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GROUNDWATER DEVELOPMENT AND MANAGEMENT IMPLICATIONS

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I - INTRODUCTION

Increasing demands to provide adequate and safe water supplies, ambitious goals of producing enough food for the increasing population, improvement of health and development activities all exert pressure on existing water sources, especially for those countries located in arid and semi-arid regions of the world. A report by the UN-Summit on Sustainable Development indicated that 40% of the world's population is facing water shortage in which the safety and quality of water have been compromised, especially in Africa and the Western Asian regions. This water situation will deteriorate further, involving nearly half of the world's population by 2025, unless management measures are put into practice. Arid regions, which depend largely on groundwater, will experience additional shortages with negative consequences on the depletion of sources, especially non-renewable groundwater sources.

During the last three decades, most Arab countries have focused their efforts on surface and/or groundwater sources development to satisfy water demand, supplementing these supplies through sea water desalination and reuse of treated wastewater and drainage water. Countries of the Arabian Peninsula and Jordan depend on shallow and deep groundwater sources and water desalination to meet their water demand. Countries such as Egypt, the Syrian Arab Republic, Iraq, and Lebanon depend mainly on surface water sources and supplemented groundwater sources. A number of these countries have implemented water development programs that emphasize the construction of hydraulic waterworks systems, with only limited attention being given to management aspects, water quality monitoring and the provision of water supplies for rural and urban centers from surface water sources.

When the water requirements for 2000 for all purposes, estimated at 171 BCM, along with those projected for the years 2025, estimated at 228 BCM, are compared with the annually renewed ground and surface water sources estimated at 161 BCM, serious questions arise concerning not only the long-term economic and environmental sustainability of existing water resources will require to face, but the challenge of meeting the water deficit of 67.1 BCM in the year 2025. This huge expected water deficit represents a large volume that cannot be realistically met by further development of sea and brackish water desalination and the treatment of wastewater, but with further extensive mining of non-renewable groundwater sources. In light of current and expected demands, resource sustainability will be difficult to achieve unless critical thinking on effective policy and strategy formulation takes place, with emphasis on a shift in water allocation and the application of economic instruments to attain better cost recovery, taking into consideration the well-being of society, especially the under privileged.

II – SHALLOW AND NON-RENEWABLE GROUNDWATER SOURCES

The carbonate aquifers are folded, fractured and karstified in the mountainous regions and are usually composed of sequences of limestone and dolomite. Owing to differences in elevation along the mountain belts, the karstic formations transmit water quickly to numerous discharge springs, especially in Lebanon, the Syrian Arab Republic, Jordan and the West Bank. Basalt and gypsum rock cover some areas of the Syrian Arab Republic, Jordan, Saudi Arabia, and Yemen. The major water-bearing formations, collectively known as the eastern Mediterranean aquifer, include the carbonate formations in Lebanon and the Syrian Arab Republic, eastern Jordan and northern Saudi Arabia; and the Jezira Tertiary limestone aquifers in southern Turkey and the Syrian Arab Republic. The principal aquifers in the western Asian region and their aerial extent, are shown in table (2). Other major aquifers include the upper and lower Fars formations, composed of gypsum interbedded with limestone in the Syrian Arab Republic and the southern parts of Iraq, and the Disi-Saq sandstone aquifer in Jordan and Saudi Arabia. The Nubian aquifer, composed of thick sandstone, extends through Egypt, the Libyan Arab Jamahiriya and Sudan. Overlying this aquifer is a large carbonate aquifer that extends through the northern part of Egypt. Groundwater from these formations is shared by a number of western Asia countries.

(A) Groundwater sources represent a dependable source for many western Asian countries. Countries in this region include those of the Arabia Peninsula, Jordan, Palestine, Syrian Arab Republic, Lebanon and Egypt al of which have varying degrees of dependence on groundwater. The countries of the Arabian Peninsula, Saudi Arabia, Yemen, Kuwait, Qatar, Bahrain, the United Arab Emirates and Oman, are the most dependent on groundwater for all their water requirements. Groundwater from shallow aquifers provides water for domestic purposes in Lebanon, Jordan, West Bank, Oman, United Arab Emirates, and Yemen, and to a certain extent some urban centers in the Syrian Arab Republic and Saudi Arabia. Deep aquifers provide domestic water supply for Jordan, Saudi Arabia and Yemen, and substantial volumes are used for irrigation in Saudi Arabia, Bahrain, Qatar, Oman and the United Arab Emirates. Also, groundwater from both shallow and relatively deep aquifers is used to supplement water requirements in Lebanon, the Syrian Arab Republic, Jordan, Iraq and Yemen. Water resources including groundwater sources are shown in table (1).

(B) Groundwater is contained in shallow and deep aquifers composed mainly of carbonate, sandstone and alluvial formations. Most of these aquifers are composed of carbonate, volcanic and sandstone formations found at varying depths. Limestone, dolomite, and basalt are predominant in Lebanon, the Syrian Arab Republic, Jordan and the West Bank and basalt and sandstone in Saudi Arabia and Yemen. Shallow Quaternary wadi deposits in the coastal plains and inland basins, as well as the alluvium of river flood plains, contain groundwater of good quality that is frequently recharged by perennial river flow. The shallow aquifers in Lebanon, the Syrian Arab Republic, western Jordan, Iraq, and the Nile Delta in Egypt hold sufficient groundwater reserves in the alluvial deposits and limestone formations to partially satisfy water requirements. These aquifers cover large aerial extent in which significant reserves of groundwater are stored; however, salinity levels may limit how the water can be utilized (ACSAD, UNESCO and IHE, 1988; Khoury Aga and Al-Derouby, 1986; ESCWA 1992, 1995, 1998; CEDARE, 1995).

TABLE 1: CURRENT STATUS OF WATER RESOURCES IN THE WESTERN ASIA REGION (MILLION CUBIC METERS)

Country/area	Conventional water resources [a/b/c/d/]			Non-conventional water resources		Water consumption	Utilization %
	Surface water	Ground water recharge	Ground water use	Desalination	Wastewater & drainage reuse		
Bahrain	0.2	100.0	218.0	75.0	17.5(3)*	310.0	309
Egypt	55,500.0	4,100.0	4,560.0	31.7	4,790 (3,800)	63,100	106
Iraq	60,850.0	2,000.0	513.0	7.4	1,500.0	49,100	78
Jordan	475.0	275.0	509.0	2.5	59.0	882.0	118
Kuwait	0.1	160.0	405.0	388.0	30.0	701.0	439
Lebanon	2,500.0	600.0	240.0	1.7	2.0	1,225.0	40
Oman	918.0	550.0	645.0	47.3	21.5	1,235.0	84
Qatar	1.4	50.0	190.0	98.6	25.0	298.0	580
Saudi Arabia	2,230.0	3,850.0	14,430.0	795.0	131.0 (24)	16,300.0	268
Syrian Arab Republic	16,375.0	5,100.0	3,500.0	2.0	1,447.0 (1,270)	9,810.0	46
United Arab Emirates	185.0	130.0	900.0	405.0	108.0	1,223.0	388
West Bank & Gaza Strip	30.0	185.0	200.0	0.5	2	440.0	205
The Republic of Yemen	3,500.0	1,400.0	2,200.0	9.0	52.0	2,715.0	55
Total	142,565.	18,500.0	28,310	1,863.7	8,183.0	147,330.0	

Source: Completed by ESCWA Secretariat from country paper presented at EGM and international sources 1995, 1976. and 1977.

[a] The flow of the Tigris and Euphrates rivers may be reduced due to upstream abstractions in Turkey;

[b] ACSAD paper submitted to the 2nd Symposium on Water Resources Development and Uses in the Arab World, Kuwait, 8-10 March 1997;

[c] Consolidated Arab Economic Report 1997;

* Drainage water reuse.

Table 2. Major Groundwater Formations in the Western Asia Region

Aquifer complex	Geological age	Aquifer
Lower continental sandstone	Palaezoic-Lower Mesozoic	Dis/Saq, Tabuk, Wajid Minjur Jordan, S. Arabia and Jordan
Upper continental sandstone	Upper Mesozoic	Biyadh-Wasia, Kurnub, Tawilah, Nubian Saudi Arabia, Yemen and Egypt
Lower carbonate	Mesozoic	Aruma, Amman-Wadi Sir, Cenomanian-Turonian of Lebanon, Syrian Arab Republic and West Bank
Alluvial	Neogene and Quaternary	Nile Valley and Delta; Jezira and Wadi Batin aquifers of Iraq; Jordan Valley and Wadi Araba alluvials; Gaza Strip sands and sandstones; Thihama alluvials of Yemen and Saudi Arabia; clastics of the United Arab Emirates; Batinah alluvials in Oman
Volcanic	Neogene and Quaternary	Basalts of the Syrian Arab Republic, Jordan and Saudi Arabia; Yemen trap volcanic rock

Although water in the deep aquifers is plentiful, the quality varies greatly, being suitable for domestic consumption in only a few areas as shown in table (3). Total dissolved solids range from 200 to 20,000 ppm. Good quality water is stored in the Saq, Tabuk, Wajid aquifers in Saudi Arabia, Paleogene (Dammam and Umm er Radhuma) in Lebanon, the Syrian Arab Republic and Neogene in Bahrain and Kuwait. Brackish water from the Minjur, Wasia, Biyadh, in central Saudi Arabia and Dammam, and Umm er-Radhuma aquifers in Jordan, Iraq and Bahrain. High salinity is found in Kuwait, Qatar, Oman and Yemen. Water from these aquifers usually requires treatment such as cooling and aeration to remove hydrogen sulfide and carbon dioxide gases and lime soda. Water temperatures vary between 40 and 65°C depending on the depth of extraction. Water from the deep aquifers tends to be saturated with calcium, magnesium and salt, and to have high concentrations of sulphate and chloride ions. There are also relatively large quantities of hydrogen sulphide and carbon dioxide gases. The brackish water from some of these deep aquifers is used without treatment for agricultural purposes, and for domestic purposes in some locations in Jordan, Southern Iraq, Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates.

Table (3) Deep aquifer groundwater Reserves

Aquifer	Reserve (mcm)	Recharge (mcm)	Water quality (ppm)
Saq	280,000	310	300-1500
Tabuk	205,000	455	200-3500
Wajid	225,000	104	500-1200
Minjur-Dhruma	180,000	80	1100-20,000
Wasia-Biyadh	590,000	480	900-10,000
Umm er Radhuma	190,000	406	2500-15000
Dammam	45,000	200	2600-6000
Khuff & Tuwail	30,000	132	3800-6000
Aruma	85,000	80	1600-2000
Jauf & Sakaka	100,000	95	400-5000
Jilh	115,000	60	3800-5000
Neogene	130,000	290	3700-4000
Total	**2,175,000**	**2,692**	

Substantial groundwater reserves exist in different aquifer systems among the western Asia member states. The amount contained in the formations depends on the hydrological characteristics and aerial distribution of the shared aquifers. Some of the hydrogeological formations are inter-connected as well, feeding particular aquifer systems according to their piezometric pressure. The type of feeding varies from one aquifer system to another, and from site to site, according to differences in hydraulic characteristics, recharge and yield.

Bahrain, Jordan and Saudi Arabia have been exploiting their non-renewable groundwater, and Oman, Qatar and the United Arab Emirates and Yemen are in the process of utilizing their fossil water resources that are over 20,000 years old to meet rising water demand in the agricultural sector. Groundwater utilization has exceeded the safe yield of the aquifers. The magnitude of safe yield, representing regional groundwater recharge or the sustainable use of groundwater, is estimated at 18.5 bcm. Groundwater utilization in the western Asia region reached 28.3 bcm in 1996, compared with 18.5 bcm of groundwater recharge, with 67 per cent of total withdrawal taking place in the GCC countries and Yemen.

In the deep aquifers, the cone of depression extends over a large area as a result of extensive pumping. The current indiscriminate pattern of groundwater development has resulted from the absence of appropriate development and management strategies. The delay in formulation of appropriate policies and strategies can, in part, be attributed to the absence of political will in attaching importance to groundwater, lack of financial resources to undertake detailed studies of potential sources, and fragmented water institutions with overlapping or nonexistent functions and lack of coordination.

III - SHARED GROUNDWATER SOURCES

In the region, there are several significant groundwater basins shared between member countries; those with the most extensive groundwater reserves as shown in table (4) include the following:

(a) Eastern, Mediterranean basin - The aquifer covers an area of 48,000 km2 and extends through the Syrian Arab Republic, Lebanon, Jordan and the West Bank. It feeds the Orontes and Litani rivers in Lebanon, as well as the Jordan River.

(b) Hauran and Jabal Al-Arab basin - This aquifer covers an area of 15,000 km2 and extends through the Syrian Arab Republic, Jordan and Saudi Arabia. The Golan plateau constitutes the recharge outcrop area for the basin. Base flow from this aquifer is considered the main source for the Yarmouk and Azraq basins through the Mazreeb, Al-Hamma and Al-Azraq springs;

(c) East Arab Peninsula basin - This aquifer covers an area of 1.6 million km2, extending through the Syrian Arab Republic, Iraq, Jordan and the countries of the Arabian Peninsula. Rainfall is the main recharge source in the northern part of the basin and the Nubian sandstone basin. This basin covers an area of 2 million km2 and extends through Egypt, the Libyan Arab Jamahiriya, Sudan and Chad. It has extensive groundwater reserves, with limited access in Chad and the Sudan, springs, oases and depressions are the major drainage areas of this basin.

Table 4. Major Shared Groundwater Basins

Basin	Sharing countries and areas	Aerial extent (square kilometers)	Discharge areas	Rock type
East Mediterranean	Syrian Arab Republic, Lebanon, Jordan, Palestine	48,000	Assi, Litani	Karstic
Hauran and Jabal Al-Arab	Syrian Arab Republic, Jordan	15,000	Yarmouk, Mazreeb, Azraq, Al-Hamma	Basalt
Arabian Peninsula	All countries of the Arabian Peninsula, Syrian Arab Republic, Yemen	1,600,000	Gulf	Sand and carbonate
Upper Jezira	Syrian Arab Republic, Turkey, Iraq	100,000	Ras Al-Ain, Al-Khabor	Alluvium and carbonates
Nubian sandstone	Egypt, Libyan Arab Jamahiriya, Sudan, Chad	2,000,000		Sandstone

Shared deep aquifers also cover most of Saudi Arabia and extend east and south into Kuwait (Aruma, and Neogene), Iraq, Bahrain, Qatar, United Arab Emirates, and Oman (Wasia-Biyadh), and Yemen (Wajid, and Wasia-Biyadh) as well as the neighboring countries of Jordan and the Syrian Arab Republic (Saq and Tabuk) (FAO 1994, 1996). The Saq and Tabuk deep aquifers that underlie the central and northern parts of Saudi Arabia and southern Jordan and the Syrian Arab Republic (MAW, 1984, Edgell, 1987) support extensive agricultural development in these regions and provide water for many towns and villages. The Wajid lies below the southern part of Saudi Arabia and the northern part of Yemen. Its water is used mainly for agriculture in southern Saudi Arabia, but is the main water supply for Yemen's urban region of Sanaa. The Wasia'-Biyadh aquifer is one of the main sources for Saudi Arabia's capital, Riyadh, and a large number of towns and villages, as well as agricultural activities in the central regions of the country. The Wasia equivalent aquifer also supplies water to Sana'a in central Yemen and a number of villages in Oman. The Neogene aquifer satisfies domestic and agricultural requirements in eastern Saudi Arabia, Kuwait, and Bahrain. Discussion on the Um er-Radhuma and the Dammam aquifers will be presented under the example of large scale Paleogene aquifers in the subsequent section.

The shared drainage basins in the region also contain shared shallow groundwater sources. Most of the shared shallow aquifers are those lying under rivers shared between Lebanon and the Syrian Arab Republic (Al Asyia, and Al Kaber), the Syrian Arab Republic and Jordan (Yarmouk) and Jordan, the Syrian Arab Republic, and Saudi Arabia (Hamad and Sirhan). In the Arabian Peninsula the main shared aquifers under the major Wadis are those lying between Saudi Arabia and the remaining countries of the Arabian Peninsula (Al-Batin Najran, Liyah and Khulab, Burami and Al-Ayn).

Uncontrolled groundwater development has resulted in the exploitation of most aquifers, resulting in detrimental effects caused by continued water level decline, increased salinity and pollution levels, and the migration of saline water. Some of the shallow aquifers have reached the critical exhaustion level and have become unfit for human consumption due to excessive nitrates, phosphates, heavy metals and fecal coli forms. This situation is particularly severe in most of the Gulf States, the Syrian Arab Republic, Jordan and Yemen.

Regional water resources management requires careful consideration, as the issue of shared aquifers seems to be a delicate political matter. Lack of management policies for the development and utilization of both shallow and deep aquifers, including those shared among several countries, have contributed to large drops in water levels, quality deterioration, migration of saline water into coastal aquifers, movement of connate water zones, mixing of water of different qualities among multi-layered aquifers, high development costs and increased competition among neighboring countries for the shared sources.

IV - EXAMPLE OF LARGE SCALE SYSTEM: PALEOGENE

The paleogene aquifer is a large aquifer system with an extensive aerial coverage covering most the west Asian region. This formation is found in southern Lebanon (Bekaa valley and Saida), northern and central Syrian Arab Republic (Hama and Aleece), the west bank (senin), central Jordan (Hamad Az Zarke and Sirla Jafir), southern Iraq (Salman), Kuwait, Bahrain, Qatar, the United Arab Emirates, eastern Saudi Arabia, southern Oman and eastern Yemen. The thickness of the formation generally increases in the northern and eastern direction, ranging from 50m to more than 1000m. Water quality is good in the recharge areas, brackish in the northwest, and very poor in the east near the Arabian Gulf.

Geological setting: The geographic coverage of the paleogene system is influenced by several major geological structures in the region which also affect the presence of groundwater. The most influential of these formations are the Arabian shield and the Arabian shelf. The Arabian shield is composed of precambrian crystalline and metamorphic rock which precludes the availability of groundwater. This formation covers southern Jordan and the western and southern parts of the Arabian Peninsula. The rock layers influence the depth of a number of sedimentary formations, which in turn affect groundwater recharge zones and sub-terrainian water movement.

The Arabian shelf contains multiple, massive carbonate and sandstone aquifers which hold significant groundwater reserves. These aquifers cover the northern and eastern parts of the western Asia region. The major topographical features that affect this formation are the anti-Lebanon mountains in Lebanon and Syrian Arab Republic, the Wadi Arab – Jordan rift valley, as well as the surrounding highlands of Jordan, the interior homocline plate formations of southern Iraq and the eastern parts of the Arabian peninsula, the Rub Al Khali depression.

Hydrogeology: The paleogene system extends from the northern and eastern parts of the region to as far as Hadrensul as shown in figure (1). This massive aquifer system covers the major portion of the Arabian shelf and consists of the hydrogeological provinces of Dammam, Umm er Radhuma and Aquitar. They are composed mainly of limestone, dolomite, chalk, marl and marly limestone. The limestone and chalk aquifers are found in Lebanon, the Syrian Arab Republic, Jordan and the west bank. Limestone and dolomite formations are found in southern Iraq and the eastern parts of the Arabian Peninsula. Major Paleogene stratigraphic features, in terms of groundwater availability, have been categorized into three major units, as follows:

1. Lower unit: Paleocene to lower Eocene in the Umm er Radhuma aquifer of southern Iraq and the eastern part of the Arabian Peninsula, and their equivalent formations in Jordan (Umm Ridam).
2. Middle unit: Lower to middle Eocene in the Rus and Dammam formations of the Hamed and Sirhan basins in the Syrian Arab Republic and Jordan, southern Iraq, and eastern parts of the Arabian Peninsula.
3. Upper unit: Eocene or equivalent formations in the Syrian Arab Republic.

The paleogene aquifer characteristics and its sequences in the central and eastern parts of the region are shown in Tables 5, 6, 7 and 8. The Umm er Rahham (UER) formation is overlain by the Dammam (Dam) aquifer and underlain by the Aruma formation. The aquifers flow under unconfined conditions around the outcrop areas, and are largely confined throughout the remainder of the Paleogene formations. Groundwater movement takes place laterally within both aquifers, and vertically, depending on the gradient.

The limited published data on the Dammam and Umm er-Radhuma and their equivalent formations indicated large variation in the transmissivity (T) and storativity (S) values. This variation can be attributed to past tectonic activities and change in deposition environment. The transmissivity can be classified as moderate to low in the northern ESCWA region covering southern Lebanon and Aleppo,Hama and Homs in Syrian Arab Republic due to nature of fracturing and Kartisfication features. For the areas located in southern Syrian Arab Republic, most of Jordan, western Iraq and northern Saudi Arabia, the T and S values indicated low range. For example for Shallala (Dammam) aquifer in Jordan, the T value was estimated at).11-1.2 m^2/d while for the Rijman aquifer at 0.03-450 m^2/d. In the eastern areas covering southern Iraq and GCC countries relatively more hydraulic properties information was available due to the extensive groundwater development. In this area the T value falls within the moderate to high range and low

Extent of Major Paleogene Aquifer Systems

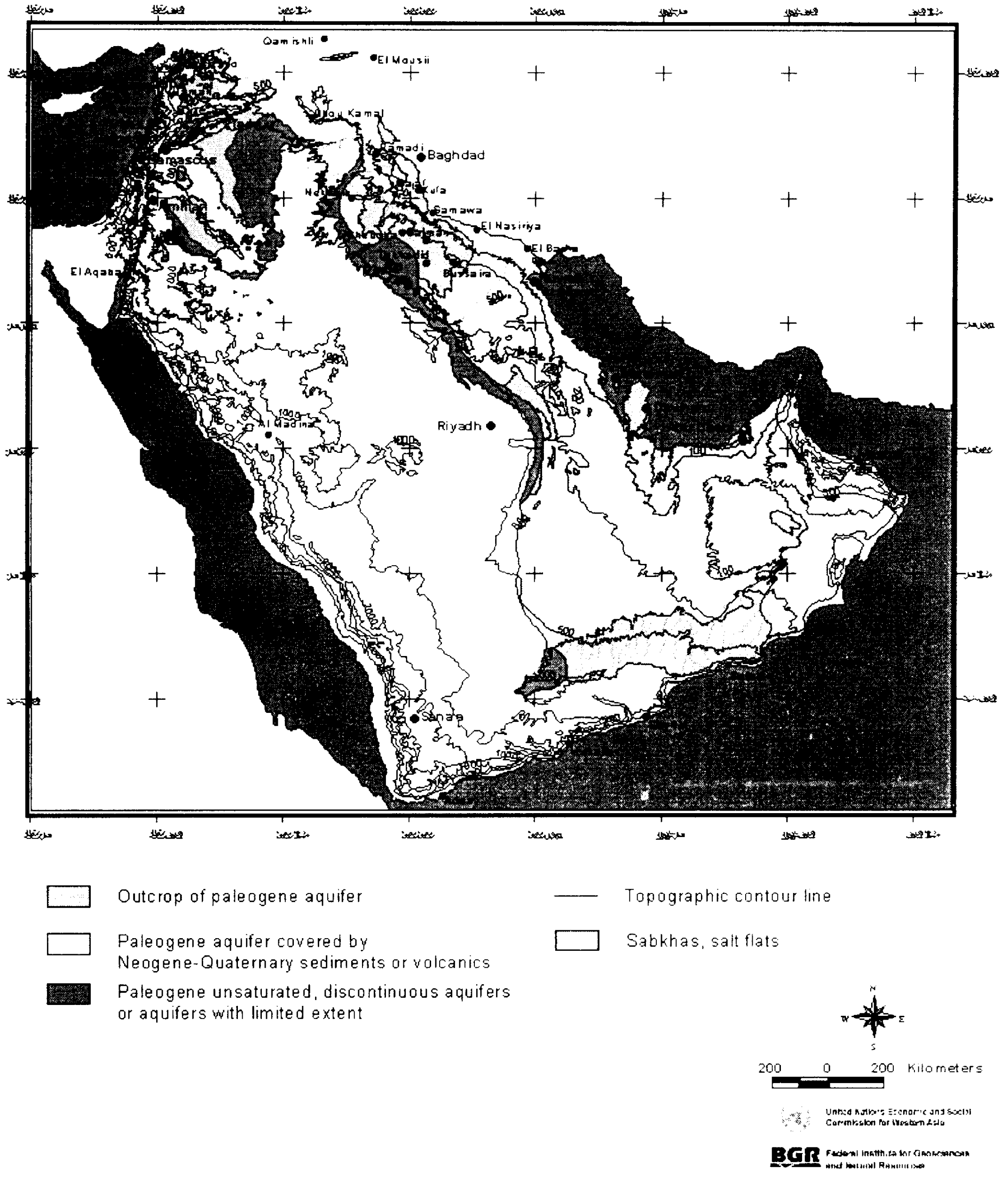

Figure 1

S range. For the Mammam aquifer the T values ranged from 2 to 25056 m^2/d while the S values ranged from 0.01 to 2x10.$^-$9 The Umm er Radhuma values reported at 10-55300 m^2/d while the S was at 1.4x10^{-2}-3.5x10^{-5}. Generally the Dammam and Umm er Radhuma aquifers can be characterized as having a T value of 20-200 m^2/d in the north while for the remaining ESCWA areas with values of 100- 8000 m^2/d. In some isolated areas near the Gulf in the east high values were reported in a range of 1000-50000m^2/d. Both aquifers were under confined conditions but water table conditions existed in areas near outcrop or structural deformities. Leakage phenomena were reported in some areas in northern Syrian Arab Republic, Jordan, Bahrain, Qatar and eastern Saudi Arabia. The aquifer hydraulics prosperities are shown in Table 7.

Most recharge takes place along the outcrop areas, located in the north and western Saudi Arabia, where relatively high levels of rainfall occur. The recharge mechanism greatly influences water quality; with recharge consisting mainly of rainfall, infiltration from wadis, and vertical leakage between formations. Water, in these formations, ranges in age from 5000 to 30,000 years. The Dammam and Umm er Radhuma aquifers are the source of a large number of springs, particularly in depression areas in northern Syrian Arab Republic (Rahab and Aleppo), Jordan valley (eastern highlands), southern Iraq (Euphrates valley), eastern parts of Saudi Arabia (Al-Hasa and Qatif), and in eastern Bahrain and Qatar in the form of sea springs. The schematic cross section of Dammam and Umm er-Redhuma aquifers in the Arabian Peninsula region is shown in figure (2).

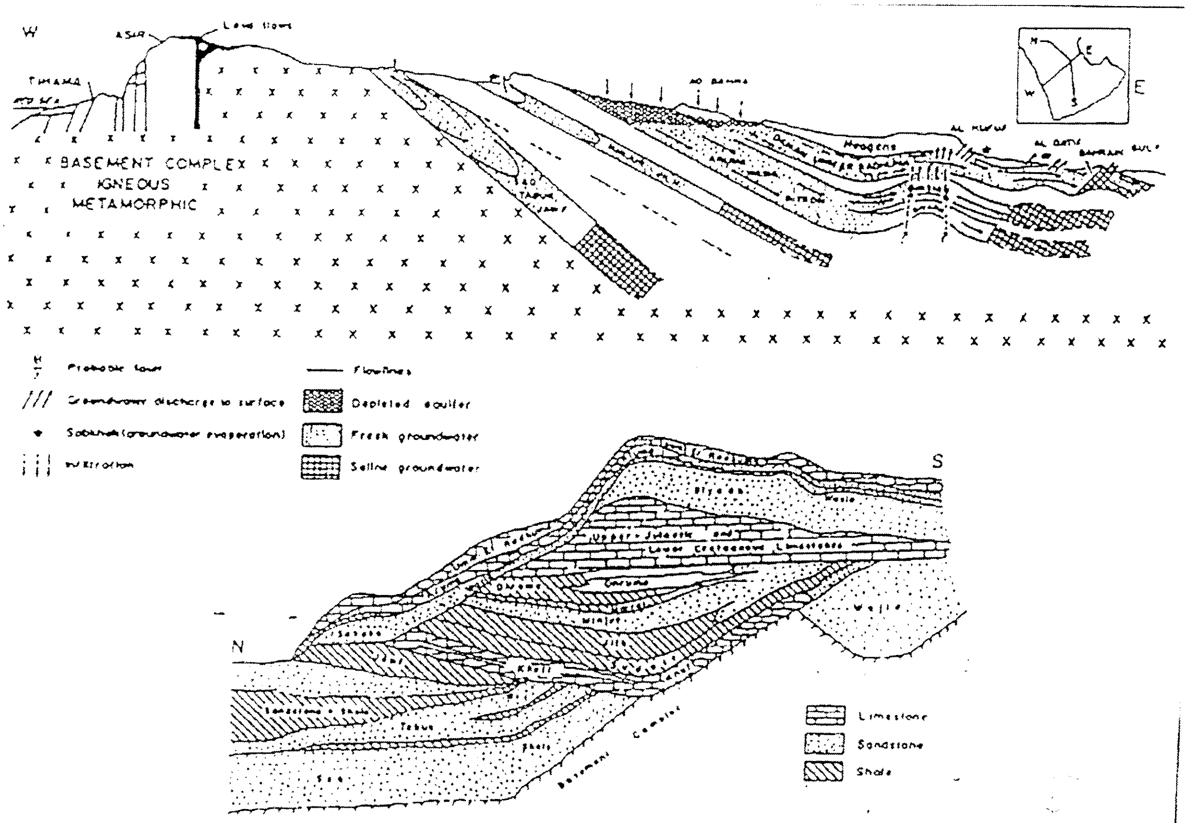

Figure 2: schematic geological section of deep aquifers

Table 5: Paleogene aquifer characteristics in different countries

Country	Aquifer Name	Thickness (m)	Productivity (m^3/h)	Transmissivity M^2/h	Storativity	Quality (mg/l)
Kuwait	Dammam	120-350				
	Umm er Radhuma	425-600		13-4500	$4x10^{-1}$ $6x10^{-7}$	2500-5000
Bahrain	Dammam	5-15	218 (1994)	730-41000	$4.8x10^{-4}$	2000-2500
	Umm er Radhuma	200-300	24	63-40000	$1.5x10^{-4}$ $3x10^{-5}$	8000-15000
Qatar	Simsima, Abarauq	10-50 0-25	1400 (1996)		1.2x10-1 $6x10^{-5}$	
	Umm er Radhuma	270-370	220	330-6700	$6.2x10^{-8}$ $2x10^{-5}$	20000
Saudi Arabia	Dammam	80-250	446 MCM		$1.4 x 10^{-2}$ $3.5x10^{-6}$	
	Umm er Radhuma	240-700	0.970 MCM	3-55000	$1.4x10^{-2}$ $1.5x10^{-7}$	
UAE	Dammam	280-500				
	Umm er Radhuma	300-550				
Syria			3.5 MCM			
			35 MCM			
Jordan	Rajan	0.4-0.94	100-300	0.03-450		
	Shallala	0.1-1.2	55-70	0.1-1.2		600-2000
West Bank	Jenin	10.4 MCM (1996)	200-325			200-1110
Iraq	Dammam	14-27	50 MCM	13-1500	$1x10^{-2}$ $2.8x10^{-1}$	
	Umm er Radhuma	9-23	9-23	10-1700	$1.4x10^{-4}$ $2.7x10^{-3}$	

Table 6: Sequence of Paleogene Formations in Saudi Arabia, Iraq, Jordan and Syria

	Saudi Arabia	**Southern Iraq**	**Hamad**	**Syria**	**Jordan**
Oligocene			Sandstone and sandy limestone	Terrigeneous sediments, clay, carbonate rocks	Tayiba F.
Upper Eocene			Limestone	Carbonate, clayey and sandy sediments	Wadi Shallala chalk F.
Middle Eocene	Dammam F.: limestoneand marl up to 260m	Dammam F.: dolomitic and marly limestone, 100m	Chalky limestone	Chalky and nummulitic limestone	Umm Rijam chert F.
Lower Eocene			Chert, limestone, marly limestone	Limestone with chert	
	Fus F.: chalky limestone, marl, anhydrite, shale, 20-100m	Jil/ Rus F.: chalky and marly limestone, dolomite, anhydrite, 300m	Northern and western Hamad: chalky limestone and marl; eastern and southern Hamad: limestone and dolomite	Marl, clay, argillaceous limestone	
	Umm er Radhuma F.: chalky and dolomitic llimestone, dolomite, chert, 320m	Umm er Radhuma F.: chalky and marly limestone, dolomite, anhydrite, 300m			
Paleocene					Murwazzar chalk, marl F.

Table 7. Sequence of Paleogene Formations in Eastern Saudi Arabia, Bahrain and Qatar

			Dhahran	**Qatar**	**Bahrain**
		Alat limestone and marl	Chalky dolomitic limestone, dolomitic marl, 0-145 m	Abarug: dolomitic limestone, marl 10m	Limestone, and dolomitic limestone, partly chalky, 15-25 m, dolomitized marl, 9-15m, termed locally Orange Marl
		Khobar limestone and marl	Dolomitic limestone, marly limestone and marl, 0-75m	Simsima: dolomite, limestone, 30m	Limestone, dolomitic limestone with basal marl, 14-45m
		Alveolina limestone	Limestone with shale and marl, 0-20m	Alveolina limestone, 1m	Nummulitic limestone and dolarenite, 4-10m
		Saila and Midra shales	Shale with gypsum lenses, 0-20m	Midra shale and Fhailhil limestone, 6m	Shale-claystone, partially dolomitic, 8-20m, termed locally as Shark Tooth Shale
Lower Eocene	Rus Formation		Chalky limestone, marl, anhydrite, shale, 20-100m	Dolomite, limestone, thick bands of egypsum, 44-82m	Chalky limestone, chalky dolomitic limestone with claystone and evaporites, with abundance quartz geods, 60-150m
Lower Eocene-Paleocene	Umm Er Radhuma Formation		Chalky and dolomitic limestone, dolomite, chert, 320m	Dolomite, chert bnads, marl, 300m	Dolomitic limestone, Calcarenite, often argillaceous, 120-350m

Table 8: Sequence of Paleogene Formation in the Rub al Khali Basin, Hadramaut

			Saudi Arabia	Eastern Yemen	Southern Oman
Middle Lower Eocene	Dammam Formation	Alat limestone and marl	Chalky dolomitic limestone, dolomitic marl, 0-145m	Habshiye F.: limestone, carbonate sandstone, interlayers of shale, marl and minor gypsum 220m	Andur F.: limestone
		Khobar limestone and marl	Dolomitic limestone, marly limestone and marl, 0-75m		
		Alveolina limestone	Limestone with shale and marl, 0-20m		
		Saila and Midra shales	Shale with gypsum lenses, 0-20m		
Lower Eocene	Rus Formation		Chalky limestone, marl, anhydrite, shale, 20-100m	Rus F.: gypsum, anhydrite, clay, marl, 300m	Chalky limestone, marl, evaporate beds
				Jeza F.: limestone, clay, gypsum, 100-150m	
Lower Eocene-Paleoscene	Umm er Radhuma Formation		Chalky and dolomitic limestone, dolomite, chert, 320m	Limestone, dolomite, 300-400m	Limestone, 80-300m
					Dolomitic limestone, 250-300m

Water Quality- Water quality, in general, ranges from very good to poor, depending on the location. Quality is affected by recharge, groundwater flow, leakage and formation dissolution. Water quality suitable for human consumption (<1000 mg/l) can be found in Lebanon and the Syrian Arab Republic. Brackish water is found in central Syrian Arab Republic, Jordan, southern Iraq, eastern Saudi Arabia and Yemen (1000 – 3000 mg/l) as shown in figure (3). In the remaining countries of the Arabian Peninsula quality is generally in excess of 5000 mg/l, and in some locations salinity can range between 50,000 – 150,000 mg/l. Substantial increases in salinity in some isolated zones may be attributed to a non-flushing position of the aquifers filled with connate water. The overall quality consisted of:

1. Bicarbonate/sulfate in the recharge areas is usually less than 1000 mg/l.
2. Sulfate concentrations in brackish water zones range from 3000 – 6000 mg/l, as a result of the dissolution of sulfate and anhydrite deposits.
3. Chloride concentrations in the Gulf area range between 6000 and 50,000 mg/l.

GroundWater Salinity Distribution

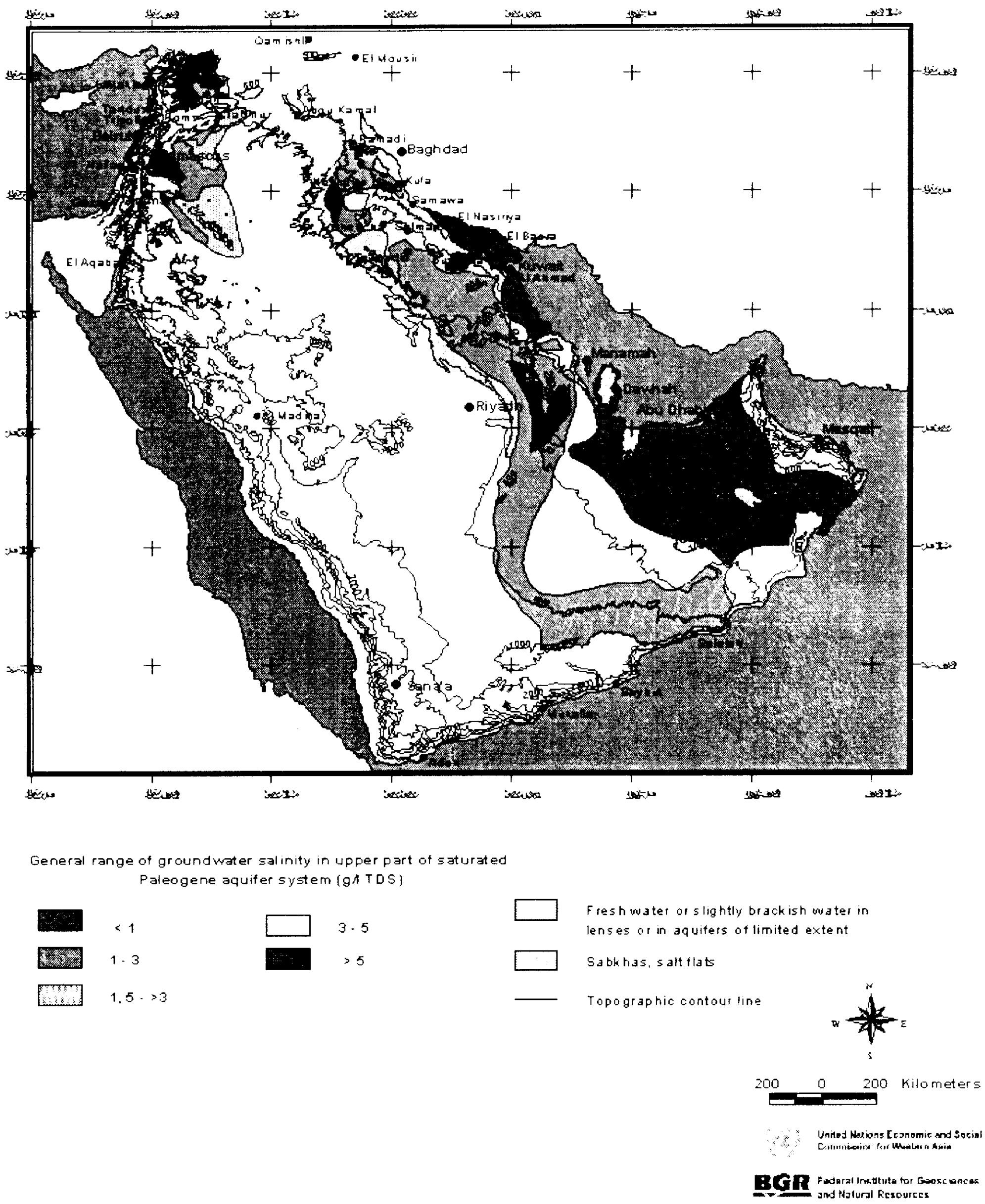

Figure 3

Aquifer productivity-Both the Dammam and Umm er Radhuma aquifers and their equivalents are the major sources of irrigation water for agriculture, and to a limited extent for domestic purposes, especially in the Gulf region. The aquifers of the paleogene formation provide water for domestic use in the northern and northwestern region, while providing water for agriculture in many countries located in the eastern parts of western Asia region. The productivity of these aquifers ranges from low to moderate, except in areas of high transmissivity where water production may be high. In northwestern Syrian Arab Republic the Umm er Radhuma aquifer produces low to moderate water volumes for domestic and agricultural purposes through wells and springs. The brackish water has been used as a domestic supply for remote nomadic communities in southern Syrian Arab Republic (Hamed) eastern Jordan (Hamed and Azzah), and southern Iraq.

In Jordan, the Razen (depth 100-300 m) and the Shallala (550 m) aquifers produce 0.4 to 0.9 cubic meters per hour. In Lebanon both aquifers have been exploited in the Bekaa valley and Saida at production rates of 20-100 cubic meters per hour. The Jenin aquifer (200-325m depth) in (country) has an annual productivity of 10.5 mcm (1996). In Iraq, the aquifers have only moderate production capacities. In the Gulf countries, both aquifers have moderate to high production capacities. In Kuwait, the brackish water from the Dammam aquifer is used for blending desalination and industrial purposes, with a limited production capacity of 120 mcm (1993). Water from the Umm er Radhuma aquifer is highly saline. The water aquifers productivities are shown in figure (4).

Aquifer Productivity

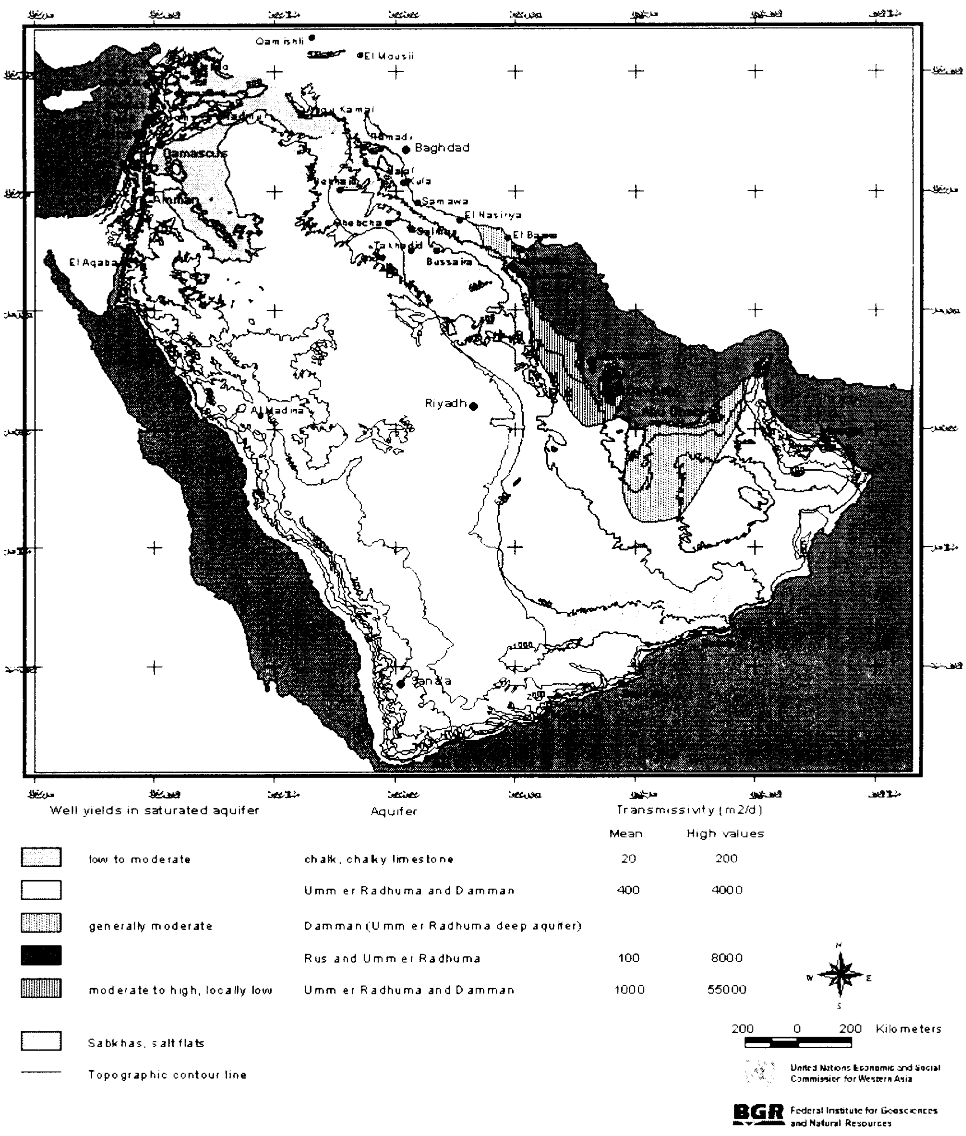

Figure 4

V – GROUNDWATER DEVELOPMENT AND MANAGEMENT IMPLICATIONS

Shared aquifers, because of their extensive aerial expanse, considerable reserves, and the political aspects of their development, present a major challenge to decision makers and water professionals. The issue of shared water resources has been ignored by governments of the region, even though it represents a potential source of dispute among some Arab countries and between them and other neighbouring states. An effective framework for regional cooperation must be established to ensure the efficient utilization and management of both surface water and groundwater resources. Strengthening such cooperation requires the encouragement and building of trust and confidence between ESCWA member countries. A sound quantitative and qualitative knowledge of the potential of available water resources is a prerequisite for planning, development and the efficient allocation of shared resources. The ultimate goal of shared basin development is the implementation of a comprehensive and multilateral plan encompassing measures that ensure the rational development, utilization and conservation of water resources, taking into account the socio-economic factors prevailing in the countries concerned. There are a number of major aquifers such as the Carbonate-Paleogene, shared between countries of the Arabian Peninsula, Jordan, the Syrian Arab Republic and Iraq, the Basalt shared by the Syrian Arab Republic and Jordan, the sandstone-Disi/Saq shared by Jordan and Saudi Arabia and Wajid shared by Saudi Arabia and Yemen. The extensive mining of some of these aquifers over the last three decades, without coordination among the sharing countries, has resulted in adverse technical with regard to dynamic equilibrium.

Evaluation of the impact of increasing water demand, especially in the domestic and irrigation sectors, requires that the prevailing administrative, legal, economic, social, cultural, religious and democratic factors be taken into consideration in order for water issues to be addressed in a holistic and integrated manner. The three most important factors are addressed below (technical, economic and social implications).

Technical Implications – The technical requirements to develop additional surface and groundwater sources, desalination, treatment of waste water, rainfall management, water imports and any other feasible source must be evaluated in order to enhance water supply availability. To meet raising demand in the absence of water management, the resources of each country must be explored. Some of the most challenging technical factors that may need to be overcome are: the construction of storage dams, diversion and long distance distribution networks, international water networks, extremely deep drilling, construction of expensive desalination and wastewater treatment facilities, and oceanic water transport.

Further development of conventional and non conventional water sources will result in the mining of shallow and deep groundwater sources and environmental degradation, as most of the western Asia counties do not carry out environmental impact studies or enforce protection measures. The pursuit of food security and self sufficiency will result in extensive mining of groundwater resources. Some countries such Syrian Arab Republic, Iraq and to certain extent Egypt, may be able to achieve this goal, while others will rely on unrealistic and unsustainable options to meet food requirements for the next 25 years. To estimate future food requirements, the application of approximate criteria may give an indication of the magnitude of water needed. The criteria are expressed as per capita water for food production, and are estimated at 1200 m3 per person. Thus, to establish food self-sufficiency for the year 2025 would require that the irrigation sector be provided with 360 billion cubic meters of water, which is substantially higher than the current available water requirement estimated at m. Higher demand may incur additional generation of liquid and solid waste, with resulting increased pollution especially of shallow groundwater. There are possibilities in surface water utilization, however, the feasibility of such development is uncertain due to: general lack of natural sources with the exception of Iraq, Syrian Arab Republic and Lebanon; lack of agreements concerning shared surface water sources; and the need for large monetary investments. In countries of the Arabian peninsula and Jordan, increases in demand would mean further mining of groundwater, especially deep aquifers, and will increase the chances of a water disputes over utilization of the shared aquifers. Also, increases in demand would require a shift in water allocation from the irrigation sector to the domestic and industrial sectors, with resulting social impacts on labor, income and rural migration.

Water import is another option, and many schemes were proposed to deliver water to a number of countries including sea transport via ships, land transport through pipelines, and matosa bags. However, given the political instability of the region and lack of trust among nations, water transport options are very risky as demonstrated by the inequitable and unreliable transfer of water from Israel to Jordan. Higher water demand with further development of conventional and non conventional water sources should not be accepted as the only option, but used in conjunction with the implementation of effective demand management measures to decrease water use such as leak detection, building code modification, water pricing, water reuse and recycling and water reallocation.

Groundwater management measures must take into consideration the data coverage and quality control regarding aquifer properties (permeability, saturated thickness and storitivity, and hydraulic gradient), recharge mechanisms, leakage, depth of aquifer, pressure head or water table, and drilling and monitoring regulations. Without complete knowledge of the parameters of the shared watersheds, including the geomorphology, hydrology, hydrogeology, hydrometeorology, agro-meteorology, climate, soil and vegetation, unilateral development of common water resources cannot succeed. A more thorough and precise understanding of these parameters would allow a more realistic, feasible and reliable development of shared water resources for the long term. Unilateral development would be guided mainly by self-interest, excluding the others involved and therefore giving rise to problems that might possibly prove so inter-actable they would halt all forms of joint action. The successful implementation of joint studies on shared surface water and groundwater sources could result in the exchange of information and views on the means of optimal development and management.

Political: Water professionals are well aware that some of the main aquifers are shared with neighboring countries. Regardless of this knowledge, they have continued to encourage development activities to meet the water requirements of various economic activities. The issue of shared sources has been looked at from the national sovereignty point view, resulting in up-stream countries ignoring the long term mining effects without considering the effects on their neighboring countries. In addition, the absence of legislature governing shared groundwater sources has allowed ministries to ignore their obligations towards sustainable utilization. The responsibility of forging an agreement or memorandum of understanding, to at least share information and experiences and promote joint development, falls on the shoulders of water professionals in the region. In failing to educate decision-makers, especially water Ministers, on the need to initiate dialogue with neighboring countries, they have given the opportunity for a rift to form between countries, further widening the gap of communication and cooperation. Some water experts believe that this sensitive issue should not be discussed publicly, as it would not be in a country's best interest.

Most of the shared aquifers have been used to develop large scale irrigation schemes in an attempt to achieve national goals of food self sufficiency. There is a lack of awareness on this issue, as the majority of highly-ranked decision makers in charge of the water sector lack academic and technical background in water related subjects. Also the attitude that groundwater is readily available and easily accessible, especially for upstream states, has compounded the problem. Past groundwater development activities in many upstream countries have resulted in extreme **piezmetric** level drop, decreased discharge, and quality deterioration. Ignoring this issue may be thought of as a way to avoid creating tension between countries extracting water from these shared sources.

In developing countries, including the Arab countries, water data have been considered as a confidential issue, even though most of the studies were carried out by international consulting companies. This belief has complicated the issue of data dissemination and cooperation among neighboring countries. The issue of water sovereignty, mistrust, and initiatives taken by regional organizations such as the Arab League or GCC secretariat, have contributed to a reluctance to start dialogue among neighboring countries on possible development and management of shared sources. Another major reason for lack of communication and cooperation is that the Arab region has been experiencing political tensions and border disputes that take precedence over water issues. ESCWA, through BGR's technical contribution, has taken the initiative in establishing a data base for some of the shared aquifers, with the objective of facilitating the exchange of information. The successful completion of a study of the Basalt aquifer, shared between the Syrian Arab Republic and Jordan, has contributed to increased awareness of the water situation, and encouraged mutual discussion among the concerned countries. An additional study is to be initiated in the near future, with the similar aim of promoting cooperation among countries that share water resources, and establishing a basis on which joint development and management schemes can be based.

Social implications - Every human being has the right to adequate supplies of safe water for his use survival. Everyone should recognize human water rights, and governments have the obligation to meet such requirements. Religions in some countries concur with this idea by implicitly or explicitly calling for compliance with human water rights, while discouraging the wasteful use of water. Social settings and family income influence water use. High standards of living have been associated with higher water consumption rates. History has conveyed to us the water demand strategies for some ancient Arab civilizations, which demonstrated that rational utilization of water and living in harmony with the desert environment in regard to limited water availability, allows a society to flourish. But when the population increased disproportionately, and the water resources were misused, some civilizations vanished.

Social settings of the past allowed the people of the Arab region to cope with water shortages as prevailing norms dictated water use and called for demand to be managed, either individually or socially. Unfortunately, such cultural and social water awareness is limited in modern Middle Eastern society. Current cultural settings in the Arab world do not encourage the conservation of water resources. Society seems to be unaware or unmindful of the water resource problems affecting them such as limited water supply and pollution which can be attributed to the economic hardship that they are experiencing. There is a trend of over consumption of water in the domestic and irrigation sectors with a seemingly total disregard to availability problems. Water use in these sectors sometimes reaches more than 300 to 600 liter per day in the urban centers of GCC countries and Iraq. The relatively smaller per capita consumption in the urban centers of Egypt, Syrian Arab Republic, Jordan and the West Bank is not necessarily associated with public awareness of water scarcity or a desire to conserve, but results from the lack of availability of water, and is sometimes due to imposed rationing. In the irrigation sector, however, farmers of the region generally use water in excess of what is required; application may sometimes exceed 10,000 cubic meters per hectare. In addition the irrigation sector seems to have the full support and protection of the decision makers, as this sector has been associated with the concept of food security and self sufficiently. Even water professionals are reluctant to speak against the wasteful water use in this sector for fear of being accused of opposing the national interest of being food self-sufficient.

Conquering the desert environment through the green revolution gives great psychological pride and a feeling of success to decision makers at the highest levels. However, such unsustainable use of groundwater will have a significant impact on future generations. Water resources should be used wisely and conserved as much as possible for the survival of the world. The desert ecosystem has its own dynamic equilibrium in relation to climate, soil, living organisms and water resources; water availability being a critical element in desert environments. Water has been taken for granted, and the population does not realize that lack of water will hinder development activities. It seems that the majority of professionals and planners in the region have ignored the fact that water is a finite resource and have continued to suggest ambitious development programs with water as one of the main ingredients expected to support the success of the project. This way of thinking requires serious modification on the part of decision makers and water professionals, in order to properly evaluate water availability and prioritize use. Financial expenditures to develop and manage water resources must be recovered in the most efficient manner, taking into consideration the prevailing social structure and the ability of the population to pay, as well as the obligations of the governments to society.

It is known that high water demand is associated with high population growth. The Arab world is characterized by high population growth of 2.2-3.5 % with low income people usually having large families. They are, however, low water users in comparison to the over-users of the small upper-class family. The only demand implication as the population increases, and in the absence of effective management measures, is higher water demand. Reducing the impacts of high population growth on water demand requires good family planning, education of the poor, halting or decreases in urban migration and the creation of good working environments in rural communities. Family size estimated at 5-7 persons per household compared to 2-3 in Europe and North America has high demand implication in absence of effective demand management measure such public education and participation, affordable water pricing, financial incentive water conservation devices and building code modification. These measured should have been easily implemented given the type of government as the public will not have the power to object as water and sanitation services were financed and operated by the public sector.

In the long run in regard to the implementation and sustainability of management programs, a slowdown in water demand requires active participation of society and the involvement of NGOs. This process is lacking in all countries of the ESCWA region. First, the public must recognize their right for adequate and safe water, sanitation coverage and to be well informed on all water issues so that any program implemented in the water sector is associated with their way of living. The public should know that each individual has the right for a minimum amount of water/day. This human water right is being debated worldwide with allocations ranging from 50 to 100 liter per day, per person for drinking, bathing, cooking and sanitation. The public's participation can be improved through the enhancement of democratization by allowing individuals to ask or demand action from appointed or elected representatives to fight for the benefit of their communities. They can participate in open public hearings on water issues of their concern. The NGOs should be supported and have the freedom to operate and defend the public rights and preservation of the environment. All these processes will contribute to the management of water demand. As previously mentioned, management of water resources requires political will to undertake drastic changes in the way water is being developed and managed, active public, private sector and NGO involvement and strong supports of the donor communities.

Economic Implications - Water resources development to accommodate future higher demand requires a great deal of financial resources. In the past, water supply, sanitation and irrigation projects were funded from national budgets including operation and maintenance costs. The availability of funds has not kept pace with the need for further expansion of existing facilities as a result of population growth, coupled with urban migration and increases in food requirements. Lack of funds has forced many governments to take a variety of actions including: limiting urban growth, providing incentives to encourage migration into suburbs and rural areas, passing on to consumers the full cost of capital construction of distribution system costs, increasing the water supply and sanitation connection fees and reducing agricultural subsidies.

Most countries of region, with the exception of the GCC countries, looked to Arab funding institutions and foreign donors to provide grants and low interest loans to finance water and sanitation projects. Recently, most governments of the region are evaluating private sector options, with leading efforts in Jordan, Egypt, Palestine, Kuwait, Lebanon and UAE. However, privatization efforts have been slow because of the existing rigid legislation, regional political instability, and the high risk of investment recovery due to the existing low charges for delivery of services. Extensive investment is needed during the next ten years to provide the basic water supply and sanitation services, especially for countries with large urban populations such as Egypt, Syrian Arab Republic, Iraq, Saudi Arabia and Yemen. Required investment, according to the World Bank estimate, may range from $30 to $45 billion over 10 years. This financial investment is substantially beyond the national financial capability of most of the ESCWA countries.

Large investments would be required for the development of storage reservoirs and distribution networks in Syrian Arab Republic a, Iraq, Lebanon and Jordan. For the shared surface water resources, international lending institutions would be reluctant to become involved because of the absence of agreements among the riparian states sharing the water of the Tigris and Euphrates rivers. Opportunity costs will be very high. In the case of deep groundwater development, drilling may be costly as aquifers with high potential are located at great depths from the ground surface. Most of the aquifers with development potential average a depth of more than 300 meters; some are located at depths exceeding 500 meters and in some instances more than 1000 meters. The water from these aquifers may also have high temperature, iron and sulfate content usually requiring treatment, which means additional capital and operational costs. In addition, aquifers with high groundwater potential may be located in remote areas far from the urban centers where the water is needed. Thus, the cost of land transport by distribution network will be very high, with typical cost estimates ranging from $1 to $1.5 per cubic meter, depending on topography.

Higher water demands in the domestic sector requires the construction of additional desalination plants, especially the GCC countries, where plant life averages 20 to 25 years. Sea and brackish desalination and waste water treatment facilities also require high capital investment. For example, capital construction costs for desalination facilities range from $1100 to 1800 ($0.55 to 3.5 cubic meter) while for wastewater it may range from $900 to 1500 cubic meter per day ($ 0.15 to 1.50 cm) depending on the treatment level. Brine disposal and air pollution from numerous desalination facilities may require treatment, at an additional cost, in order to protect the environment. If treated wastewater is not fully or partially reused, its disposal on land or sea requires additional investment. The involvement of the private sector in the provision of water supply and sanitation services, as well as large irrigation projects can be a solution to reduce the burden on governmental budgets. However, regulations must be in place to protect the public interest in terms of improved services, reasonable pricing and combating monopoly. Therefore, it can be seen that the implementation of demand management measures to slow the increase in water demand would lead to smaller investment requirements.

VI - CONCLUDING REMARKS

In meeting water demand in the domestic, industrial, tourism and irrigation sectors especially from groundwater sources, countries of the region must put water high on their agenda and initiate actions to formulate short and long term policy statements and implement action-oriented strategies and comprehensively evaluate the technical, economic, social, legal and administrative aspects of such actions within realistic financial, private sectors and human resources capabilities in order to meet the water shortage challenge within the next 50 years. Otherwise, serious water crises and public discontent could take place. The increasing water shortage has been taking place during the last decade. The fact that the irrigation sector is responsible for the majority of water depletion mainly the groundwater sources are unsustainable in the long run for uneconomically grown crops. The implication of the World Trade Agreement, which many countries of the region are trying hard to you to, must be evaluated in light of the water requirements of other sectors. The biased approach toward the agricultural sector as it is depleting the groundwater sources must be removed, and evaluation or preferably implementation of water allocation shifts from irrigation to the domestic and industrial sectors are in order. Ignoring or delaying action in addressing water shortage issues, excluding water demand, will not make the problem go away but will exert tremendous pressure on the social and economic order in many countries of the region. Given worldwide trends in demanding and experiencing the democratization process, society, when it is faced with harsh water shortages, will exert immediate pressure on local municipalities and national government to provided the needed services and improved quality. This will create major difficulties for decision makers if they are not well prepared to handle such situations by having in place well-establish policies and implementable strategies.

The public must understand the expected changing role of governments from provider to regulator and planner. The public must share the burden of expenses in an equitable and just manner. Reasonable cost recovery, perhaps partial at first, and later the full cost, must be understood by the public, taking into consideration the difficulties of the less fortunate. Society is required to contribute to the effort of water conservation, especially the irrigation sector, and educate their children of the practical and ethical value of water conservation for future generations and environmental protection. Public and NGO involvement in the water affairs in each country of the ESCWA region should not be viewed as a choice but as a requirement needed to establish checks and balances for effective management of the region's scarce water resources.

The time has come to meet the challenge of bridging the gap between supply and demand at the national level, by placing the issue of water management at the top of the political agenda. This will ensure the commitment of decision makers to assign the highest priority to water issues, commit the necessary investments, and introduce enforceable legislation and regulations capable of creating a favorable environment for policy implementation which will attract public and private sector participation at the human and national levels. Water development and management problems, and their degree of severity can be minimized if the countries can initiate serious action to formulate and incorporate in their polices and programs the concept of integrated water management, in conjunction with the action programs detailed in chapter 18 of Agenda 21, taking into consideration the characteristics of the region in terms of meteorology, environment, social, political, and financial resources and the interests of donor countries.

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