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WATER RESOURCES ASSESSMENT: PROGRESS AND CONSTRAINTS

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Contents

1- INTRODUCTION

Water is vital for life and a unique component of the environment. It is essential for social and economic development and for all forms of human activities.

In the ESCWA region, due to prevailing aridity, water resources are scarce. In such circumstances reliable and accurate information on water availability is indispensable for the well-being of the people of the region.

The pressures on water resources in the ESCWA region increased rapidly during the past three decades. The main pressure is population growth. Other pressures on the water systems include economic growth and food demand. The construction of reservoirs enlarged freshwater supply potential to some extent. Pollution and aquifer depletion, on the other hand resulted in a net reduction of freshwater supply potential. Driven by a strategic aspiration to attain food security, the allocation of water for irrigation increased substantially. Concerns about "Water security" has encouraged countries to examine the relationship between food security and water security and review the balance between supply and demand.

The continued and rapid decrease in per-capita water availability (Table1) and increase of water stress evaluated as a ratio between withdrawal and availability has indicated clearly that serious problems have risen and urgenent attention must be given to the intensive management of the resource and demand made on it. It was evident to many countries that the present patterns of use are not likely to be sustainable and scarcity of water could become a limiting factor for economic growth.

Water stress is highest in countries which lack perennial streams or wadi runoff. This is the case in the hyper-arid part of the region which encompasses Kuwait, Bahrain, Qatar, the United Arab Emirates, and parts of Saudi Arabia. Runoff generated on mountain ranges has helped in reducing water stress in Yemen and Oman and to some extent in Saudi Arabia.

In spite of relatively low water vulnerability countries of the Mashrek experience locally high pressures on their water resources. This is mainly due to urban expansion or expansion of groundwater agriculture. Desalination has substantially increased during the past two decades. In Saudi Arabia, the United Arab Emirates, Bahrain and Oman desalination accounted in the early 1990s between 47% and 75% of domestic and industrial water supply whereas Qatar and Kuwait have sufficient desalination capacity to meet their entire domestic water demand (Dabbagh ,1995).

Evolution of Per-Capita Water Availability in ESCWA Region

	Total Resources (X 1000000) m^3	1995 Pop. Inh. (X 1000)	1995 Pc/a m^3	2000 Pop. Inh. (X 1000)	2000 Pc/a m^3	2010 Pop. Inh. (X 1000)	2010 Pc/a m^3	2025 Pop. Inh. (X 1000)	2025 Pc/a m^3
MASHREK									
Jordan	968	4095	**236**	4859	**199**	6679	**145**	10185	**95**
Syria	21450	14186	**1512**	16651	**1288**	22424	**957**	33281	**645**
Iraq	63899	20449	**3125**	24276	**2632**	33390	**1914**	50960	**1254**
Lebanon	9050	4500	**2011**	5143	**1760**	6590	**1373**	9155	**989**
Palestine	491	2110	**233**	2526	**194**	3530	**139**	5505	**89**
ARABIAN PENINSULA									
UAE	305	2377	**128**	2780	**110**	3720	**82**	5475	**56**
Bahrain	120	516	**233**	633	**190**	928	**129**	1543	**78**
Saudi Arabia	5550	17880	**310**	21831	**254**	31634	**175**	51747	**107**
Oman	1925	2000	**963**	2440	**789**	3530	**545**	5766	**334**
Qatar	40	551	**73**	652	**61**	892	**45**	1352	**30**
Kuwait	182	1576	**116**	1921	**95**	2777	**66**	4534	**40**
Yemen	5050	14501	**348**	16816	**300**	22138	**228**	31878	**158**
NILE VALLEY									
Egypt	59670	60000	**995**	66680	**895**	81406	**733**	109554	**545**

Source: ACSAD
1997

The desalination production in the Arabian Peninsula estimated at 1.56 BCM in 1992 (Alawi and Abdurazzak, 1993) is expected to increase to 4.7 BCM in 2000 and to about 5.8 BCM in the year 2010.

In spite of these great efforts and large investments to supplement the limited water resources in the region, water resources assessment, improved knowledge of water availability, projections of future demand and the presentation of development options and their potential impacts **constitute the basis for the sustainable management of region's water resources into the future**. The scarce water resources of the region must be protected and conserved to meet the needs of the present and future generations.

Water resources assessment will continue to play an important role in this regard, at the national and regional level.

2. IMPACTS OF EXTENSIVE AND INTENSIVE DEVELOPMENT

Groundwater is the main resource in the Arabian Peninsula and the principal source of domestic water supply. In the ESCWA region, in general extensive and intensive developments aiming to contribute to the socio-economic development of the countries concerned has had some adverse impacts. These comprise: (Khouri 1993).

A. Impacts on the Resource Base

- **Depletion of aquifers:** This has occurred in the Tertiary Carbonate regional aquifer system in Bahrain, and Qatar. Simulation indicates that at present extraction rates the aquifers will be completely depleted in few decades.

- **Rapid and excessive decline in water levels:** This has been demonstrated to have taken place in certain parts of Paleozoic sandstone aquifer system in Jordan and Saudi Arabia as a result of recent intensive development for agricultural purposes.

- **Corrosion of mineral encrustation of filter parts and other wells parts:** It occurred in deep wells in Saudi Arabia and in the New Valley in Egypt mainly from sulfa-chloride water and varies from moderate to extreme.

- **Deterioration of groundwater quality**: Such impacts are the most common occurring mainly;

(a) in areas that are near or act as the discharge zones for the regional aquifer system of Kuwait, Qatar, Bahrain, Siwa (Egypt).
(b) Up-or down coning from underlying or overlying saline water bodies.

This is a serious problem in Siwa (Egypt), Sarir (Libya).

B. Environmental Impacts

They are related to both water use and water from surface and groundwater sources. Important impacts include;

(1) **Land subsidence**, due to high rate of groundwater abstraction.
(2) **Salinization** of land irrigated by brackish groundwater, particularly in desert **depressions and oases.**
(3) **Destruction** of natural vegetation due to decline of water levels.

The approach of intensive cultivation although socially acceptable have created several hydrologic problems. An approach to farm by isolated distant limited farms may be an appropriate alternative (Hefny, 1991). The expansion of the area of water production would minimize the hydrologic problems, but such an approach may create socio-cultural or socio-economic problems. The choice could then be between two alternates. In-situ isolated distant farms or conveyance of water from isolated distant well fields or individual wells to collective intensive cultivation in areas where the soil and socio-economic conditions are more favorable.

3. WATER RESOURCES ASSESSMENT

Water cannot be efficiently developed and protected unless its occurrence, quantity and quality are understood and evaluated. Water resources assessment (WRA) is "the delineation of the sources, extent, dependability and quality of water resources for their utilization and control (WMO-UNESCO, 1997).

A resource is a substance that can be drawn up for use: It is defined as "the water available or capable of being available for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand".

In areas with abundant surface water groundwater is frequently under-exploited. Such a state of resource development is of rare occurrence in the ESCWA region. On the contrary groundwater have been intensively developed in several parts of perrenial river basins and over-development of groundwater in these basins markedly influenced the base flow during the dry season. In areas without perennial streams groundwater is almost always over-exploited. This is the general conditions in the ESCWA region.

Water resources assessment is carried out at different scales to meet the requirements of countries at different stages of socio-economic development. In general "basic water resources assessment" is a fundamental need to all countries at all times. Such assessments are carried out at the basin (or aquifer) level and need to be updated regularly. It is essential for national planning and water policy development. Basic assessment is usually followed by more detailed evaluation to meet the requirements of water resources development projects, and collection of additional data and information is also required for the management of water resources.

How water resources assessments are evaluated and at what spatial scales depends primarily on the need of the development and management procedures (Fig1).

With respect to temporal scale, the collected data must reflect temporial variability, and special attention should be devoted to water qulity parameters (Fig1). For example surface water quality changes rapidly while groundwater quality changes relative slowly. Both spatial and temporal scale depend on possible uses of data. If planning is the goal of the assessment, daily variations are not important but for operational assessment of water resources then daily variability must be measured (UNESCO, 1994).

3.1 Water Resources Assessment Units

The definition and delineation of water resources assessment units is an issue which need careful consideration because it affects future planning and management procedures.

In theory the basin of a river or a wadi is the natural and most convenient water resources assessment unit area(Fig2), especially when a water budget approach is used in quantitative assessments. Difficulties may arise when boundaries of the river or wadi catchments do not coincide, with the limits of jurisdictional regions. This is the region or water management unit area where the water management executive bodies have authorities with regard to the basic use of water resources. Hydrologists often assume that drainage divides of surface water systems also separate groundwater systems. In practice the hydrologic situation is not so simple, especially in arid and semi-arid regions. Watersheds are either too large such as the Nile and Euphrates river basins are too small as is the case in the African or Arabia platform areas drained by wadi systems.

In coastal areas or in closed desert basins it is more realistic to delineate multiple wadis or river basins. The Tihama and Batina drainage networks are examples of coastal "multiple" basins and the Palmyra basin exemplifies the latter drainage patterns. In mountainous terrain surface and groundwater systems often coincide in intermontane basins, but in limestone massifs inter-basin flow is common and groundwater resources need to be assessed at the regional level.

A possible solution to the hydrologic and administrative issues is dividing of large watersheds into small water management unit areas (UNESCO, 1994), that are usually under different planning or management Juresdictions. This allows for a system of spatial and temporal water resources data collection to be established and satisfactorily implemented. In global assessment large hydrologic units or regions have been chosen for appraisal of water resources. The extent of renewable water resources was estimated from river runoff. Thus estimated resources include both runoff generated from precipitation and groundwater discharge from aquifers feeding rivers (Shiklomanov, 1998). Part of groundwater especially in regional or deep aquifer system does not enter rivers but discharge directly in the sea or evaporates in sabkhas.

In the ESCWA region, as is the case in several arid regions, different assessment units are deliniated for surface and groundwater systems. An example of this approach is the assessment of water resources of the Nile basin and Nubian Aquifer Systems. These systems are however huge water bodies and represent special hydrologic regimes. In other regions special attention should be given to interchanges between the two systems. This is important in the Euphrates, Orontes, Jordan and several coastal basins in Syria and Lebanon.

3.2 The System Approach

For several decades "aquifers" have been proposed as basic units for groundwater studies and evaluation (Todd, 1959, Waltan, 1970) Adoption of a "system approach" has introduced new concepts regarding the "natural groundwater unit", thus the ideal delineation of a groundwater flow system involves locating the **recharge and discharge zone and linking these part by identifying the zone of lateral flow** and establishing boundaries of the system. Unfortunately reliable flow system delineation is difficult in some areas due to paucity of fluid potential information, and because areas of recharge cannot be directly proven in arid and semi-arid zones. Investigations regarding the "natural groundwater unit" which is most suitable for groundwater resources assessment has lead to the definition of "groundwater flow system" as a region within saturated earth material where there is dynamic movement of groundwater from source to sink (Mifflin, 1968, Freeze and witherspoon 1967, Engelen, 1984, Toth 1963) modeled

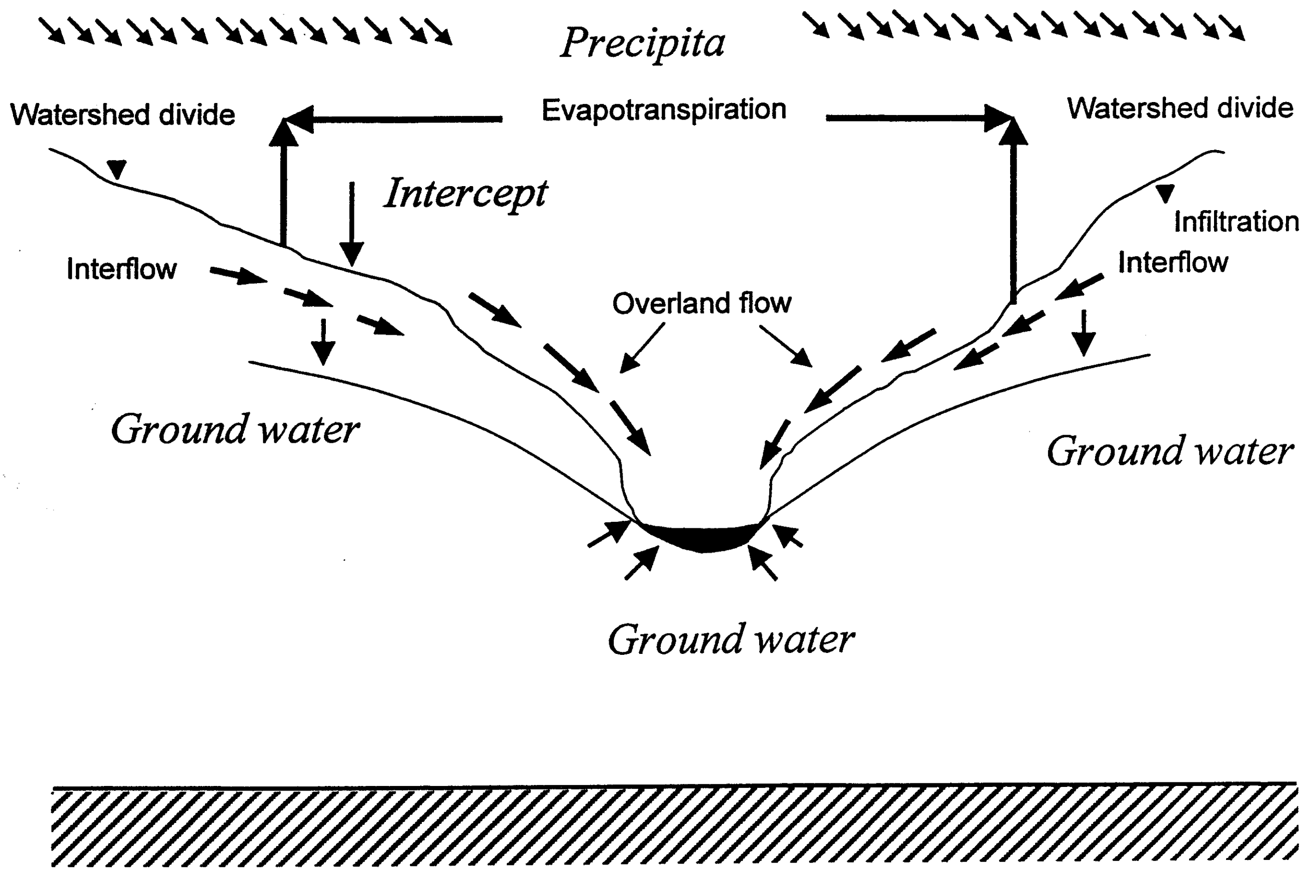

Fig 2 : Water Resources assessment at the basin level hypotentical systems and concluded that given certain boundary conditions it is possible to recognize local, intermediate and regional systems. The so-called zone of lateral flow between recharge and discharge zones is commonly extensive in arid and semi-arid zones.

The concept of regional aquifer system has a world-wide recognition at the present time. In the ESCWA region the groundwater resources of the Nubian basin have been evaluated by developing a numerical model of groundwater flow. (Thorweihe and Heinl, 1996,). **The Nubian aquifer system** has been considered the basic unit instead of the conventional unit, the "Nubian Sandstone Aquifer". In United States 25 regional aquifer systems were delineated, using computer based numerical models, regional groundwater budgets were assessed, and the groundwater development effects were evaluated. In the ESCWA region 20 regional aquifer systems were recognized (ESCWA, 1992). As seen by Engelen (1984), a groundwater system has input, throughput and output of energy in various forms, and usually evolves passing through stages of growth in time and space. This advanced concept is applicable to groundwater systems in arid zones: Paleo-recharge and paleo-discharge are indicative of the system's evolution "The stages of growth" of the Nubian Aquifer System have been described by Thorweihe and Heinl (1996).

It can be concluded from this review of the system approach that several decades of investigations within individual countries have yielded a wealth of information which could be used more effectively if regional aquifer systems are defined and delineated, and their resources are evalued as natural hydrodynamic units.

Broad regional evaluations with or without regional simulations, can establish a framework of background information, geologic, hydrologic and geochemical that can be used for regional assessment of groundwater resources in support of more detailed local studies.

3.3 Data needs

The type of data required depends on the stage of water resources assessment. As indicated earlier three stages are recognized: basic, detailed for development projects and detailed final stage of water resources management. A large range of water-related data is required to meet the needs of countries at different levels of economic and social development. For basic water resources assessment data needs are shown in figure 3.

Due to the vulnerability of the natural environmental and the impacts of human activities, an important area of need is information on the vulnerability of groundwater to pollution. The data required for the

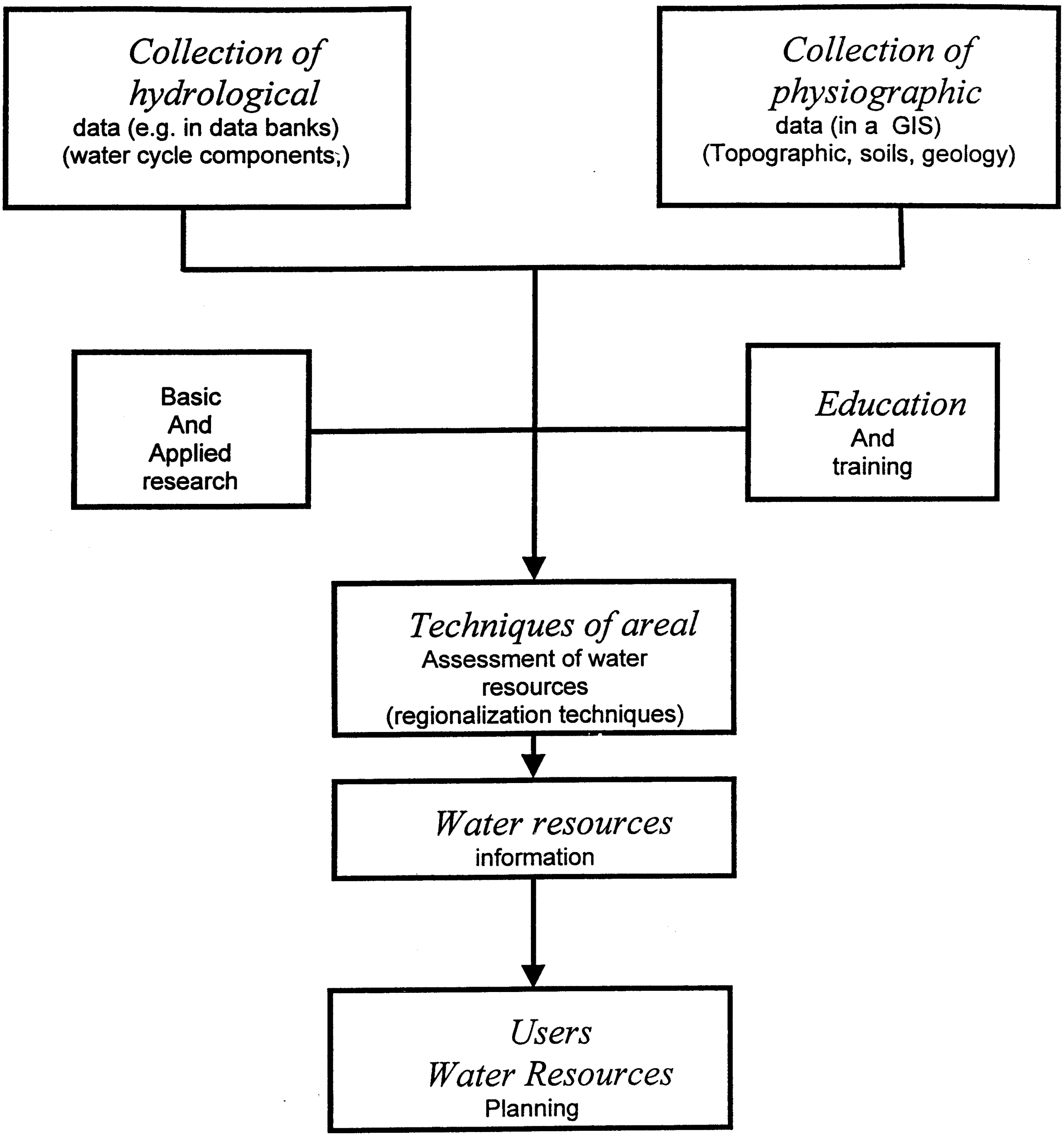

Fig3 : Components of a basic Water Resources Asessment Programme

Sorce UNESCO – WMO 1997

assessment of groundwater vulnerability comprise hydrogeological, hydrochemical and contamination data. Collection of such data can be quite difficult and expensive, so it is imperative to use data acquired for water resources assessment and collect a limited amount of additional data.

New data should include data on contamination sources and on soil properties and on the unsaturated zone. The soil has an important attenuation or purification function and is a critical attribute when groundwater vulnerability to diffuse contamination sources (fertilizers, pesticides...) is assessed. The main soil parameters related to vulnerability include texture, structure, thickness and the content of urganic matter and clay minerals. Groundwater vulnerability assessments and maps are used with basic water resources assessment results for planning and decision making. Their primary purpose is to serve as guidelines for land use zoning and development of policies and strategies for groundwater protection and management. (Vrba, and Zaporozec, 1994). Assessment of groundwater vulnerability to contamination and salinization and evaluation of sensitivity of aquifers to drought and its susceplibility to depletion and over exploitation could assist planners in minimizing adverse effects of development.

3.4 Methodologies

Once the appropriate water resources assessment unit is chosen and adequate data is collected, the most reliable assessments are those utilizing water budget approach, involving all definable elements of the hydrologic cycle. A distinction is usually made between **"water budget or water balance" and water resources balance** (UNESCO, 1994). The second term includes withdrawal and discharge in the balance equation whereas the former does not (Fig 4) .

As mentioned earlier, in many instances the boundaries of aquifer systems do not coincide with surface water divides, and it is necessary to determine groundwater resources balance separately. Tools such as GIS and mathematical models have been extensively used in recent times, particularly for the estimation of quantitative and qualitative groundwater resources balance.

Groundwater in arid zones comprises two main groups, renewable and non-renewable resources. Earlier studies over-estimated availability of the resource in hyper-arid environment. For example the "Safe Yield" of the Kufra-Sarir Sub-Basin was estimated at 2400 MCM/a (Ahmed, 1980) Later estimate of "recharge" ranged between 70 and 160 MCM/a (Wright, et al, 1982).

Development of groundwater resources in the Kufra-Sarir Sub-basin were based on a more realistic approach and the **Great Man-Made River**,

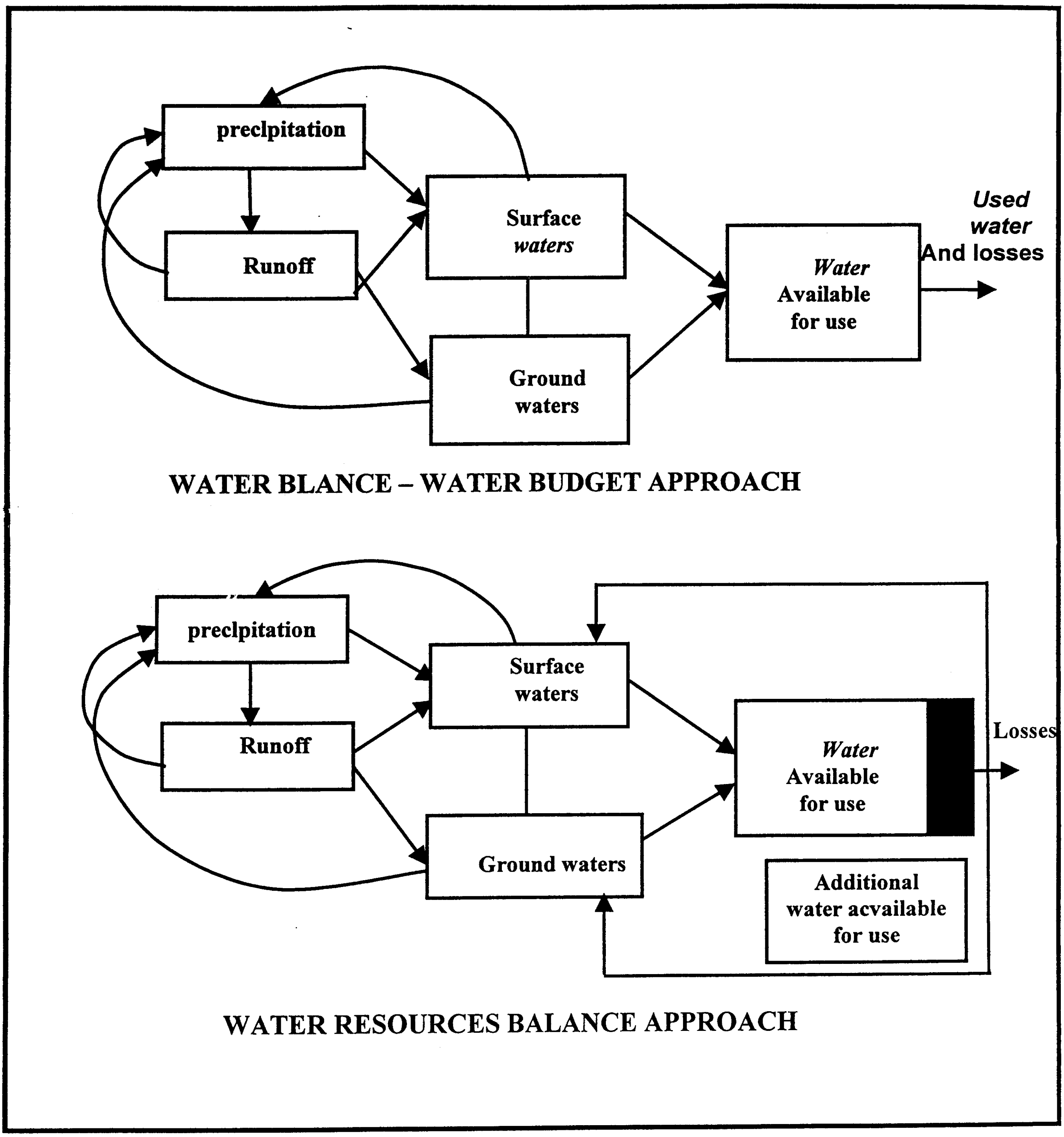

Fig 4 : Differences between the water balance and water resources balance approaches

Project was designed on the basis of "mining of a non-renewable resources" Salem (1991).

Intensive and extensive development of groundwater in the Arabian Peninsula has lead to an improved knowledge of regional aquifer systems underlying vast areas in arid and hyper-arid environment. Simulation of groundwater flow provided better understanding of the aquifer systems and their response to development. On the basis of this experience and improved knowledge two major types of aquifer systems were recognized in Saudi Arabia (Al-Ibrahim, 1990, Al-Turbak, 1999).

1. **Shallow wadi aquifer systems** containing renewable water resources

2. **Fossil aquifer systems** storing non-renewable or depletable groundwater resources.

The former resources were estimated at 950 MCM/a. The reserves of non-renewable groundwater resources were estimate at 500,000 MCM "out of which 67% are stored in major regional aquifer systems and 33% in minor aquifer. It was also estimated that about 35% of groundwater resources was used by 1995 (Al-Turbak, 1999).

The Dammam-Umm Rhaduma (Paleogene) aquifer systems is the most extensive regional aquifer system in the Arabian Peninsula. The recharge of the system and the flow patterns is a controversial issue. It is generally accepted that a significant recharge accurred during the pluvial periods and present day recharge is limited or negligible. Since the last pluvial some 600-8000 years ago (ESCWA 1982), the region has entered into the arid phase.

This is of course a well established Paleo-climatic change and should be distinguished from present day climate change due man-made impacts. The recharge mechanism which needs be considered is whether Paleo-or present recharge occurs only upstream in the recharge zone of the regional flow system or and perhaps more important recharge has an input to the system occurring as an areal and extensive phenomena; and thus water could enter the flow system whenever climatic and infiltration-hydrogeological conditions are favorable; according to this concept wadis and karstified areas and certain depressions are possible recharge areas in the Arabian Peninsula.

The concept is favored in northeast Africa (Thorweih et al, 1996), and explains the existence of high quality water in the form of local systems or lenses superimposed on the regional system, even in discharge zones.

The age of these local systems is of course younger than the age of water in the regional flow estimated at 10,000 to 30,000 years.

Although water resources assessment is traditionally a scientific procedure, the approach for the evaluation of a non-renewable resources need to be examined within the framework of long-term strategy formulation or socio-economic development planning

The choice is difficult because it influence the rights of future generation and the basic principles adopted by the international community regarding the environment and sustainability of the development. In arid zones the basic concept of sustainability has to be redefined because the resource is vulnerable and to a large extent no-renewable. The choice is between a **long lasting sustainable production** and **maximizing present day production** to enhance socio-economic development. Mathematical models are able to predict future responses. Naturally they need to be periodically re-calibrated. Decision makers could use such tools to examine various types of development scenarios, but they could also assess "replacement solutions". Desalination is the most important replacement solution, but in spite of progress in this field a breakthrough is not foreseen. Energy becomes the resource to be evaluated when groundwater is depleted, but unfortunately in many countries oil and water resources are both depletable resources and therfore developments in the area of renewable energy sources would be an important factor for ensuring a sustainable development.

Managers and planners do not usually base their long-term strategies on uncalculated risks. However recent developments in areas such as brackish and saline water use in irrigation, demand management techniques, improved rain-fed agricultural production are among many efficient water use methodologies that have been successfully applied in many semi-arid and areas. If used more widely in an efficient and effective manner they could ameliorate the impact of high pressure on groundwater resources, especially if re-use and artificial recharge are included in national water resources management plans. Many of these techniques have been tested, and under certain natural and socio-economic condition they could be viable techniques for augmentation and sound management of available resources.

Since the greater volume of non-renewable water resources occursin regional aquifer systems **regional water budgets** should be calculated, especially when these aquifer systems are shared by several countries. Regional water budgets are estimated by using regional simulations of pre-development and development conditions, and utilizing regional hydrogeologic data bases. Two important on-going regional projects utilize this approach:

The Nubian Aquifer System Regional project (Egypt, Sudan, Libya, Chad) and the North Sahara **regional aquifer system** (Continental Intercalaire (IC) and Complex Terminal IC). These projects apply a "regional system approach" and regional simulation for groundwater assessment and management. For other regional aquifers such as the Hamad aquifer systems and the Dammam aquifer systems comprehensive and integrated data bases are available. Mapping and GIS techniques have been used to represent various hydrogeological and hydrochemical aspects of the regional aquifer systems and therefore these systems could be easily simulated at regional and sub-regional scales with only limited updating of water levels and present abstraction rates.

A common characteristic of both arid and humid hydrogeological is that rates of regional flow are almost always increased by development. In humid regions new hydraulic gradients are established in the ground water system which either reduce natural discharge or induce recharge. In arid areas, however, continued decline of water levels occurs and the eventual result is reduction of the saturated thickness of aquifers. Intensive development would lead to severe conditions of dewatering. This can destroy the usage of parts of the aquifer system. In the Qualamoun arid basin in Syria the upper aquifer has been almost totally depleted and present development is based on the deep aquifer system in lower Cretaceous limestones which extend from the Antilebanon to Syrian Desert. ACSAD, upon request from the government of Syria developed a mathematical regional model for the carbonate aquifers underlying the Palmyrian mountains and the desert fereland.

Simulation of the Nubian aquifer system, underlying some 2 million square Kilometers in parts of Sudan, Egypt, Libya and Chad, showed that the groundwater body estimated at about 150,000 Km3 formed in earlier "pluvial periods occurring in late Pleistocene older than 20,000 years and in the Holocene between 14000 and 4000 BP (Thorweihe and Heinl, 1996).

The regional model developed for the Nubian Aquifer System simulated, the impacts of climatic change towards arid conditions during the last 8000 year. The simulation showed that groundwater was primarily formed by local paleo-recharge, and natural discharge decreased from 2400 million m3/year during the last pluvial to 500 million m2/year today. The model has also demonstrated that recent aquifer recharge is negligible and withdrawal from the system is "mining of a non-renewable resources" (Thorweihe and Heinl, 1996).

The implementation of regional projects contributed to the overall understanding of the regional aquifer systems and how regional ground water flow systems in arid zones function under natural and developed conditions. This has lead to the development of concepts or general principles regarding the exploitation of non-renewable groundwater resources. Two approaches are proposed (Margat, 1992).

1. **A geometric approach**, involving calculation of the volume of water presumed to be extractable from the groundwater reservoir according to a **priori**-feasibility constraints independent of time and development plans. The inaccessible depths or the saline parts of the aquifer system could be eliminated. The method is based on average value of statistics and assumes uniform drawdown (Margat, 1992). It is therefore an oversimplification of the real development issue.

Assuming an effective pore volume of about 7-10%, the reserves of the Nubian aquifer system was estimated at 150.000 Km3. The exploitable reserves of the upper water-bearing formation in Egypt and Libya, down to a depth of 100m was estimated at (1000 km^3). In Saudi Arabia the non-renewable reserves were estimated at 500 Km3 (Al-turbak , 1999). A review of assessments of reserves in various groundwater basins in arid zones estimated by different authors shows a wide range of figures.

2. **The second approach is based on model simulations**. It provide information on aquifer response to difference development schemes. Simulation is considered a more realistic approach, and is widely used because it takes into consideration all possible development plans and their physical and chemical consequences on the aquifer system (Lowering of water level depletion of reserves, deterioration of groundwater quality). It offers therefore elements of decision.

The information on reserves is, however, a useful starting point but **over-estimation** of exploitable reserves is as harmful for planning agricultural development as **under-estimation** of the water reserve potential. When estimate of the reserves is based on accurate data, **the planner could choose the period of production in accordance with national water policies**. In Saudi Arabia a relationship between annual abstraction and duration of production has been worked out for each aquifer and for the total resources (Fig5)

The basic concept in computing the water balance is the hydrologic equation, which is a conservation statement, assuming water can neither be gained or lost:

Input – Output = Change in Storage

The hydrologic equation can be expressed in the form of an ordinary differential equation;

$$I(t) - O(t) = \frac{ds}{dt}$$

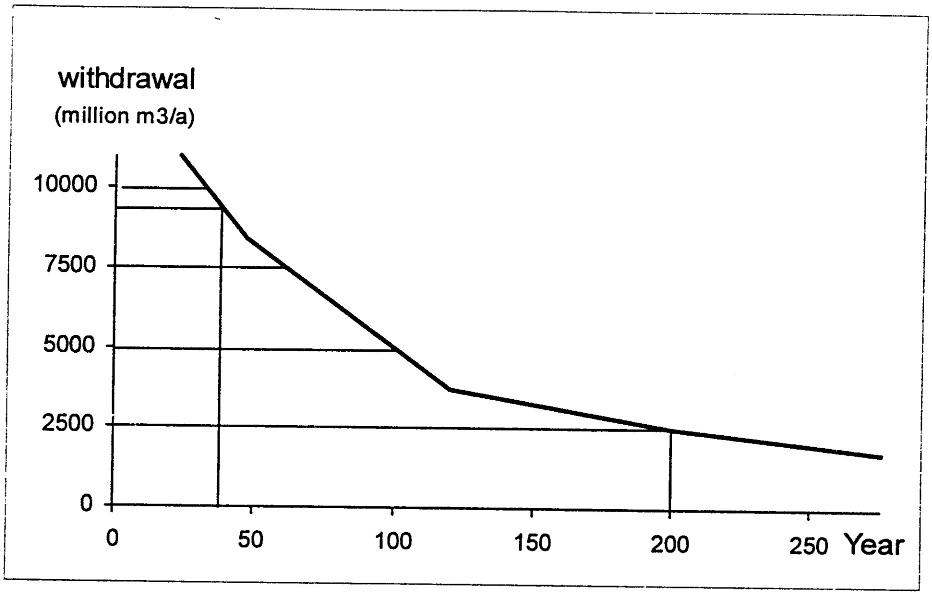

Fig 5 : Relationship between total withdrawal and projected Periods of Water production (line – time of ground water) in Saudi Arabia

C. Source : H. Neuland 1988

Where; I is input and O is output. Both taken as a function of time and in practice the equation is applied at the basin level (Fig 2):

$$P - E - T - R_o = \Delta S$$

This general equation can be expanded or appreviated depending on available data base and the part of the hydrologic cycle under investigation, thus for groundwater;

$$R_N - Q_I - T - Q_o = \Delta S$$

Or $$R_N + Q_I = T + Q_o \text{ for steady state}$$

And $$R_S + Q_I - T - Q_o - Q_p = \Delta S$$

Where Qp is withdrawal .

Expanding of the equations allow for the calculation of surface or groundwater resources balance (UNESCO, 1994).

Simulation models form the core of most groundwater assessments. The models have the power to integrate the complexities hydrogeologic settings, hydrogeologic processes and water utilization. The main steps required in the construction of groundwater models include the development of a conceptual model, construction of the model, Calibration and verification (Fig 6). Some hydrologist have objected the use of the terms verification and validation and suggest more meaningful terms such as model testing and sensitivity testing.

The conceptual model includes the hydrogeologic framework, the boundary conditions and the distribution of stresses in the aquifer due to pumping. With transient models the initial conditions need to be defined. Input data typically include transmissivity, storage coefficient, recharge and discharge.

The wide occurrence of extensive regional aquifer systems in the ESCWA region underlying large basin ranging in from 500,000 to 2 million Km2, justifies the development **regional models**. Such regional models are intended primarily for regional assessments. The large extent of aquifers modeled and lack of data in large areas preclude the use of these models to address local and site-specific water resources issues. To provide the greater resolution needed for a more detailed analysis of the effects of groundwater development, the regional flow model may, however, be further divided into **sub-regional models. Boundary conditions** are **supplied by the regional flow models**. For investigating site-specific groundwater problems local models with small block size (1 Km2 or less) are used.

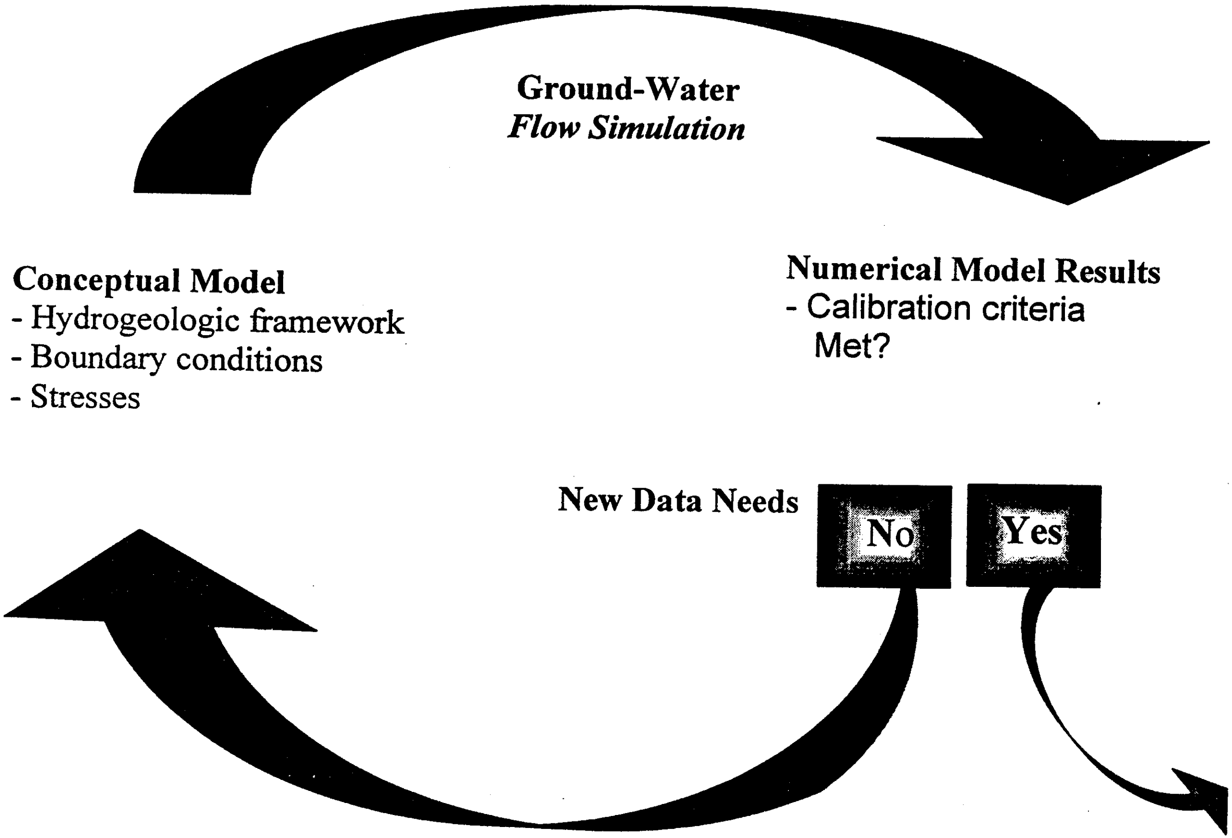

Fig 6 : Synthesis of the modeling process.

Source : Dominico and Schwartz 1998.

4 – MODERN CONCEPTS: SPECIAL ASSESSMENTS

Traditional water resources assessment is the " basic water resources assessment" targeted mainly to planners. (UNESCO - WMO 1997). The internationally developed guidelines in this respect, presume that the information produced by the "basic WRA" is used primarily for planning purposes. The information needs of water resources development and management entails additional detailed investigations and therefore are carried in the second and third stages of the assessment of water resources. Such an evaluation requires consideration of economic and social factors.

Recent concepts in the area of water resources assessments include **special assessments** of groundwater systems which are used as effective tools for planning and decision making. The results of basic water resources assessments may be combined with the outputs of special assessments for planning future development of the resources taking into consideration the sustainability of development which implies protection of groundwater resources in terms of quantity and quality.

Traditional planning procedures are based on the results of basic water resources assessment and the impacts of existing development schemes which may or may not indicate over-exploitation diagnosed " a posterioro". The new methods assess " a priori" the sensitivity of the groundwater systems to possible pressures, in terms of quality or contamination and quantity or depletion: Assessments in this regard include

1- Assessment of groundwater vulnerability (to contamination).

2- Assessment of aquifer susceptibility to over- exploitation (depletion).

3- Risk assessments.

Sustainability of groundwater resources has been introduced within the context of the general concept of sustainability to address problems of contamination and depletion of groundwater resources. In the search for effective tools to address the problems of groundwater contamination the **concept of** vulnerability was introduced in the late 1960s and further developed during the past two decades.(Fig7).

The original concept was concerned with groundwater quality and it was subsequently developed to include the quantitative aspects of vulnerability. Emphasis has been placed on the hydrogeological properties of aquifers. Vrba (1991), recognizing the importance of both natural processes and human impacts suggested that "vulnerability on the human time scale is an unchanging natural intrinsic property of the unsaturated and saturated parts of a groundwater system and depends on the ability or inability of this system to cope with natural processes and human impacts". On the basis of a comprehensive review of recent development in this regard, the IAH/IHP joint

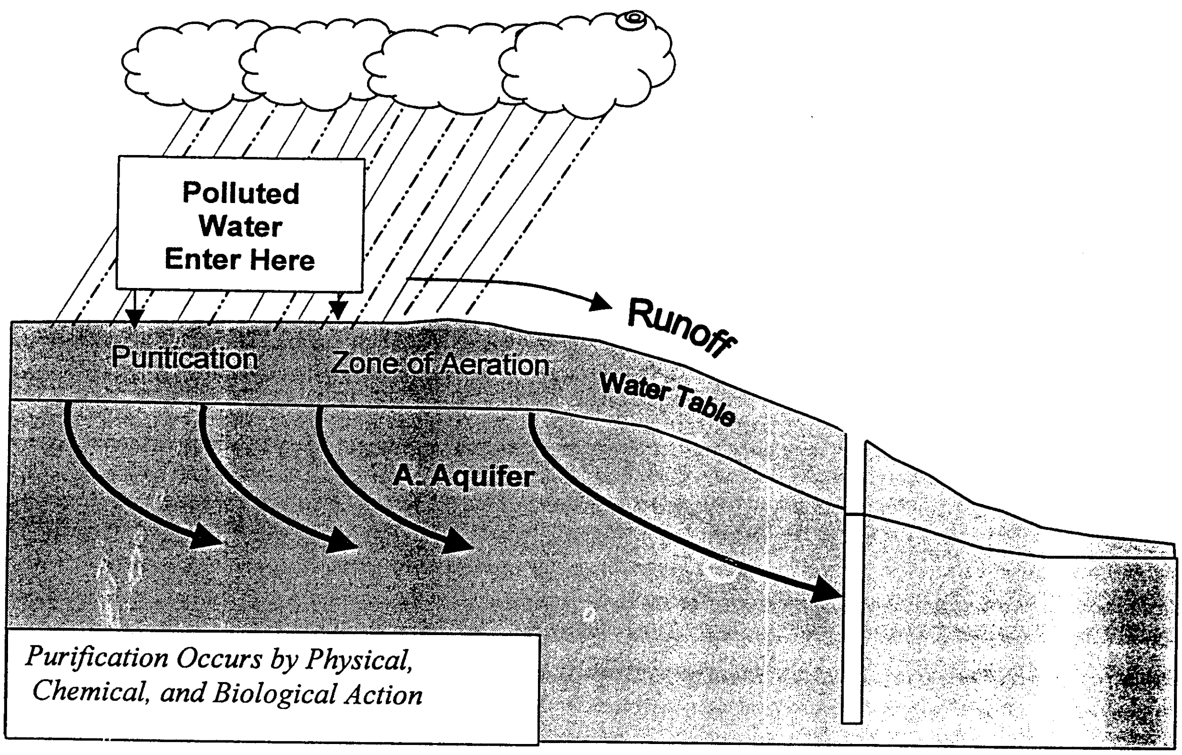

Fig7: Natural purification of contaminated water

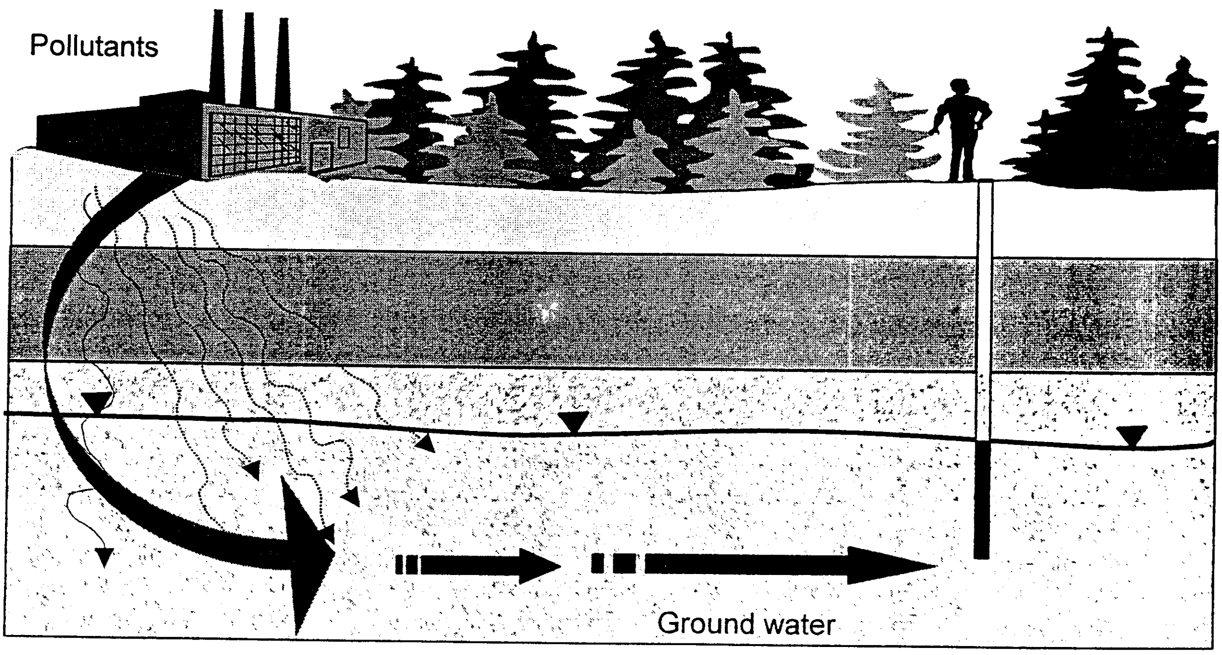

Fig 8 :Conceptual model for risk "assessment"

working group on mapping groundwater vulnerability proposed the following definition:
"Vulnerability is an Intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts". However, distinction is made between intrinsic vulnerability and specific vulnerability assessed in terms of risk of the groundwater system upon exposure to contaminant loading.

The concept of groundwater vulnerability has gradually evolved from a mere assessment of hydrogeological factors to an assessment of the contamination risk placed upon the groundwater system by human activities. (Fig8).

Risk assessment involves an evaluation of exposure assessment, toxicity assessment and health-risk assessment, and although risk assessments are used commonly to examine risk of human health the approach can be applied to evaluate "environmental risk assessment". The objective is to determine whether the contaminant detected at a particular site have the potential to adversely affect the existing biological community (Plants, wildlife...). The USEPA prepared a guideline (1989) which can be used in this respect.

The health impact of a contaminant depends on the dose that the body receives, and not on the intake to the human body; and to determine this dose the intake is multiplied by a factor: "the bioavailability factor" thus the total dose (TD) of a contaminant is obtained (Dominco and Schwartz, 1998):

$$\mathbf{TD = EI_1 . B_1 + EI_2 . B_2 + \ldots Ei_n . B_n}$$

Where ; B_1 bioavailability factor (available from medical literature)
TD units (mass / time) is normalized by dividing by the body weight; mg/kg Bw day.

The hazard quotient HQ for the human receptor is assessed by comparing the total daily dose (TD) to reference standards.

$$\mathbf{HQ = \frac{TD}{RfD}}$$

HQ > 1 indicates risk to the receptor

When thresholds do not exist as is the case with cancer even a small dose may have health implications.

In arid zones there are several factors that influence groundwater vulnerability. Due to hight temperatures a large portion of organic compounds released as a surface spill might be released to the atmosphere. Higher groundwater and air temperatures may lead to accelleration in biochemical processes, and low rates of recharge results in a very slow movement of contaminants. The result is delayed detection (Khouri and Miller, 1994). In this context Margat proposed the term sensitivity to natural impacts instead of vulnerability and he proposed to reserve the latter to human impact.

Adams and MacDonald(1995) examined the Susceptibility of aquifer systems to over-explaintation side effects **(aquifer susceptibility)** and suggested further development of this concept to produce **aquifer susceptibility maps** to be used by planners in parallel with aquifer vulnerability map.

There is a growing recognition of the significance of the quantitative aspects of groundwater vulnerability since it is often difficult to separate the qualitative and quantitative aspects of vulnerability. Overexploitation of an aquifer system, therefore, need not to be expressed only in quantitative terms but also in a changed composition of groundwater (Vrba and Zaporozec, 1994). Vulnerability in terms of quantity is of special importance in arid regions, it would be equally pertinent to consider groundwater vulnerability to desertification and drought since desertification tends to increase runoff and decrease infiltration. However, because of low recharge the main quality problem is likely to be salinization (Khouri, 1993,1996, Edmund, 1996). These concepts are of particular significance for groundwater protection in semi-arid regions.

5- PROGRESS AND CONTRAINTS

In order to assess progress in water resources assessment in the region a criteria for evaluation need to be established: Such a creteria has been developed by international expert groups involved in the assessment of global water resources issues in the present decade and potential problems envisaged in 21^{st} century. The author was involved in the preparation of the "Comprehensive Assessment of the Freshwater Resources of the World" and "Groundwater Resources of the Earth and their Use" and "Water Resources Assessment in Arid Zones and Semi-arid zones".

These monographs have consideral methodologies for water resources. The criteria or evaluating water resources assessments and national capabilities for implementing such assessments have been reviewed and further developed by a limited expert group (Khouri, B.Stewart, G. Arduino, and O.Staroslszky) representing the Asia-Africa, Australia, America and Europe respectively. The Handbook published by UNESCO and WMO in 1997, could form a basis for the evaluation adequacy, constraints, needs and current levels of water resources assessment, and still more important is the use of reference levels developed in the handbook for evaluating national capabilities and the adequacy of the information bases.

5-1 Progress Attained

The most important achievements of the present decades in the ESCWA region is application of more advanced and appropriate approaches and methodologies, which has led to a more reliable and detailed availability values. The assessments of the past decades has been refined and updated. This is evident in countries possessing relatively large resources.

	1986 WRA(BCM)	**1996 WRA (BCM)**
Egypt	66.5	59.6
Iraq	81.0	62.0
Syria	25.3	21.4
Saudi Arabia	5.5	2.2
Lebanon	1.2	3.8

The table indicates an over-estimation of the resources in the earlier decades Improvement is due to improved data bases and methodologies and distinction between renewable and non-renewable water resources.

In countries which possess limited or scarce resources, mainly groundwater, progress can be evaluated mainly by producing refined values of available resources. The extensive use in these countries of modeling techniques for groundwater assessment and planning has provided the information base required for planning and decision making.

Simulations have improved understanding of groundwater systems and was critically needed in support to improved groundwater management. This has been, particularly, useful in countries facing increasing scarcity and groundwater depletion such as Qatar and Bahrain.

The recognition of two major types of aquifer systems in the ESCWA region in general and in the Arabian Peninsula in particular is considered a significant progress in the state of knowledge on groundwater. Thus in Saudi Arabia Aquifers have been classified into (Alwai and Abdulrazzak , 1993, Al-Turbak, 1999):

1. Shallow wadi aquifers characterized by renewable water resources

2. Deep regional aquifers containing fossil or non-renewable water resources

Enhanced knowledge and accumulated experience has enabled countries to arrive at a more reliable estimate of groundwater reserves. Thus the reserves of "deep aquifer" in 7 countries in the Gulf region was estimated at 2175 BCM. The approach was based on lowering the water table to a depth of 300 m. Such a uniform lowering is not possible in practice, but the value estimated seem reasonable and could lead to a sound management of reserves.

A more informative statement is the estimate of depletion of reserves- For example, In Saudi Arabia depletion of ground water reserves during the past decades was estimated at 35% (Al Turbak 1996,1999).

Significant progress has been reported in the area of surface water assessments (table2). This is due to improved monitoring, longer records with regard to time -series and conducting studies relating to storage dams in the Mashrek and 'recharge dams' in the Arabian Peninsula. Rainfall stations increased in Jordan to 217 stations in 1996 and discharge stations increased to 45 stations. Ground water networks include 135 observation wells. (Rabaa and Samara 1998). In Lebanon data collection networks was highly developed from the 1960s to 1975. The networks rapidly deteriorated during 1975-1990. Of a total of 150 rainfall stations. 30% has been rehabilitated by 1998 and out of 70 surface water station 20 stations were improved and are functioning during the 1990s.

Qatar, Bahrain and Kuwait also published reports or papers about their groundwater and meteorological climatic networks The densities of observation stations in these countries exceed the required reference levels for water resources assessments. Some 200 dams were constructed in Saudi Arabia, Oman, and the United Arab Emirates. Existing networks were improved to meet the requirements of feasibility studies of these dams . In Yemen, with the exception of certain wadis, both surface and groundwater networks need further development to update and refine previous assessments of water resources at the national level.

In the Mashreq, Syria, Iraq and Palestine have given special attention to the development of spatial data bases and introduced GIS for this purpose . What need to be addressed, however, are problems related to the maintenance of existing data collection networks. Groundwater which is intensively developed in Syria needs improved networks and observation programmes. In certain basins such as the Palmyra and Damascus basins groundwater networks, quality and quantity, have been significantly developed, and improved assessment has lead to enhanced management of groundwater resources in both basins in Iraq.

Table (2) Water Resources Assessment in the ESCWA countries Progress during the last decade (1985 - 1995)

(million m3 / year)

Country	S . W	G . W	Total	Ref.	Date	S . W	G . W	Total	Ref.	Date	S . W	G . W	Total	Ref.	Date
Egypt	62000	4500	# 66500	2 / 42	1985	55500	3100	58600	2 / 31	1990	55570	4100	# 59670	21	1995
MASHREK															
Jordan	900	590	1490	2 / 42	1985	670	280	# 950	17	1991	900	275	1175	11	1994
Syria	22100	2935	25035	1 / 42	1985	4400	4540	9940 *	3 / 31	1990	7335	5075	12410 *	27	1996
Iraq	80000	1000	81000	2 / 42	1985	60480	2000	62480	2 / 42	1990	60000	2000	62000	11	1997
Lebanon	4800	3000	7800	2 / 42	1985						1800	800	2600	46	1996
Palestine	4000	950	4950	2 / 42	1985	4000	950	# 4950	35	1990	340	710	1050	11	1997
ARABIAN PENINSULA															
U. A. E	150	134	284	2 / 42	1985	125	120	# 245	16	1992	185	120	# 305	26	1995
Bahrain	90		90	2 / 42	1985	90		90	35	1990	90		90	11	1997
Saudi Arabia	3208	2338	5546	2 / 42	1985						3210	2340	# 5550	7	1996
Oman	1470	564	# 2034	2 / 42	1985	1432	955	# 2387	15	1992	1450	475	# 1925	7	1996
Qatar		55	55	2 / 42	1985		56	56	4 / 31	1992		40	40	28	1994
Kuwait		160	160	2 / 42	1985		101	101	12	1992		40	40	30	1997
Yemen	3500	1400	4900	2 / 42	1985	3500	1400	# 4900	35	1991	2260	1600	3860	49	1995

S . W : Surface Water
G . W : Ground Water
Source : ACSAD 1997.

 # Computed by addition
*** Shared resources not included**

5-2 Constraints

Constraints that are related to water resources assessment are mainly country specific issues, but certain constraints are due to factors or stresses imposed on the whole regions.

In this regard constraints are classified into 4 groups;

1. Institutional constraints
2. Natural and Environmental constraints
3. Inadequate Data bases and data collection networks
4. Constraints related to assessment methodology

5-2-1 Natural and Environmental Factors;

Rainfall in the region is characterized by high temporal and spatial variability. Thus long time-series are essential for water resources assessment in arid and semi-arid environment. The implications of rainfall variability is inaccuracies in the "input" component of surface water balance and to a certain extent the recharge component of groundwater resources balance. The mean annual or even monthly rainfall does not represent adequately the amount falling on catchments of surface water basins or "recharge zones" of aquifer systems. The spottiness of rainfall demonstrated in the Red Sea wadi catchments, indicates the difficulties encountered in hydrologic studies of wadi systems (wheater 1996).

Inadequacies of water resources assessment related to rainfall variability could be approximately evaluated by computing the coefficient of rainfall variation. In the Mashrek the coefficient of rainfall variation ranges from 25% to about 50%. In the arid areas of Jordan the coefficient of variation exceeds 55% whereas in the northern semi-arid areas it ranges from 20 and 30% (Kawasma, 1983). Wheater and Brown (1989) analysed rainfall patterns in Wadi Ghat catchment in Saudi Arabia. The relation between "Observed" rainfall and runoff volume was Rather ambiguous. The runoff coefficient ranges from 6 to 80%. Due to spatial variability the greatest runoff was "generated" by the smallest observal rainfall.

In spite of difficulties imposed by temporal varriations, the gap in data and information base is due to the low density and geographical distribution of rainfall stations. An important area of need is characterizing of spatial variability. Basic requirements are high quality data of rainfall and generated wadi flow.

5-2-2 Institutional Constraints

Institutional constraints are inadequate co-ordination among assessment institutions. Feedback from management and development agencies is not always possible or satisfactory and such deficiency could lead to loss of valuable data and increased cost of data collection from the data collection networks. Training and manpower development in the area of water resources assessment continues to be a basic need for the region. Continuous Education and training is rarely practiced, regional training courses is an effective approach to promote human resources development.

The constraints in this domain is the development of a well co-ordinated programme that responds to the changing needs in accordance to the stage of social and economic development. A network approach could improve the quality and co-ordination of training activities.

5-2-3 Data acquisition and Data Bases

Most countries in the region have developed computerized data bases. GIS has been introduced and some countries have initiated activities based on coupling of GIS and hydrologic models. A joint Syrian–ACSAD project have used this approach for the development of a regional mathematical model for the Palmyra Basin in the Syrian Desert.

The main problem, however, is not the establishment of a spatial data bases, which is a simple technological issue; Such data bases have been already established in Jordan, Syria, Egypt, Bahrain, Saudi Arabia. The main issue concerning data availability is data acquisition. Extreme climatic conditions and unpredictable or infrequent hydrological events are problems that need to be addressed by the operating staff, in situ bound observers and itinerants such as flow measurement teams are lacking in many countries. Flood events in wadis are not easily monitored by such teams, especially very large or small floods. Automatic, equipment for measuring hydrological or meteorological elements could often be damaged by sand storms or high sediment load carried by large floods.

Although it is conceivable to use remote sensing technique, these techniques are used mostly for collection of real-time and special survey data. However there is an increasing trend towards the use of these techniques in saudi Arabia and other countries for the calibration of historical data. Lebanon and Syria are planning to use the technique for collecting data on snowfall and snowmelt processes. ESCWA, ALECSO, and ACSAD have implemented several activities for promoting the use of remote sensing techniques.

Due to high spatial and temporal rainfall variation and spottiness of precipitation it is difficult to establish adequate hydrologic networks in all wadi basins. As mentioned earlier due to sparce population, infrequent hydrolgic events, and access problems in mountain terrains, the infrastructure needed far data collection is usually deficient. The existence of stations per se without adequate staff, maintenance facilities is insufficient for obtaining high quality water resources data.

5-2-4 Methodological constraints:

Applicability of existing WRA methodologies in the ESCWA region, under arid and semi arid conditions does not yield always the desired results. The need to adapt water resources assessment methodologies to prevailing environmental conditions has been demonstrated in the area of groundwater vulnerability.

Methods of groundwater vulnerability assessments, were originally developed for temperate and humid climatic conditions. The assessment of both natural and specific vulnerability under conditions of climatic extremes that exist in arid and semi arid areas need to take into account several influencing factors on the principal and secondary attributes used in the assessment of intrinsic ground water vulnerability such as recharge, soil properties and characteristics of the unsaturated and saturted zone.
Under conditions of extreme heat contaminant solubility and mobility as well as other physical, chemical processes acting on the soil-rock-groundwater system are substantially modified. These processes affect the purification capacity of the systems.

The principal constraints connected to WRA methodologies are however, related to the use of groundwater flow simulation. Predictability becomes a problem because grounwater systems are often poorly characterized. It is usually unrealistic to compile data sufficient to describe hydrological processes in space and time. Thus the model design depends significantly on the "informed judgement" of its builder rather than real information. This uncertainity does not disappear when the model is constructed; the calibration process does not lead to a unique description of the hydrologic system. For poorly known systems, as those existing in extensive desert areas, a large numbers of different models can be developed without ensuring which is correct; different hydrologists given the same hydrogeologic or hydrologic data will develop different conceptualization of the systemm each of which can be calibrated and verified.

In summary hydrologists must use the power provided by computer models carefully. They are useful tools that should be used with full knowledge of their limitations.

6. *IMPROVING WADI RESOURCES ASSESSMENT, ADDRESSING KEY ISSUES, AND MAJOR CONSTRAINTS*

Since constraints related natural conditions influence the final results of water resources assessments, focus should be on manageable constraints such as data adequacy and quality, methodologies and approaches for analysis and assessment, institutional issues and infrastructure.

In order to address the hydrological and hydrogeological problems in vulnerable hydrologic environment, a basic requirement is high quality data of rainfall, wadi flow and groundwater. A key issue which is directly related to quality and adequacy of basic data is the development of infrastructure, particularly operating staff.

One possible solution in this respect is the establishment of representative "wadis" or "basins". Such a solution has been adopted recently at the Arab level. In the ESCWA region representative and experimental basins were established in Syria, Egypt, Jordan and Yemen. For Saudi Arabia the suggestion has been continuation of monitoring of two or more of the /5/ basins subjected to intensive studies in the Asir mountains. These are wadi Lith, wadi Tabal, wadi Yiba and wadi Liyyah. In Egypt, the monitoring in wadi Firan includes 15 climatic and rainfall stations, /3/ hydrometric stations and /54/ wells. The basin could be considered experimental basin with a representative sub-basin ($32km^2$).

In Syria modern hydrological equipments were installed in the Syndiane basin to study hydrological processes mainly rainfall relations, erosion and surface groundwater interrelationship. The equipments installed in the basin comprise digital recorders for water level, temperature, rainfall and evaporation. The solar energy source renders such stations suitable for arid zone conditions. An integrated modeling approach was developed for Wadi Ghulagil (758 km^2) in Oman to evaluate options for groundwater recharge management.

The Arab Wadi Hydorlogy network could contribute to the assessment of water resources of wadis in the Arab region; an area of need and deficiency is regional and national hydrologic knowledge. Improved methodologies adapted to semiarid condition, hydrologic parameters and better understanding of hydrologic processes are among the objectives and current activities of the network . The solution of hydrologic data deficiencies is a natioal task. WMO and UNESCO developed and updated a useful guide to deal with this issue in a comprehensive and systematic manner. Reference levels for surface and groundwater in arid zones were established. The quality and adequacy of water resources assessment reflects national capabilities to monitor, assess and continuously update the water resources information. This, depends of course on institutional capabilities and manpower status. A comprehensive assessment of professional, technical and skilled manpower in the field of water resources assessment is critically needed to address the human problems.

Experience of hydrological agencies in the region has indicated that a minimum hydrological network is necessary for planning and development of water resource. Reference levels for minimum densities have been established for rainfall, evaporation runoff, groundwater and water quality netwroks, for arid and humid regions. Hydrologic networks established in most countries in the region comply with WMO and UNESCO reference levels, particularly groundwater networks in Bahrain, Kuwait and Qatar.

Recent developments in Jordan, in this regard, have lead to improved networks in major basins, accorded high priorities in national planning. These include the Amman, Zarka and Azrak basins. It seems that socio-economic technical and climatological considerations are involved in the establishment and development of data collection networks in the greater part of the ESCWA region.

In general, water resources data provided by the networks are considered adequate, when the "cost of increasing further the collection or accuracy of such data would exceed the economic benefits resulting from an increased amount of data or their increased accuracy" (WMO- UNESCO 1997).

7. RECOMMENDATIONS

Since water resources assessment faces several constraints in the ESCWA region due to natural, institutional and technical factors, countries in the region need to upgrade and update continuously their water resources assessment. An information support component of water resources assessment need be developed or strengthened in most member countries.

During the past decades water resources assessment is carried out at the basin level, country level and regional level and in the present decade comprehensive assessment of the freshwater resources of the world has been prepared in response to a request by the Commission of Sustainable Development.

The objectives of such assessments is to assess availability of water resources and identify problems and needs. The fundamental issue is to formulate a cost effective programme for the assessment that can be fully implemented to the satisfaction of local, national and regional interests.

The following recommendations are based on the assessment of progress in the state of knowledge on water availability in the ESCWA region in the 1990's , and on the identification of constraints and future needs:

Recommendation directed to countries.

- Evaluate adequacy of existing information on quality and quantity of water resources, and identify deficiencies in knowledge base required for the planning and sustainable development of available water resources.
- Assess data collection networks, infrastructure and institutional capabilities to conduct water resources assessments, using criteria and reference levels developed by WMO and UNESCO (1994, 1997).
- Expand inadequate or poorly developed networks and optimize relatively dense networks, using an integrated network design, in order to maximize the cost effectiveness of the basic network.
- Review institutional arrangements for water resources assessment, paying particular regard to:
    - Coordination and Co-operation between agencies responsible for the collection, storage and analysis of water resources data.
    - manpower requirements for water resources assessment.

- ♦ Develop cost-effective WRA system based on feedback-evaluation loops and a progressive process, and upgrade the data base periodically on the basis of data accumulated since the previous upgrading, and by additions of data collected to fill informational gaps. The system allows for the basins management plans to be periodically revised using information from progressively enhanced databases.

- ♦ Manage water quantity and quality together in an integrated and comprehensive manner, taking into account the upstream and downstream consequences of management actions, regional and sectorial relations and social equity.

- ♦ Enhance water resource assessment capabilities and measurement networks and establish water resource information systems that enable people to understand the options available for sustainable urban, industrial, domestic and agricultural development in combination with environmental conservation.

Recommendations directed to ESCWA.

* Assist in the evaluation of national capabilities for conducting comprehensive water resources assessments and for periodic updating and evaluation.

* Develop a continuous programme on mechanisms for providing support to water resources assessment institutions to upgrade of WRA capabilities of the ESCWA countries to enable them to develop and manage more effectively their scarce and vulnerable water resources.

* Organize training activities to meet regional and sub-regional needs, according to priorities set by countries. Principal themes may include WRA and management data collection networks, data processing, methodology for evaluating water balance and water demand, use of GIS and mapping of groundwater vulnerability.

* Assist in the development of data collection and processing systems at the national level, upgrading facilities and procedures for storing and processing hydrological data and standardization of data collection, storage and retrieval procedures and application of modern technologies for data acquisition and establishment of users friendly data management system.

* Support national programmes aiming at identification and development of approaches for the assessment of future demand by utilizing multi-sector scenarios to investigate the parameters controlling future trends in water use.

* Promote testing the applicability and adaptation of selected new techniques and approaches for the assessment of renewable and non-renewable water resources in the arid and semi-arid zones, and application of tested and

adopted cost-effective technologies in pilot areas, to test their viability and acceptability by water resources institutions.

* Establish practical and effective means for the exchange and dissemination of data and at the basin level and strengthen links between data bases at the national, sub-regional and regional level
  The system envisaged is the exchange of data in deferred time (CD-ROM and on line on INTERNET).

* Establish, within ESCWA, a regional water information network to compile information with particular emphasis on water quality, water quantity and water use. ESCWA Water information programmes should be implemented at the national level, and ESCWA should propose models to ensure compatibility between data of individual countries. There is a need for a periodic review .

* Enhance Co-ordination and Collaboration with regional and UN organizations involved in water resources assessment activities such as UCO , ACSAD , ALECSO and CEDARE.

8. REFERENCES

Abdulrazzak, M. , 1994 Rainfall – runoff management in the Arabian Peninsula, Working Group on Rainfall Water Management : UNESCO, Cairo. 15-17 November 73p.

Abdulrazzak, M., 1999. The role of water legislation in the management of water resources in the ESCWA Region, the Fourth Gulf Water Conference 13-17 February 1999, State of Bahrein.

ACSAD, 1986, Khouri, J. Rasoul Agha, W. and Droubi, A. Water Resources in the Arab region and future water potential . ACSAD, AFESD. KFAED, Kuwait

ACSAD, 1997. Water Resources and its use in the Arab region. 2nd Arab Symposium on Water Resources and its Uses in the Arab World. ACSAD-AFSED-KFAED-Kuwait, 8-10 March, 1997.

ACSAD, 1998. Water Resources Data Bank for the Arab Region. ACSAD, R11b Damascus.

Adams, B. and MacDonald, A. (1995). A Diagnostic approach to the determination of aquifer susceptibility to exploitation side effects. International Association of Hydrogeologists. 26th . International Congress, Edmonton, Alberta.

Al-Turbak, A.S., 1999. Future Water Supply and Demand Predictions in Saudi Arabia. The Fourth Gulf Water Conference, 13-17 February 1999. State of Bahrain.

Dabbagh , T.A. 1995. The role of desalination and water management in sustainable economic growth in the Gulf. I D A. World Congress on Desalination and Water Science 18-24 November, Abu Dhabi.

Dominico, P.A. and Schwartz, F.W. (1998). Physical and chemical hydrogeology, second edition. John Wiley & Sons, Inc., New York, 506 p.

Engelen, G.B., and Jones G.P. Development in the Analyses of Groundwater Flow Systems. IAHS Publication No. 163.

ESCWA 1992. Water Resources Data Base in the ESCWA Region E/ESCWA/ ENR/1992/6, U.N.

Hefny, k., 1991. Planning for groundwater development of the Nubian Sandstone Aquifer for Sustainable agriculture Round Table Meeting 5-9 October, Cairo.

Khouri, J. 1987. A hydrogeological outline of the Mashrek and Arabian Penisula . International Workshop On the Hydrological Map of Africa , Addis Ababa 1-18 December.

Khouri, J. Amer, A. and Salih, A., 1995. Rainfall water management in the Arab region, Stale of the Art, ROSTAS (UCO), Cairo, 147p.

Khouri, J. and Miller, J.C. (1997) . Groundwater vulnerability in areas of climatic extremes. Guidebook on mapping Groundwater Vulnerability. Vrba and Zaporozec (eds). P. 49-56, IAH, v. 16. Heise, Hannover.

Khouri, J.(1982). Hydrogeology of the Syrian Steppe and adjoining arid areas Q.J. eng. Geol. London, v. 15,p.

Mifflin., M.D, 1968. Delineation of ground water flow system in Nevada DRI, Reno, 53 p.

OSS, 1992. Aquifers of the Great basins; an overview and implementation programme, a document presented to the workshop on aquifers of the Major Basins, Cairo 22-25 November 1992, 46p.

OSS-UNESCO, 1995. Water Resources of OSS countries, evaluation, utilization and management, 80 p.

Rbaa, z. And More, M., 1998. Water Resources in Jordan . Workshop on Water Resources in the Arab World . Damascus 3-14 July.

Rofail, N., 1981. Mathematical Model for the Dawa Basin, ACSAD, Damascus.

Rofail, N., Zahra,M.S., Droubi, A., Abou Abdullah, M., & Ibraheem,Y., (1998). Mathematical Model of Sabkhet Al-Mouh, ACSAD,Damascus.

Shiblomanov , I. , A., 1998. World Water Resources, UNESCO. Paris. 37 p.

Sun,R.J., and Johnston, R.II., 1994. Regional Aquifer Analysis Program of the U.S. Geological Survey 1978-1992, U.S.G.S. CIRCULAR 1099, Washington.

Thorweihe, Uif., and M.Heinl, 1996. Groundwater resources of the Nubian aquifer system. OSS- Technical report, OSS- Paris, 95 p.

UNESCO, 1994. Water Resources Assessment Studies for Use in the Preparation of Water Resources Master Plans and Environmental studies, I H P I V Project M-1-1(a). Paris.

UNESCO-WMO, 1994, Water Resources Assessment Handbook for review of National Capabilities , Paris, 153p.

Vrba, J. and Zaporozec, A. (1994). Guidebook on mapping groundwater vulnerability. IAH, vol. 16. Heise, Hannover, 131 p.

Wagner, W , and W. Muller 1999. Hydrogeological Conditions of Paleogene Aquifer in the ESCWA Region . The 4th Gulf Water Conference , 13-17 February, 1999, State of Bahrain.

Walton, 1970. Groundwater Resources Evaluation , Mc.Graw Hill,New York

WMO-UNESCO, 1991. Report on water Resources Assessment. Paris – Geneve 64p.