, for drinking and domestic purposes, may lead to over exploiting the available aquifers at those localities which may cause thus groundwater depletion.

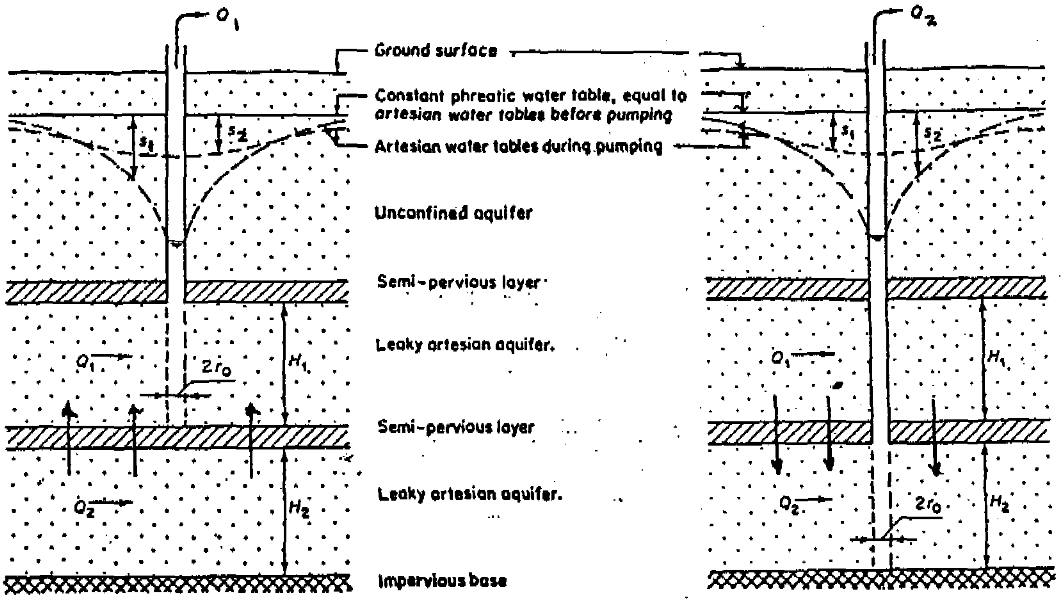
II.2 Groundwater Depletion

Depletion of groundwater is reflected on minimizing the magnitude of discharges that can be withdrawn from a basin, and/or the lowering of the water table or piezometric surface of the groundwater. There is no doubt that both actions are interrelated at points of extraction at individual wells as well as at the regional level. The term safe yield, by definition, if strictly respected, implies avoiding harmful impact on the groundwater basin quantity and quality.

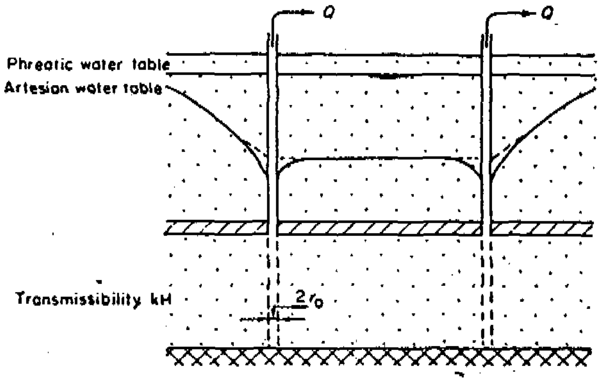
II.2.1 Actions Generating Groundwater Depletion and their Impacts

In the absence of adequate assessment, design and planning of the groundwater field, one or more of the following actions and their respective impacts may result. Fig. II.1 illustrates few examples of additional drawdowns resulting from specific well designs. For further detailed calculations of these various boundary conditions, reference is made to Walton (1970); Hantush (1971); Huisman (1972).

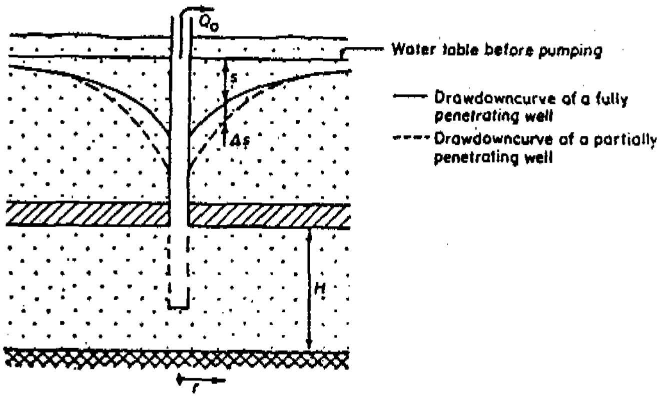
i. Overabstraction from groundwater basins, at rates exceeding the natural rate of recharge from various resources, will have a direct impact which threatens the sustainability of the water field production. Also, in case where the productive wells are close to coastal regions, salt water intrusion may take place.



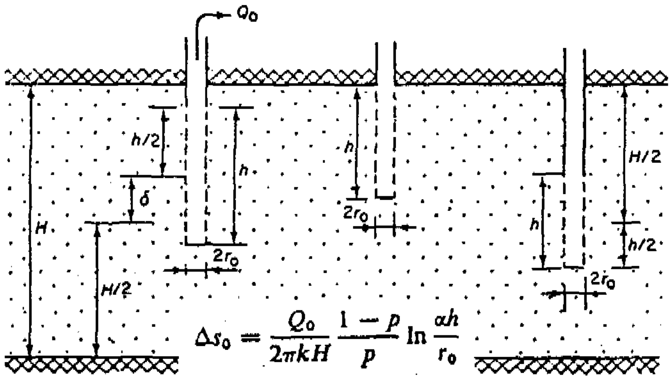
a) Effect of screen position in multi-layered aquifer



b) Additional drawdown due to well interference



c) Additional drawdown due to partial penetration



$$\Delta s_0 = \frac{Q_0}{2\pi kH} \frac{1-p}{p} \ln \frac{\alpha h}{r_0}$$

p =	e = 0	0·05	0·10	0·15	0·20	0·25	0·30	0·35	0·40
0·1	α = 0·54	0·54	0·55	0·55	0·56	0·57	0·59	0·61	0·67
0·2	0·44	0·44	0·45	0·46	0·47	0·49	0·52	0·59	0·89
0·3	0·37	0·37	0·38	0·39	0·41	0·43	0·50	0·74	
0·4	0·31	0·31	0·32	0·34	0·36	0·42	0·62		
0·5	0·25	0·26	0·27	0·29	0·34	0·51			
0·6	0·21	0·21	0·23	0·27	0·41				
0·7	0·16	0·17	0·20	0·32					
0·8	0·11	0·13	0·22						
0·9	0·06	0·12							

penetration $p = h/H$

eccentricity $e = \delta/H$.

(ref.Huisman,1972)

d) Additional drawdown due to screen position (approx. equation)

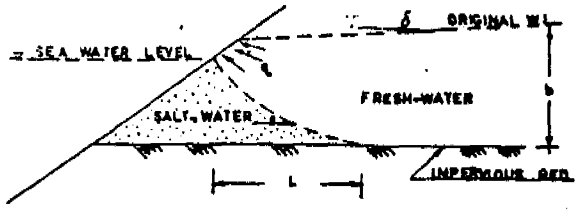
Fig (II.1) - Examples of Additional Drawdowns due to well Designs

ii. Close spacing of production wells, due mainly to miscalculation of the well hydraulics and behaviors, will lead to interference between the wells, and as a results of which additional lowering of the groundwater table or piezometric surface may occur. The direct impacts of such action are reflected on the economy and efficiency of water production with respect to power.

iii. Improper design, regarding well penetration and screen position will lead ultimately to disruption of the hydrodynamics of the stratified or adjacent aquifers. The results of such action will be directly reflected on additional lowering of water levels, in case of partially penetrating wells. Migration of the groundwater from an aquifer of higher piezometric head to another underlying or overlying aquifer of lower heads will take place, in case of improper screen position. This later case is known as thieving between aquifers. The direct impact of this action is related to the discontinuity and irregularity of water production, which in turn threatens the sustainability of the development. Also, in cases where the productive wells are close to coastal regions, salt water intrusion may occur, which accordingly will harm the aquifer water quality. Fig. II.2 illustrates the advancement of salt water horizontally inland, and vertically into the productive well (Saad, 1964).

II.2.2 Factors Leading to Groundwater Overabstraction

The factors which may lead to groundwater overabstraction originate principally from certain attitudes and behaviors currently practiced at the official levels and simultaneously reflected on the individuals. The main



28 a. NATURAL DISCHARGE OUTLET.

i = hydraulic gradient

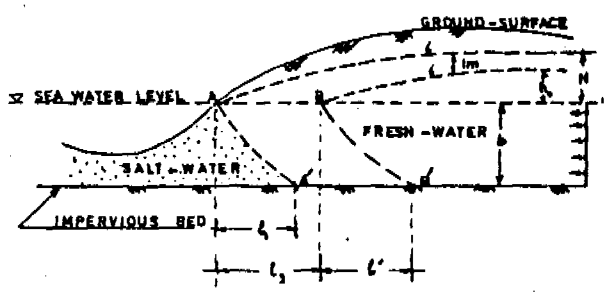
$a = (d_s - d_f)/d_f$

d_s & d_f = salt and fresh water densities

k = coef. of permeability

$L = (a.b)/2i$

$q = 1/2 .a.(kb^2)/L$



28 b. HORIZONTAL INTRUSION OF SALT-WATER

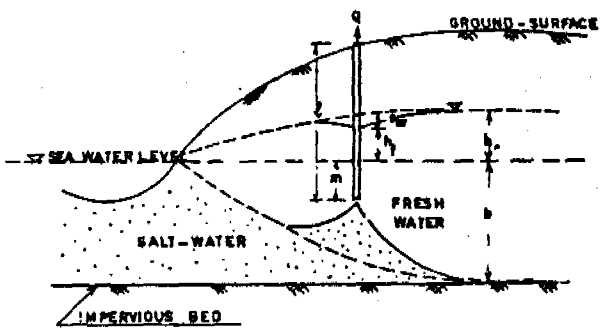
Lowering of wâter table by 1 meter, will result in advancement of point A to point B ; $L_2 = 1/i$

for water table aquifer

$$l' = \frac{a(a+1)}{2i} \cdot \frac{b^2}{b+h_o}$$

for artesian aquifer;

$l' = a.b/2i$



28C. VERTICAL INTRUSION OF SALT-WATER

To avoid rise of salt water into the well ;

$h_f = h_o - s_w \gg 1.5\ a\ m$

Fig.(II.2)- Diagrammatic Representation of Sea-Water Intrusion (Ref., Saad 1964) factors that have pivoted impact on groundwater discharge, and levels can be pronounced as follows (Tawfic et al, 1992).

i. Policy of encouraging private agricultural development: Although privatization in agricultural development, using groundwater resources, is in itself a useful and rather important policy in the overall economic development in any country, yet in the absence of well defined ground water assessment and regulations, uncontrolled exploitation will lead ultimately to overabstraction. Examples of such case are numerous in the Arab region, where the individuals tend to drill as much wells as they can, regardless of the actual potentiality of the groundwater basin which in fact is shared by many other individuals.

ii. Concept of land and water ownership: This concept is not well defined or pronounced in the Arab region, in regards to the rights of ownership of the individuals to their land property which should not extend to the groundwater beneath their lands. As groundwater is considered a national property, its utilization should be managed equally between the landowners, within the actual potentiality of the pre-assessed groundwater basin shared by these individuals. If such concept is not strictly respected, uncontrolled extractions from the groundwater would lead to depletion of the basin and consequently to collapse of the individual projects.

iii. Diversity of the organizations responsible for water management: It is evident, in most of the Arab countries, that management of water resources do not belong to one particular specialized organization, a situation which may lead to the absence of responsibility, and consequently to the complexity of the impacts.

iv. Pricing of water: Although some countries tend to grant water free of charge, perhaps for economic and political justifications, yet individuals may illuse such grant, and consequently overexploitation of the groundwater may occur.

All these factors beside others, may lead ultimately to continuous depletion of the groundwater, and to collapse of the economic projects depending on groundwater utilization.

II.3 Groundwater Contamination

Water quality is influenced by a wide range of natural and human processes. It is important to consider the impacts of these processes on both the quality and quantity when assessing the availability of water resources.

The chemical composition of the natural water is formed of a wide variety of dissolved constituents, including gases, and suspended material in the atmosphere. These constituents are normally derived from the atmosphere and dissolution of rocks and minerals in the soil and water bearing formations. The water composition is also influenced by external factors, such as, evaporation and human activities. The reactions are controlled by a series of chemical and physical laws, such as, precipitation, dissolution, adsorption-disorption, and dispersion. These laws are influenced by a number of environmental factors; climate, geologic structures, lithology of rocks, topography, and hydrological and hydrogeological conditions. Fig. II.3 shows

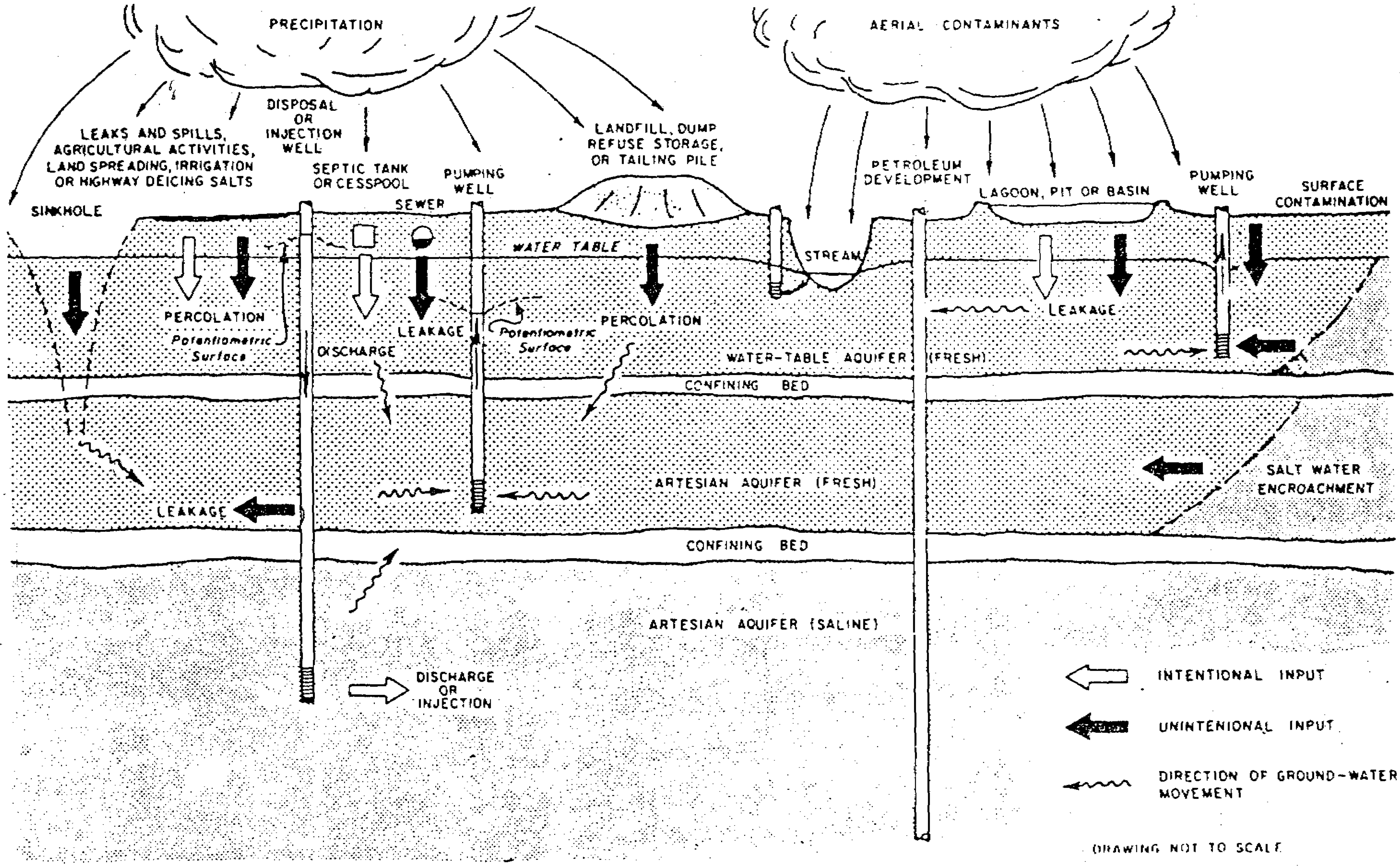


FIG.(II.3)-TYPICAL ROUTES OF GROUND WATER CONTAMINATION a diagrammatic representation of typical routes of groundwater contamination.

II.3.1 Activities Generating Groundwater Contaminants

(i) Urban Contamination

Liquid and solid sewage wastes are mainly responsible for the groundwater contamination, both chemically and biologically, due to leakage from inadequate municipal sewage system and septic tanks, (Fig. II.4).

(ii) Industrial Contamination

This covers the entire industrial activities due mainly to the disposal of liquid wastes directly into surface water and groundwater, without treatment. These wastes normally contain heavy metals and various toxic trace elements.

(iii) Agricultural Contamination

Return flow from the irrigated lands normally contains leachates from the soil salts, fertilizers and pesticides. Also, high rates of evaporation, particularly in arid and semi-arid zones cause salt concentration in the soil zone. Insufficient drainage system also increases direct infiltration of contaminated water to the water table, (Fig. II.5).

II.3.2 Types of Groundwater Contaminants

i. Chemical Contaminants

The natural chemical constituents contained in water are affected by anthropogenic sources e.g., industrial processing, fertilizers and municipal

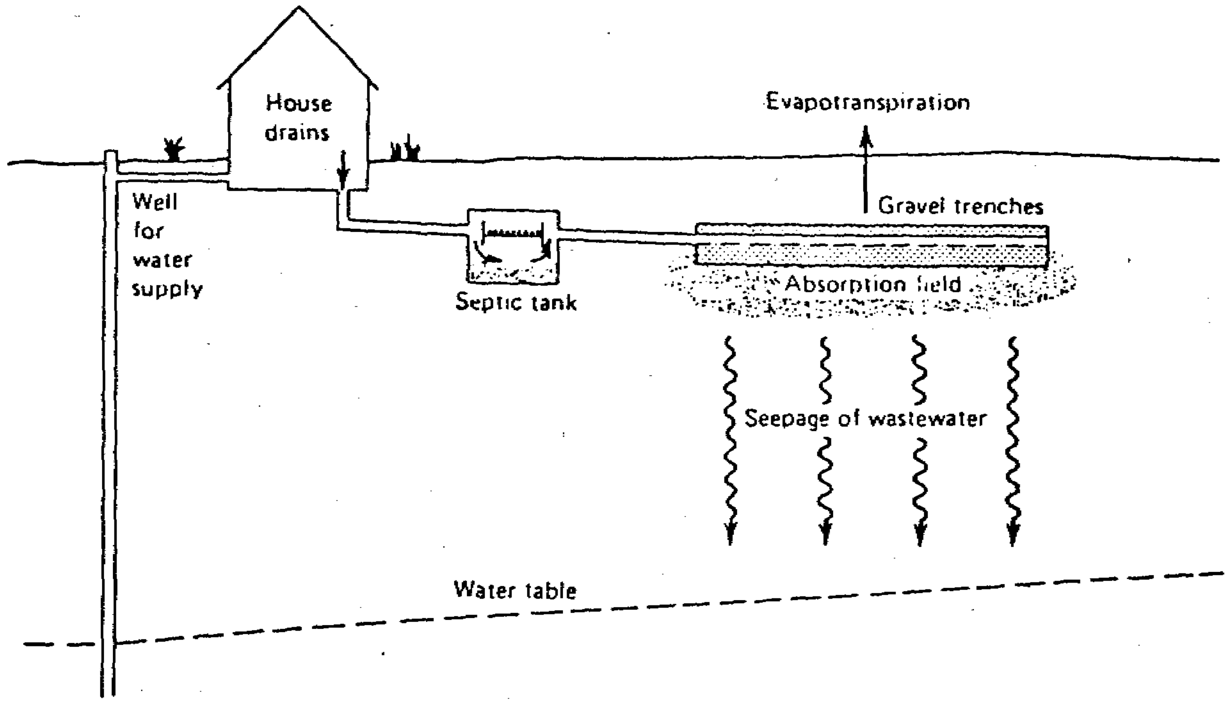
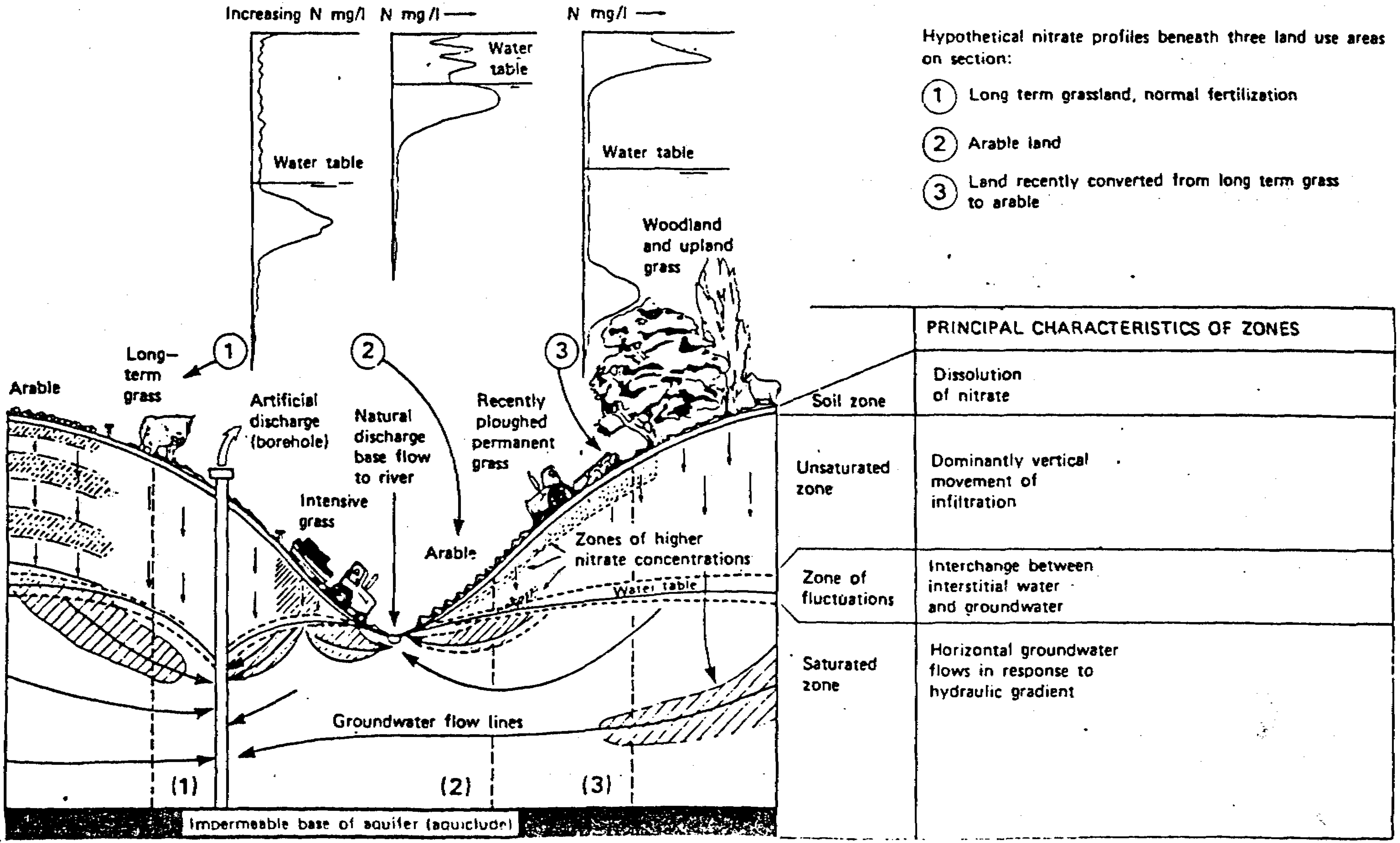


FIG. (II.4). A typical household system for disposal of wastewater on the building site. The septic tank reduces plugging of the percolation bed by removing large solids. The absorption field permits biological decomposition of waste organics and seepage of the water.



'IG.(II.5) Diagrammatic section of a groundwater catchment illustrating possible distribution and movement of nitrate through the unsaturated zone wastes. The potential sources of chemical contamination can be summarized as follows:

- Geological Weathering. This is the source of "background levels" characteristic to the metal-bearing rock formation of the area.
- Industrial Processing and Use of Metal Compounds. The discharge of industrial effluents in violation of regulatory standards, is an evident example in many countries.
- Heavy Metals in Animal and Human Excretions. These chemical constituent become concentrated in excretion and find their way to the water environment.
- Leaching of Metals from Domestic Wastes and Solid Waste Dumps.

However, the presence of elevated concentrations of naturally occurring contaminants in groundwater is increasingly being recognized as a limiting factor in guaranteeing the potability of water from both shallow and deep groundwater resources. This is especially true in semi-arid regions where high demand, and the scarcity of water, preclude the use of alternative, less contaminated sources. In a region with inadequate rainfall in time and space, high evaporation rates, unreliable variation in climate, and the conversion of precipitation to runoff will compromise the chemical quality of the rechargeable water resources.

For example the groundwater in the upper aquifer system in Jordan's metropolitan area, demonstrates that the partial pressure of carbon dioxide values as calculated for more than 60 wells are greater than those prevailing in the atmosphere, i.e., $10^{-3.5}$. The values of log PCO_2 ranged from -1.3 to -2.0 in almost 85 percent of the studied wells. It is interesting to note that the increase of PCO_2 is associated with high concentration levels of nitrates and salinity. This is particularly true for those wells located along the effluent-dominant streams close to industries with high biochemical content in their emissions.

ii. Biological Contaminants

Bacteria possess tremendous variability in metabolic abilities and environmental tolerances, and therefore are ubiquitous in aquatic environment. They are found over broad ranges of pH, temperature and oxygen concentration.

A large group of heterotrophic micro-organisms consumes organic material (many of which may be pollutants) bringing about the generation of mineralized end products. Some bacteria are pathogenic either by causing diseases directly through infection or by producing toxins which bring on illness or death. Therefore, the microbiological aspects of a water resource are important for assessment of its quality and usage. It is acknowledged that shallow groundwater are more susceptible to pollution from human and animal waste discharges, domestic sewage effluents, storm sewer runoff and from feed lots.

Under these conditions, bacteria and viruses are the most important among microbiological constituents of human excreta due to their relatively small size, and mobility in the soil. Misidentifying the cause or route of contamination can lead to the adoption of inappropriate and ineffective protection measures. However, it is becoming evident that many cases of contamination by pathogens are caused by human activities either near the water source or in the recharge area of groundwater basin. These activities may include the movement of particles of fecal waste, paper and garbage from sewage waste, streams and faulty septic systems into the groundwater.

Constantly elevated indicative bacteria of pollution in shallow groundwater have occurred in some vulnerable settings, apparently due to their location near point sources of contamination such as livestock feedlots, septic systems, or disposal sites. In many areas, wells and springs exceeding the drinking water standards have been documented in the country reports of Jordan, Syria and Gaza Strip.

A case from the north of Jordan can shed some light on the extent of biological contamination. Recent monitoring results have revealed that three main springs were affected by leaching of contaminants from cesspits scattered all along recharging area. The microbiological water quality of these springs exceeds the health related national standards, where the indication bacteria of pollution, i.e. fecal coliform exceeds 1000 colony count/100 ml (MPN). These shallow water sources have been currently prohibited for water use bearing in mind that chlorination alone cannot ensure safety of water supply under the prevailing potential risk. Similar cases do exit in the Middle East countries.

The pollution risk in general is determined through many factors; type and thickness of unsaturated zone, the regime of groundwater movement which is controlled by hydraulic characteristics of the soil, and the survival characteristics of microorganisms found in groundwater depending on temperature, moisture and water chemistry.

Beside exogenous sources of biological contamination, indigenous sources are also essential in assessment of groundwater quality. The sulfate-reducing bacteria may create clogging problems in wells and distribution systems. Furthermore, some iron bacteria species can create main pipes problems. In Jordan, relatively high concentrations of sulfur and iron do exist in some groundwater resources, as Muhkheiba and Baqa wells, yet there is no microbiological study to specify types and counts of endogenous microorganism of significance.

iii. Radioactive Contaminants

Radioactivity in groundwater is essentially due to the emission of radium which is present in all rocks. Radium is barely soluble but its daughter product radon-222 is very soluble. Potential types and sources of natural contamination are diverse, but natural contamination of groundwater by naturally occurring radionuclides from the uranium and thorium decay series is potentially high and surprisingly widespread.

It is recognized that waters associated with granitic rocks and sedimentary rocks can demonstrate natural radioactivity in drinking water and may represent a significant factor in increasing the radiation exposure of the population where the potable supply is obtained from groundwater.

The vulnerability of a particular groundwater resource to contamination from naturally occurring radionuclides is not just a simple function of its proximity to mineralization. It is a function of geochemical, geologic and hydrochemical environment in which the groundwater evolves. Uranium enriched phosphorites of the Late Cretaceous period form an extensive depositional facies throughout North Africa and the Middle East (Wininger, 1954).

Around Amman these phosphate facies form an integrated part of a major, overexploited aquifer unit within the Amman-Zarqa basin which contributes approximately 30 percent of Amman's potable water supply.

Increased permeabilities in this system along the bed of the Zarqa River and Wadi Zarqa are consistent with a high degree of vulnerability to anthropogenic pollution and natural radioactive compounds leached from the phosphatic wastes.

On the basis of the implications to health and water quality and analytical data in the survey, it is clear that groundwater from two producing wells greatly exceed even the conservative guidelines values. The rest of the sampled sites generally show uranium concentrations < 20 ug/1 and as such do not present a significant risk. Data from the survey indicate that as greater than 90 percent of the wells have concentrations less than 1 Bq/1 (27 pci/1, the Canadian MAL).

Similar investigations are required in other areas to identify the source of radioactive contamination and to identify other downstream wells that are at risk in order to assess the need for remedial measures to reduce amounts of U, Rn and Ra entering public supply from a point source responsible for the enhanced radio element content. However, the ingestion of radioactive products can have a somatic effect on man, causing malignant tumors or mutation that might appear in future generations. The water supplied must meet regulations of WHO guideline values in each country. Treatment of water includes precipitation by lime, ion exchange or reverse osmosis.

II.4 Groundwater Deterioration due to Climate Change

In earlier decades it was emphasized that groundwater is vulnerable, in various degrees, to human impacts. However, as a result of the application and development of the vulnerability concept in the past decade, under different conditions and particularly under arid climatic conditions, it has been demonstrated that groundwater systems are vulnerable to human impacts as well as to natural processes.

The natural processes which influence aquifer systems are dealt with in this section. These processes comprise climate change, drought, desiccation and desertification. The significance of these phenomena varies from region to region and from place to place. Moreover, aquifer systems are heterogeneous and their vulnerability to natural processes vary with area and depth.

Considerable disagreement exists about the concept of climate change, drought and other forms of the "dry environment" (Fig. II.6), and therefore numerous definition of these phenomena have been proposed. It is important, however, to determine their essential characteristics. Certain definitions may lead to poor understanding of the dimension of the concepts and the range of impacts of these phenomena on the resource base.

II.4.1 Climate Change

There is a considerable consensus within the international scientific community that the gradual warming of the earth is a major environmental threat facing the earth. Although the extent and timing of global warming is still uncertain, greenhouse effect has the potential to create serious problems for future generations. It is therefore necessary to take action to deal with the wide range of potential problems associated with the global climate change.

The United Nations Conference on Environment and Development (UNCED) recognized that among the most important impacts of climate change is its effects on the hydrologic cycle, and water management systems.

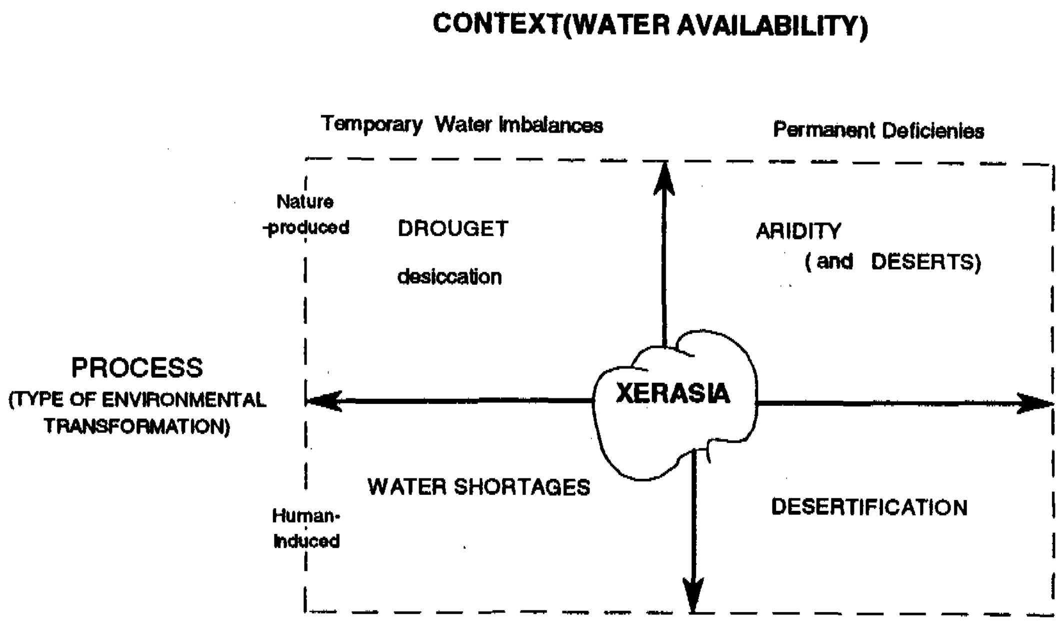


FIG. (II.6)
Categories of dryness (xerasia)
after Valchos & James, 1983.

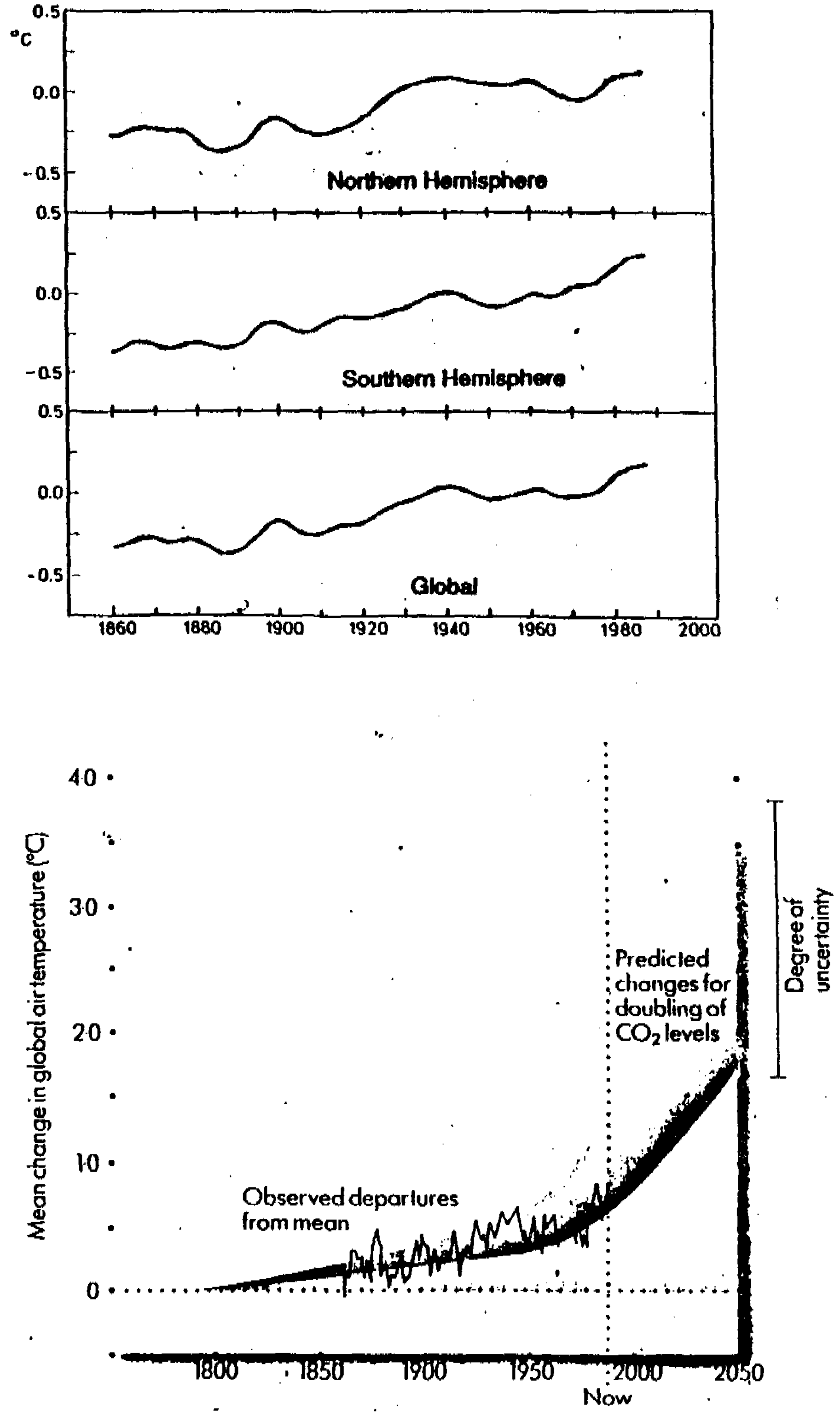
Currently CO_2 emissions are the major contributors to the greenhouse effect (about 55 percent) with Ozone depleting substances being responsible for about 20 percent and methane, nitrous oxide and tropospheric ozone contributing some 25 percent.

Global climatic models (GCMs) currently forecast a mean temperature increase of about 0.3°C per decade. This would represent an increase of about 1°C by the year 2025 and 3°C before the end of the 21st century (Fig. II.7). The second World Climate Conference (November 1991), agreed that without actions to reduce emissions, a global warming is predicted to reach 2 to 5°C over next century. Thus, if correct, by the end of the next century our planet will be warmer than any time in the last two million years, and it seems likely that the rate and magnitude of climate change which will be experienced by future generations will exceed any previous human experience. Simulation models also predict an average rate of global mean sea level rise of about 6 cm per decade in the next century, International Conference on Water and Environment (ICWE, 1992) (Fig. II.8).

II.4.2 Drought

Drought refers to a temporary feature of climate, but when a severe persistent drought occurs in a region, somebody may wonder whether it is some sort of climatic change. However, drought is a recurrent phenomenon and climate change need not be invoked as the cause. The global climate change varies slightly when observed over a time scale such as decades, but climate can change perceptibly on a scale of centuries, millennia or on a geological time scale. Drought is experienced on a human time scale. The Arab region for example, was effected by several droughts during the late

Temperature changes 1860-1988

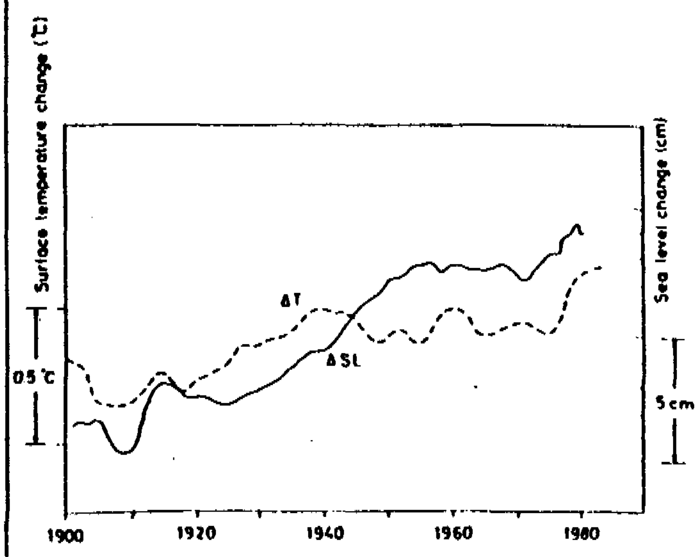


Observed global temperatures (expressed as a departure from the mean) since the beginning of the century and predicted temperatures for the next 60 years.

FIG. (II.7) Observed and projected temperature changes at the glopal level.

(Source: Ministry of Planning and Environment, Australai Department of the Environment, U.K., 1989).

Changes in Sea Level and Sea Surface Temperature 1900-1985



Source: '*The Greenhouse Effect, Climatic Change and Ecosystems*' ed. B. Bolin and others, 1986.

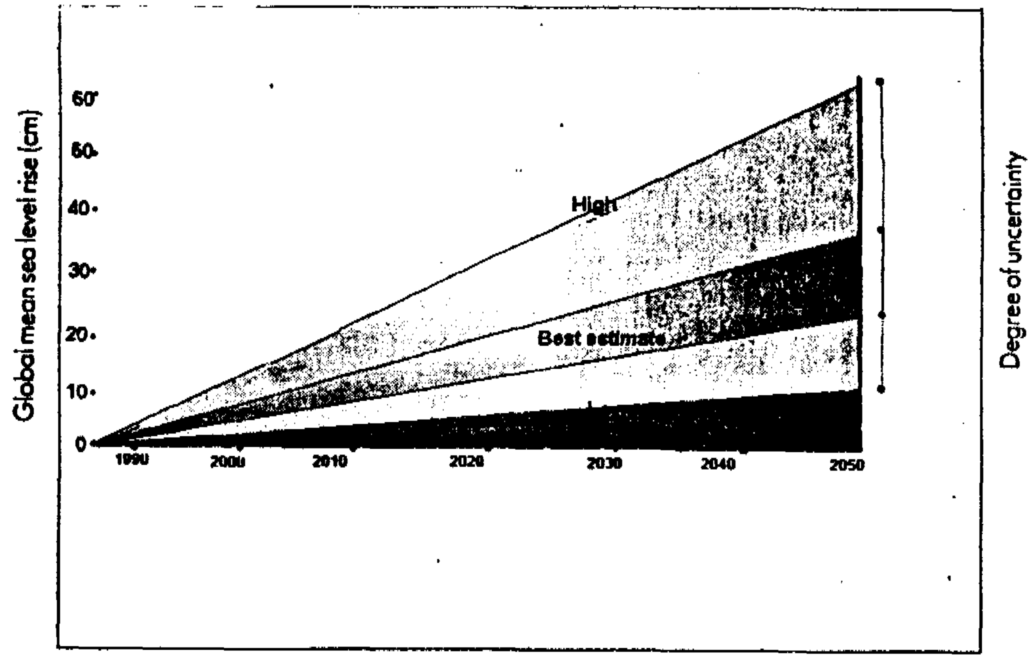


FIG. (II.8)Predicted changes in global sea level.

(Source: Dep. of the Environment, U.K. 1989) fifties, early sixties and 1980s. These droughts were of moderate to severe intensity and affected the Mashrek, Maghreb and the watersheds of the Nile Valley. On a global level, the occurrence of a severe drought during 1982-83 is shown in Figure II.9. It is clear that drought occurs in high as well as low rainfall areas.

Drought is frequently defined according to disciplinary perspective. Four types are usually recognized: meteorological, hydrological, agricultural and socioeconomic (Wilhite and Glantz, 1987). Only two types, namely meteorological and hydrological droughts will be considered.

Meteorological definitions of drought are the most prevalent. It is defined on the basis of the degree of dryness and the duration of the dry period. A large number of definitions are based only on rainfall, whereas other definitions are based on rainfall with mean temperature. The Planer Drought Severity Index (PDSI) is widely used in the United States to evaluate long-term rainless conditions. Gibbs and Maher (1967) applied the concept of rainfall deciles for the classification of drought in Australia's Drought Water System. Severe drought is equated with periods not exceeding the fifth decal range over a period of three or more months. Extreme drought occurs when precipitation does not exceed the first decal range over a period of three or more months. Hydrological drought occurs when there is a depression of surface and groundwater levels and diminution of stream flow under some threshold.

II.4.3 Desiccation

Desiccation is a prolonged period in which drought intermittently intensifies (Hare, 1987). Natural ecosystems which outline drought episodes

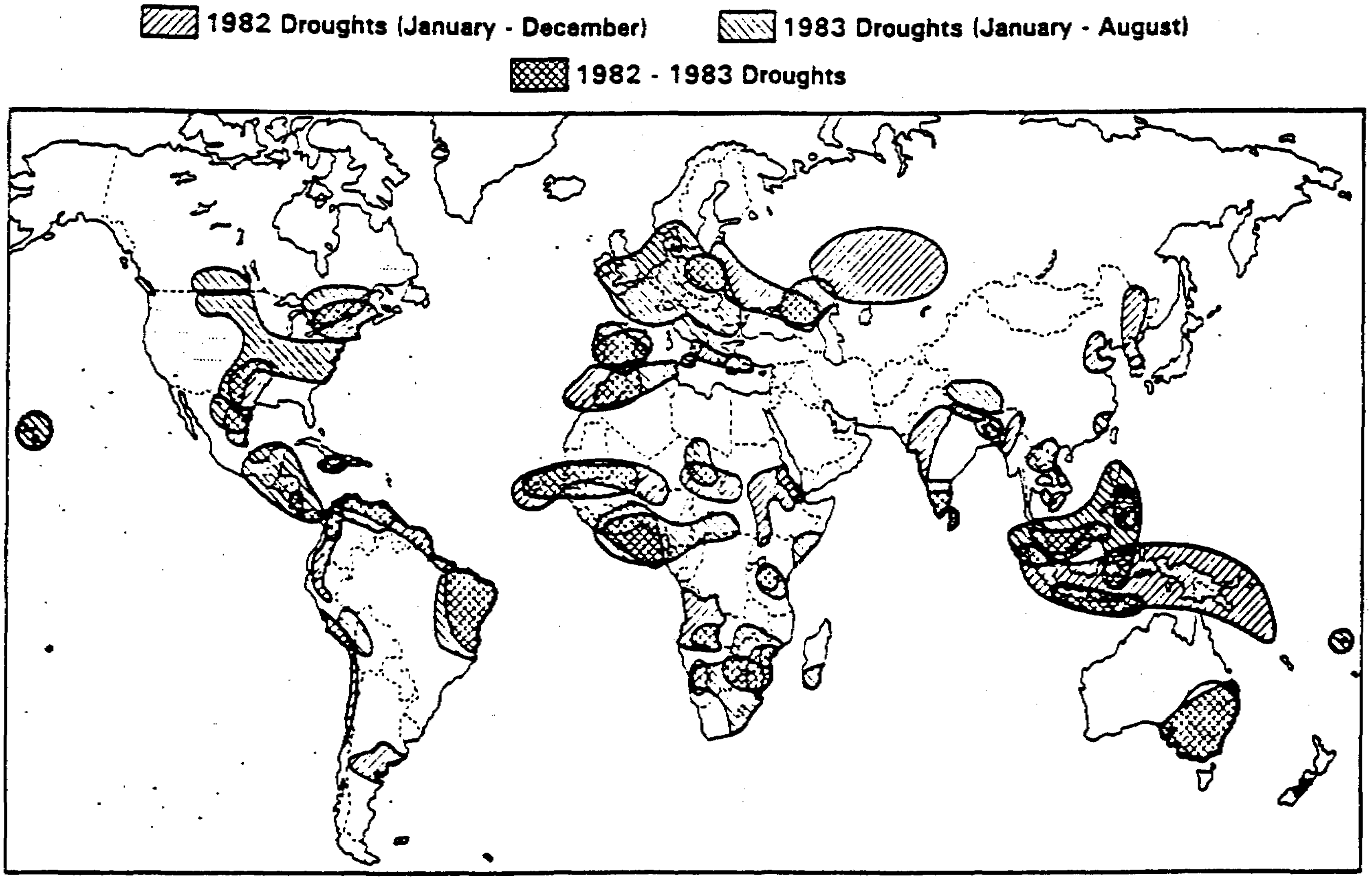


FIG.(II.9) -The occurrence of drought, January 1982 to August 1983.

(Source: Wiehite & Glantz, 1987).

with little or no changes may be confronted by 2 to 3 decades of progressively decreasing rainfall (Hare, 1987), and of course desiccation means a great drawdown of water levels and extensive mining of groundwater. The Sahelian drought of 1968-73 was a part of a prolonged, and profound disturbance, of rainfall over most of Africa. Not only groundwater but the great rivers in West Africa, Senegal, Niger, and Chad, have progressively fallen until the inland delta of the Niger and the flood plains of Senegal have become difficult and in many areas impossible to farm (Hare, 1987).

II.4.4 Aridity and Desertification

Aridity is a permanent climatic feature of a region. It is usually defined in terms of low average rainfall. In the Arab region aridity is restricted to regions of high temperature. Desertification is the process of land degradation that ultimately leads to the transformation of productive land into an ecological desert. It involves degradation of the vegetation cover, soil erosion, soil compassion, salinization and water logging (Dregne, 1983). Desertification may be accelerated by drought. Poor management or misuse of land is considered to be a basic cause, of increased drought impact and evolution towards desertification.

II.4.5 Potential Impacts of Climate Change and Climate Related-Phenomena

Despite uncertainty with regard to the prediction of climate change, at the global, regional and national level, it is necessary to take action to reduce potential impacts and deal with the wide range of problems that may result from climate change.

Both positive and negative effects on water systems are expected at this stage. Expected shifts in global and local climate zones have the potential to alter the water balance and balance of advantage and disadvantage in water resources and water supply systems. The crucial issue is the long-term effect of predicted changes. There is some uncertainty to the timing and specific impact on local weather patterns. There are also many uncertainties to contend with as part of climate change, namely, the direction of change at the sub-continental and regional level, the rate of change and response of individual basins to climate change.

The global atmospheric warming is likely to cause profound changes that may result in substantial change in the hydrologic regime of vulnerable water system. Dry lands are sensitive to minor shifts in their water and energy balances. Relatively small changes in climate can cause large change in runoff. This would affect groundwater systems which derive the greater part of their recharge from Wadi runoff. The greenhouse effect is also likely to affect rainfall levels and therefore result in changes in the volume of water, but while these changes may have impacts on future water supply security, and water quality, the nature, direction and magnitude of changes are still uncertain and therefore may be beneficial as well as adverse effects.

Models have consistently shown that warming will be experienced in both summer and winter if CO_2 is doubled, and temperatures at high latitudes will be greater than those in lower latitude. Changes in rainfall patterns are also likely with increased winter rain and snowfall in higher latitudes, intensified rain in the currently rainy lower latitude, and a possible decrease in rainfall and soil moisture in middle latitudes.

The second World Climate Conference recognized that among the most important impacts of climate change is its impact on the hydrologic cycle, (UNCED, Agenda 21). "Increase of incidence of extremes such as floods and drought would cause increased frequency and severity of disasters" (Agenda 21, 18.94). The rise in sea level would cause flooding of low coastal areas and increase sea water intrusion in coastal aquifers. This would pose a major threat to the fragile alluvial aquifer systems in the coastal areas of the Red Sea, Gulf of Oman, Mauritania, Somalia and the lower Senegal river basin. The problems of sea water intrusion would become more serious in areas where the highly permeable piedmont zones or fissured aquifers are in direct contact with the sea (e.g. Northern Oman and UAE).

In general, higher temperatures and decreased precipitation would lead to decreased water supplies and increased water demand which has to be met partly by mining groundwater. The deterioration of freshwater bodies would put further stress on the already fragile balance between supply and demand. Water crises and present water shortages will be heightened in several Arab countries with scarce water resources. Water management and planning may, therefore, need to make greater use of alternative sources of supplies such as desalinated water, recycling and water conservation measures.

Changes in the risk of drought are probably the most serious impacts of climate change on water resources. The sensitivity of aquifers to drought depends on the hydrogeologic conditions, natural attributes as well as the "degree of aridity".

In arid and hyper-arid regions recharge is negligible. The regional aquifers underlying large basins in the Sahara and deserts of Africa and the Arabian peninsula were recharged during the Quaternary Pluvial periods. The aquifers are now independent of the present climatic cycle and therefore are not vulnerable to drought (Khouri and Miller, 1994). In semi-arid regions vulnerability to drought varies with the degree of aridity. The hydrogeological framework and aquifer characteristics also affect the response of the aquifers system to drought, thus an aquifer having low transmissivity, storage capacity and limited areal extent is highly vulnerable to periods of drought (Vrba and Zaprozec, 1994), whereas a regional aquifer system with great storage capacity and high to moderate transmissivity would have high resistance to drought. The response of aquifer systems to development could be much more significant than the aquifer sensitivity to a variable recharge. Such structural sensitivity if combined with the risk to drought that affects the aquifer system, could be assessed and mapped. It is a useful concept for planning water supply projects since it indicates the reliability of the resource.

In addition to drought, desertification could affect the groundwater systems, since it tends to increase runoff and decrease infiltration. The vulnerability of aquifers to desertification depends on the degree of soil compaction and other effects which influence recharge and water quality of the aquifer systems.

Special consideration should be given to response strategies because of the essential value of groundwater to the community and environment of the Arab region. Agenda 21 included a number of recommended actions for climate change and drought planning and response. Those which are appropriate and implementable in the Arab region include the followings:

1- Assessing the vulnerability of aquifer and water management systems to drought and climate change.

2- Improving monitoring systems, including groundwater quality networks, and special observation networks for collecting data related to climate change.

3- Enhancing knowledge, forecasting groundwater balance, and conducting studies to investigate possible linkage between climate change and frequency and severity of drought events.

4- Developing methodologies and conducting studies for assessing the potential adverse effects of climate change on groundwater.

5- Implementing water conservation measures and making irrigation practices more effective and efficient.

6- Addressing the ever-increasing demand for water through proper institutional and pricing mechanisms.

7- Development of a climate change and drought assessment and response strategy at the regional and national level by creating an infrastructure to supply basic data and research needed for assessment and response.

8- Formulation of a general climate change and drought plan. The planning procedure should be viewed as a dynamic process requiring continuous evaluation and updating. Highly vulnerable areas need to be identified as a matter of priority.

PART III

STATE-OF-THE-ART OF THE GROUND WATER DETERIORATION IN THE ARAB REGION

Groundwater occurs in the Arab region in an essentially dry environment. The greater part of the region lies in the latitude belt between 20°N and 30°N, which embraces the driest climatic zones of Africa and southwest Asia.

The Arab region embraces an area of about 14.15 million square kilometers situated in southwest Asia and North Africa. The Asian and African parts of the Arab region are considered the main subregions of the Arab world. They encompass areas of about 3.94 and 10.21 million square kilometers, respectively.

The total renewable water resources of the Arab region is estimated at 340 BCM (billion cubic meters or Km^3) (Khouri and Drouby, 1990). Renewable groundwater resources are estimated at 42 BCM (Saad, 1993) of this total some 28 BCM occur in the African part of the Arab region and about 14 BCM occur in the Asian part of the region. With the exception of Egypt and Iraq, groundwater constitutes about 25 percent of the total water resources of the Arab countries in the Mashrek and Maghreb subregions. In the Arabian peninsula it forms the principal part of available water resources ranging from 40 to 98 percent of the total resources (Khouri, 1993). In addition to renewable groundwater resources, the greater part of the Sahara of North Africa and the deserts of the Arabian peninsula is underlain by extensive aquifers containing huge reserves of limited or non-renewable groundwater resources (Margat and Saad, 1984).

The following gives the state-of-the-art of the groundwater situation in the four regions of the Arab states:

i. The Arabian peninsula; Saudi Arabia, Kuwait, Bahrain, Qatar, U.A. Emirates, Oman, and Yemen.
ii. The Mashrek; Syria, Jordan, Iraq, and Lebanon.
iii. The Nile Valley; Egypt, Sudan, Somalia, and Djibouti.
iv. The Maghreb; Libya, Tunisia, Algeria, Morocco, and Mauritania.

III.1 Arabian Peninsula

III.1.1 Saudi Arabia

The Paleozoic sandstone regional aquifer system shared between Jordan and Saudi Arabia has been heavily developed for irrigated agriculture in both southern Jordan and northwest Saudi Arabia. In the Riyadh area the Minjour sandstone aquifer was developed intensively by wells drilled into depths of 1200 to 1400 m, for the water supply of Riyadh (Othman et al, 1986). Some 2.5 m^3/sec of groundwater had been pumped annually, and the hydraulic head declined considerably. Adverse effects include increase of salinity of the originally brackish groundwater (1000-1500 mg/l) (Othman et al, 1986). Other adverse effects include corrosion of well casings by thermal sulfurous water developed from the deep aquifer system.

These effects and other potential impacts have lead to corrective measures aiming at reducing stresses on the aquifer system, which included the conveyance of desalinated water from the Gulf to Riyadh. Groundwater pumped from the deep sandstone aquifer system is used today, only for blending with desalinated water.

Wells drilled into Saq aquifer in northwest Saudi Arabia range in depths from 150 m to 1500 m., and the average depths is 400 to 500 m. The annual withdrawal from the confined area of the aquifer system was estimated in 1986 at 175 MCM and total annual withdrawal from the Saq amounted to about 290 MCM in 1980 (Othman, 1983). The abstraction of groundwater was increased considerably in order to contribute to the achievement of the goal of food security particularly with regard to wheat production.

Wheat production amounted to 1.7 million tons in 1985 (Othman et al, 1986). The tremendous expansion of irrigated agriculture could be perceived from the following published figures on agricultural water use in Saudi Arabia during the 1980s (Al-Mokren, 1989).

Evaluation of Agricultural Water Use in Saudi Arabia during the 1980s

Year	MCM/Yr
1980	1860
1985	7430
1990	14000
2000	20000 (projection)

The water resources offered by the Paleozoic regional aquifer have been subjected to a great stress in order to meet the needs of ambitious agricultural projects.

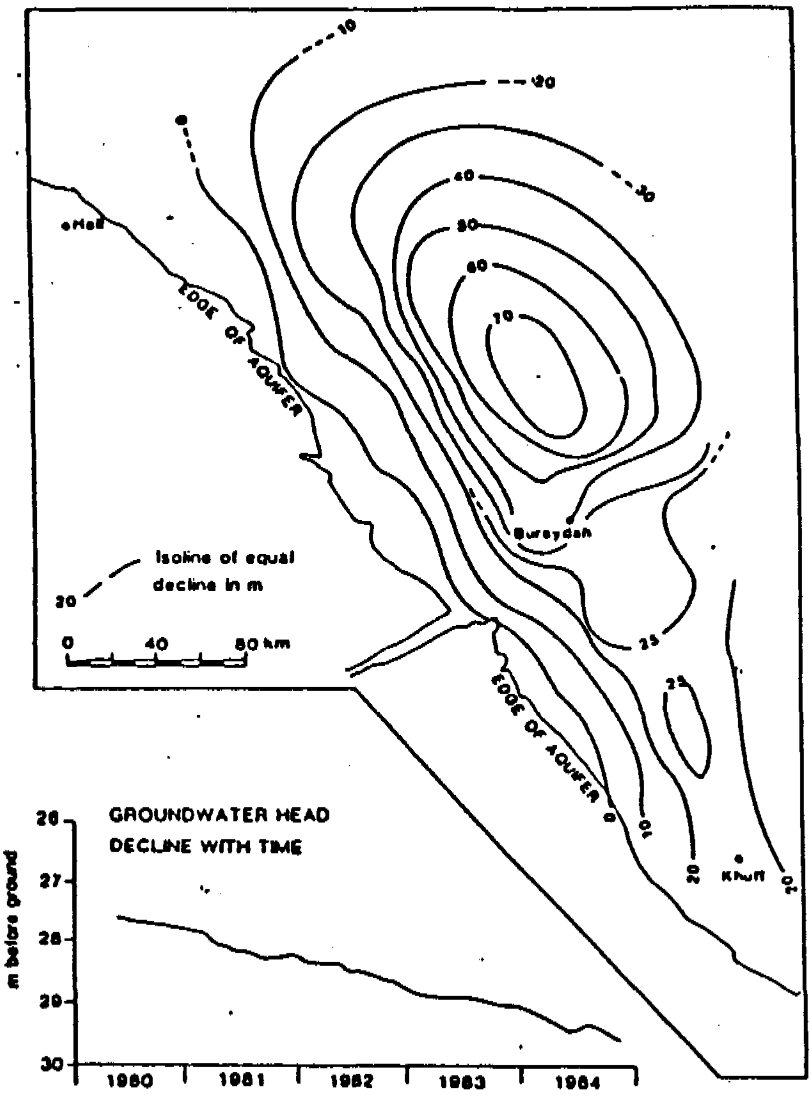
The Tertiary carbonate regional aquifer system has been extensively developed in Kuwait, Bahrain, Qatar and Saudi Arabia. The Dammam and Hufuf formations in Saudi Arabia, Bahrain, and southwest Qatar are among the most heavily developed areas; and most of them are over-exploited resulting in serious impacts on the resource base.

In Eastern Saudi Arabia extraction rates increased from 250 MCM in 1976 to about 750 MCM in late 1980s (Rasheedudeen et al, 1989). It was estimated that some 10,000 MCM were extracted from the aquifer system by 1990. If extraction trends of 1980s continue in the 1990s, simulation shows that water levels will continue to decline uniformly, and a large cone of depression will develop. Maximum drawdown will range from 15 m in Nejmah area to 43 m in Abqaiq by the year 2000. This will cause a dewatering of the aquifer in individual wells (Rasheedudeen et al, 1989). Regional analysis of the aquifer system indicates that minor effects are anticipated in other countries that share the same aquifer system.

Lessons drawn from the intensive development of the Saq-Tabuk sandstone aquifers (Fig. III.1) which underlie the "Great Nafud Sedimentary Basin" of Saudi Arabia have lead to an adjustment of agricultural development plans. A regional study was conducted, involving an inventory of all water points and assessment of the major Paleozoic aquifer system and other overlying or hydraulically connected aquifers. Simulation was used to provide a quantitative understanding of the aquifer system and to evaluate the impacts of present and future development schemes.

III.1.2 Kuwait

In Kuwait large scale exploitation of the Tertiary carbonate aquifer system took place during the period 1960-1988 (Fig. III.2). The present annual extraction, estimated at about 300 MCM, has already resulted in reversing the direction of vertical leakage, which was originally upwards.



Source: BRGM, 1985.

FIG.(III.1)-Development of a cone of depression in the Saq (Disi) aquifer in northern Saudi Arabia.

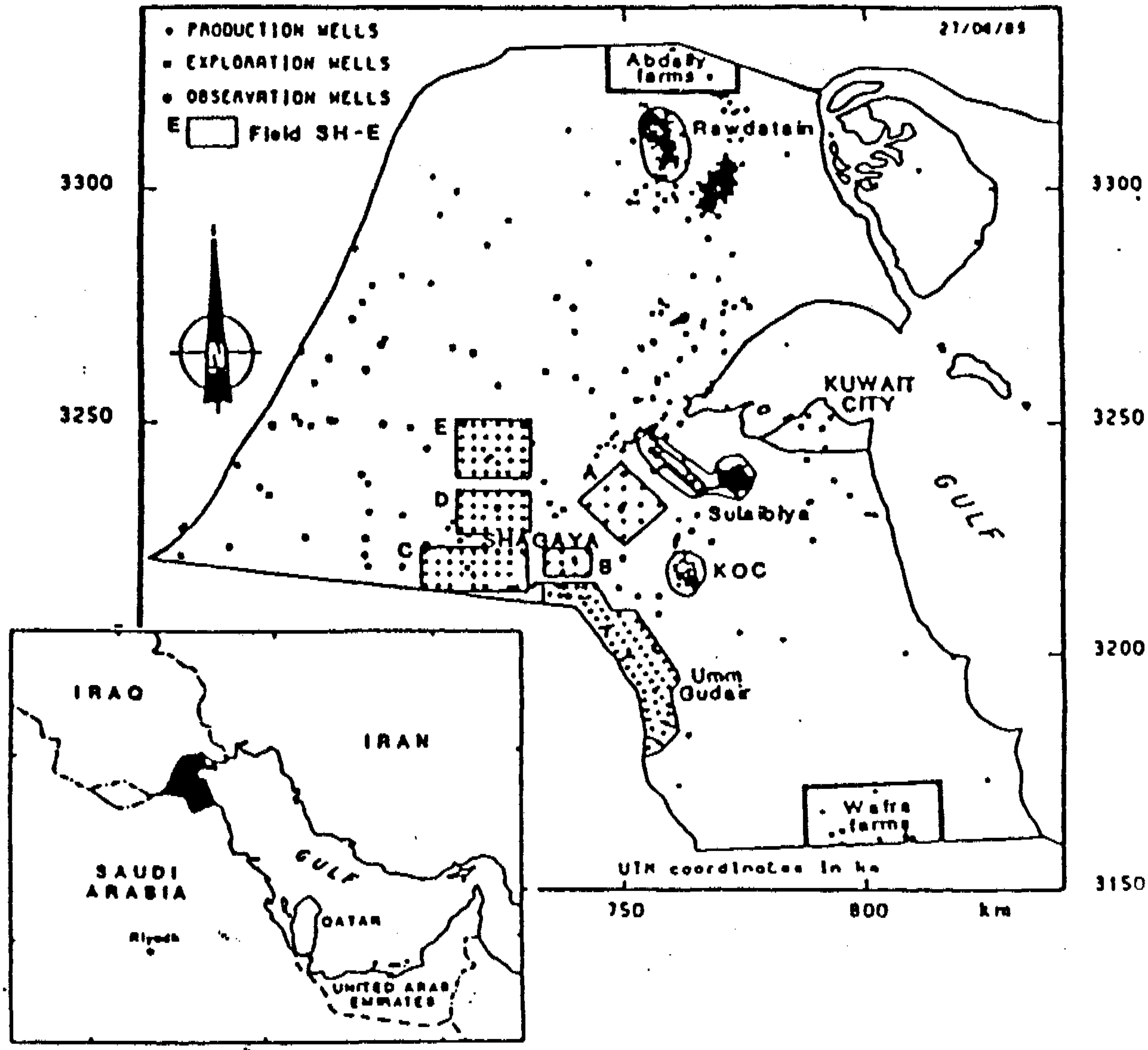


FIG.(III.2)-Intensive development in the regional carbonate aquifer system in Kuwait.

Source: Barrat et al 1991, VII th world congress on water resources Rabat , May,1991.

Simulation showed that due to effective mining of the carbonate aquifer, it would not be possible to meet the projected water demand, and in areas of intensive irrigation, drying of wells will commence by the year 2000. With the continued heavy exploitation and the increasing rate of extraction from 11 m^3/s to 16 m^3/s, the decline of the potentiometric surface would amount to 200 m. Sea water intrusion will occur in several places (Barrat et al, 1991).

III.1.3 Bahrain

Annual abstraction from Dammam and Umm Er Radhuma aquifers in Bahrain, increased from 63 MCM in 1990 to about 220 MCM in 1992 (Alnaimy, 1992), which is more than double the amount of recharge from the mainland in Saudi Arabia, estimated at 90 MCM. Thus, about 130 MCM is being taken annually from storage. The impact of over-development on the resources base and on the environment can be summarized as follows:

a) Decline of water levels; long-term records are not available, however, the decline rendered some central and coastal regions unproductive due to depletion and pollution of the aquifer (UNEP-UNESCWA, 1991).

b) Contamination of the aquifer by sea water intrusion and upward invasion from underlying saline aquifers have already reached alarming levels since it is estimated that about half of the original aquifer fresh water volume has been contaminated.

c) As a result of deterioration of groundwater quality, water supplies for irrigation became increasingly more saline. Over-irrigation and lack of drainage system have caused water logging and led to the accumulation of salts in the soil. It is estimated that the agricultural land has declined from 6460 ha in 1956 to 3748 ha in 1982 (UNEP-UNESCWA, 1991).

Corrective measures, taken in the 1980s have, however, resulted in reversing this trend. The agricultural land increased from 3748 ha in 1982 to 4020 ha in 1988.

The management of land and water resources are considered of primary importance. The national strategy on control of environmental degradation puts special emphasis on protecting the groundwater from over-exploitation and deterioration of quality. Since agriculture is the major user of water resources, the strategy includes provisions for conserving and restoring agricultural lands. The prevailing social behavior and economic system are considered among the primary causes of degradation of the environment.

The state of Bahrain has taken the following corrective measures to protect land and water resources.

- Several amiri decrees were issued to protect water and agricultural land, and regulate groundwater development and water use.
- Research activities have been carried out to evaluate the magnitude of problems related to intensive groundwater development; salinization of soils, improved irrigation methods and water distribution and use efficiencies.
- An artificial recharge study was conducted. The study tested the temporary storage of treated waste water in the deep Umm Er Radhuma aquifer and its feasibility particularly in its upper part where the quality is relatively good. The study included the best practices for such storage procedures.
- Several models were developed to provide detailed assessment of the aquifers. The studies recommended that the overall water production to be reduced to 90 MCM. Present abstraction is about 220 MCM (Alnaimy, 1992). The modeling studies showed that if this recommendation is

implemented the saline interface will retreat to approximately its 1955 position by the year 2000. Furthermore upward leakage of saline water in the central areas will decline markedly by the year 2000 (UNEP-UNESCWA, 1991).

- Mass media and awareness started in 1984 with the aim of rationalizing water use at the State level.

System analysis design is proposed, in order to arrive at optimal solutions, and gradually construct an integrated development plan. The plan simultaneously covers most pending requirements, and does not have detrimental effects on both natural resources and environment (UNEP-UNESCWA, 1991).

III.1.4 Qatar

Qatar is another area where intensive development of the Tertiary Carbonate regional aquifer system produced serious adverse effects. Total annual extraction from the carbonate aquifers in 1980 was estimated at about 80 MCM. Withdrawal will increase to 132 MCM in 2000 (Al Hajiry, 1992). Computations indicate an average depletion of aquifer storage at a rate of 20 MCM/yr. At such abstraction rate, it was estimated that the aquifer storage will be depleted in 20-30 years (Al Hajiry and Almusand, 1992). The present rate of sea water intrusion was estimated at 1 km/yr. A recent estimate of water demand has shown a rapid growth. Estimated annual water demand for agriculture was about 110 MCM and for domestic use about 87 MCM (desalinated water is blended with extracted groundwater).

Water demand will increase to 146 MCM for domestic use and to about 139 MCM for agricultural use (Fig. III.3). This rapid growth would undoubte-

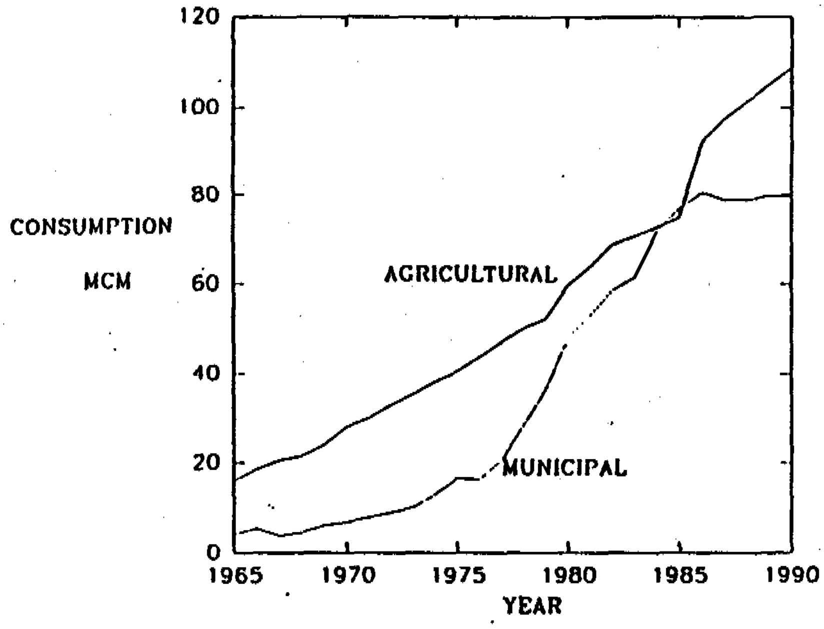


FIG.(III.3)- A: Water Consumption for Municipal and Agricultural Purposes in Qatar, 1965-1990

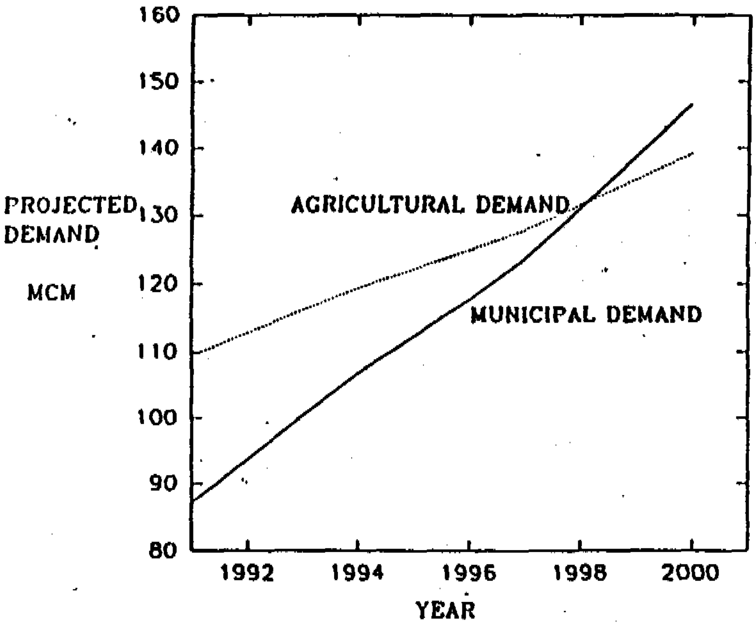


FIG.(III.3) B: Municipal and Agricultural Water Demand in Qatar, 1992-2000.
(Source: Al-Hajari & Al-Mousannad, 1991)

dly lead to the depletion of reserves by the year 2000 (Al Hajiry and Almusand, 1992).

Several options were considered in Qatar to deal with this serious problem. They include large water transfers, increasing the production of distilled sea water, water reuse, and demand management.

III.1.5 United Arab Emirates

Major aquifers in the UAE are shallow Quaternary alluvial aquifers, the most important of which extends along the western side of the Oman mountains from Ras El Khaymah to Al Ain. A less extensive aquifer occur on the eastern side of the mountains. Most of the recharge to the western and eastern aquifer systems is received at the heads of alluvial fans by infiltration from wadi flows which originate in the mountain zone.

Due to change of facies from limestone to marls, the prolific Dammam aquifer of the Arabian peninsula becomes saline and of low productivity in the greater of the UAE.

In 1975 the total withdrawal from the main, western alluvial aquifer was estimated at 224 MCM and the mean annual recharge at 100 MCM leaving a groundwater overdraft of about 124 MCM. In 1985 total amount of groundwater mined was estimated at 1000 MCM, whereas the total amount stored in the "gravel plain" is estimated at 8000 MCM. The high rate of depleted groundwater levels are lowered to be of about 2 m per year. In the Ras El Khaymah, and the eastern region, intensive development of the coastal aquifers has lowered the water table below sea level. The interface between fresh and salt water has moved inland. Fig. III.4 shows the magnitude of sea water intrusion in the Fujayrah area.

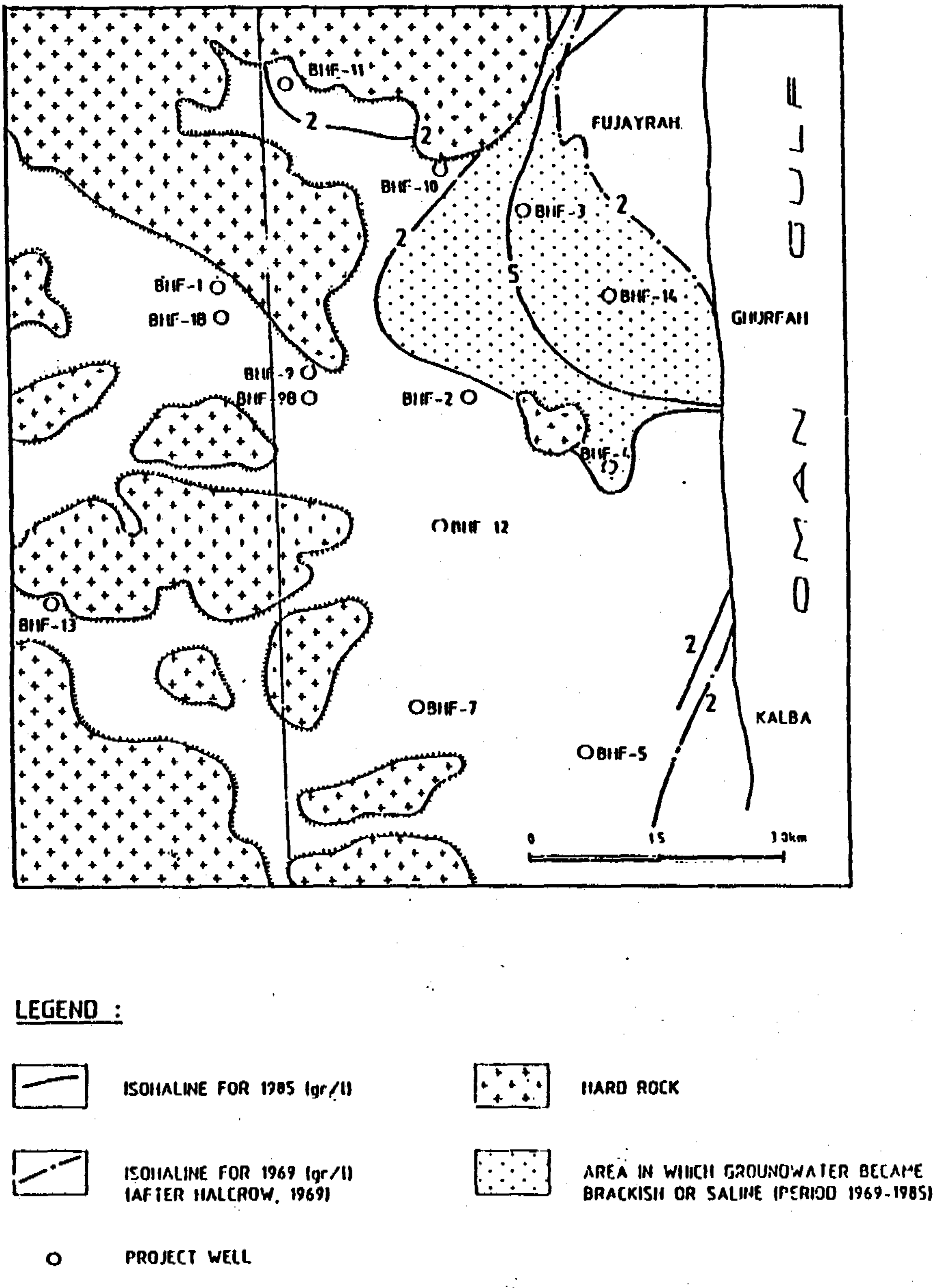


FIG. (III.4) Sea Water intrusion in the Fujayrah coastal aquifer, UAE (Source: UAE Project 21181 Main report, IWACO, 1986).

III.1.6 Oman

The inland and coastal sub-montane basins, which extend along the foot of the western and eastern flanks of the N-S trending Oman mountains, constitute the principal source of renewable freshwater resources for both Oman and the United Arab Emirates. The principal aquifers in the eastern sub-montane basin occupy the Batinah coastal plain. They consist of gravels conglomerate, coarse and medium grained sands, silts and clays or clayey gravels.

As is the case in most sub-montane arid zone alluvial basins, two distinct hydrogeologic and geomorphologic zones are distinguished in the Batina coastal regions, these are the piedmont zone and the coastal plain.

In the coastal plain zone (Fig. III.5) the wadis broaden and become braided. Their deposits in the plain consist of sand and gravel. The alluvial deposits generally become finer grained towards the coast in the interfluve area between the system of braided channels. Nearer to the coast the coastal plain is underlain by fine grained sands and silts of alluvial and aeolian origin. The last major feature of the coastal plain zone is a sand dune line adjacent to the sea. At places, the sea has broken through the dune line and forms lagoons and sabkhas.

Most of the water used in Oman is developed by Falaj systems. The Batina and Salala plains, are, however, developed by wells. Of the total annual water use estimated at 1260 MCM, 73 percent is exploited by Falajes.

The western and southern alluvial basins of Oman consist of a large number of coalescing alluvial fans, deposited to the south and west of the Oman mountains. In Bajada of interior Oman there are two major aquifers;

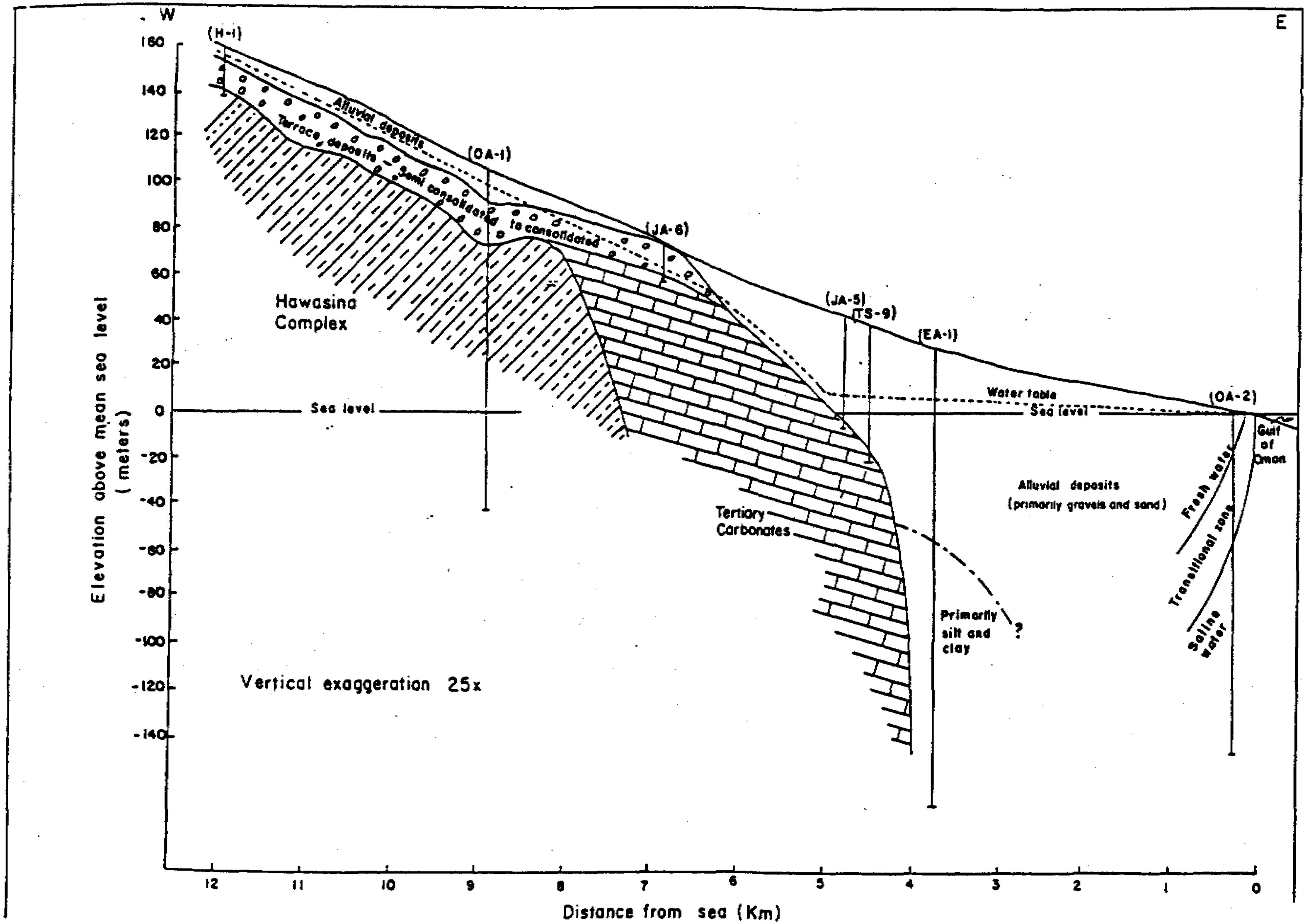


FIG.(III.5)- HYDROGEOLOGICAL CROSS SECTION OF BATINA AQUIFER SYSTEM the Quaternary alluvium, and Fars group. The underlying formations are lower Tertiary carbonates.

Infiltration from direct precipitation on the sub-montane basin is not considered a significant source of recharge. Precipitation which is intense enough to cause runoff in wadis channels often results in recharge. Underflow from consolidated formations of adjacent mountains is negligible. The main source of recharge is surface runoff and underflow in wadi fill.

Water from gravel aquifers in major wadi-basins such as wadi Bat-ha has a low-medium dissolved solids concentrations. The conductivity of groundwater generally increases from about 1000 micromhos/cm near the base of the mountain to about 3000 micromhos/cm in the zones of lateral flow away from the mountains. The quality of groundwater in the gravel aquifers of interior Oman ranges from good to fair. Higher concentrations of dissolved solids are mainly due to continued recycling of irrigation water. During dry periods the conductivity of water from alluvial aquifers in agricultural areas reaches 2000 micromhos/cm.

The Batinah region is underlain by highly permeable gravel deposits. Actual measurements in selected wadis has shown that in major wadis about 20 to 40 percent of wadi-flow recharges the upper gravel aquifer. However, the various components of groundwater balance, recharge, losses to the sea, evapotranspiration, and runoff vary widely from one area to another according to physiographic and hydrogeologic characteristics. Wadi-flow reaches the sea only after extreme events of flash floods. In general, losses to the sea are greater in northern Batinah than in eastern Batinah.

Table III.1 summarizes available information on water resources of Oman. It is clear that important resources exist in the Batinah aquifer complex (about 40 percent of total groundwater resources). Due to high demand, a deficit exists in the balance between withdrawal of water and average recharge (about 45 MCM per year).

The chemical quality of groundwater in the Batinah is fair to poor for most uses. The salinity of groundwater increases with the direction of flow. The conductivity ranges from about 1000 micromhos/cm in the piedmont and mid-Batinah zone to 10,000 micromhos/cm or more in the lower coastal zone. In most areas of eastern and northern Batinah, the conductivity is greater than 6000 micromhos/cm. In these areas, withdrawal of groundwater has diminished the flow of fresh water reaching coastal areas, and consequently intrusion of salt water has occurred.

Table III.1. Groundwater Resources and Water Use in Sultanate of Oman (MCM)

Area	Surface Runoff	Recharge	Water Use
Musandam	23.4	18.0	12.0
Eastern and Central Batinah	180.2	105.5	147.4
Northern Batinah	168.1	119.0	121.6
Interior Oman (northern area)	121.7	58.8	16.6
Interior Oman	143.2	75.1	48.7
Eastern area	95.9	70.8	29.2
Qurayat and Sour	90.1	36.9	15.4
Salalah and southern area	67.9	52.8	16.3
Zofar and northern wadis	27.3	27.0	-
Total	917.8	563.9	407.2

Source: Report to the Kuwait Symposium, 1986.

Groundwater is available in the alluvium throughout the southern and western piedmont zones. Commonly, the gravel deposits near the mountain yield larger quantities of good quality water. However, larger quantities of potable water also occur locally in the detrital marine sediments away from mountains.

The Upper Fars constitute an unconfined to semi-confined aquifer system, which is hydraulically connected to the overlying quaternary deposits. A basal clay layer acts as an aquitard, which probably accounts for the lower yields and poorer quality water found in the underlying tertiary carbonates.

III.1.7 Yemen

With the exception of local occurrences of groundwater in the Yemen highlands (Tawilah sandstone in Sana'a basins, and Wajid sandstone aquifer in Sadah area) groundwater occurs essentially in alluvial aquifers in major wadis and piedmont zones. The Tihama sub-montane basin which together with *Hadramout, Tuban and Abian wadi basins rank among the most important* basins in Yemen.

Groundwater quality of the Tihama alluvial aquifer system ranges between fair to good in the upper zones of recharge and lateral flow. The water quality deteriorates in the lower zone of lateral flow and in the coastal discharge zone. This is caused by lower permeabilities in the coastal zone and the presence of evaporites in silt and clay sediments of the coastal strip. Evaporation from shallow water table is also an important factor for salinization.

Water quality deteriorates also vertically with depth (Fig. III.6). Good quality water is generally associated with wadi-recharge. Heavy withdrawal in areas lying near coast or saline water bodies have resulted in the deterioration of groundwater quality due to salt-water intrusion.

Groundwater constitutes the most important permanent source of water supply for agriculture, it is also the main source of water supply for urban centers. In 1988, the amount of water pumped from the Tihama alluvial aquifer

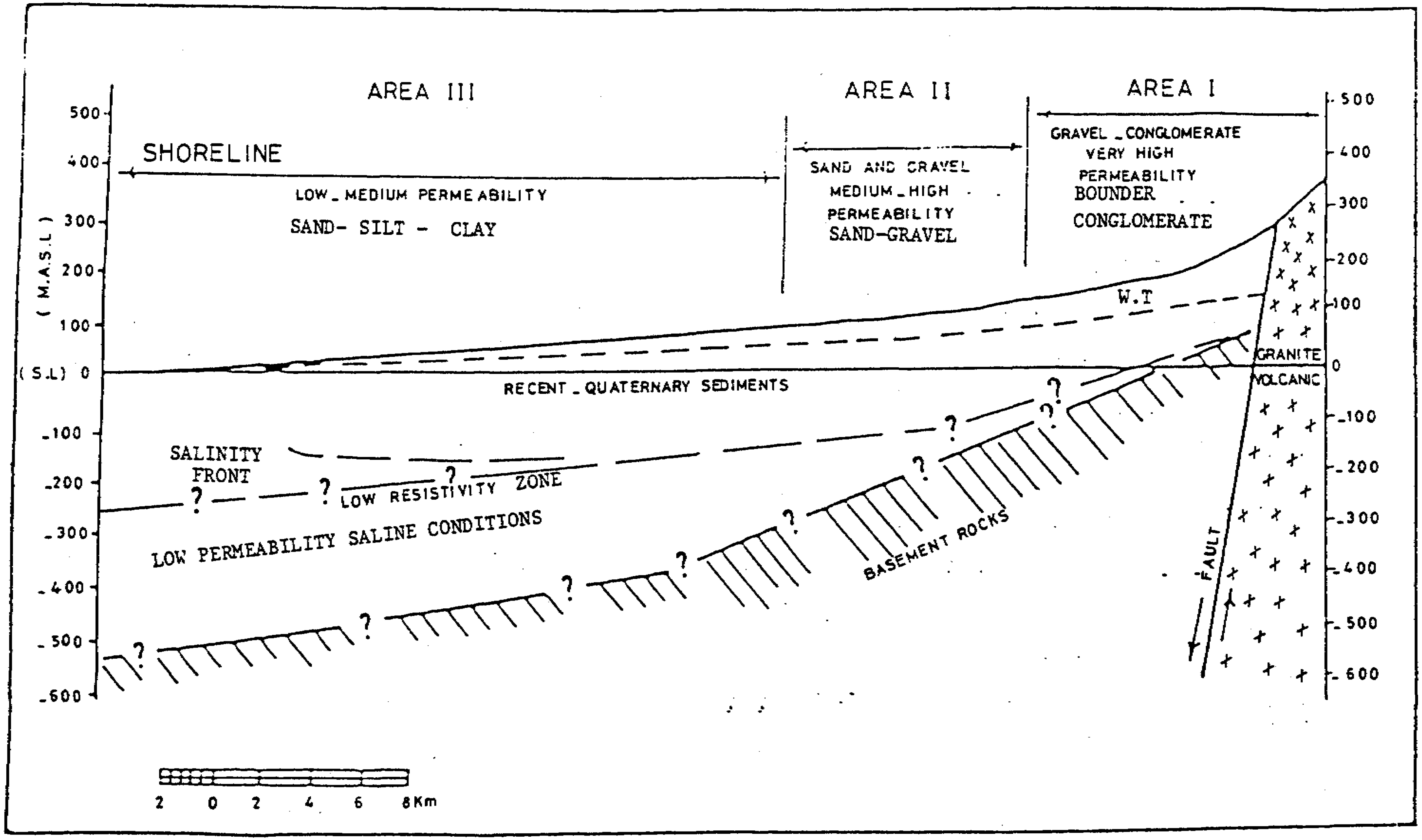


FIG.(III.6)-HYDROGEOLOGICAL(HYDROGEOELECTRICAL)SECTION OF TIHAMA AQUIFER SYSTEM,YEMEN for Hudeidah was estimated at 4 MCM. In general, groundwater in several parts of Tihama is overdeveloped. Heavy groundwater withdrawal has resulted in a general water level decline in wadi Zabid of about 4 to 16 m during the period 1970-1982. In wadi Rima the rate of water level decline is about 35 cm/year. Overdraft and sea water intrusion seem to be major problems in Tihama. However, poor quality of the groundwater may be due to the presence of salt deposits in the alluvium. The conjunctive use of surface and groundwater resources in the Tihama plain renders overdraft conditions much less serious than in other parts of Yemen.

Total annual abstractions estimated at 159 MCM balance discharge (Sogreah, 1979 and Fareh, 1989). Both dug and drilled wells have been constructed for the development of groundwater from the shallow alluvial and deeper sandstone aquifer. Pumpage is concentrated in the middle section of the principal wadi between Seiyun and al Qat'n, and in the tributary wadis. About 63 percent of water pumped for irrigation is saline water.

Groundwater in the Montane plain is generally of good quality for most domestic and other users. Water from Yemen volcanics and Tawilah sandstone aquifers has dissolved solids content ranging from 500 to 600 ppm.

The volcanic aquifers are generally capable of yielding small quantities of water to shallow or even deep wells. The Tawilah sandstone aquifer is more productive, and overdevelopment of groundwater has caused a permanent lowering of the water levels in the Sana'a, Mobar and Dhamar areas. The rate of water level decline in the Sana'a basin was about 0.5 m/year in 1972. It increased to 1.5-3 m/year in 1979, and it ranged between 1 and 10 m/year during 1980-83. In the Sana'a, Taiz, Mobar and Dhamar areas, the annual withdrawal exceeds the estimated groundwater recharge (ESCWA, 1981).

Measures are taken in wadi Hadramout to seal off the saline water bodies of the upper aquifer in the new tube-wells. Contamination of water of the lower aquifer, will however, continue through old and abandoned wells. Water quality monitoring need to be improved and pumpage should be controlled in the whole multi-layered aquifer system. In certain areas conglomerate and clay layers which occur at the base of the alluvial aquifer helps in decreasing the vertical movement of saline water. Improved management of Hadramout groundwater basin is a fundamental issue which need to be addressed.

Due to unfavorable climatic and hydrogeologic conditions the aquifer system in Yemen are vulnerable to both contamination and pollution. Salt water intrusion, as exemplified above could occur from sea or sabkha-water intrusion, or from upconing from heavily pumped multilayered aquifers which often contain saline water horizons. Spot irrigation seems to be an appropriate technique well adopted to the extreme climatic condition. A feedback mechanism need to be introduced to monitor the hydraulic and hydrochemical impacts and take appropriate action whenever necessary.

III.2 Mashrek

The conjunctive use of surface and groundwater resources in Syria, Jordan and Iraq has minimized the negative impacts of groundwater resources development. However, little attention has so far been given to water quality management and almost all rivers of small and medium size are now contaminated and have become unsuitable for industrial and domestic use without a costly treatment. Shallow aquifers which are hydraulically interconnected with polluted surface water have been partly contaminated.

The level of pollution depends on the degree of confinement and the pollution load. Unconfined aquifers in urban areas of Damascus and Aleppo basins, for example are highly polluted, due to high water table, high permeability, industrial expansion, and lack of sanitation facilities in periurban areas. Contamination by salt water intrusion from salt water bodies has occurred in several areas particularly in coastal or arid regions (Palmyra, Dawa, Radd, basins, Latakia and Akkar coastal plains). Salinization resulting from water logging has also occurred in several parts of the rift valley in Syria and Jordan and in a large part of the Euphrates flood plain in Syria and Iraq. The Cretaceous carbonate aquifer which is a major aquifer in Syria, Lebanon and Jordan is also a high vulnerable aquifer because of the extensive development of karstic features and open fissures systems. Pollution has been reported locally in the unconfined parts of the aquifer in Amman (Jordan) and Homs areas and in the intermontane basins of the anti-Lebanon range (Khouri, 1987).

However, a groundwater protection strategy has been developed and implemented recently in Syria and Jordan for preventing further pollution and protecting some important potential sources of domestic water supplies. Several examples could be cited in this respect. In Syria protection zones have been defined for all major springs, particularly those used for drinking water supplies (Sinn and Fijeh large springs which are used for the water supply of Latakia and Damascus respectively). Well head protection zones have also been delineated in the neighborhood of large cities in Jordan and Syria.

The extent and level of contamination in both fissured and granular aquifers of Syria, Lebanon and Jordan is not adequately known. A groundwater quality monitoring network is a major and urgent need, to meet the requirements for future groundwater protection programmes.

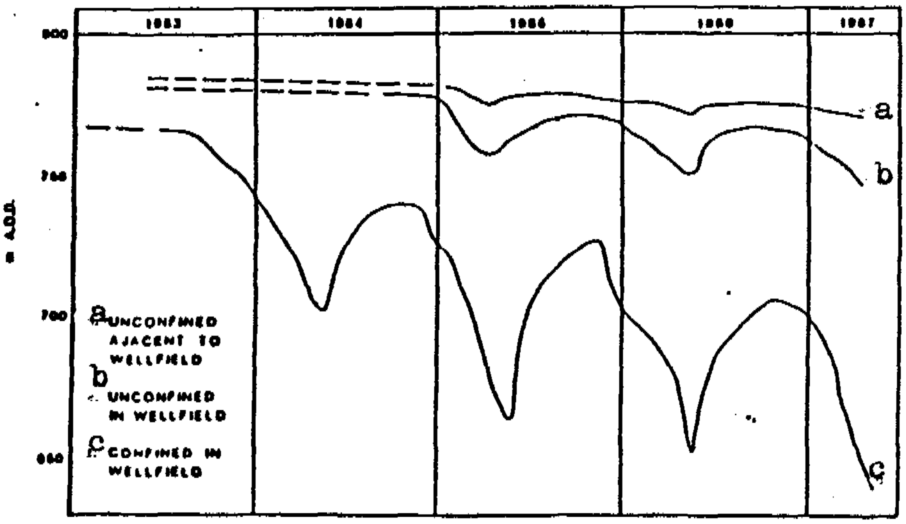
The Paleozoic sandstone aquifers have been also intensively developed in Jordan. The aquifers are generally capable of yielding large quantities of good quality water to wells in many localities. Extraction of water in Jordan increased from 15 MCM/yr in 1983 to 80 MCM/yr in 1989.

It is generally accepted that the Disi-Saq aquifers do not receive major replenishment, and consequently groundwater is drawn mainly from storage. The impacts of intensive development on the Disi aquifer in Jordan have been summarized by Salameh (1989) as follows:

- The total pumpage of about 300 MCM during the period 1983-89 had caused a decline in water levels amounting to more than 9 meters in some areas.
- The Disi aquifer is hydraulically connected with several overlying aquifers. Heavy exploitation will affect other sources of water in Jordan and is expected to cause a general drop in water levels.

Groundwater abstraction from the Disi-Saq aquifer is considered a mining operation (Lloyd, 1992), so the main impact is in terms of drawdown and supply degradation. Regional cones of depression have developed in the confined section of the aquifer in Jordan and northern Saudi Arabia. The confined part of the aquifers shows, clearly much wider development impacts than the unconfined section (Fig. III.7).

During the late 1980s groundwater quality showed an increase in different constituents indicating an upconing of deeper mineralized waters.



Source: Lloyd and Pim, 1990.

FIG. (III.7) Hydrographs from the Saq(Disi) aquifer in Northern Saudi Arabia showing differing impacts under differing aquifer conditions.

Since the Disi aquifer is a strategic water reserve for Jordan and is only long-term source for the water supply of Aqaba, there is a fundamental need to establish a long-term strategy for its development. The aquifer is a part of larger aquifer system shared with Saudi Arabia, and coordination of plans for its exploitation is an important step towards an environmentally sound management of this very important and vulnerable freshwater resources (Khouri, 1982).

III.3 The Nile Valley

III.3.1 Egypt

The country is characterized by limited precipitation rates ranging between 20 mm/year in the south to less than 200 mm/year in the north. Accordingly, rainfall does not constitute considerable source for recharging the main aquifers in the country, with the exception of the northern coastal strip along the Mediterranean sea and few other local aquifers in Sinai. On the other hand, the Nile River, the irrigation network system, and the cultivated lands which occupy only 3 percent of the Egyptian territories, are considered the main recharging source for the aquifers in contact with the Nile Valley and Delta. Perhaps the most important and potential groundwater basin in Egypt is that of the Nubian sandstone, which occupies considerable extensive area in the Western Desert. This basin is known to have extremely limited recharge from outside the Egyptian borders, specifically Chad and Sudan, but contains meanwhile huge groundwater reserves which are being exploited in both Egypt and Libya, with limited utilization in Sudan.

In quantitative terms, the total natural recharge of all groundwater basins and aquifers in Egypt is estimated to be of the order of 8.5 billion

m^3/year. These basins are mainly recharged from the Nile, the irrigation and drainage system and the cultivated lands, and only 0.4 billion m^3/year is recharged from the prevailing local rainfall.

In regards to utilization of groundwater in Egypt, the major exploitation is restricted to the Nile Valley and its fringes, which is presently estimated to be about 3 billion m^3/year. Groundwater exploitation from the Nubian sandstone basin in the Western Desert is about 0.365 billion m^3/year. The exploitation of groundwater in other areas in Egypt, specifically Siwa, Natrun and Sinai may not exceed 80 million m^3/year. Therefore, the total amount of groundwater exploited and used at present is of the order of 3.5 billion m^3/year.

Since the main recharge of the water bearing formations adjacent to the Nile Valley is derived from the Nile River, canals and irrigated lands, and taking into consideration the inappropriate water quality of these sources, it is believed that some risks may arise, if groundwater is used directly in some localities for drinking purposes, without adequate systematic testing (chemical, and biological) before utilization.

In general, the groundwater basins in Egypt can be represented geographically in five main regions; (Fig III.8)

i. The Nile Valley and Delta; This region extends along the Nile River and its canal's network from the southern borders of Egypt to the Mediterranean Sea. The basin consists of gravel, sands, and silts of thickness ranging between 100 m to 500 m in the Delta and from 15 m to 250 m in the valley (RIGW, 1992). The aquifers in this region are in hydraulic connection with the Nile River. Prior to the construction of the High Aswan Dam, the groundwater levels at the fringes of the Nile

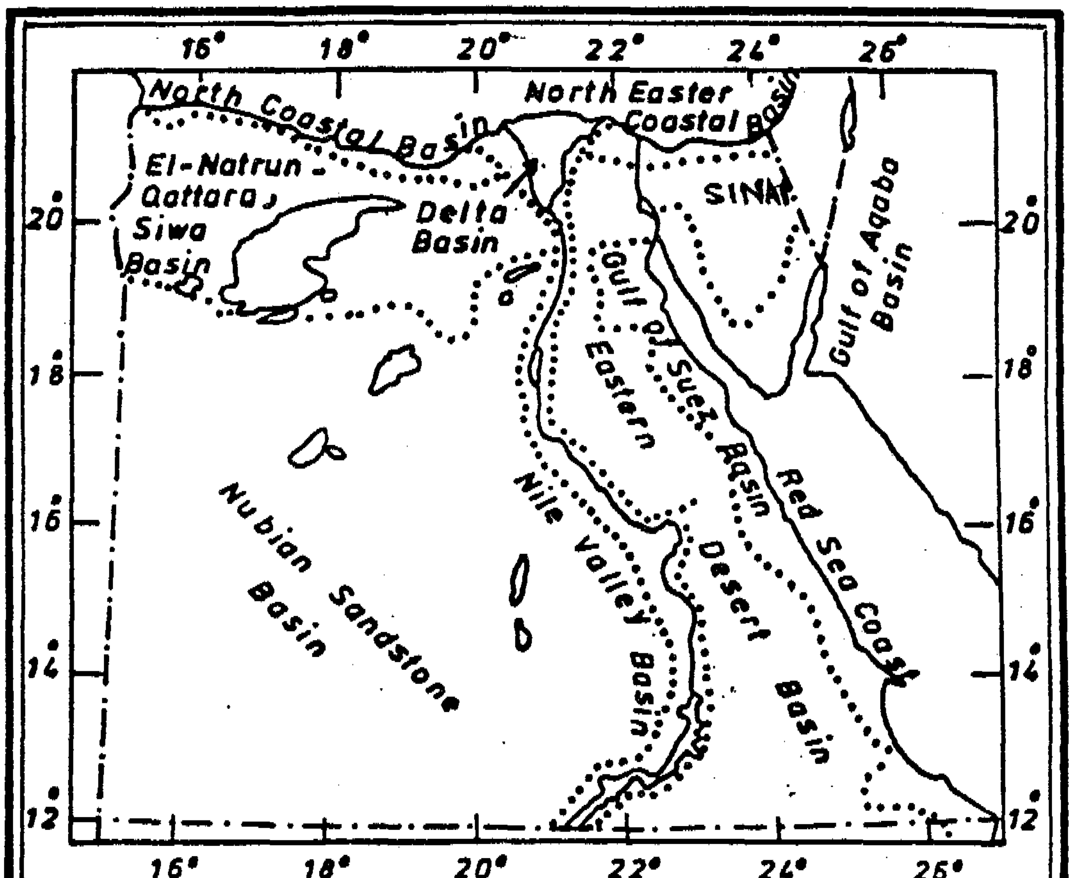


FIG.(III.8)- Map Showing Locations of Hydrogeographic Basins in Egypt

Valley fluctuated seasonally following those of the Nile River, its branches and main canals. The fluctuations in the groundwater levels diminish away from the recharge sources. The hydrologic situation, however, has been changed after the construction of the High Aswan Dam and the consequent intensive expansion in land reclamation at the Delta fringes to the west and east. The direct impact of the new groundwater regime is represented in a steady rise of the groundwater levels at these regions accompanied by the formation of local groundwater mounds and reversals of the groundwater flow direction (Schulze et al, 1973). Such rise in the water levels, although tending to reach a steady state, has created water logging in some localities which may threaten soil productivity and drainage efficiency in the Delta and Nile Valley (Saad and Bishay, 1994). Also, the rise of the water table is associated with rise in groundwater salinity in some newly reclaimed areas. This latter phenomenon is mainly attributed to the presence of some marine and/or lacustrine deposits, in some localities of the lands under cultivation, which has created accordingly some water quality problems at the fringes of these newly reclaimed areas.

ii. The Western Desert; This region occupies an extensive area in Egypt, Libya, Sudan and Chad, and comprises a number of water bearing formations, where the Nubian groundwater basin is the most important. This basin is known to have limited recharge or perhaps nil, but contains huge water reserves. The basin had maintained a state of dynamic equilibrium until 1956 when intensive exploitation of groundwater started to take place at some localized oases (Kharja, Dakhla, Farafra and Baharia). As a result of this intensive exploitation, which is concentrated at these small localized areas of the vast desert, the piezometric surface has continuously declined since then, and the majority of the artesian wells have stopped flowing. The rate of decline in the piezometric surface ranges from 0.5 m/year to 2 m/year, according to the rate of exploitation (Fig. III.9). Taking into consideration the complexity of hydrogeologic and hydrogeochemical situation of the basin, coupled with the fact that the groundwater is being extracted from several stratified water bearing formation of various piezometric surfaces and chemical compositions, the hydrologic regime renders more complicated. Such situation has created some environmental problems reflected directly on the shallow wells of the individuals, as well as to the economy of the agricultural project as a whole. Consequently, reclamation activities have slowed down, and remedial measures are being focused, to develop feasible exploitational strategy and to cope with some field problems as well casing corrosion caused by the aggressive groundwater.

iii. The Eastern Desert; This region, although occupies extensive area, is subject to limited recharge from rainfall. Accordingly, the sporadic water bearing formations are only exploited at a rather very modest levels, and the groundwater situation does not pose any considerable problem other than its natural scarcity.

iv. Sinai; This region comprises a number of isolated groundwater bearing basins of limited potentialities as these are restricted to surface drainage patterns which are subject to considerably low rates of rainfall. In view of the strategic importance of this region, for mining and tourism, these

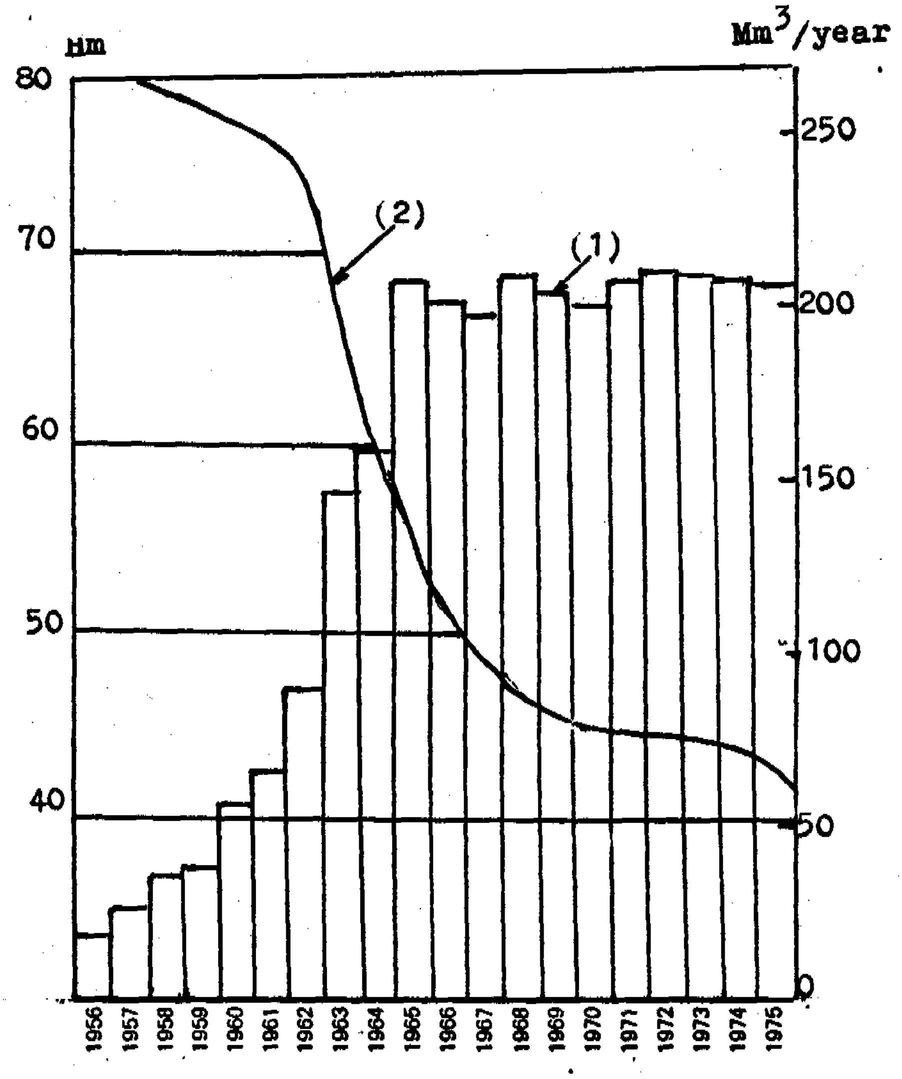


Fig.(III. 9)- Exploitation of the deep Nubian sandstone aquifer in the western Desert of Egypt;
(1) graph showing annual withdrawals from the deep wells in Kharga and Daghla oases
(2) curve showing changes in piezometric surfaces in Kharga

Ref., Groundwater Resources, Report FAO/UNDP 1977, and Margat and Saad (Unesco, 1984) isolated small scale groundwater basins are being heavily exploited, and in some localities are overexploited. As a result of this, some harmful impacts are observed as depletion of the basins, and salt contamination of the coastal aquifers by salt water intrusion, along the Gulfs of Suez and Akaba.

v. The Mediterranean Coastal Strip; This region occupies the most northern strip, along the Mediterranean Sea of the Western Desert and Sinai. This strip, although comprises isolated small scale groundwater basins, yet it has an economic importance due mainly to its favorable touristic and recreation possibilities. Recently, some measures have been taken to transfer Nile water through pipes for tourism and canal system for irrigation, in the western coastal strip, and establishment of an irrigation system, through El-Salam canal, in the eastern coastal strip. Groundwater thus will be considered ultimately as a supplementary water resource in this strip.

Due to the stress of water shortage, Egypt plans to increase the groundwater abstraction from some 3.5 billion m^3/year in 1990 to about 7 billion m^3/year by the year 2000 (MPWWR, 1990). Table III.2 gives some hydrologic parameters regarding recharge and utilization.

Table III.2. Estimates of Groundwater Recharge and Utilizations in Egypt

Region	Recharge ($10^9 m^3$/year)	Storage ($10^9 m^3$)	Salinity (ppm)	Utilization ($10^9 m^3$/year) 1990	Utilization $10^9 m^3$/year 2000
Nile Valley and Delta	8.1	500	300-1000	3.0	4.9
Western Desert	0.3	6000	300-1000	0.42	2.0
Eastern Desert	limited	limited	1500	limited	limited
Sinai	limited	limited	variable	0.05	0.1
Coastal Mediterranean	0.1	limited	1000-2000	0.03	0.05
Total	8.5			3.5	7.0

Source: MPWWR, 1990

III.3.2 Sudan

The rainfall rate in Sudan ranges between 1600 mm/year in the south and south west to about 25 mm/year in the far north. The high evaporation rate which ranges between 3000 mm/year to 1200 mm/year, is responsible for the loss of considerable amounts of rainfall.

The groundwater basins occupy about 50 percent of the surface area of Sudan and are mainly represented by (Fig. III.10), (El-Tayeb, 1992).

i. Nubian Sandstone; occupies about 700,000 km² (28 percent of Sudan) located in the northwest Sudan, Khartoum, north Kordofan, Darfour, and extends to some localities in the middle and eastern regions.

ii. Um Rawaba Sediments; occupy about 500,000 km² (20 percent) located in Bara and Bakara basins, and the Blue Nile of Sud region.

iii. Valley Sediments; occupy about 50,000 km² (2 percent), located in the valleys of Wadis, such as, , Niyala, and Al-Kash.

The annual recharge varies considerably with time, due to the extreme variation of rainfall rate. The available records show high discrepancies for the estimates of recharge. While some records gave values reaching 8 billion

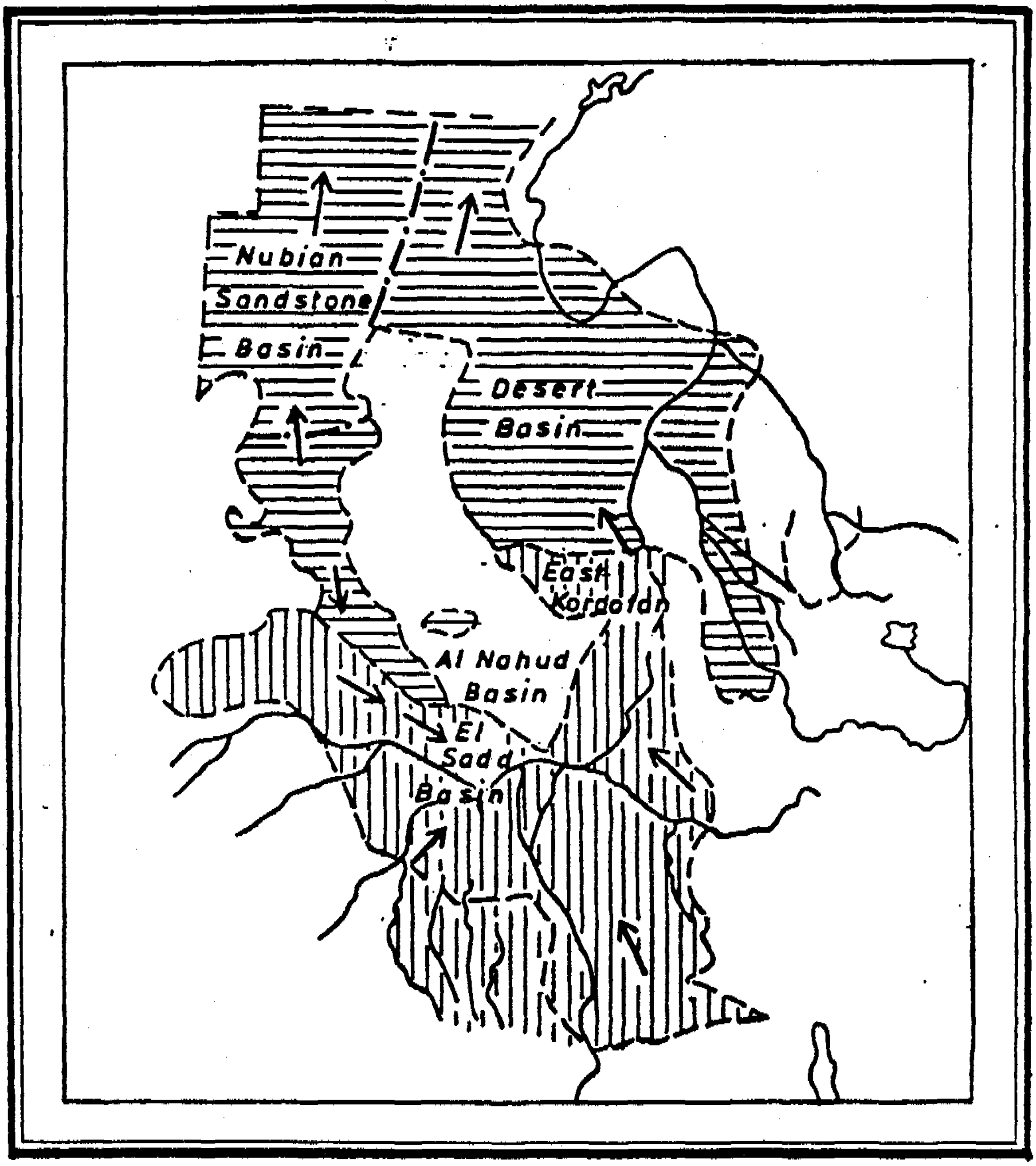


FIG. (III. 10) - Map of groundwater basins in Sudan.

m^3/year, others show that the annual recharge varies between 0.13 to 0.9 billion m^3/year. However, it is evident that the amount of water storage is huge enough, estimated to be about 4700 billion m^3, to enable sound economic development (UNESCO/ACSAD, 1988).

The groundwater in Sudan, does not constitute a major water resource, as compared to the prevailing surface water, except in remote areas away from the Nile River and its tributaries. However, due to the extreme variation in the climatic conditions, the country is oftenly stricken by waves of drought and desertification which encourage accordingly continuous migration of the inhabitants from the areas of poor groundwater to areas rich in surface water. The areas, where scarcity of groundwater prevails are mainly located in the north and middle of Sudan. However, the main utilization of groundwater in Sudan is restricted to domestic and drinking purposes. Therefore, little attention has been given to the groundwater problems, until very recently when the country offered plans for the exploitation of deep groundwater from the Nubian sandstone aquifers, with joint efforts with Egypt and Libya which share the same basin.

The following list gives estimates of the amounts of groundwater utilized in the various regions in Sudan which amount to about 767 million m^3/year; i.e., less than 10% of the available annual groundwater recharge (UNESCO/ACSAD, 1988).

- Northern region 476 million m^3/year
- Eastern region 145 million m^3/year
- Middle region 30 million m^3/year
- Khartoum region 35 million m^3/year
- Kordofan 38 million m^3/year

- Darfour 43 million m^3/year

III.3.3 Somalia

The rainfall rate in the country ranges between 150 mm/year in the north to about 600 mm/year in the south and along the Indian Ocean. These rates of precipitation, along with the surface water in Shibilly and Jouba rivers constitute considerable sources for sufficient water supply to the country. However, little attention is focused on the groundwater situation, as the main interest is devoted to surface water. Accordingly, the groundwater basins are poorly identified, and managed. The groundwater is only used sporadically for drinking purposes in the main cities, i.e., Mogadishu, and Harguiza where about 17 million m^3 is extracted annually (Asaad and Rofail, 1986).

The groundwater in Somalia is found mainly in eight basins which can be grouped geographically in two regions; along the coastal region and in the interior region (Khouri and Drouby, 1990). Although little information is available in respect to estimates of recharge and utilization, it is evident however, that the coastal region is continuously subject to salt water intrusion, while the interior region is subject to continuous depletion of the groundwater. The salinity of the groundwater ranges between 1.5 and 10 g/lit at the coastal region, and from 0.5 to 5 g/lit at the interior region.

Nevertheless, the major problem in Somalia in respect to water resources is directly linked to extreme shortage of specialists and trained personnel in this particular field (Saad, 1993).

III.3.4 Djibouti

The rainfall rate in the country is very modest, as it ranges from 50 to 150 mm/year. In the absence of surface water streams, the groundwater constitutes the main and perhaps the only water resource in the country. Despite this fact, groundwater basins are poorly identified and very little information is available about annual recharge and utilization. The only estimates of groundwater is that used for drinking purpose extracted from the aquifer at the capital Djibouti, where about 16 million m^3/year is being used. However, it is believed that far more amounts of groundwater is being exploited at various localities of the country, but with inadequate plans and poor management (Riyala, 1992). As a result of this, most of the groundwater basins are subject to both contamination by salt water intrusion, and continuous depletion. It is evident however, that the country suffers from extreme shortage in specialized and trained personnel, besides some prevailing economical constraints (Saad, 1993).

III.4 Maghreb

With the exception of the mountain ranges in northern Morocco and Algeria (Atlas and Kabylie), the groundwater forms the principal water resource in the Maghreb countries.

III.4.1 Libya

The groundwater in Libya constitutes at least 95% of the total water resources. The main groundwater basins are (Salem, 1992).

i. The Djefara plain in northwestern Libya.

ii. The Jebel al-Akhdar in northeastern Libya.

iii. The Nubian sandstone basin (Kufra and Sarir) covering an area of about 650,000 km^2 in south and northeastern Libya.

The former two basins receive considerable annual recharge, while the latter, although the most potential basin in Libya, is known to have only extremely limited recharge.

The Djefara plain has an important economical potential as it provides more than 50% of the agricultural production and houses more than 40% of country's population. The annual extraction from the groundwater basin in this plain increased from 210 million m^3 in 1960 to 553 million m^3 in 1980. As a result of this intensive exploitation, a decline in the water level of about 24 m has been observed in the last 10 years, (Fig. III.11). Also, sea water is intruding inland at the rate of 0.5 to 3 km/year. The groundwater quality is also deteriorating, as the salinity varies from 1 g/l to 7 g/l. The groundwater extraction in 1990 from the plain was estimated to be more than 500 million m^3/year, while the recharge varies between 130 and 360 million m^3/year. It is expected that the groundwater levels will further decline at a rate of 5 m/year.

In Jabal al-Akhdar region, which covers the Benghazi and coastal plains, the main aquifer consists of fissured and highly karstified limestone where an estimated amount of about 300 million m^3 is annually lost in the formation cavities. The aquifer is continuously subject to sea water intrusion depending on the rate of withdrawal. The normal groundwater salinity varies between 0.3 and 0.6 g/l.

The Nubian sandstone aquifer is the most important basin in Libya and is being largely exploited in two areas; the Kufra and Sarir basins. These basins constitute the north western portion of the huge Nubian basin covering parts of Egypt, Sudan, Chad, and Libya. Detailed studies have been conducted

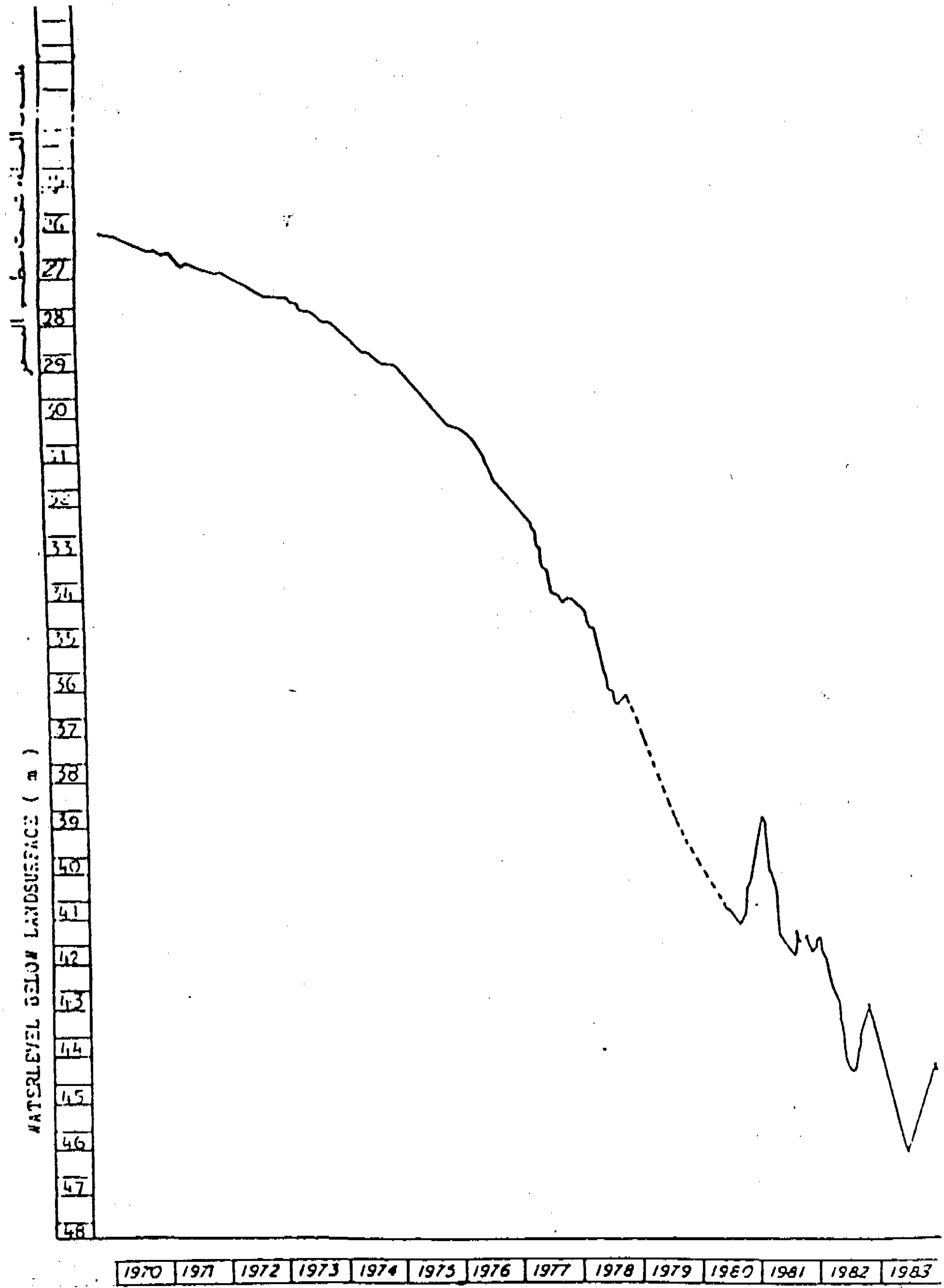


FIG.(III.11)- Variation of Ground water Levels in the Shallow Aquifers in Djeffara Plain, Libya (from Salem and Talha, 1984) on the Nubian basin within the framework of the Great River Project (Salem et al, 1994). Table (III.3) shows the groundwater extraction from the main aquifers for the various purposes in the year 1985 and projection for the year 2000. It appears that the total extractions will reach about 4270 million m^3/year by the year 2000. This however, will result in further salt water intrusion in the coastal plains and continuous decline of the water levels in all aquifers.

Table III.3. Groundwater Extraction in Libya

Basins	Extraction, year 1985 (million m3/year)		Extraction, year 2000 (million m3/year)	
	Agriculture	Domestic & Industry	Agriculture	Domestic & Industry
Fezan	465	45	1150	95
Middle Region	210	60	270	130
Djefara plain	600	120	700	220
Jabal Akhdar	100	105	190	210
Kufra & Sarir	370	40	1230	75
Total	1745	370	3540	730

Source: Salem, 1991

III.4.2 Tunisia

The groundwater resources in Tunisia exist in two main types; the phreatic aquifers in which the total estimated recharge is about 586 million m^3/year, and the deep aquifers of annual recharge of about 1139 million m^3/year (Table III.4). Therefore, the total available groundwater recharge in Tunisia is about 1725 million m^3/year, which represents about 40% of the total available water resources, in the country, which amounts to about 4355 million m^3/year (Basha, 1992).

Table III.4. Available Groundwater in Tunisia (in million m³/year)

Region	Shallow Aquifers	Deep Aquifers	Total
Northern Region	325	148	473
Middle Region	194	267	461
Southern Region	67	724	791
Total	586	1139	1725

It is worth mentioning that the natural recharge of the shallow aquifers is almost totally exploited, while only 75% of that of the deep aquifers is being extracted. The groundwater salinity varies between 0.5 and 1.5 g/l in the shallow aquifers, and between 1.5 and 8 g/l in the deep aquifers. As a result of intensive exploitation, although within the natural recharge rates, the groundwater levels decline in localized areas, besides the occurrence of salt water intrusion in some coastal areas at the north and east of the country. Salinization and alkalization of the irrigated lands have been observed in the Kayrawan plain and other areas in Tunisia.

III.4.3 Algeria

The groundwater in Algeria is found in two distinctive types of basins; the northern basins in the form of isolated aquifers of limited extension and storage, and those located in the desertic areas. The formers are of good quality water and are being exploited presently at the rate of about 1.7 billion m³/year, while the latters have salinity ranging between 1.5 and 5 g/l, and the estimated abstraction is about 2 billion m³/year (ACSAD, 1993). In general, the shallow aquifers in the country are subject to serious contamination from the surface water streams which act as drains to most of the sewage waste water, as well as from infiltration of irrigation water which is rich in nitrates derived from fertilizers. Examples are found in Mitidja plain in southern Algeria, and in Sidi Bel Abbas and Saida, where the nitrate content exceeds 50 mg/l. Scanty information on the ground water quality is available, due mainly to inadequate monitoring network.

III.4.4 Morocco

The total groundwater recharge in Morocco is estimated to be about 10 billion m^3/year, in addition to some considerable reserves in the basins located at the south of the country, which are known to have limited annual recharge (Shawi, 1992). The groundwater presently used in agriculture, at Souss, Tadla, and Sois, is estimated at about 3 billion m^3/year. The groundwater is also used for drinking purposes, particularly in the major cities in the country; Merrakesh, Agadir, Fes, Meknas, Kneitra, Oujda, and Al-Ayoun, as well as in many rural areas. Salt water intrusion prevails in most of the coastal areas. Considerable contamination of shallow wells takes place, due to infiltration of irrigation water in which the nitrate content exceeds 50 mg/l.

III.4.5 Mauritania

With the exception of the Senegal River, the groundwater remains the principal water resource in the country. However, estimates of this resource is still uncertain due to the absence of systematic assessment. The groundwater is exploited sporadically and without adequate management, which resulted, accordingly, in serious deterioration of the groundwater basins both in quality and quantity (Gadou, 1992).

PART IV

ADEQUATE METHODOLOGY FOR GROUNDWATER PROTECTION

Groundwater protection had long been neglected in the past, due mainly to the considerable delay in the response of the impact of some specific actions that cause deterioration of the groundwater quantity and quality. In other words, development of shallow and deep aquifer systems in some Arab countries started long before reliable groundwater assessments were made. It seems that responsible authorities, faced with water shortage problems, could not afford to wait for the results of such assessments. However, the impacts of early developments has lead to a growing recognition of the need for reliable assessment, sound planning and rational management of groundwater resources.

At present, and in view of the increased interest in groundwater, wherever it is found, to meet the rapidly growing demands to water resources, the need to protect the groundwater from deterioration is becoming a must. Groundwater resources should be adequately conserved and rationally utilized same as surface water resources. This is particularly pronounced in the Arab region where aridity and scarcity of surface water prevail.

There is no one single method through which groundwater can be protected, as the forms of groundwater deterioration are diversified, and that the abused actions in groundwater development and exploitation are numerous. However, there is one agreed upon issue, in regards to the groundwater protection policy, which implies preventing the components involved in the groundwater deterioration, or at least limiting their impacts. This is rather due to the fact that prevention of deterioration is always less expensive than post-treatment and rehabilitation of the deteriorated groundwater basin.

The strategy leading to adequate protection of the groundwater implies the integration of systematic operations and practices at the local, national and regional levels. Each of these levels has specific criteria aiming primarily at protecting the small scale groundwater basins or aquifers, as well as those having vast areal extent.

The integrated systematic methodology for groundwater protection is considered a rather long-term procedure which primarily necessitates continuous monitoring and observation of the regime both in quantity and quality. Scientifically based assessment, planning and management constitute the main key for any sound socioeconomic groundwater development. Simultaneously with this, capacity building in respect to human resources and public awareness, should take utmost endeavor. Legislations are considered also most active tools in groundwater protection. Also, appropriate treatment of waste water before utilization, and selection of adequate localities for liquid and solid waste disposal, are of particular importance as measures for preventing groundwater from contamination. Other complementary approaches are also necessary for mitigating eventual deterioration of groundwater, e.g., protection zones of groundwater fields, and artificial recharge. The following gives a brief exposé of the above mentioned components involved in the methodology for groundwater protection.

IV.1 Groundwater Assessment, Planing, and Management for Sustainable Development

IV.1.1 Groundwater Assessment (GWA)

Assessment of groundwater is a prerequisite for rational utilization, and the basis for its sustainable development and management. Groundwater assessment theoretically implies the study of the basin, or the water bearing formation from its natural recharge areas to its natural discharge areas. With this concept in mind, such study requires the availability of reliable information and data on the geologic setting, extension of the basin and its aquifers and their hydraulic properties, as well as sources of natural recharge, and natural and artificial discharge and their evaluation. However, since groundwater is a part of the environment, it is thus related to many other static and dynamic components of the environment in a rather complex manner, which renders any endeavor for reaching definite assessment of the groundwater a real hard task and rather economically unrealistic. This is also ascertained by the fact that some dynamic factors may change sharply both in time and space. Also, the assessment of the demands for groundwater is similarly subject to changes according to the intrusion of some unforeseen environmental factors. Accordingly, groundwater assessment should be considered as a long-term and continuous endeavor.

The procedures and techniques for water resources assessment are numerous, but available in the literature. However, the basic components of a water resources assessment program have been outlined by UNESCO/WMO in 1988. The following gives a modified program:

i- Collection of hydrological data, including precipitation, evaporation, surface runoff, and groundwater levels, both quantitatively and qualitatively.

ii- Collection of physiographic and hydrogeologic data including topography, soil, geology, surface drainage pattern, aquifer system and regime.

iii- Application of areal assessment of groundwater including flow direction, hydraulic properties (transmitting, storage and leakance parameters), groundwater quality distribution, hydraulic interconnection with streams, channels, adjacent aquifers, and lakes, seas and oceans, and finally evaluation of natural recharge and natural and artificial discharge.

iv- Establishment of information system including data bank and digital maps (GIS).

v- Dissemination of information to users for planning design, and operation.

The theories of groundwater flow, solute transport, and prediction of homogeneous isotropic, non-homogeneous anisotropic, and stratified media at steady and transient conditions, including decay, adsorption and dispersion are numerous and diversified. The literature is quite rich in these theories, which can be used according to the specific boundary value problem of each individual case. Although it is beyond the scope of the present document to elaborate on this aspect, yet a particular reference to the advantages and benefits of the use of simulation modeling has to be pronounced. In view of the fact that the capacity of computers and the diversity of the hydrodynamic modeling have recently been raised considerably, and efforts are being made to cover a wide spectrum of groundwater flow system both in quantity and quality, it may be useful, however to depict some relevant modeling programs including their functions and applications. Fig. IV.1 shows the classification of groundwater flow and contaminant transport prediction models (UNESCO, 1993) and table IV.1 gives the features of some relevant models (UNESCO, 1993).

IV.1.2 Groundwater Resources Planning (GWRP)

Planning for groundwater requires four principal components to be adequately identified as follows (UNESCO, Dijon, 1983): (i) an assessment of groundwater availability; (ii) an assessment of the demands from the groundwater resources; (iii) determination of the technologies to be used for developing groundwater; and (iv) an assessment of project cost and operating costs. However, a number of other parameters are to be considered during the process of planning as they may change the scope of the groundwater development project. Important among these parameters are: the development of technologies pertaining to augmenting the natural replenishment through recharge dams, and water conservation techniques, and to reducing the water requirements for irrigation and industrial purposes, through the advancement of biotechnology for low water consumption in cultivation and low water consumption machinery in industry, or in other words, the optimization of water recharge availability and minimization of water demands. However, in view of the fact that groundwater serves many functions for nature as well as for man, which are meanwhile changeable both in time and space, it may thus be most practical if short-term planning operation be adopted. This, coupled with the continuous change in technology, the United Nations experience suggest that planning for groundwater development should not exceed a decade. Such a strategy impliescontinuous revision of the planning operations relative to development and management.

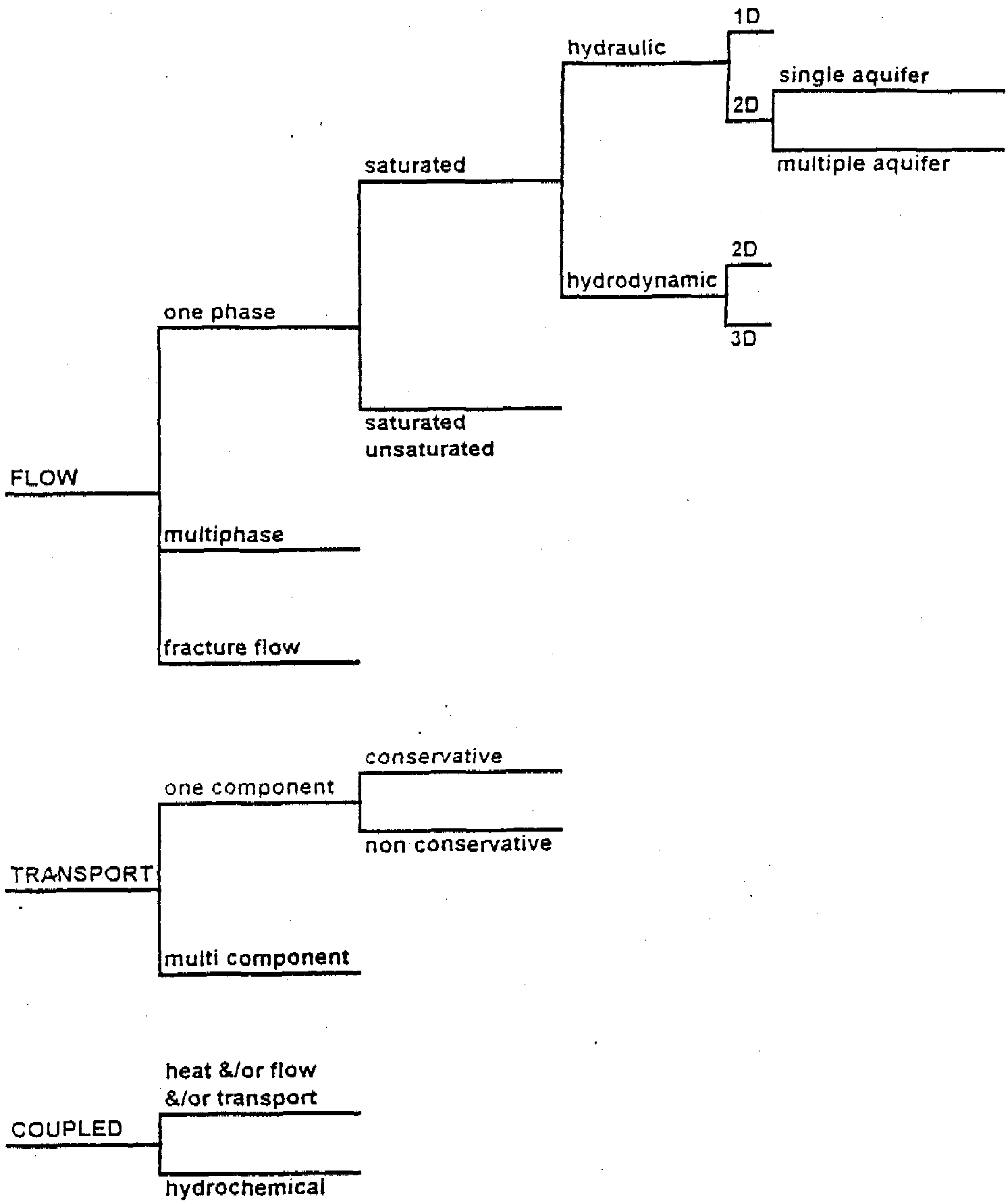


Fig. (IV.1)-

Classification of groundwater flow and contaminant transport prediction models

Ref. UNESCO, 1993

Table (IV.1)- Features of some relevant models

KEY FEATURES	AQUA	ASM	AT123D	CFEST	CHEMTRN	FASTCHEM	FEMWATER\ LEWASTE	FTRANS	HST3D	MMT	MOC\ MOCDENSE*	MODFLOW	MT3D	NAMMU	PATHS	RANDOM WALK	SUTRA	SWIFT	USGS2D/ USGS3D	VERA
FLOW	X	X		X		X	X	X	X		X	X		X	X	X	X	X	X	X
TRANSPORT	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X
1D			X		X	X				X						X		X		
2D	X	X	X				X	X		X	X	X	X		X	X	X	X	X	
3D			X	X			X	X	X			X	X	X				X	X	X
F.E.M.	X			X		X	X	X						X			X			
F.D.M.		X			X				X		X	X	X			X	X	X	X	X
M.O.C.											X		X							X
R.W.		X								X						X				
ANALYTICAL			X												X					
SATURATED	X	X		X			X	X	X	X	X	X		X	X	X	X	X	X	X
NON-SATURATED							X			X							X			
ADVECTION	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X
DISPERSION	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X		X
ADSORPTION	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X
ION EXCHANGE					X	X				X	X				X			X		X
DECAY	X	X		X		X	X	X	X	X	X		X	X	X	X	X	X		X
PRECIPIT/DISSOL					X	X				X										
FRACTURE FLOW								X						X				X		
MULTI SPECIES					X	X					*									
2 PHASE																				X
VARIABLE DENSITY				X					X		*			X			X	X		
COUPLED HFT				X					X					X			X	X		X
HYDROCHEMICAL					X	X														

Ref., UNESCO, 1993

IV.1.3 Groundwater Resource Management (GWRM)

Management of groundwater is based principally on the output of both the assessment and planning conditions. It aims at achieving sound economical. and safe utilization of groundwater, through rational use, effective protection and sustainability of development. More specifically, future management approaches will have to deal effectively with the following major issues as proposals for the years 1990-2010 (UNESCO, 1991 edit. Hufschmidt Kindler). Although these issues apply for water resources in general, however, some specific reflections and modifications, in respect to groundwater, can be cited and elaborated as follows:

i. Environmental and Social Consequences: These comprise mainly the adverse effects of groundwater development projects subject to any sort of deterioration either quantitative or qualitative or both. Perhaps, the most active tool in this regards is the approach for environmental impact assessment.

ii. Land-Water Linkages: In respect to groundwater development the linkage between land and water pertains mainly to the development of water sheds and drainage patterns, and their adverse effect on deterring surface water from naturally recharging the water bearing formations if conservation or divergent dams are to be constructed in the upstream. Also, excessive or concentrated exploitation of the groundwater in a particular locality may considerably abstain lands at the downstream from groundwater utilization.

iii. Rational Water Allocation: In view of the fact that groundwater is limited and perhaps rare, particularly in arid region, as in the Arab states, management pertaining to rational allocation of this water resources becomes rather imperative. At present adequate attention is being paid to optimize the efficiency of the groundwater use through applying modern techniques in irrigation and industry. This coupled with the water conservation measures in respect to enhancing groundwater recharge and minimizing evaporation losses, groundwater can be rationally allocated and environmentally protected.

iv. Effective Implementation: The most important elements needed for effective implementation of groundwater projects are specifically those related to post-implementation. It is important therefore to establish groundwater monitoring system, and to put limitations on any eventual expansion in using groundwater beyond safe yield. The monitoring system for water levels and quality is particularly important, due mainly to probable rapid changes in parameters in response to continuous exploitation. On the other hand, implementation of groundwater projects in newly reclaimed areas will encourage migration of populations and establishment of new communities that will grow in time, and the water needs will grow accordingly. Therefore, it is imperative to restrict the project objectives to their originally planned targets, with minimal expansion, only if deemed necessary, in order to maintain its safety and sustainability.

In addition to the above cited proposed management issues (UNESCO, 1991), some other specific aspects of groundwater management, in regards to the protection of local small scale groundwater basins, and those having vast extension or shared among countries, can be cited as follows:

i. Local Small Scale Groundwater Basins: This type of basins widely prevails in all Arab countries with varying areal extents. They are located mainly at the outlets of drainage network or intermountains, at coastal regions, or at plain areas. They are either hydraulically interconnected or isolated in nature. Appropriate management of such basins should avoid, in the first place, concentration of the production wells. Spacing between wells should be carefully studied, in order to avoid the creation of sharp local groundwater depressions resulting from excessive and interfered drawdowns. In the case of coastal groundwater basins, utmost care should be taken to study the hydraulics of the phenomenon of salt water intrusion, particularly in respect to the discharge of each individual well, and its depth of penetration in the aquifer.

ii. Extensive and Shared Groundwater Basins: In view of the fact that groundwater velocity is comparatively small, the effect of rainfall fluctuation, at the recharge areas, is not spontaneous, specially at remote localities of exploitation, but will take a long time. Also, the effect of groundwater withdrawal in one country will not be directly sensible in other neighboring countries sharing the same basin, particularly if these countries are at great distances apart. Management should focus thus on exploiting the groundwater storage regardless of the rate of recharge, in a wise and well studied strategy as to guarantee sustainable development. It should be strictly understood here, that overexploitation or concentrated withdrawal of the groundwater from such type of basins will have a direct disastrous impact in the particular country exploiting this source, long before any appreciable effect may reach the neighboring countries. With this concept in mind, each country has to draw up its management operations accordingly.

iii. Development Strategy: The choice of a strategy is between maximizing production for the benefit of the present generation in order to speed up socioeconomic development, or spreading production out over a relatively long period. In other words, the choice is between priority for growth and priority for a long-lasting system. Numerical models for simulating the behavior of fossil and/or shared groundwater basins are appropriate tools in decision making.

IV.2 Groundwater Monitoring

Management of groundwater requires adequate knowledge and accurate data base on both the quantity and quality of the groundwater. These can be achieved by establishing appropriate groundwater monitoring network, which serves both management and contamination problems.

VI.2.1 Groundwater Quality Monitoring

The physical, chemical, and biological characteristics of the groundwater are the main governing factors that define the mode of its utilization, whether for drinking, irrigation, or industrial purposes.

The American Environmental Protection Agency (EPA, 1991) has defined the groundwater quality monitoring as follows: "Monitoring of water quality might be defined as a scientifically designed program of continuing surveillance, including direct sampling and remote quality measurements, inventory of existing and potential causes of change, and analysis of the cause of past quality changes and prediction of the nature of future quality changes".

Therefore, quality monitoring is not simply a point to collect a sample from a well or a spring, but it is rather an integrated and continuous operation including sample collection, analysis, interpretation and prediction.

However, selection of the type of network depends mainly on the specific program objectives;

i. To define the natural variation of the water quality as a base to detect any source of pollution.
ii. To survey the water quality variation due to different known or unknown sources of pollution.
iii. To control the groundwater quality for a specific utilization.
iv. To assess water pollution in a given area.
v. To acquire experience for predicting possible aquifer contamination.

Prior to the establishment of groundwater monitoring network, the geologic, hydrogeologic and hydrologic settings of the water bearing formations should be known. Also, the parameters that are required to be monitored vary from one network to another depending on their specific objectives.

In practice, there are two types of groundwater monitoring network; local and regional systems.

1. Design of Local Monitoring System

This system aims primarily at monitoring a point - source pollution. Prior to the design of the system, the following measures should be considered:

i. Evaluation of the evidence of groundwater pollution and assessment of the scope of the problem.
ii. Collection of information regarding the potential pollutants, and the eventual uses.
iii. Collection of information on the hydrogeology, aquifer parameters, and flow direction.
iv. Selection of observation wells.
v. Preparation of a program for sampling and analysis.

2. Design of Regional Monitoring System

This system aims at monitoring the variation in water quality of a specific aquifer during exploitation, e.g., aquifer subject to salt water intrusion. The following measures are to be considered for the design of the system:

i. Identification of the sources of pollution.
ii. Collection and analysis of all available data.
iii. Conducting some additional hydrogeologic studies aiming at a better definition of the specific problem.
iv. Selection of observation wells in the light of the readily available network.
v. Provision of necessary equipment.
vi. Operation and sampling systematically at well defined frequencies.
vii. Treatment and interpretation of data, and dissemination of results to decision makers.

In general, selection of the measured parameters should be in accordance with the pre-defined objectives and type of installed network.

VI.2.2 Groundwater Quantity Monitoring

There is no doubt that quantitative monitoring of groundwater is an important component for appropriate development and management of the groundwater basins. Such monitoring can serve a number of objectives in regards to assessment, planning, design, development and management.

Various types of groundwater monitoring network can be installed to serve specific purposes. Among these are:

i. Principal monitoring network which is used to monitor all possible groundwater parameters for the entire basin.

ii. Specific hydrogeologic monitoring network which is used to monitor some specific parameters.

iii. Temporary hydrogeologic monitoring network which aims primarily at collecting data necessary for the design and development of a groundwater project.

In view of the fact that the installation of the groundwater monitoring network is normally an expensive matter, the selection of the number and location of the observation wells, as well as the frequency of sampling and measured parameters should be given serious consideration as to serve appropriately the specific objectives while avoiding unnecessary or unused data.

IV.3 Groundwater Vulnerability

The original concept of vulnerability was based on the assumption that the sub-surface material provides a certain degree of natural protection to groundwater. However, the potential for natural protection is extremely variable. Groundwater systems in different areas may have varying capacities for attenuating contaminants.

Vulnerability mapping is defined as the technique of quantifying the assessment of vulnerability and displaying it in a way that makes it useful in the decision-making process. The main purpose is to serve as guidelines for land use zoning and for the development of policies for groundwater protection (Vrba and Zaprozec, 1994). The concept of vulnerability has evolved in the past decade from the mere assessment of hydrogeological attributes to the assessment of contamination risk placed upon aquifers by human activities.

According to Vrba and Zaprozec (1994) a groundwater system is vulnerable in terms of quality and quantity. The quantitative aspects are particularly significant in arid and semi-arid zones (Khouri and Miller, 1994).

An IHP/IAH joint working group on "groundwater vulnerability maps" has reviewed previous work on the concept and definition of vulnerability and in the light of recent developments, defined groundwater vulnerability as "an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts". Thus vulnerability maps should include, according to this definition, vulnerability to human impacts as well as natural processes and should cover both quantitative and qualitative aspects of vulnerability. Published maps however, represent only the qualitative (contamination) aspects of vulnerability. Maps displaying the quantitative aspects (depletion) need to be tested in areas where such impacts are significant. Guidelines on both qualitative and quantitative aspects of vulnerability will be published by UNESCO by the end of 1994.

The natural quality of water is subject to considerable changes upon reaching the surface of the earth and subsequently in the subsurface. Changes in groundwater quality are caused by natural processes and human activities. An important factor contributing to natural changes in arid zones is climate. Evaporites are of common occurrence in the Quaternary and Neogene sediments. As groundwater moves from areas of recharge to discharge zones it dissolves minerals from the rocks through which it moves. Due to low solubility of crystalline and pure sandstones, groundwater transmitted through these rocks, e.g., Nubian sandstone is characterized by low total dissolved solids. Carbonate rocks and Lower Fars evaporites, which are of widespread occurrence in the Mashrek and Arabian peninsula, store and transmit water of relatively high TDS content.

However, the duration time water contact with different types of rocks determines the amount of chemical constituents of groundwater. High calcification in the Mediterranean basins, for example, results in rapid groundwater movement and exceptionally freshwater is available in these coastal basins.

Inland, however, as in the Dammam carbonate aquifer of Arabian peninsula, for example, low transmissivities and higher contents of marls and evaporites result in extensive occurrence of brackish and saline groundwater. Groundwater is degraded when its quality parameters changes beyond the natural variations. The type, extent, and duration of man-induced changes of groundwater quality is controlled by the type of human activity, the geochemical, physical and biological processes occurring underground. Although natural processes generally reduce the magnitude of groundwater contamination, several contaminants remain, essentially after entering the aquifer system, and some aquifers or parts of aquifer may be damaged beyond repair.

Sources of contamination include two broad categories, namely point and non-point sources. Point sources comprise municipal and industrial waste water, land fills, oil storage tanks and other sources which join water bodies through pipes and channels. Application of fertilizers and pesticides, and saline water bodies are non-point sources. Another classification of contamination sources is shown in Table IV.2. Contamination sources are subdivided into six categories. For each category, the potential hazards in terms of the primary parameters for water quality standards is presented by Mackay, (1990).

Assessment and mapping of vulnerability entails the consideration of individual factors or attributes and their capacity for attenuating contamination. The preparation of vulnerability maps is based on the assessment of important attributes such as recharge, soil, the unsaturated zone, and the aquifer. As regards specific groundwater vulnerability, hydrogeological factors, as well as land use practices and contaminant loading are taken into account.

There are several methods for the assessment of intrinsic (or natural) vulnerability of groundwater (Civita, 1991). In general the widely used methods could be classified into 4 groups (Civita, 1991, 1993; Vrba and Civita, 1994).

i- Hydrogeologic setting methods

ii- Parametric system methods

iii- Analogical relations methods

iv- Numerical methods

A widely used method is drastic. An example which illustrates the use of this method is given in Table IV.3. A computerized system derived from DRASTIC names SYNTAX has been tested and applied in several areas.

Table IV.2. Major Sources of Groundwater Contamination and Types of Contaminants and their Relative Significance

Source	Type of Pollutant				
	Physical	Inorganic Chemical	Trace Elements	Organic Chemical	Bacterio-logical
Municipal					
Sewer leakage	Minor	Primary	Secondary	Primary	Primary
Sewage effluent	Minor	Primary	Secondary	Primary	Primary
Sewage sludge	Minor	Primary	Primary	Primary	Primary
Urban runoff	Minor	Secondary	Variable	Primary	Minor
Waste disposal	Minor	Primary	Primary	Primary	Secondary
Septic tanks and cesspools	Minor	Primary	Minor	Secondary	Primary
Agricultural					
Leached salts	Minor	Primary	Minor	Minor	Minor
Fertilizers	Minor	Primary	Secondary	Secondary	Minor
Pesticides	Minor	Minor	Minor	Primary	Minor
Animal waste	Minor	Primary	Minor	Secondary	Primary
Industrial					
Cooling water	Primary	Minor	Primary	Minor	Minor
Process waters	Variable	Primary	Primary	Variable	Minor
Water treatment plant effluent	Minor	Primary	Secondary	Minor	Minor
Hydrocarbons	Secondary	Secondary	Secondary	Primary	Minor
Tank and pipeline leakage	Variable	Variable	Variable	Variable	Minor
Oil field wastes					
Brines	Primary	Primary	Primary	Minor	Minor
Hydrocarbons	Secondary	Secondary	Secondary	Primary	Minor
Mining	Minor	Primary	Variable	Minor	Minor
Miscellaneous					
Surface water	Variable	Variable	Variable	Variable	Variable
Sea water intrusion	Primary	Primary	Primary	Minor	Minor
Transport	Minor	Minor	Minor	Primary	Variable

(Based on data from Todd et al., 1976).
Source: Biswas, 1990.

The various methods proposed for the assessment of groundwater vulnerability are based on the assumption that groundwater occurs under temperate climatic conditions. Assessment of groundwater vulnerability under arid conditions, should, however, take into account that parameters such as extreme dryness, high temperature and evaporation, affect the processes that influence the transport and fate of contaminants (Khouri and Miller, 1994).

Beside contamination, important human impacts in arid climates include depletion and salinization. Drought is also an important factor which should be considered whenever the vulnerability of aquifer is assessed, in terms of quantity. The sensitivity to drought, generally, increases with increasing aridity.

The results of vulnerability assessment are portrayed on maps which show areas characterized by different levels of vulnerability. A large variety of vulnerability maps has been proposed during the last decades. The experience gained and lessons drawn from the compilation and use of these maps have contributed to the development of the concepts of vulnerability. Vulnerability maps are constructed manually or generated by computers, and GIS has been increasingly used for the preparation and updating of such maps.

Vulnerability maps are used mainly as a planning tool to deal with problems of undesirable activities having adverse impacts on groundwater quality. They support also managerial and decision-making activities.

The scale plays an important role in the applicability of vulnerability maps. Small scale maps are used for formulating strategies for the protection of groundwater resources, at the national and regional level. Maps of specific groundwater vulnerability are used for decision making in environmental

S1 - Outcropping Gneiss

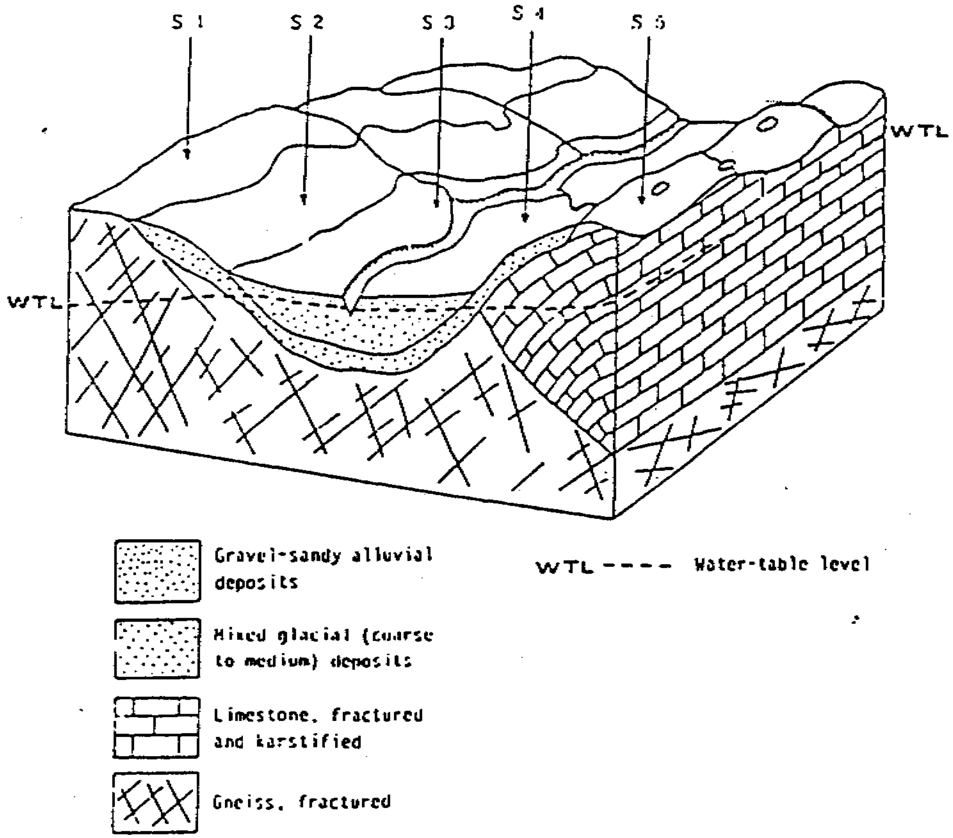
FACTOR	D A T A	RATING	* WEIGHT=	NUM.
D	>30 m	1	5	5
R	300 mm	9	4	36
A	Gneiss fract.	5	3	15
S	Absent	10	2	20
T	>18%	1	1	1
I	Gneiss, fract.	4	5	20
C	E-05 m/s	9	3	27
			DRASTIC Index	124

S2 - Glacial deposits over Gneiss

FACTOR	D A T A	RATING	* WEIGHT=	NUM.
D	25 m	2	5	10
R	300 mm	9	4	36
A	Gneiss, fract.	5	3	15
S	Sandy	9	2	18
T	13%	3	1	3
I	Sand/grav/gneiss	5	5	25
C	E-05 m/s	9	3	27
			DRASTIC Index	134

S3 - Alluvial deposits

FACTOR	D A T A	RATING	* WEIGHT=	NUM.
D	3 m	10	5	50
R	300 mm	9	4	36
A	Gravel & Sand	8	3	24
S	Sandy loam	6	2	12
T	2%	10	1	10
I	Gravel & Sand	8	5	40
C	E-02 m/s	10	3	30
			DRASTIC Index	202



S4 - Glacial deposit over Limestone

FACTOR	D A T A	RATING	* WEIGHT=	NUM.
D	10 m	7	5	35
R	300 mm	9	4	36
A	Limestone, karst.	9	3	27
S	Sandy loam	6	2	12
T	18%	3	1	3
I	Sand/grav/Limes.	7	5	35
C	E-03 m/s	9	3	27
			DRASTIC Index	175

S5 - Outcropping Limestone

FACTOR	D A T A	RATING	* WEIGHT=	NUM.
D	>30	1	5	5
R	300 mm	9	4	36
A	Limestone, karst.	9	3	27
S	Absent	10	2	20
T	>18%	1	1	1
I	Limestone karst.	10	5	50
C	E-03 m/s	9	3	27
			DRASTIC Index	166

Source : ALLET al : 1985

Table (IV.3)- An example illustrating the application of DRASTIC system for the assessment of groundwater vulnerabilit environmental protection. Vulnerability maps can be combined with land use maps, groundwater quality data and contamination source inventories for targeting management efforts to the most vulnerable aquifer to both contamination and depletion.

IV.4 Groundwater Treatment Processes

Selection of water treatment techniques for the improvement of contaminated groundwater depends on the nature and extent of the contamination and the desired quality of the treated water. The available technology for reduction of contaminants is relatively sophisticated and expensive to apply. Table IV.4 summarizes the contaminants generally encountered with the general methods for their removal (UNESCO, 1980).

Water quality criteria for drinking, industrial and agricultural uses are listed in Appendix 1 (UNESCO, 1980).

Table IV.4. Removal of Contaminants from Groundwater

Contaminant (1)	Process Option (2)	Comment (3)
Bacteria	Chlorination Other disinfectants	Chlorination can also benefit removal of other pollutants, e.g. iron
CO_2	Aeration Neutralization	Hydraulic mechanical chemically stoichiometric
H_2S	Aeration-filtration Chlorination	Similar to iron and manganese chemically stoichiometric
Iron	Aeration-filtration Coagulation-filtration	
Manganese	Oxidation-filtration	
Hardness	Precipitation Base exchange	

(1)	(2)	(3)
Salinity	Demineralization Electrodialysis Reverse Osmosis Distillation	
Nitrate	Ion exchange Surface storage Biological reactors untried for groundwaters	Slow and seasonal rapid
Arsenic Copper Lead	pH adjustment Coagulation-filtration	
Fluoride	Lime and alum coagulation Dolomitic lime softening	Shource should be avoided where possible
Ammonia	Chlorination Biological oxidation-reduction	
Phenols	Chlorine Dioxide Ozone Carbon adsorption	
Mineral oils	Carbon adsorption	
Carbohydrates fatty acids, etc. Organo-halide compounds and polycyclic aromatic hydrocarbons Tastes and odors	Chemical oxidation Biological oxidation Carbon adsorption Carbon adsorption Aeration Oxidation Carbon adsorption	If activated carbon requirements are low and filtration required for other purposes, powdered activated carbon can be used rather than granular carbon filtration

Source: UNESCO, 1980

IV.5 Protection Zones and Water Well Fields

In temperate climates groundwater resources are often underutilized, whereas in most arid and semi-arid lands they are overutilized. Overutilization can lead to depletion in quantity or degradation in quality or both. Groundwater constitutes a high portion of the total water resources in the Arab region, amounting, as mentioned before to about 25 percent in most Arab countries and exceeding 50 percent in the countries of the Arabian peninsula.

Although intensive development of groundwater resources in many countries has had adverse effects, the economic and social benefits derived from development of these resources should not be underestimated. Groundwater development, like any other natural resource development has its positive and negative impacts.

Groundwater quality has deteriorated in the Arab region because of human activities in rural, urban and industrial areas. Contamination from untreated municipal and industrial waste has caused health threatening conditions. Movement of contaminants between interconnected groundwater and surface water is a primary source of aquifer pollution in several urban areas. These problems have reached serious levels in certain urban areas such as Damascus and Cairo metropolitan areas and in the densely populated area of the Nile Delta and Damascus plain and to certain extent in Aleppo, Amman, Algiers and several other large cities. Problems posed by agriculture have been also increased in range and intensity. In general, adverse impacts on groundwater have resulted from poor planning and management.

The strategy for groundwater protection must be preventive and protective. Experience gained in many countries has proved that remediation is far too expensive to be the main approach to manage the quality of groundwater resources. Instead, preventive contamination measures are becoming sound basis for action for environmental protection. Regulatory and technological measures must cover all major categories of point and non-point sources.

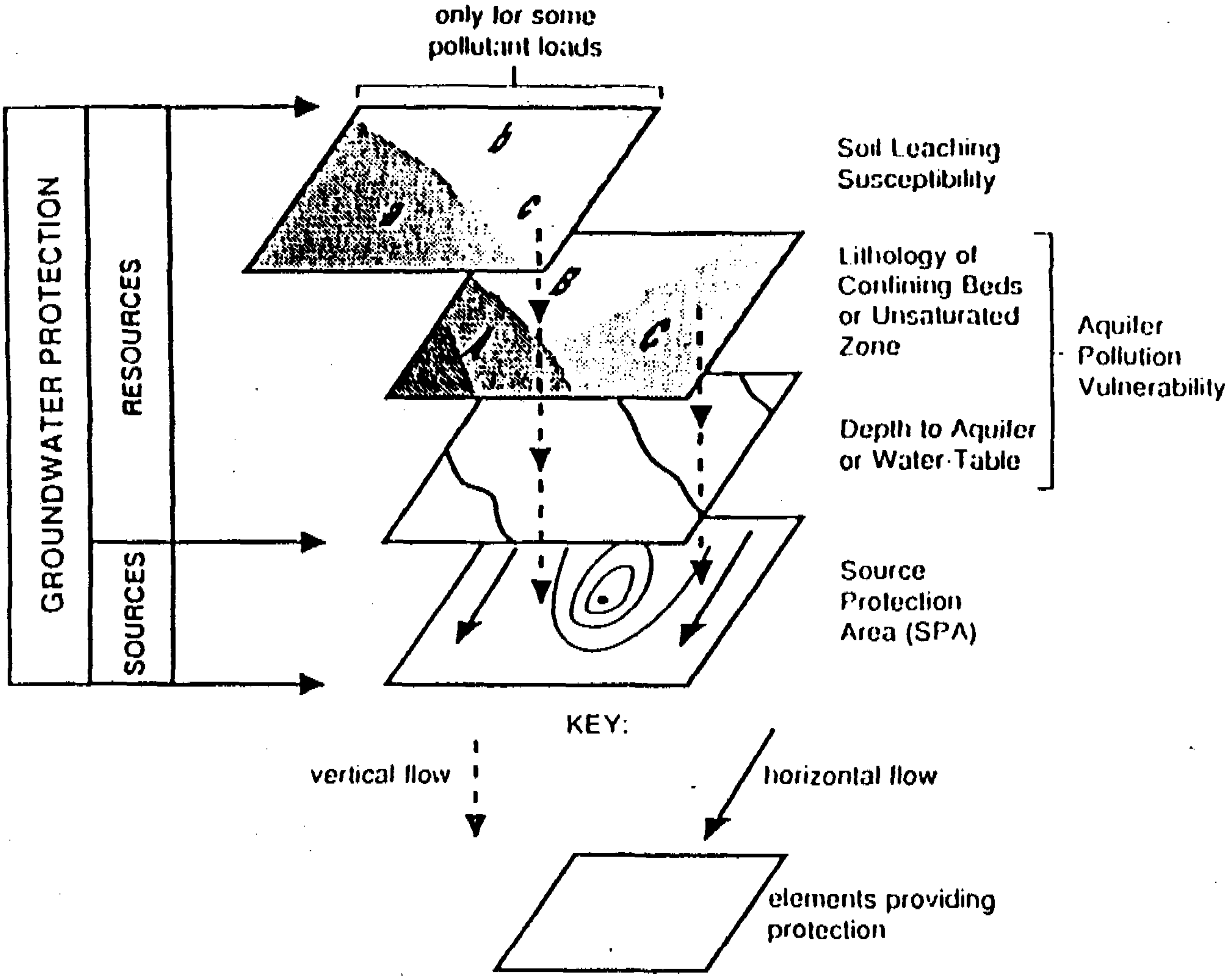
The present attitude and perception of groundwater protection is reflected in the widely used approach for groundwater quality management which comprises both resource and source protection (Fig. IV.2). Accordingly, land surface is divided on the basis of the vulnerability of the underlying aquifers to contamination and on the definition of individual source protection areas (Adams and Foster, 1992). A similar approach was proposed by the UNESCO working group on Integrated Land-use Planning and Groundwater Protection in Rural Areas (1991). The group recognized two categories of groundwater protection management. "General protection of groundwater resources" and "comprehensive protection around public water supplies".

Although aquifer-based protection strategy is the most comprehensive approach because it encompasses all usable groundwater resources, the most effective approach is to give greatest protection to those areas that supply recharge to public drinking water sources (wells, springs, etc.). The source protection programmes meet the mandate of Agenda 21 in "prevention of aquifer pollution through the establishment of protective zones in groundwater recharge and abstraction areas" (Agenda 21, Rio de Janeiro, 1992).

IV.5.1 Resource Protection

The general protection of groundwater resources requires a sound information base to determine existing and potential groundwater contamination problems. Part of this information needs to be displayed on vulnerability, land suitability, and groundwater protection maps.

Measures proposed to protect groundwater against contamination must make use of the natural capacity of the sub-surface materials to attenuate contaminants, otherwise they will be unnecessarily restrictive on other activities.



FIG,(IV.2)- Conceptual Framework for groundwater protection.

(Source: Adams et al, 1992)

The natural and specific vulnerability of groundwater systems need to be assessed and mapped. Aquifer vulnerability is a function of inaccessibility of the saturated zone, in a hydraulic sense, to the penetration of contaminants and attenuation capacity of strata overlying the saturated zone, as a result of physico-chemical, retention or reaction of contaminants.

Specific vulnerability of a groundwater system depends on the contamination scenarios. Vulnerability maps should be compiled for individual contaminants and specific pollution scenarios. This approach to vulnerability is the basis of groundwater protection policy in several countries which have developed or applied this technique. Both small and large scale maps are required for planning and management of groundwater quality.

IV.5.2 Source Protection

The objective of source protection strategy is to provide additional element of protection for selected groundwater sources (boreholes, well fields, springs, etc...) which supply drinking water to rural and urban communities. As stated above resources protection is achieved by dividing land surface on the basis of vulnerability of the underlying aquifers to contamination. Source protection is achieved by subdivision of the capture zone of individual sources into several source protection zones (Adam and Foster, 1992; Wyssling, 1979). The recharge capture zone of a source is defined as an area within which all aquifer recharge is captured at that source. In order to eliminate the risk of source pollution, all potentially polluting activities have to be controlled to the required level in this zone. This is generally untenable due to economic considerations. The recharge capture zone needs to be subdivided into a number of protection zones. The level of groundwater protection varies with the distance from the source.

For general applications, horizontal flow lines and distance are considered appropriate criteria for such subdivision (Adams and Foster, 1992). A system of three protection zones around domestic supply wells has proved to be workable in a number of countries (EPA, 1967; Adam and Foster, 1992; Wyssling, 1979).

Zone I: Well Zone

It extends for tens of meters around the source, normally its radius ranges from 10 to 30 m. The size of this area, however, is not defined by any objective criteria. No activities related to water withdrawal are permitted, in this zone. Even these need to be controlled to prevent probable pollution of the source at the well head.

Zone II: Inner Protective Zone

It is defined on the basis of horizontal flow time which is sufficient to prevent pathogenic contamination. A delay or residence time of 50 to 60 days has proved to be adequate in temperate climates. Data required to suggest a suitable delay time in arid and semi-arid regions are inadequate or lacking. It is worth noting that the delay time has been determined so as to protect sources of water supplies from the risk of microbial contamination, but it might be inadequate for viruses and chemical pollutants.

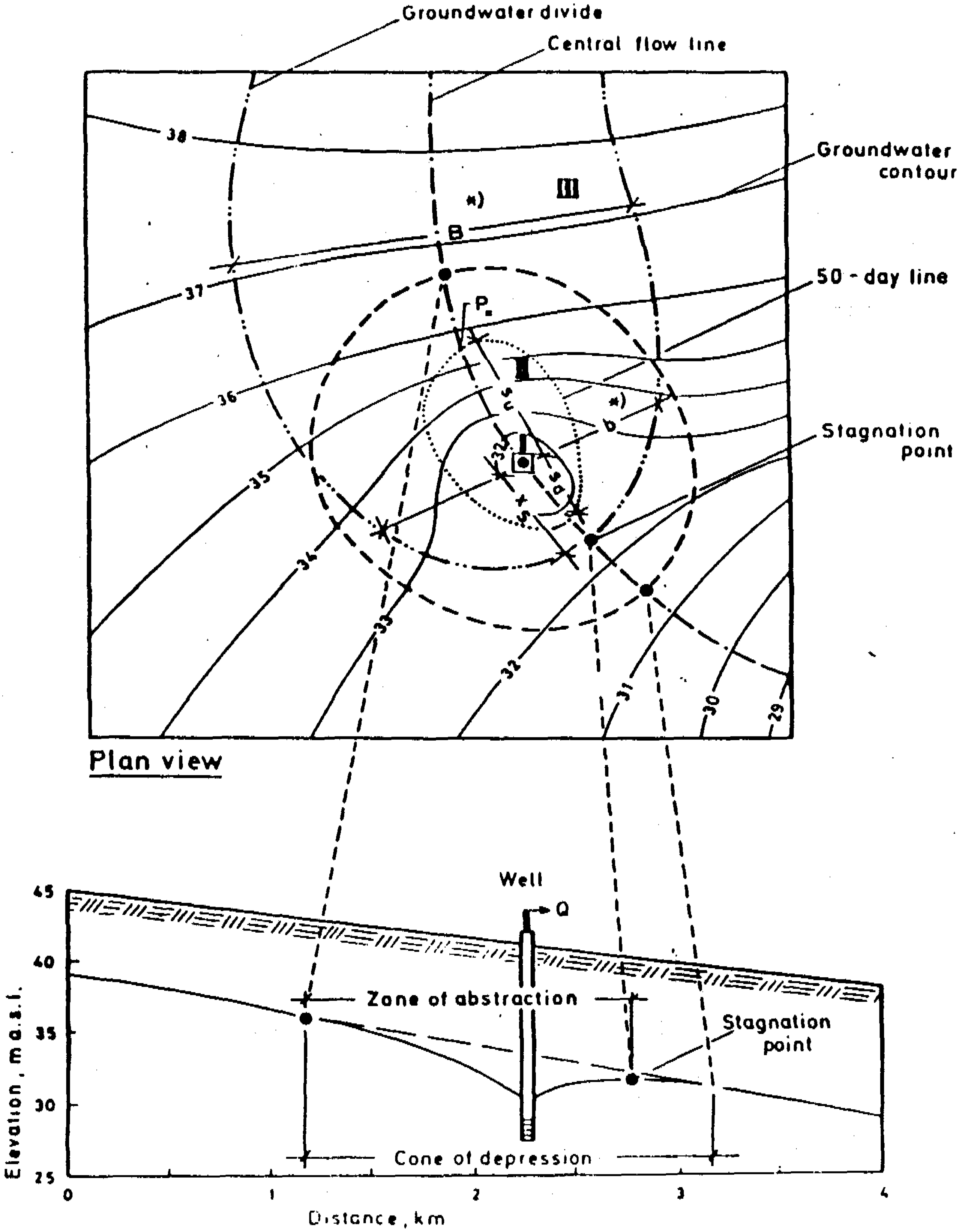


FIG.(IV.3)General layout of a groundwater catchment area with pumping well and groundwater protection zones

Zone III: Outer Protection Zone

It is an extensive zone which may comprise the entire catchment area. It is delineated to allow differential control of point or diffuse source pollution. The main objective is to protect the water quality of the sources from persistent chemical pollutants. It is the most extensive zone, but there are less restrictive measures. Current uncertainty of the rates of subsurface degradation of various types of contaminants renders its definition criteria somewhat arbitrary. Adams and Foster 1992, suggest a horizontal flow time of about 365-500 day. Waegeningh(1985) recommends 10-25 year residence time. Proposed restrictions in zone I, II and III are given in Appendix (2).

The inner and outer zones defined by isochrons (specific time of travel to the source), cannot be directly delineated. The method invariably used to determine these zones is to track the movement of water starting from the source in small steps (Adams and Foster, 1992). However, a combination of up-to-date methods and techniques should be used to minimize the degree of uncertainty in the definition of these zones. Simple mathematical approximations have been established to estimate the extent of zone II (Wyssling, 1979), (Fig. IV.3). These methods are based on Darcy law and Dupuit-Thiem steady radial flow equation for a well pumping within a uniform flow field.

Ideally, three dimensional flow modeling would be used to delineate source protection areas. In practice, however, there are rarely adequate information about the aquifer vertical permeability and hydraulic head variations to allow for applying such models. Two dimensional areal formulations with relevant parameter selection is a possible alternative.

Overprotection of the source is not desirable because it leads to economic losses. Underprotection may cause groundwater pollution, requiring long-term and costly remedial action. A cost-benefit analysis is required for the selection of an appropriate method. Higher input costs leading to an accurate delineation of protection zones will lead to reduced operation costs for water supply wells or well field protection.

IV.6 Artificial Recharge

Artificial groundwater recharge has been practiced for many years throughout the world. The purpose of artificial recharge is manifold. Among these are; to increase the rate of recharge, reduce groundwater decline and depletion, renovate and improve groundwater quality from deterioration and contamination, control sea water intrusion in coastal areas, reduce land subsidence, and overall, conserve surface water runoff.

There are two broad types of artificial recharge which are; surface water spreading and well system. Recharge water can be of fresh water origin or acceptable treated used water. However, both techniques are mainly governed by the hydrogeologic conditions of the water bearing formation to be artificially recharged, and by the availability of water to be used for recharge. The flow pattern of the recharged water obeys the same groundwater laws of infiltration in the subsurface.

IV.6.1 Water Spreading System

The main source of recharge is normally the surface runoff discharged from drainage catchment areas. Availability of this source thus depends entirely on the geomorphologic parameters of the drainage basin and channel network, and the characteristics of the rainfall and evaporation. The drainage and channel network are evaluated in the context of their shape, and linear, areal and relief basin aspects, specifically, the basin shape, bifurcation ratio, stream length, stream area, drainage density and stream frequency. Definition and role of each of these parameters, on the behavior of the runoff are described in many literature of hydrology, (e.g. Chow, 1964).

As for the rainfall characteristics, these are governed mainly by its intensity, frequency and duration. Several tools are available in the literature for the analysis of the physics and hydrodynamics of the rainfall, e.g. (Chow, 1964 and Dewiest, 1965). Evaporation and evapotranspiration form free water surface and soil surface are also main controlling factors for estimating the balance and the accumulated magnitude of runoff that can be made available for water spreading operation.

On the other hand, the magnitude of the infiltration water to the subsurface is also controlled by; the water contact time with the surface, the soil properties, sub-soil, and aquifer hydraulic parameters, and the surface area of inundation.

Also, other factors influence the efficiency of the artificial recharge operation, e.g., thickness of the aquifer, depth to water level, proximity of the recharge site to the groundwater well field, and the topography of the area of inundation.

The types of water spreading recharge systems currently used in this regards include flooding, basins, ditches, natural channel method, and irrigation (Todd, 1959). Recharge dams of various capacities are now gaining much interest in some Arab countries, e.g., Oman and Saudi Arabia. Other traditional works are still in use in most of the Arab region, e.g., Terraces, Muskat's, diversion canals, and dykes (UNESCO/ACSAD, 1985). However, the bases of the traditional works are similar to those previously mentioned. Examples of artificial groundwater recharge by water spreading system are shown in Fig. IV.4.

IV.6.2 Recharge Well System

This type of aquifer recharge is mainly used in deep seated water table (unconfined) aquifers, or in artesian (confined) aquifer. The flow system obeys the same laws of groundwater hydraulics of water supply wells except that water is injected into rather than pumped out of the aquifer. Accordingly the casing taps only the formations overlying the aquifer or the saturated zone, while the drilling extends in the full length of the water bearing formation. Screen may be used in the case of unconsolidated formations, for preventing the aquifer from caving into the bore hole and for permitting access to the water bearing formation. Also, more than one casing may be installed coaxially in one bore-hole, in order to recharge several stratified aquifers interbedded with confined layers.

In general, recharge well techniques, although advantageous over the spreading techniques, in regards to their ability to tap deep aquifers, and in small space requirements, yet they are disadvantageous in respect to coast wise and maintenance. Also, the recharge well system has the disadvantage of its tendency to be blocked by the accumulation of fine materials and sediments which may, in return, retard the infiltration of the injected water in the well. Examples of artificial groundwater recharge by well system are shown in Fig. IV.5.

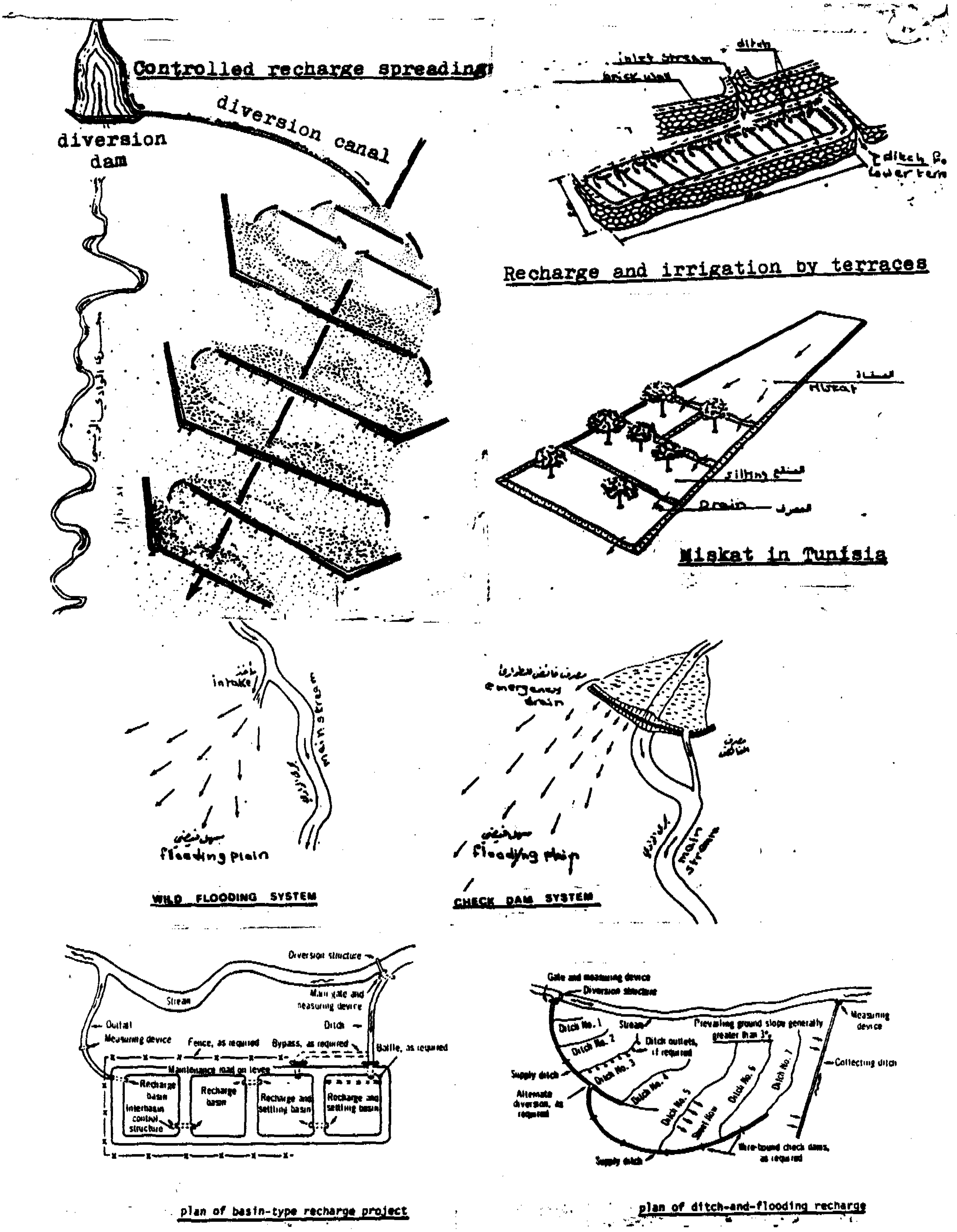


FIG. (IV.4)- **Examples of Artificial Ground Water Recharge by Water Spreading Systems**

IV.7 Regulations and Enforcement

Regulations and rules pertaining to the control, development and protection of water resources have long been recognized, but their application and enforcement have not received serious attention until the middle of this century, where harmful impacts, resulting from misuse of these resources, became a real threat to human life.

Water legislation can be defined as a set of rules and regulations that organizes the relationship between the water users and the relevant national authorities, and through which water resources can be adequately protected, conserved, managed and rationally used, within the framework of the national water policy which should reflect the physical, socio-economical, and political situation of the country and society.

VI. 7.1 Basic Concepts of Water Legislations

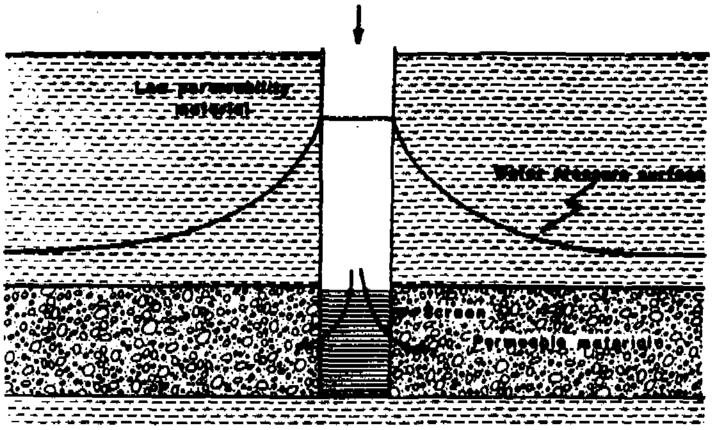
i. Groundwater is a public property, hence its utilization is subject to prior authorization.

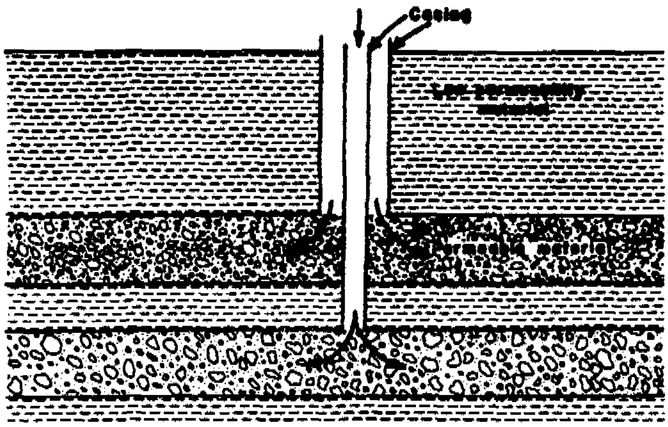
ii. Groundwater and surface water resources are interrelated, and therefore should be considered as one hydrographic unit to be managed by one single administrative authority.

iii. Traditional and conventional practices of water utilization should be respected as these have inherited law force.

iv. Protection zones and well fields should be considered as complementary and integral procedures to other administrative regulations pertaining to prevention and/or mitigation of pollution sources.

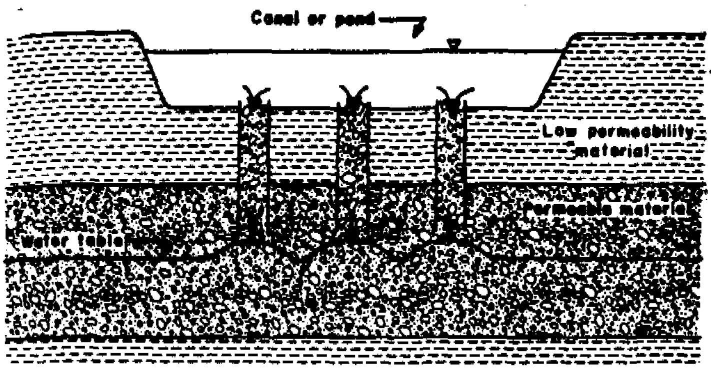
v. Water legislations should be adapted to take into consideration eventual climatic changes.

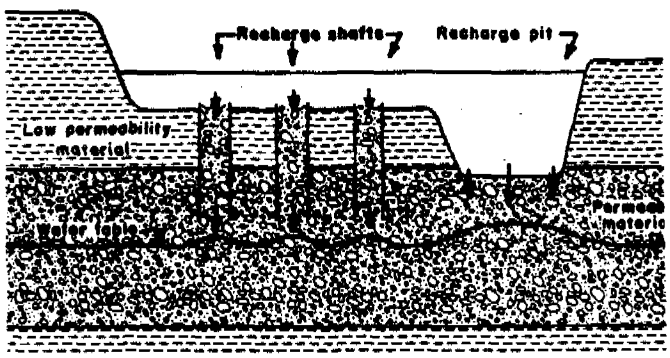




Recharge wells are commonly screened in the injection zone, which may be separated from the land surface by a considerable thickness of low permeability strata.

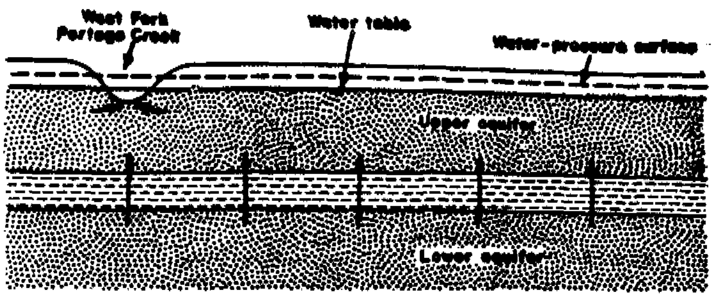
Some recharge wells consist of several lengths of pipe of different diameter installed one inside the other, which permits recharging several aquifer interbedded with confining layers.



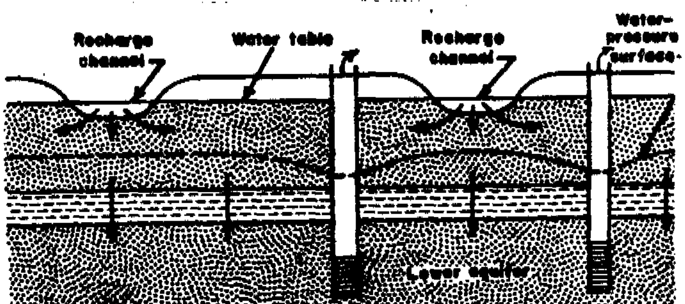


Recharge shafts are designed to provide a conduit through materials of low permeability and permit direct access to the aquifer.

Where land is not readily available for recharge facilities, a combination of recharge shafts and pits permits achievement of maximum rates.



Under natural conditions, water from the lower aquifer leaked upward through the confining bed to the shallow aquifer ...



When the lower aquifer was pumped, water migrated from the recharge channel to the upper aquifer and then through the confining layer to the lower aquifer permitting higher sustained well yields.

FIG. (IV.5)- **Examples of Artificial Ground Water Recharge by Well System**

vi. Water permits should clearly include the permissible quantities of water extraction.

vii. Water legislations should be based on adequate knowledge of the groundwater basins both quantitatively and qualitatively.

viii. Water legislations should include well identified specifications for the water for the various utilizations.

ix. Water legislations should be integrated with other legislations concerning air and earth pollution.

VI. 7.2 Legislative Aspects for Groundwater Protection

The main constraint which confronts most of the countries is the active application of the water regulations and laws. Therefore, it is currently practiced to issue various types of permits specifically for; drilling wells, drillers and drilling companies, purpose for water utilization, and permissible exploitable quantities. Also, legislative aspects include well defined permissible locations for liquid and solid waste disposals. In its broad sense, water legislation should include land use planning and zonations as to acquire appropriate knowledge on eventual sources of pollutions and their impacts on water. Effective supervision should be provided as powerful controlling tools for groundwater protection against those who breach the prevailing rules and regulations.

Some countries have introduced a number of specific regulations and rules for further groundwater protection measures, which are;

i. Classification of groundwater to categories for utilization.

ii. Prevention of disposable of any sort of water or solid wastes into the groundwater.

iii. Prevention of some activities along the coast and river banks.

iv. Identification of protected zones.

IV.8 Human Resources Development

IV.8.1 Introduction

Water shortages in the Arab world is becoming a development constraint seriously impeding the economic growth of many countries. To many experts it is not only the issue of scarcity but also mismanagement of these resources, as a result of considerable deficiencies in qualified human resources, that should equally cause great concern. Human resources development has been recognized as an essential factor for achieving sustainable water resources management. Alaerts (1991), for example, has concluded that "training and education have proven to be key capacity building instruments which support long-term development strategies".

IV.8.2 Education and Training Requirements in the Water Sector

In general, estimations of manpower demand within the water management development plan of a country should be available prior to any forecasts of the number and level of personnel requirements. It must be emphasized, however, that the reliability of estimates of manpower needs decreases with the increasing length of the anticipated plan. Though, there are many techniques recommended in the literature for performing such estimates, it would not be possible to apply them in the case of the Arab region due to the lack in basic detailed information necessary for the application of these techniques. In a global study performed by UNESCO (1982), all the available manpower surveys and studies were reviewed and a relationship between the demand for professionals and technician in the fields directly related to water resources and the country's population was derived for different economic and hydrologic characteristics and water use practices. Table IV.5 illustrates the study results and suggested relationships.

Table IV.6 shows a simplified framework of education and training requirements for the different levels of personnel required in the water sector. Each of these levels shall be considered briefly.

Table IV.5 Ratio of Professionals and Technicians in the Water Resources Field to Population (in base year 1980)

Natural and Economic Characteristics of the Country	Number of professionals per million inhabitants	Number of technicians per million inhabitants	Ratio of professionals to technicians
Low economic development; simple hydrological regime; no major problems in water use	5	30	1:6
Average conditions	15	80	1:5.3
High economic development; complicated hydrological regime; major problems in water use; multiple use of water	40	200	1:5

Source: Salih, 1993.

i) Research and Development (R and D)

In the absence of any worthwhile statistics on the R&D situation, other regional contributions can be reviewed to serve as guidelines for this work. Important of these are the current reports prepared to UNESCO/ROSTAS on the "Arab Network for Science and Technology" (Daghestani, 1992) and on "Development of Engineering Education" (Salih, 1992). Daghestani's study indicated that expenditure on R&D is around 0.3 percent of the GNP in Arab countries while this ratio is around 2.5 percent in OECO industrial countries. Comparable figures were quoted in the second report. This is a good indication to the poor situation of this sector in Arab countries.

Table IV.6 Education and Training Requirement for Different Levels of Personnel

Requirement/ Level of Personnel	Education		Training	
	Level	Certificate	Formal	Continued
R&D + University Professors	University, Under and Post-graduate Studies	B.Sc. M.Sc. & Ph.D.	-	Technical meetings, academic visits, sabbatical leaves, published materials
Professionals	University, Undergraduate Studies	B.Sc. & may be M.Sc.	With recognized organizations and perhaps time and stop exams requirements to obtain chartership or membership of professional societies	Short specialized courses, technical and professional meetings, published materials
Technicians	High Secondary Schools plus Technical Colleges	Diploma	With recognized organizations and perhaps stop exam to obtain membership of technical associations	Short training courses
Craftsmen	Technical Secondary Schools or Vocational Training Centers or on-job-training	Certificate	On-job-training and stop exam to obtain license for specific craft	On-job-training or special courses for promotional purposes

Source: Salih, 1993.

ii) Professional Personnel

Current regional surveys and studies clearly identified the quantitative needs in this category (ESCWA, 1989). These findings are quite consistent with the conclusion reached from similar studies in the region (ROSTAS, 1992). However, other studies indicated worries about the standards of the graduated professionals and deterioration in the system of education.

Hence, any new project should aim at improving the standards of the graduates as well as closing any gaps in the number of graduate professionals. It is worth mentioning that some countries in the region have already started reducing the intake number of undergraduate students in favor of improving the quality of the graduate professionals.

As indicated in Table IV.6, what makes a competent professional is not only university education, but also proper training that follows. For example in Britain, a new graduate has to work as a trainee professional with a recognized firm for a minimum period of four years before he is considered qualified enough to sit for professional examinations leading to chartership or membership of the corresponding professional institute. To keep in pace with new developments and excellencies in his profession, the chartered engineer has to follow a regular programme of continued training such as that shown in Table IV.6.

iii) Technicians and Craftsmen

According to current regional surveys, there is a considerable deficit in the number of technicians in the region. Evaluation of the status of craftsmen level in the region has received much less attention in these studies, perhaps due to absence of any worthwhile relevant data on this subject in the surveyed countries. A recent WHO report on recruitment problems in the water supply and sanitation subsector in 105 Third World countries stated that craftsmen and technicians are the most difficult to recruit compared to other personnel (professionals, managers, administrators, etc...). This is a good indication of possible shortages in these categories.

IV.8.3 Public Awareness

Public awareness constitutes an important active tool complementary to many other technical means pertaining to the conservation and rational utilization of water resources in general, and to the protection of groundwater in particular. The available tools in the media are numerous and diversified ranging from those readable (press, publications), to audible (radio, broadcast, lectures, seminars, symposium, etc...), to visual and audible (television, films). The effectiveness of public awareness to fulfill the objective depends primarily on two main aspects, these are; appropriate selection of the relevant means for public awareness, and adequate preparation of the subject contents. Each of these two aspects has certain specific conditions depending mainly on the character and status of the audience to receive and respond favorably, and on the nature of the content of the problem to be feasible, applicable and void of ambiguities (ALESCO, edit. Samaan, 1993 and UNESCO, edit. Saad, 1994).

i) Factors governing the selection of means of awareness

The selection of appropriate shape of the means for public awareness depends on a number of conditions related mainly to the nature of the audience. Most important among these are:

- Actual number of audience which is liable to receive the information conveniently.
- Diversity of the public which necessitates their classification to categories of common features; and

- Permanent residence of the actual audience.

In so far as the groundwater protection is concerned, the agricultural, industrial and household and commercial sectors are normally involved in this context. However, the selection of relevant means, as well as periodicity of communicating the information for awareness varies from one sector to another.

ii) *Content of information for public awareness*

The contents of subjects on water awareness are numerous and diversified. However, they normally comprise direct reflections of the prevailing problems with respect to groundwater depletion and pollution. These imply the preparation of contents that deal with the dangers of over-extractions of the groundwater basins, and of the disposal of liquid and solid wastes into water directly or indirectly. Also, the contents should include firm directives to avoid the actions leading to groundwater deterioration.

In the light of the above mentioned aspects, the subject of public awareness should be carefully identified and the methodology for awareness be factually analyzed and formulated for each particular country of the Arab region. This is mainly due to the fact that the audience and their current and traditional practices and behavior in utilizing the groundwater differ considerably from one country to another. However, the general shape of and the bases for public awareness are although the same, but the details and approaches are expected to be slightly different.

PART V
CONCLUSIONS AND RECOMMENDATIONS

The greater part of the Arab region embraces the driest climatic zones of Africa and southwest Asia. Perennial streams and rivers, which are mainly fed from outside the region's borders, are restricted only to a very few number of the Arab countries, whereas groundwater is available underneath most of the Arab lands. Groundwater is considered the only natural water resource to the majority of the Arab countries. However, this source is continuously threatened by unwise utilization and inadequate management, which will ultimately lead to serious deterioration both in quantity and quality. If such behavior continues in the same trend, development of groundwater cannot be sustained, while dangerous impacts, unavoidable risks, health hazards, and soil destruction may arise. Therefore, protection of groundwater should remain a primary goal, due to its pivoted importance to all Arab countries.

Summary and Conclusions

The groundwater basins in the Arab Region can be subdivided to six distinctive hydrogeologic groups ranging in age from Precambrian crystalline rocks to Tertiary and Quaternary alluvium rocks. These groups encompass some 27 sub-basins, including 137 hydrogeologic units, (UNESCO/ACSAD, Hydrogeologic Map, 1988). Also, there exist, among these sub-basins, eight major groundwater basins which are shared between Arab countries, either due to their lateral extension, or due to vertical or horizontal hydraulic interconnection.

The groundwater basins in the Arab region have diversified sources responsible for naturally recharging their water bearing formations and aquifers. The natural discharge outlets of these basins, which are responsible for maintaining the hydraulic equilibrium are also numerous and diversified. The total average annual groundwater recharge in the Arab Region is about 39.5 billion m^3, while the annual amount of the groundwater used for various purposes is only 26 billion m^3, representing about 66 percent of the total recharge. Despite the fact that the discharge does not exceed the recharge, however, it is evident that the groundwater, in most of the Arab countries, is generally suffering from serious deterioration both in quantity and quality. This is due mainly to intensive concentration of groundwater production fields at some localized areas.

Deterioration of groundwater basins may be due to depletion in regards to permissible exploitable discharge and/or water levels, or due to contamination of groundwater either chemically, biologically or by radioactivity. However, both forms of groundwater deterioration would ultimately render the groundwater basins out of any standard acceptable measures for sustainable economic development. The activities generating groundwater deterioration are numerous, however, some of these would lead to depletion, while others are responsible for contaminating the groundwater bearing formations. The agricultural expansion and the continuous need for establishing irrigation projects are particularly responsible for both depletion and contamination of the groundwater, whereas the industrial, domestic, and commercial activities are evidently the main reasons for contaminating both the groundwater and surface water alike. The actions generating groundwater depletion in the Arab region are due mainly to absence of adequate groundwater assessment and accordingly improper design, planning, and management. In general, overabstraction from the groundwater basins, and uncontrolled disposal of all types of liquid wastes into the groundwater, besides the prevailing phenomena of salt water intrusion, constitute the major actions leading to the deterioration of the groundwater in the Arab region. Also, the global climatic change, in form of rise in temperature, drought, and desiccation, has direct impacts on the groundwater system in the Arab region.

The state-of-the-art survey of the groundwater situation in the Arab countries depicts a variety of typical case-histories relating the available groundwater potentialities, and the adverse impacts of the groundwater utilization and management. However, it is evident that scarcity of water resources, other than groundwater, plays an important controversial role towards the deterioration of most of the groundwater basins in the Arab region.

In view of the increased interest for groundwater in the Arab region, to meet the rapidly growing demands to water resources, the need to protect the groundwater from deterioration is becoming a mere must. There is no one single method through which groundwater can be protected, as the forms of groundwater deterioration are diversified, and that the abused actions in groundwater development and exploitation are numerous. However, there is one agreed-upon issue, in regards to groundwater protection policy, which implies preventing the components involved in the groundwater deterioration, or at least mitigating their impacts. This is rather due to the fact that preventing or mitigating deterioration is always less expensive than post-treatment and rehabilitation of the deteriorated groundwater basins.

The strategy leading to adequate protection of the groundwater implies integration of systematic operations and practices at the local, national, and regional levels. Each of these levels has specific criteria aiming primarily at protecting small scale groundwater basins or aquifers, as well as those having vast areal extent. The integrated systematic methodology for groundwater protection is considered a rather long-term procedure which primarily necessitates continuous monitoring and observation of the groundwater regime both in quantity and quality. Scientifically based assessment, planning, and management constitute the cornerstone for any sound socioeconomic ground water development. Simultaneously with this, capacity building particularly in respect to human resources and public awareness, should take utmost endeavor. Legislations are considered also most active tools in groundwater protection. Also, appropriate treatment of wastewater before re-use, and selection of adequate localities for liquid and solid waste disposal, are of particular importance as measures for preventing groundwater from contamination. Other complementary approaches are also necessary for mitigating eventual deterioration of groundwater, e.g., protection zones of groundwater production fields, artificial recharge, and water spreading and conservation.

Recommendations

In considering the general groundwater situation in the Arab region, in the light of the foregoing expose and analyses, attention is directed towards certain remedial measures and the provision of some basic data leading to sound relief of groundwater deterioration. These measures and basic data can best be acquired through the endorsement of some follow-up sub-projects pertaining to; development of research, groundwater assessment, technology transfer, human resources, public awareness, and organization of an international conference on regional groundwater protection. Details including objectives, actions to be taken by national institutions and regional, and international agencies, duration and cost estimates of each sub-project are given in the annexed project document.

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Appendix 1-a*

Water Quality Criteria for Drinking, Industrial and Agricultural Uses

Determinants	Units	WHO International Standards ('71)	WHO European Standards ('70)	USPHS (1962)	SABS (1971)	USSR (1970)	EEC		Comments on EEC Standards
							Guide Level	Max. Admis-sible Conc	
1. Elements Al	mg/l	NS	NS	NS	NS	500	0.05	0.2	
AS	µg/l	50	50	10	50	50	NS	50	
Ag	µg/l	NS	NS	50	NS	NS	NS	10	
Ba	µg/l	NS	1000	1000	NS	4000	100	NS	
Be	µg/l	NS	NS	NS	NS	0.2	NS	NS	
Ca	µg/l	75	NS	NS	NS	NS	100	NS	
Cd	µg/l	10	10	10	50	10	NS	5	
CI	µg/l	200	200	250	250	NS	25	200-600	MAC depends on circumstances
Co	µg/l	NS	NS	NS	NS	1000	NS	NS	
Cr (VI)	µg/l	NS	50	50	50	100	NS	50	as total Cr.
Cu	µg/l	50	50	1000	1000	100	100	NS	should not exceed 3000 after standing 12 hrs at consumer's tap
F	µg/l	600-1700	700-1700	600-1700	1000-1500	1500	NS	1500	
Fe (total)	µg/l	100	100	300	300	500	50	200	
Hg	µg/l	1	NS	NS	NS	*5	NS	1	
Mg	mg/l	30-150	30-125	100	100	NS	30	50	
Mn	mg/l	0.05	0.05	0.1	0.1	NS	0.02	0.05	
Ni	µg/l	NS	NS	NS	NS	100	NS	50	
Pb	µg/l	100	100	50	50	100	NS	50	MAC depends on whether lead pipe present
Se	µg/l	10	10	10	NS	15	NS	10	
Sr	µg/l	NS	NS	NS	NS	2000	NS	NS	
Zn	µg/l	5000	5000	5000	5000	1000	100	NS	Should not exceed 5000 after standing 12 hrs at consumer's tap

* Ref.: Aquifer Contamination and Protection, (1980), edit. R.E. Jackson, SRH. 30, UNESCO, Paris

Determinants	Units	WHO International Standards	WHO European Standards	USPHS (1962)	SABS (1971)	USSR (1970)	EEC Guide Level	EEC Max. Admissible Conc	Comments on EEC Standards
2. Inorganic Compounds									
CN	μg/l	50	59	10	10	100	NS	50	
NH_3-N	mg/l	NS	0.05	NS	NS	2	0.05	0.5	
NO_3-N	mg/l	10	11.3	10	10	10	5.65	11.3	
SO_4	mg/l	200	250	250	250	NS	25	250	
H_2S	μg/l	NS	50	NS	NS	nil	nil	nil	Undetectable organoleptically
3. Quality Parameters									
Total Hardness as $CaCo_3$	mg/l	100	100-500	NS	20-200	NS	NS		Minimum possible required for drinking water
Total dissolved Solids	mg/l	500	NS	500	500	NS	ϕ		
Dissolved Solids	mg/l	NS	>5.0	NS	NS	NS	ϕ		
pH	pH units	7.0-8.5	NS	NS	6-9	NS	6.5-8.5		
4. Organic Compounds									
Methylene blue active substances, as Lauryl sulphate equivalents	mg/l	0.2	0.2	0.5	0.5	0.5	NS	0.2	
Carbon chloroform extractables	μg/l	NS	200-500	200	NS	NS	100	NS	
Phenol compounds	μg/l	1	1	1	1	1	NS	0.5	as dry residue excluding natrual phenols which do not react with chlorine
Anionic detergents	mg/l	1.0	NS	NS	NS	NS	ϕ	ϕ	
Mineral oils	mg/l	0.3	NS	NS	NS	NS	ϕ	ϕ	
Polycyclic aromatic hydrocarbons	mg/l	0.0002	NS	NS	NS	N	ϕ	ϕ	
Pesticides									

Determinants	Units	WHO International Standards ('71)	WHO European Standards ('70)	USPHS (1962)	SABS (1971)	USSR (1970)	EEC		Comments on EEC Standards
							Guide Level	Max. Admis-sible Conc	
- Endoin	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	
Aldoin	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.001 Water Quality Criteria
Dieldrin	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.017
Lindane	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.017
Toxaphene	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.056
Haptachlor	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.005 US Dept. of Interior, 1968
Hexpoxide	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.018
DDT	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.018
Chloradane	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.042
Methoxychlor	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.003
Herbicides (in total)	mg/1	NS	NS	NS	NS	NS	ϕ	ϕ	0.035
							ϕ	ϕ	0.1
5. Bacteria	No.	NS	nil/100 ml	NS	nil/100 ml	NS	10/1 at 37°C 10/1 at 27°C		
Viruses	No.	NS	nil per 1 testing 10 1	Ns	NS	NS	to be examined for		

Source: UNESCO, 1980

Notes: * For organic compounds

ξ As SeO_3

ϕ The full list of EEC parameters include color, turbidity, taste, temperature, sodium, dissolved oxygen, free carbon dioxide, oxidisability, TOC, hydrocarbone and mineral oil, pesticide and organo-halogen compounds, polycyclic aromatic hydrocarbons and fascal pathogens.

NS Not stated.

Appendix 1-b Water Quality Criteria for Agriculture Use

Determinant	Livestock	Irrigation	
		Continuous	Intermittent
1. Elements			
Al		1.0	20.0
As	0.05	1.0	10.0
Ag			
B		0.75	2.0
Ba			
Be		0.5	1.0
Ca			
Cd	0.01	0.005	0.05
Cl	variable		
Co		0.2	10.0
Cr	0.05	5.0	20.0
Cu		0.2	5.0
F	2.4		
Fe			
Hg			
K + Na			
Li		5.0	5.0
Mg			
Mn		2.0	20.0
Mo		0.005	0.05
Ni		0.5	2.0
Pb	0.05	5.0	20.0
Se	0.01	0.05	0.05
Va		10.0	10.0
W			
Zn		5.0	10.0
2. Total dissolved solids	< 10,000		
3. Herbicides			
Acrolein		15-80 varies with crop type	
Xylene		800-3000 varies with crop type	
Amitrole-		3.5 varies with crop type	
Dalapon		0.35-7.0 varies with crop type	
Diquat		5-125 varies with crop type	
Na and K salts of Endothall		1-10 varies with crop type	
Dimethylamines		25	
2, 4 - D		0.7-10 varies with crop type	
Dichlobenil		1-10 varies with crop type	
Fenac		0.1-10 varies with crop type	
Picloram		0.1-10 varies with crop type	

Appendix 1-c
Water Quality Criteria for Industrial Use
(Water Quality Criteria, U.S. Dept. Interior, 1968)

Determinant	Steam Generation								
	Low Pressure	High Pressure	Textile Industry	Paper Industry	Chemical Industry	Petrochemical Industry	Iron & Steel Industry	Cement Industry	Leather Industry
1. Elements									
Al	5.0	0.01							
Ca				20.0	68.0	75.0			75
Cl				200	500	300		250	250
Cu	0.5	0.01	0.01						
Fe	1.5	0.01	0.1	0.1	0.1	1.0		25	0.1
Mg				12.0	19.0	30.0			
*Mn	0.3		0.01	0.05	0.1			0.5	0.01
2. Inorganic Compounds									
NH_3-N	0.07	0.07							
NO_3-N					5.0			250	250
PO_4					100			35.0	
SiO_2	30.0	0.01		50.0					
3. Quality Parameters									
Hardness Alkalinity	20		25	100	250	350	100		150
(as $CaCo_2$)	140				125			400	
HCO_3	17.0				128				
Total dissolved solids	700	0.5	100		1000	1000		600	
Suspended solids	10	0	5	10.0	30	10		500	
Dissolved oxygen	2.5	0.007							
pH units				6-10	6-8	6-9		6.5-8.5	6-8

Appendix 2

Restriction for Proction Zones

Restrictions turn more and more rigorous from the boundary of the catchment (zone III) towards the well zone (I).

Restrictions in force for zone III (II) are automatically valid for zone II and I.

Zone I; shall prevent any kind of human activities from the immediate environment of a well except those necessary to run the water supply.

The following activities are hazardous and as a rule not acceptable within zone I.

- All activities referred to in zone III and II.
- Any kind of traffic.
- Any kind of agriculture.
- Application of herbicides, pesticides, and growth regulators.
- Organic fertilizing.

Zone II; shall particularly protect a well from any bacteriological or virological impact and shall ensure the elimination of any pathogenic germs or viruses along the flow path to the well.

The following activities are hazardous and as a rule not acceptable within zone II:

- All activities referred to in zone III.
- Buildings, especially for industrial and farming operations, stables, silage silos.

- Construction sites, depots of building material.
- Roads, parking places.
- Camping sites, sports facilities.
- Carwash, oil-change.
- Cemeteries.
- Earthworks beyond the normal activities of agriculture and forestry.
- Intensive grazing, concentration of livestock, livestock pens.
- Organic fertilizing unless the manure is immediately spread out, or if rinsing of manure towards the well is possible, fertilizing in excess.
- Storage in the open air and improper application of mineral fertilizers.
- Allotments, horticulture.
- Storage of fuel and diesel oil.
- Transport of radioactive or water-quality endangering materials.
- Sewers, sewerage.
- Fish ponds.

Zone III; shall protect the entire river catchment area in which the well (field) to be protected is located from far-reaching contamination hazards, especially from non or hardly degradable chemical and radioactive pollutants.

The following activities are hazardous and as a rule not acceptable within zone III:

- Sinking or disposal of radioactive material and waste water including that drained off from roads.
- All deposits from which radio material, various oil products, pesticides and toxic materials can contaminate the groundwater (e.g., petrol

stations); storage of fuel oil for household use and diesel for agricultu is expected only if necessary precaution measures can be undertaken.

- Pipelines conducting liquids which may endanger water quality.
- Industrial facilities where potential pollutants are used or produced.
- Mass animal husbandry
- Storage in the open air and application of solid or water-quality endangering chemicals for plant protection, herbicides, pesticides, and growth regulators.
- Sewage irrigation and absorption pits.
- Housing developments and industrial facilities, if the sewage is not completely and with certainty removed from zone III.
- Any kind of waste disposal.
- Sewage treatment plants.
- Disposal of sewage by tank lorries.
- Military maneuvers and facilities.
- Earth works which lead to a considerable reduction of the purification capacity of the unsaturated zone.
- Development of new cemeteries.
- Application of water-quality endangering materials for road-path and water-engineering works that can be leached out.