Sustainable Water Resources Development in Kuwait: an integrated approach with comparative analysis of the case of Singapore

by
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ABSTRACT

This thesis assesses the water resource status of Kuwait and Singapore, both countries considered as water scarce. The institutional aspect of Integrated Water Resource Management (IWRM) efforts in both countries is closely examined at international, regional, national and administrative levels. Aspects of the institutional framework which have contributed to the successful water management scenario in Singapore are identified in order to draw lessons for the case of Kuwait. Although complete emulation of the national and administrative bodies of Singapore may not be justified, specific activities, methodologies and structures are recommended for the institutional capacity building of Kuwaiti water management.

Artificial surface aquifers are proposed as a suitable solution for enhancement of water storage capacity in Kuwait, one of the main aspects of sustainable water resources development for the country. The drainage depressions of Rawdhatain and Umm Al-Ahish, locations of water and oil resource development and the surrounding area are assessed for suitable sites. Impacts on the land use, land cover and natural drainage pattern are assessed. A specific design is recommended for the artificial surface aquifers and the storage capacity is computed. Storage of up to 70% of the 2010 projected water budget is found to be possible. However, a similar analysis using a digital elevation map with better spatial resolution and extensive site surveys on the ground should precede further feasibility studies in order to decrease the margin of error on the computed water storage capacities.

Thesis Supervisor: Elfatih Eltahir
Title: Professor of Civil and Environmental Engineering

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Chapter 1
Water Scarcity

1.1 Overview

A comparative study of water resources in Kuwait and Singapore is informative and worthwhile because of their differences and similarities. The potential renewable water resource level in both countries is similar. However, in Kuwait the hot and dry climate is a limiting factor whereas in Singapore the small land area is a limiting factor in transforming this potential into a useable reserve of fresh water [6] [7]. The following table summarizes the climactic and geographic features which contribute to these unfavorable situations.

	Land Area (km^2)	Annual Mean Rainfall (mm)	Potential Evaporation (mm)	Potential Renewable water (km^3)	Population (2006 estimate)
Kuwait	17818	127	1365	2.26	2,765,290
Singapore	699.4	2413	1723	1.68	4,379,659

Table 1-1 Showing potential renewable water resource and limiting factors (data from http://www.urbanclimate.net/ and http://unstats.un.org/unsd/default.htm)

Figure 1-1. Map of Singapore (www.pilotfriend.com) showing large portion of developed area.

Factoring in the population and water demand per capita in each country, we can designate Kuwait and Singapore as two of 18 "water scarce" countries [1]. In order to meet the deficit between internal renewable water and water demand, non-conventional water sources such as importation of water from neighboring basins, desalination of sea water and recycling of treated wastewater have been sought out by the two countries. Non-renewable or fossil groundwater is also being mined, in the case of Kuwait, at unsustainable levels. A paradigm of integrated water resource management (IWRM) is adopted in both Kuwait and Singapore, however with different emphases and in different institutional settings. Therefore a comparison of the two scenarios will afford some transferable lessons between the countries and their water authorities.

Figure 1-2. Map of Kuwait. Development is concentrated around the capital, Kuwait City. (www.pilotfriend.com)

Kuwait is an arid country in the Middle East and North Africa (MENA) or West Asia and North Africa (WANA) region where a majority of the water scarce countries are located [1]. The Gulf Cooperation Council, GCC, countries share a regional aquifer system which is the main natural water resource. Brackish to saline groundwater from deep aquifers in Kuwait originates in recharge zones in Saudi Arabia, and is therefore a shared resource among the GCC countries. The long time scale of recharge and current high abstraction rates make this source a non-renewable or fossil groundwater [2]. Renewable groundwater of better quality is encountered in shallow aquifers with localized recharge, but quantities are extremely limited [2] [3]. The third classification of water resource in Kuwait is "non-conventional", namely desalination and treated wastewater [3].

In spite of the water scarcity of Kuwait, the demand for fresh water has been increasing rapidly since the 1990's and domestic per capita consumption is one of the highest in the world, having increased from 113 l/d in 1970 to 464 l/d in 1998 [5]. This high consumption can be attributed to increased piped water availability to growing residential areas at a government subsidy. Increasing affluence and a decreasing supply of brackish water to residential areas have resulted in the wasteful use of freshwater for gardening [5].

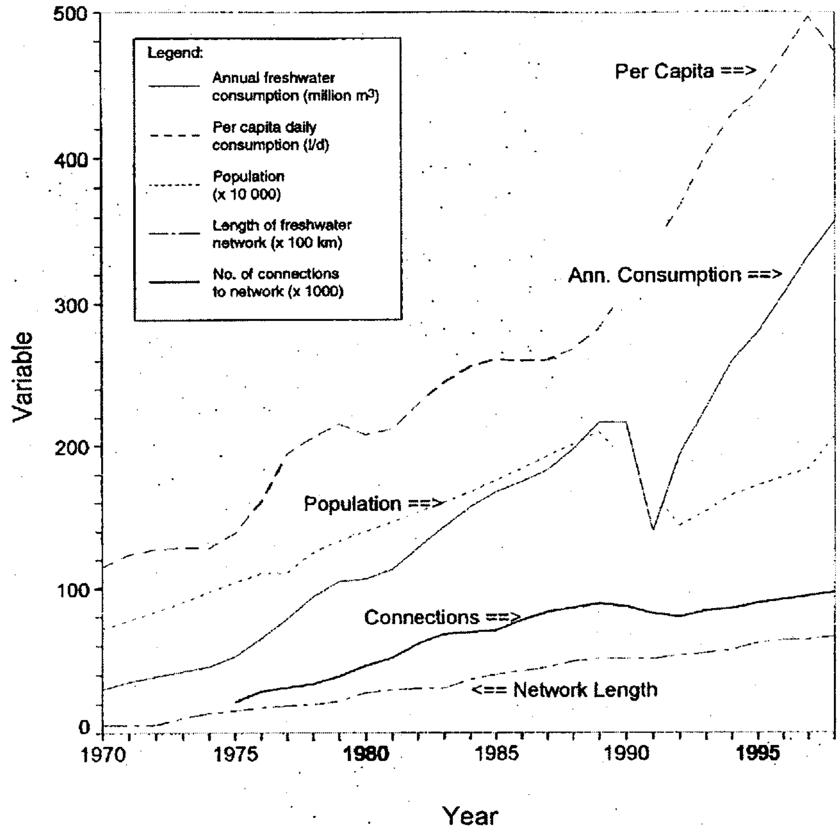


Figure 1-3. Population and water consumption trends in Kuwait (source [5])

In the case of Singapore, an "urban city state with no rural hinterland" [7], land area limits the amount of water that can be captured and stored. As compared to Malaysia, from which Singapore seceded in 1965, the internal renewable water resource is 91 times lower. The Malaysian state of Johor provides about 40% of Singapore's current water needs [7]. Due to its concern for long term water security and self sufficiency, Singapore is diversifying its water sources through treated wastewater reuse, called NEWater, desalination, and implementation of an efficient integrated water resource management.

Water demand in Singapore is incorporated into the management effort unlike in Kuwait. The domestic per capita water consumption has been responsive to water conservation measures, and decreased from 172 l/d in 1995 to 160 l/d in 2005. Singapore's economy is one of the strongest in the region and has been steadily growing, although the population growth has been slower than in Kuwait. The demand management implemented in Singapore sets it apart from Kuwait in the success of keeping water consumption at sustainable levels.

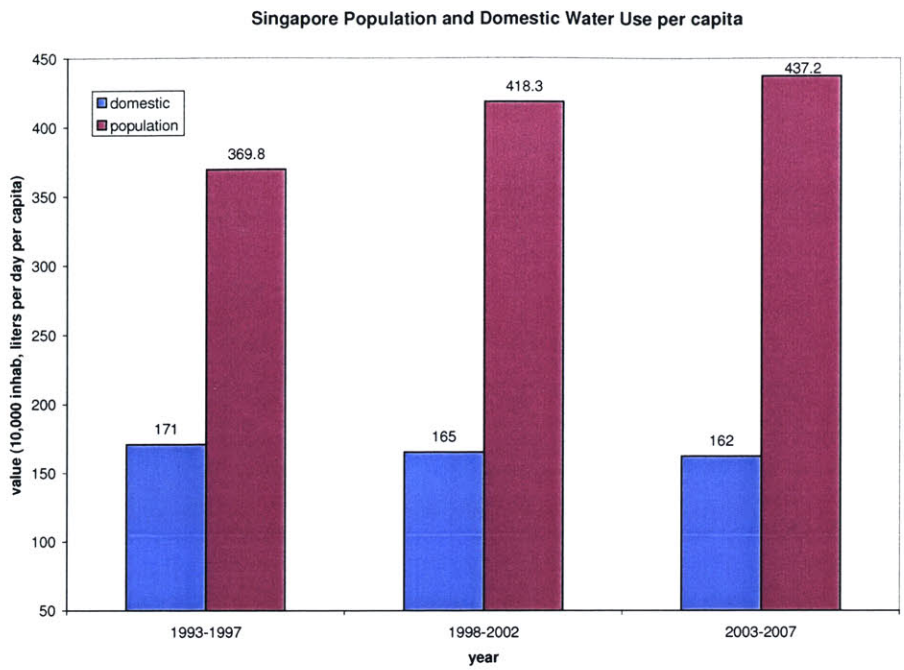


Figure 1-4. Population and water consumption trends in Singapore (data sourced from [6])

Particularly in Kuwait, water use and availability is intimately coupled with the ecosystem and the climate. Desertification through overgrazing, land degradation through unsustainable farming practices, climate change and water problems are not unrelated and studies are focusing on this overall picture [8]. Water and food (from agriculture and livestock), and therefore the economy of the country, lifestyle of the rural population, and environmental change are all factors that need to be considered in addressing the water management problem in Kuwait.

The permanent crop to arable land area ratios are 0.17%/0.84% for Kuwait and 1.47%/1.47% in Singapore (CIA Factbook). A thorough economic study which examines water and agriculture in tandem would be informative, but it is beyond our scope here although we will return to the topic in addressing sectoral water management priorities for Kuwait.

1.2 Renewability and Reliability

It is essential to examine the managed water cycle in finer detail in order to identify areas for improvement. The Ministry of Electricity and Water in Kuwait is responsible for one of the biggest desalination capacities in the world. It meets 90% of domestic fresh water needs and accounts for 59% of the total water budget of the country [3].

> In 1999 the MEW budget was 398.125M KD (includes construction projects of 218M KD, but not fuel cost). Its income from selling are 31.54M KD for 26.962 M MWh electric power, 18.4M KD for 355M m^3 fresh water, and 1.35M KD for brackish water. [9]

Clearly the government subsidizes a large portion of the water and electricity production. The reliance on the abundant oil resources of the country in cogeneration plants utilizing the less efficient multi-stage flash MSF distillation method (as compared to reverse osmosis RO, which is coming into line in planned additions) allows the Kuwaiti public and the industrial sector not to carry the true cost of the water. The financial implications of the reliance on government subsidy and on oil reserves are conceivably deleterious, not to mention the questions of environmental sustainability and economic stability of oil power generation.

Sectoral water allocation and groundwater and desalination capacities for ten water scarce countries are compared in the figures below. We can see that the agricultural sector plays a relatively more important role in the case of Kuwait as compared to Singapore. Future planning in water resource management takes into account the anticipated increases in water demands as well as capacities. The question of reliability of the resource is therefore tied intimately to the type of user and the importance of the end product of the water use to the country as a whole.

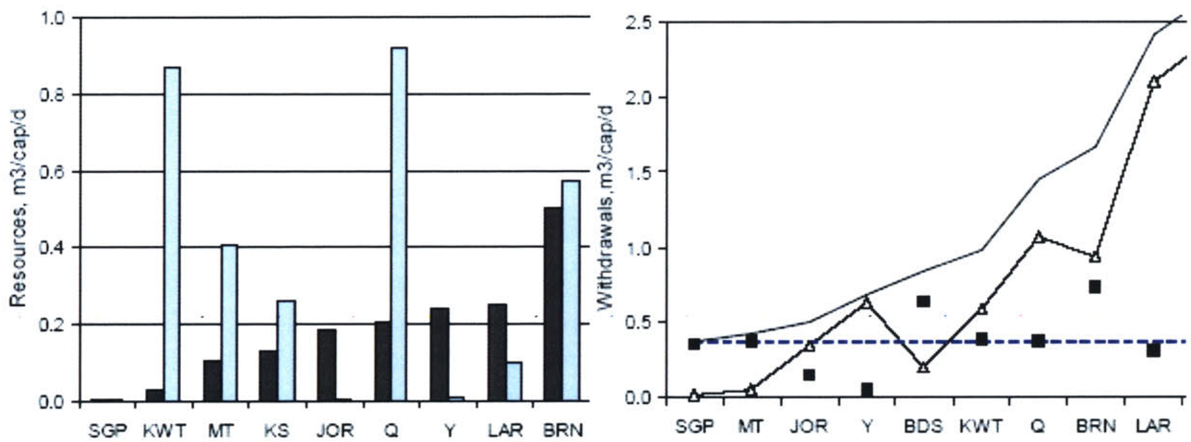


Figure 1-5 (from [1]) Right: Per capita water withdrawals: total, solid line, for agriculture, open triangle, and municipal use, solid Square. Left: per capita renewable groundwater resources, dark bars, and per capita desalination capacity, light bars. Selected water scarce countries: Singapore (SGP), Malta (MT), Jordan (JOR), Yemen (Y), Barbados (BDS), Kuwait (KWT), Qatar (Q), Bahrain (BRN), Libya (LAR), and Saudi Arabia (KS).

The aquifer systems in Kuwait can be classified into two main formations (see appendix), the Kuwait Group (KG) and the Dammam Formation (DM) below it [3]. Groundwater is produced by the Ministry of Electricity and Water (MEW), the Kuwait Oil Company (KOC) and private farmers. The total recharge at steady state to the Kuwaiti aquifer system through lateral flow from Saudi Arabia is estimated to be 121,000 m^3/d, totaling 44.165 Mm^3 in a year. The annual groundwater production from MEW and KOC fields alone amounts to 118 Mm^3 allocated for irrigation and blending with desalinated water (only 10% of domestic water needs) [3]. The Rawdhatain and Umm Al-Ahish depressions are suitable locations for rainfall infiltration and a limited amount of fresh groundwater is available in these locations. However, characterizing the resource base is difficult and requires ongoing research. Infiltration in the Rawdhatain drainage system, for example, varies widely from 4 cm/hr to 67 cm/hr [4]. The rough estimate [3] of the recharge in these freshwater aquifers is 2600 m^3/d, and the total natural reserve is 182 Mm^3. Even with the recognition of these sources as a "national strategic reserve", and decreasing production since the late 1970's in order to recover the quality, commercial water bottling proceeds at about 137,000 m^3/d [3]. These figures indicate that Kuwait is not harvesting its groundwater resources at safe yield levels.

The Ministry of Public Works (MPW) is planning to expand the capacity of wastewater treatment plants by 4% to meet 7% of the anticipated total 2010 water demand (in irrigation) [3]. This is more or less a drop in the bucket considering the anticipated additions of 52% in groundwater and 44% in desalination and recognizing the renewability and reliability of the various sources of water in Kuwait.

Water use/sector	**2001**	**Anticipated (2010)**	**Needed Additions**
Irrigation	239	389	150
Domestic	416	537	121
Total	655	1020 (with additional 10% to account for unforeseen needs)	335

Water Source	**2001**	**Planned Additions**	**Total (2010)**
Distilled/ Desalinated	386	187	572
Brackish groundwater	211	224	435
Treated Wastewater	58	18	76
Grand Total			1083

Table 1-2 and 1-3. Sector-based anticipated water needs, Mm^3 and anticipated available water according to planned projects Mm^3. Source [3].

In the case of Singapore, the priority of self sufficiency necessarily implies a lack of confidence in the reliability of the imported water from Malaysia. In reality Singapore's concern is with the political leverage that Malaysia is exercising due to its privileged position with regard to water. The examples range from strictly bilateral issues to foreign policy [10]:

> These have included the visit of the Israeli President Chaim Herzog to Singapore, the relocation of Malaysia's Customs, Immigration and Quaratine checkpoint, violations into Malaysian airspace, the disputed ownership over Pedra Banca, over-the-counter trades of Malaysian shares on CLOB International after Malaysian shares have been officially delisted, land reclamation, and construction of a new causeway bridge.

The idea of importing water from neighboring countries is not inherently bad as long as it is economically advantageous and water is not used as security leverage, even in political rhetoric. The 1991 agreement between Singapore and Indonesia is a case in point. Other Association of Southeast Asian (ASEAN) countries can benefit from economic cooperation with Singapore and water trading across borders [7]. Singapore has decided to allow the 1961 agreement with Malaysia to lapse at its expiration in 2011, and implement strategies to become more self-sufficient. The 1962 agreement will last until 2061, and Johor State, Malaysia will continue to supply Singapore at renegotiated prices, as it seems at least that water issues are currently "desecuritized" [7].

Before we turn to the non-conventional water sources which have become increasingly important in both Kuwait and Singapore, we can mention that a key part of Singapore's water strategy is more conventional but exemplary catchment management. 5% of the land area is protected catchment, whereas half (two thirds by 2009) is protected and partially protected catchment. The storage capacities of the reservoirs undergo continuous expansion and are projected to meet about 42% of the total water demand in a scenario of water self-sufficiency [6, 7].

	2002	2003	2004
Number of raw water reservoirs in Singapore	14	14	14
Number of NEWater Plants (For Recycling Water)		2	3
Volume of Used Water Treated Per Day (1,000m^3/day)[16]	1,315	1,360	1,369
Water Tariffs			
Domestic (consumption $\leq$ 40 m^3 per month) (cents/m^3)	117	117	117
Domestic (consumption > 40m^3 per month) (cents/m^3)	140	140	140
Shipping (cents/m^3)	192	192	192
Sale of Water in Singapore	1,259	1,224	1,203
Domestic (1000 m^3/day)	687	690	686
Non-domestic (1000 m^3/day)	572	534	517
Domestic water consumption per person (litres/day)	165	165	162

Table 1-4 Water statistics from Ministry of Environment and Water Resources, Singapore. Source [7].

Year	Domestic	Shipping	Commerce/ Industry	Government and Statutory Boards	Total Annual Consumption
1960	**40,786.9**	**NA**	**21,697.6**	**36,997.2**	**99,481.7**
1970	**71,024.0**	**2,276.9**	**35,718.3**	**43,923.6**	**152,942.8**
1980	**113,478.0**	**3,347.0**	**75,991.3**	**23,750.0**	**216,566.3**
1990	**177,343.3**	**2,914.4**	**113,148.6**	**29,391.8**	**322,798.1**
2000	**241,388.0**	**1,841.0**	**181,477.0**	**30,742.5**	**455,488.5**

Table1-5 Water consumption by sector, values in thousands m^3. Source [7].

Total Water Requirement for Singapore		1.2 to 1.3 million m^3 (264 to 286 million gallons
Domestic Reservoirs and Catchments (a)	**0.68 million m^3 (149.58 million gallons)**	
Desalination (b)	**0.40 million m^3 (88 million gallons)**	
NEWater (c)	**0.55 million m^3 (121 million gallons)**	
Total: a+b+c		**1.63 million m^3 (358.58 million gallons)**

Table 1-6 Major sources of water anticipated. Values are given per day. Source [7].

1.3 Non-conventional Sources

There are various barriers to the use of non-conventional water resources such as desalinated sea water and treated wastewater. Therefore countries that have sufficient conventional resources, such as surface storages, do not resort to the use of alternative sources. The main barrier is economic feasibility. The MSF distillation method is energy intensive and expensive, but has its advantages as well in the particular context of Kuwait [11]. The Kuwait Institute of Scientific Research (KISR) and MEW have undertaken extensive research in the RO method for desalination, and future capacity expansion will include increasing amounts of RO desalination plants [12]. As technologies emerge and evolve, the financial feasibility of alternative methods of desalination also changes, as experienced by Singapore where a 136,000 m^3/d capacity RO plant has been in operation since 2005. The project cost S$200 million and the cost to the consumer (during first year of operation) was S$0.78/$m^3$ [6]. The RO method along with the multi-effect distillation (MED) was favored over MSF for being more cost effective [7].

The other barrier to non-conventional resource use is social. Recycled wastewater will have objections in certain societies based on religion, aesthetics, or taboos. Therefore in Kuwait, it is exclusively used for non-food irrigation [3], and in Singapore for industrial and commercial activities for which NEWater is particularly suited because of its high purity. A small fraction of NEWater (2.5% of water consumption by 2011) is redirected to the raw water reserve which is treated for domestic use. Singapore's efforts at breaking the taboo against treated wastewater is exemplary and a successful case to emulate.

Although water import/export is considered to be a non-conventional water source/use, there is nothing natural about political borders, especially in today's world of regional and global cooperation. Intra-basin and inter-basin exchange should therefore proceed on principles of sustainable development and integrated water resource management and political arrangements should work in support of these principles.

1.4 Sustainable Development and Integrated Water Resource Management

A "new definition" of sustainable water resource development is (from lecture by Professor Elfatih Eltahir, MIT):

> a flux of water that is managed with the objective of maintaining the availability and quality of water for as long as the current climate prevails.

IWRM can be understood as the methodical tool to bring this about (Global Water Partnership GWP 2000 definition quoted in [13]):

> IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Sustainability has the general meaning of stewarding the resources that we enjoy today for future generations. It is also informative to think of water resources in the context of sustainable development of a society in all aspects, including economic and social. We can therefore propose a sustainability equation that needs to be balanced in undertaking water resource planning or any other organized social activity. The sum total is the benefit (in optimization methods, the objective) that is sought from the plan, and the component parts need to balance (constraints) the needs of all stakeholders, as well as conserving natural ecosystems as far as possible. Tradeoffs are therefore part of sustainability. Many other definitions are valid, and reflect slightly different emphases necessitated by different circumstances and approaches. The global consensus is represented in the Dublin Principles [13]) (or the Dublin-Rio Principle[14]), one of which states that "water is a finite, vulnerable and essential resource… to sustain life, development and the environment".

The new definition of sustainability and the principles of IWRM point out that spatial and temporal scales of the management problem need to be sensitive enough to account for global changes in the climate and the ecosystem, as well as changes in the society. Some of the tradeoffs of sustainable development are encountered in rapidly growing economies and urbanizing countries. Food security is also intimately related to water resources. IWRM aims to understand the managed water cycle in its totality in the physical and social environment. The economics of demand management and cost allocation is not a merely political topic, and lessons should transfer from one country to another if at all applicable. For example, the private farmers and pastoralists of Kuwait are different from the urban water clients of Singapore. Water metering and equitable pricing in Singapore may be emulated in the urban centers of Kuwait, but different approaches, perhaps policies at the national level and grassroots organizations are needed to manage farmers who pump their own groundwater.

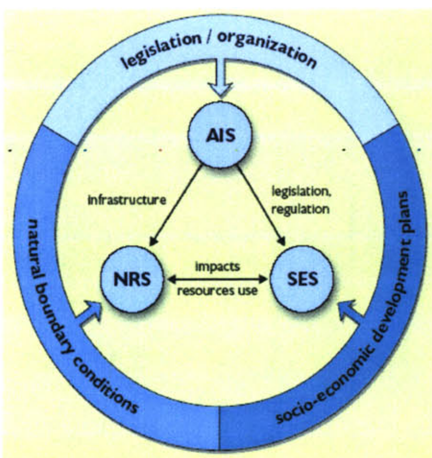


Figure 1-6 Interactions among subsystems and the environment. Source [13]

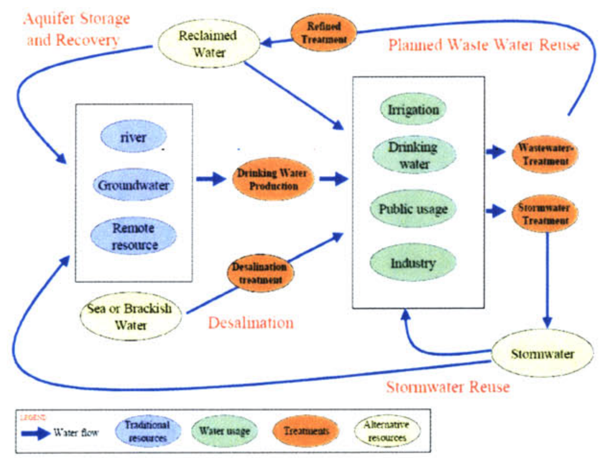


Figure 1-7 A planned water cycle management. Source: [14]

The figures show the interconnectedness of environments, natural or man-made, as well as a closed loop of water management for maximum efficiency and lowest impact to the ecosystem. Singapore, for example has [15]

> Probably the best managed utility in the region, reflecting the high management salaries (US$ 145,010 p.a.). Very low unaccounted for water UFW (6%). All its capital requirements now come from its own sources (of) revenue.

Kuwait MEW can therefore emulate certain practices of the Singapore Public Utilities Board (PUB). The data book cited above outlines best practices of water utilities and provides evaluation criteria, which should aid regular appraisals and improvment. In the following chapter, we will discuss the three levels at which a paradigm of sustainable development and IWRM is implemented, from international and regional to national and finally to utilities and individual water client level.

1.5 Previous Works

A brief discussion of two previous Master of Engineering theses in MIT Department of Civil and Environmental Engineering is appropriate in order to contextualize the continuity of the present work. The Kuwait-MIT Center for Natural Resources and the Environment (Kuwait-MIT CNRE) is conducting research which connects climate-hydrology models with water resources [8]. Murtaugh and Milutinovic worked in 2006 on two aspects of the water resource problem in Kuwait. Milutinovic analyzed demand management strategies. As discussed earlier, heavy government subsidization of the water provision has created wasteful consumption practices in Kuwait. Milutinovic proposes a pricing scheme of 150 liters/capita/day of free allowance followed by \$1 per m^3 in excess of this. His findings suggest a possible reduction of demand by 20 – 40% due to this type of pricing intervention [23].

In her thesis [24], Murtaugh focused on water supply enhancement options for Kuwait. In particular, she analyzes several methods for increasing the water storage capacity in the country, which would in principle make water importation a feasible alternative. A surface or aquifer storage reservoir of some magnitude would decrease the political leverage a water supplier (exporter) may otherwise have in case the water supplies were directly and in real time connected as a life-line of the population. Water can also be supplied to the proposed reservoirs from desalination and wastewater treatment plants within the country during seasonal demand lows. This may also allow for indirect potable use of the purified wastewater. Rainwater harvesting in the drainage depression of Rawdhatain was modeled, highlighting the lack of thorough hydrological data for the area. However a site of about 143 km^2 in this area was shown to be suitable for construction of a surface reservoir of a potential to store 1 km^3 of water, enough to meet the demand of the country for three years. Solutions for covering such a structure to prevent evaporation losses and the question of security from sabotage remain as open questions in addition to the construction challenges.

In the present work, I build on some of the ideas for enhancing the storage capacity of Kuwait as an infrastructural basis for a new water management scenario in Kuwait. Prior to this, chapter two will provide an understanding of the institutional basis for effective water resource management.

Chapter 2
Institutional Settings of Water Resource Management

2.1 Overview

> It is widely accepted that sustainable and equitable water management must be undertaken using an integrated approach, that assessment of the resource is the basis for rational decision-making, and that national capacities to undertake such assessments must be further supported and expanded at local through international levels. It is therefore paramount to provide the best possible understanding of the state of the world's freshwater resources to the world at large [16].

The institutional environment which is conducive for successful water resource management can be classified into three levels. The international and regional bodies such as the United Nations (various agencies), International Water Association (IWA), Global Water Partnership (GWP), World Water Council/World Water Forum, and the like help bring a global vision to bear on the water problem through the Millennium Development Goals, World Water Vision, and similar overarching visions for the future. These agencies also help to bring researchers together to develop standards of the theory and practice of water management, such as concepts of sustainable development, IWRM, etc. Bridging the gap between international and national levels are the regional bodies such as UN Economic and Social Commission for Western Asia (UNESCWA), UN Economic and Social Commission for Asia and the Pacific (UNESCAP), the Gulf Cooperation Council (GCC), Association for Southeast Asian Countries (ASEAN), the Asian Development Bank (ADB), and more. These agencies coordinate implementation efforts of the international visions through agreements and policies, and address particular needs of the specific region. They assist each member nation to meet its particular goals through funding, facilitating intergovernmental cooperation and other similar activities (see, for example, the ESCWA report [19]). The national government bears the heaviest responsibility for supplying water to its citizens even though it may rely on partnerships with the private sector and seeks innovative financial frameworks and management techniques of IWRM. The tools of government in discharging its responsibility are the administrative level agencies or utilities which are critical to the efficient management of government resources and service to the citizens.

The government of a country has to be the focal point of the institutional framework, coordinating the various levels of organization to meet its agenda, bringing good governance to bear on best practices in water utilities and translating global visions into reality, while assisting other governments to do the same. It is important to note that water issues cannot be seen apart from other national development concerns, as Tortajada emphasizes [6].

> A main reason as to why Singapore has been very successful in managing its water and wastewater is because of its concurrent emphasis on supply and demand management, wastewater and stormwater management, institutional effectiveness and creating an enabling environment, which includes a strong political will, effective legal and regulatory frameworks and an experienced and motivated workforce. The Singapore example indicates that it is unrealistic to expect the existence of an efficient water management institution in a country, in the midst of other similar mediocre management institutions, be they for energy, agriculture or industry. Water management institution in a country can only be as efficient as its management of other development sectors. The current implicit global assumption that water management institutions can be improved unilaterally when other development sectors remain somewhat inefficient is simply not a viable proposition.

Reading the mission statements of any of the regional bodies mentioned above can give us an idea of what goals and activities are paramount in the organizing principles of each one. The IWA motto seems to sum up the advantages of the multi-tier approach to water management: "Global Force: Local Presence".

2.2 Regional and International

One of the major contributions that the United Nations and subsidiary or similar organizations can make for the case of improved water resource stewardship is education and awareness for the international community. To sample a few of the roles played by these organizations, UN Educational, Scientific and Cultural Organization UNESCO implements three programs:

- UNESCO-IHE (Institute for Water Education) provides training at the Masters level for water professionals;
- International Hydrological Programme (IHP) organizes conferences and publications to disseminate the science of water;
- World Water Assessment Program (WWAP) is responsible for periodic assessment of the global problems, and solutions to be published in World Water Development Reports.

However, the role of such organizations is not entirely passive. For example, since 2003, UN-Water [31] is a dedicated

> mechanism for follow-up of the water-related decisions reached at the 2002 World Summit on Sustainable Development and the Millennium Development Goals. It will support Member States in their efforts to achieve water and sanitation goals and targets.... UN-Water acts at global, regional and country level. It adds value to the work and expertise of separate UN agencies and programmes. It brings coherence and integration among them, and serves as the common voice of the UN system on water and sanitation. It will improve cooperation with external partners, and provide timely information on status and trends of the world's freshwater resources.

The various regional bodies such as GCC, ASEAN, ESCWA, ESCAP, ADB and their efforts in the water sector as part of the overall development picture of the respective regions of Kuwait and Singapore fit into the same category as the bigger UN agencies. Their guiding principles are the same, whereas their scopes are reduced so that more tactical activities are carried out to make the implementation link between the recommended solutions for water problems and policy interventions at the national level. The member states can work together through these networks to implement intergovernmental agreements and share experiences and resources. Admittedly, the terms in the above UN-Water mission statement such as "mechanism" and "brings coherence and integration among them" can be vague, and possibly point to lack of streamlined and focused solutions to the global water challenge.

A closer study of the UNESCWA and related agencies can provide some insight into the role of regional bodies and what contributions they could make to create conducive institutional arrangements in Kuwait. The stated aims of the ESCWA Sustainable Development and Productivity (SDPD) in water management are [32]:

- Promoting the application of Integrated Water Resources Management (IWRM)
- Disseminate and promote the Guidelines for water demand management measures
- Building capacity of water professionals & decision-makers in water related ministries

- Cooperating on regional and interregional level regarding management of national & shared water resources
- Endorsing ESCWA Ministerial Sessions Resolutions 233 & 244 for the cooperation between ESCWA member countries with respect to shared water resources
- Supporting AWARENET: Arab Integrated WAter REsources Management NETwork

The natural question arises, what does AWARENET do and what is the organizational principle behind it. AWARENET is one of the regional networks which comprise Cap-Net (a UNDP, GWP program), an international network for capacity building in IWRM. It is self described as a "partnership of training institutions, knowledge centers and water managers around the world" with the aim of helping countries "to build the human and institutional capacity in water management to reach the Millennium Development Goals". Their key strategy is to tap into "the power of networks" and to create a "cascading effect" through the "training of trainers". To appreciate the efficacy of these strategies, we may look at the challenges faced by ESCWA countries as identified by AWARENET in its executive summary of September 2002 [32], shortly after it was formed at the initiation of ESCWA and IHE.

- Limited awareness about IWRM due to shortages in adequate and relevant formal education, training and research on the subject. The main issue at stake is the quality of the education and training delivered rather than the quantity. While there seems to be no shortage of training courses in the region, the quality and relevance of the training programs remains problematic in most countries
- Fragmented water related institutional framework with ill defined or overlapping mandates
- The absence of comprehensive national water policies. Current policies are often unfeasible or unrealistic due to limited technical, financial and institutional resources available for implementing them
- Water-related legislation is often outdated and cannot keep pace with changing conditions on the ground, such as increasing scarcity of water and continuous deterioration of water quality
- Unavailability and inconsistency in data on water resources due to extreme variability in annual rates of natural recharges or diversity in water evaluation methodologies
- The prevalence of unsustainable patterns of water consumption, in the absence of effective water conservation techniques or improved system efficiency

A regional network of water professionals therefore becomes an ideal method of institutional capacity building because

- A network can identify and consolidate thinly spread regional knowledge and capacity;
- A network can effectively and efficiently disseminate knowledge and build synergy of action among stakeholders or network members, which is an empowering process;
- A network stimulates regional communication and co-operation, which is a vital objective for ensuring a sustainable development process in the Middle-East region.

A status list of members of AWARENET [32] shows that Kuwait Institute of Scientific Research (KISR), Kuwait University and Ministry of Energy (a 2003 merger of Minisitry of Electricity and Water and Ministry of Oil) are the stakeholders representing the country's water sector. KISR and Kuwait University hosted an organizational meeting for AWARENET in 2005 along with "Training of Trainers (ToT)" in IWRM application. KISR also holds the distinction of participating as host in a "training needs assessment" and "knowledge mapping" as part of the preparation of an AWARENT constitution and an IWRM manual. It seems then, that Kuwait is taking the right steps in implementing corrective measures to revitalize its water institutions.

Although a picture of the organizational structure of the regional bodies in operation in the ESCWA countries is emerging, it requires further clarification. A survey of the most relevant publications from ESCWA can illustrate the works in progress. We will also look closely at the first of the papers in this list which focuses on the institutional aspects of a "regional mechanism" for managing shared water resources.

1. A Pre-Feasibility Study: A Regional Mechanism for Building Capacity to Manage International Water Resources, 2006? [25]
2. The Role of Desalinated Water in Augmentation of the Water Supply in Selected ESCWA Member Countries, 2001 [18]
3. Implications of Groundwater Rehabilitation on Water Resources Protection and Conservation: Artificial Recharge and Water Quality Improvement in the ESCWA Region, 2001 [17]
4. Sectoral Water Allocation Policies in Selected ESCWA Member Countries: An Evaluation of the Economic, Social and Drought-Related Impact, 2003 [20]
5. A Survey of Measures Taken by the ESCWA countries During the 1990's for the Optimization of Water Resource Management and Capacity Building in the Water Sector, 2004 [21]

With regard to the consultative study listed as number 1 above, we may perhaps inquire, with the principle of streamlined operations and coherence among different agencies in mind, whether or not there is some duplication of effort and confusion of mandates. Within the ESCWA region, the GCC countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the UAE) share the same groundwater basins and many of the same water challenges. Moreover, these countries are similar in many of their socio-economic as well as infrastructural features. One of the stated areas of cooperation is in electricity and water, certain projects of which were planned in a Kuwait summit in 1997 [33]:

> The Unified Economic Agreement asserts that Member States shall coordinate and establish infrastructure projects, including power stations and water desalination plants, in order to attain joint economic development and link the existing economic activities.

The ESCWA countries have successfully identified their lack of capacity in dealing with joint management of shared resources and mandated the agency to propose another "regional mechanism" which would address this problem. Trondalen explicitly discusses [25] the concerns we stated above, in other words, do the regional bodies mirror the fragmentation of the institutional frameworks and confusion of mandates which is evident in the national and administrative level of water management? He states that ESCWA has an "exclusive mandate with respect to international water resources", and that it is the only regional body with "substantive work" in "building capacity". Moreover, ESCWA is perceived to be apolitical and professional in its approach. The proposed Capacity Building Center for Shared Water Resources Management (CBC-SWRM) would be a independent unit working alongside the Sustainable Development and Productivity Division and answerable to the executive committee of ESCWA. Some reasons for its independence from the SDPD are for increased visibility and influence with other regional bodies, and operational distinction for funding and staffing purposes.

The above analysis serves to illustrate the involved process of forming an institutional framework which is at once effective, and smoothly fitting in an intricate and sometimes not necessarily optimal institutional environment. In section 2.4, we will turn to the other publications listed above for a quick overview of the progress of the individual member countries in their goals of water management. In order to appreciate the challenges that remain for Kuwait to tackle, it is paramount to understand the assessment methodologies used in these studies as well as the conceptual principles behind what we consider as a conducive institutional framework for IWRM. The next section therefore adds to the discussion initiated in section 2.3 and at the beginning of this chapter, while it transitions us to the next level of institutional arrangements, that of national governments.

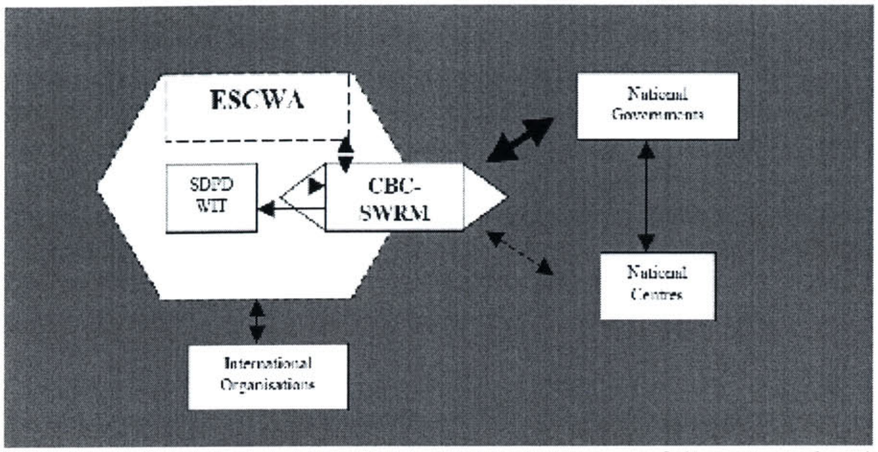


Figure 2-1. From Trondalen [25] showing the organizational structure of the proposed regional mechanism, and interrelationship between the SDPD (Sustainable Development and Productivity Division) and the Water Issues Team (WIT) with the proposed Capacity Building Center for Shared Water Resources Management (CBC-SWRM)

We will mention the counterparts of these regional bodies in the case of Singapore and save a more detailed comparison for the national and administrative levels. UN-ESCAP houses an Environment and Sustainable Development Division, with a dedicated Sustainable Development and Water Resources Section since January 2006. The smaller subset of Asian countries, ASEAN, also hosts a working group on the environment as a transnational issue, under which water resource management is a major unit working also on planning, funding and research. Finally, the Asian Development Bank has a serious focus on sustainability, whether in energy initiatives or in water resources, through its Water for All vision and Water Financing Program, which aims to double investments in water from 2006 to 2010. ADB can also be credited for initiating important publications such as the Second Water Utilities Data book for the Asia and Pacific Region [15].

2.3 Conceptual Model for IWRM: Institutional Aspects

The document number five listed above sets out by "(establishing) an analytical framework that would enable us, in a systematic and orderly way, the various rationalization and reform measures taken by the ESCWA states in the area of their water resource management and facilities" [21]. The measures are divided into supply management and demand management distributed among institutional, legislative and economic measures. Moreover, "institutional arrangement...denotes the full range of official laws, systems, standards, rules and mechanisms, in addition to unofficial or popular rules and mechanisms, including customary practices that are used by governments to determine and implement their water-related policies." An *IWRM Toolbox* developed by the GWP is used as an assessment tool for progress in achieving IWRM. Table 2-1 summarizes the toolbox.

(a) Enabling Environment	(b) Institutional Roles	(c) Management tools
1. Policies: setting goals for water use, protection and conservation. (a) Preparation of a national water resources policy; (b) Policies with relation to water resources.	1. Creating an institutional framework: forms (institutional arrangements) and functions. (a) Trans-boundary organizations for water resource management; (b) National apex bodies; (c) River basin organizations; (d) Regulatory bodies and enforcement agencies; (e) Service providers and IWRM; (f) Civil society institutions and local community organizations; (g) Local authorities.	1. Water resources assessment: understanding resources and needs. (a) Water resources knowledge base; (b) Water resources assessment; (c) Modeling in IWRM; (d) Developing water management indicators.
2. Legislative framework: water policy translated into law. (a) Water rights; (b) Legislation for water quality; (c) Reform of existing legislation.	2. Building institutional capacity: developing human resources. (a) Participatory capacity and empowerment in civil society; (b) Training to build IWRM capacity in water professionals; (c) Regulatory capacity; (d) Participation in knowledge.	2. Plans for IWRM. (a) Basin management plans; (b) Risk assessment and management.
3. Financing and incentive structures: financial resources to meet water needs. (a) Investment policies; (b) Institutional reform in the public sector; (c) The role of the private sector; (d) Cost recovery and tariffication policies; (e) Investment evaluation.		3. Efficiency in water use: managing demand. (a) Improved efficiency of use; (b) Recycling and reuse; (c) Improved efficiency of water supply.

		4. Social change instruments: encouraging a water-oriented society. (a) Education curricula on water management; (b) Training of water professionals; (c) Training of trainers; (d) Communication with stakeholders; (e) Water campaigns and awareness raising; (f) Broadening of the participation base in water resource management.
		5. Conflict resolution. (a) Conflict management; (b) Shared vision planning; (c) Consensus building.
		6. Regulatory instruments. (a) Regulations for water quality; (b) Regulations for water quantity; (c) Regulations for water services; (d) Land-use planning controls and nature protection.
		7. Economic instruments: using value and prices for efficiency and equity. (a) Pricing of water and water services; (b) Pollution and environmental charges; (c) Water markets and tradeable permits; (d) Subsidies and incentives.
		8. Information management and exchange: better knowledge for better water management. (a) Information management systems; (b) Sharing national and international data.

Table 2-1. IWRM toolbox (from [21])

> Solanes and Jouravlev [26] have focused a detailed and informative study on (identifying) the characteristics of water institutions which promote the sustainable integration of water, both as a resource and as a service, into socioeconomic development. As this does not depend only on formal institutional factors, such as legislation and organizational structure, there are also references to dynamic conditions, such as socioeconomic circumstances and the quality of the administration, summarized in the concept of governance, understood as the capability of a social system to mobilize energies in a coherent manner, for the sustainable development of water resources.

Their case studies focus on the ECLAC (UN- Economic Commission for Latin America and the Caribbean. However, the study is applicable in a general setting and sheds light on the context in which we have to view the problem of good "water governance". The context, in our case of the regional entities under discussion or of the individual countries, encompasses the overarching macroeconomic environment, the social, economic and political challenges and advantages and the status of the state and the civil society, its strengths and weaknesses. The issues that need to be addressed are [26]:

- the legal nature of water in sectoral as well as lower level water allocation and reallocation and the role of the state
- the institutional structure for water management
- economic rationality and social demands
- the role of the state in regulating public services: water rights and water markets
- the appropriate level of government
- public participation
- environmental stewardship
- protecting the interests of the marginalized section of society
- conflict resolution and
- public policy decision making

In elaboration of the problems faced by institutional structures and potential solutions, Solanes and Jouravlev point out the lack of technical and impartial decision making criteria, resulting in allocations and uses which may run counter to economic and sustainability principles. This is in addition to fragmentation of management functions, such as provision and post-use processing, groundwater vs. surface water, and similar traditional divisions which obscure the need for an integrated vision. Some of the solutions to such problems are that "the authority should have a sufficiently high position within the government hierarchy, that it consolidate multiple responsibilities related to water management, that it enjoy real administrative capacity and that it effectively be autonomous." It follows clearly that several of the responsibilities of the water agency may not devolve to water using industries, such as agriculture and energy [26]. We will discuss the implications of these concepts in the particular case of Kuwait in the next sections.

In the case of the ESCAP region, a detailed 2004 publication, "Guidelines on Strategic Planning and Management of Water Resources" [27] is a good source for an analytical framework for understanding and implementing good water governance. ESCAP region seems to be ahead of ESCWA in implementation of the mentioned principles as we briefly alluded to earlier. The regional bodies appear to be maturely formed and working efficiently.

2.4 National

The government is the key actor in the water management scenario. Some responsibilities of the government cannot rightly be consigned to any other party without violating principles of equity and financial feasibility. For example [13], the government has to act as the owner of the water resource and resolve conflicts among different users, it should secure large and long-term investments for water infrastructure, and it should apportion or mitigate the externalities so that equitable use of the freshwater resource is assured.

A country's progress in "creating an enabling environment for strengthening of IWRM" can be measured in three tiers: policy, legislation and funding [21]. Policy can also find expression through the organization of higher level government agencies such as the MEW and MPW of Kuwait. A government is also responsible for adopting international standards for water management and associating with regional bodies. Tortajada's [6] emphasis on good governance across all development sectors highlights the added burden on the government. For example, the agricultural and energy sectors in Kuwait are interlocked with the water sector much more than this is the case in Singapore. Independent or semi-independent assessment of the individual governments' progress in establishing the enabling environment inside a country has been carried out by the regional bodies such as ESCWA [17—21], GCC [2] and ADB [15, 22]. These research documents are an invaluable service to the respective governments, and for other countries that can draw relevant lessons from them. Each government also does well in this respect by adopting a transparent system and making internal publications and data books easily available for the world at large.

Implementing sustainable water resource development according to the recommendations made by water professionals in publications such as we have discussed requires political will and active involvement from the Kuwaiti government. We can summarize the recommendation of the ESCWA papers in the following way.

Groundwater [17]. Groundwater is overexploited in most ESCWA countries. Pollution from wastewater and industrial byproduct disposal, agricultural return water, and sea water intrusion is a major threat to sustainability. Preserving the groundwater and preventing contamination are better options than remediation. Resource characterization is not sufficiently done.

Desalination [18]. In Kuwait and other Gulf countries, oil wealth and reduction in desalination costs have resulted in its preference over other water schemes. However costs of production are still high in comparison with conventional sources, emphasizing the need for conservation measures, economically sound allocation and pricing and further technological research and institutional capacity building. Private sector involvement should be sought as a solution to the financial challenge of developing increasing magnitudes of water projects for an increasingly urbanized population.

Importation [18]. ESCWA countries have major barriers to water import-export schemes because of political mistrust as well as the status quo inequitable surface water allocation among certain nations. There have been two major proposals which deserve further consideration. The Turkish Peace Pipeline, costing $20 billion, would supply Syria, Jordan and the Western part of the Arabian Peninsula in one branch and the Eastern Gulf states in a second branch. Kuwait would be supplied 220 million m^3 annually in this project. The construction period of such a pipeline is estimated at 10 to 12 years, and the initial capital cost from $1.735 to $1.758 per cubic meter of water at destination. The other pipeline [36], from Iran to Kuwait, 330 km through Iran over land and 210 km under the Gulf Sea, would cost $2 billion, and would supply Kuwait with 200,000 m^3 per day.

One of the main ideas advocated in this thesis is that the inherent political and security concerns of water importation can be addressed politically as well as mitigated by enhancing the storage capacity of the importer. The next chapter elaborates this idea.

Sectoral Water Allocation Policy [20]. It is recognized that water scarcity in the region and future challenges arising from fast population growth, urbanization and industrialization require a solution orchestrated at the national level, considering all sectors of economic activity, with a view to addressing the totality of the problem rather than treating specific issues as they arise. Agriculture is the major water use sector in most ESCWA countries and reallocation policy should focus on it. Establishment of water markets will complement government regulation in identifying water use with the best economic value. Correct pricing is a prerequisite to a water market, so that some sectors are not heavily subsidized while others sacrifice quantity and quality in their water provision. True cost of water provision should factor into pricing policies to insure the effectiveness of the water institutions responsible for it.

In Kuwait, as in other Gulf countries, irrigated agriculture should be more closely regulated. As it is, low costs of groundwater to farmers has resulted in overexploitation, increased salinity, waterlogging and consequently low crop yields. Kuwait is moving in the right direction of reallocation of water away from agriculture, with percentage of allocation in 1990, 2000 and projected to 2025 decreasing from 21%, 19% to 10% [20].

Domestic water consumption, on the other hand is proceeding at excessive levels and requires drastic demand management measures.

Optimization of Water Management and Capacity Building [21]. This paper surveys the measures taken by each of the ESCWA countries in implementing an IWRM approach through the various "tools" summarized in table 2-1 above. It is a good example of the type of assessments that should be done regularly within each country and shared among the different water authorities for exchange of experience and lessons. In actuality, not all ESCWA countries are covered in equal detail because national and administrative level data is not readily available. The main headings under which progress is measured are: legislative, financial, institutional framework (see next section), institutional capacity building, demand management, social change (awareness and education), conflict resolution, regulation (allocations, restrictions, environmental stewardship), economic instruments for efficiency and equity, and information management.

In the next round of publication of such assessment papers, it is hoped that more countries will have had the opportunity for comprehensive self-evaluation. We also recommend that multiple publications focus on different levels of water governance within each nation. Specifically, each of the topics mentioned above deserves closer focus on the details.

2.5 Local or Administrative

The local or administrative level of water resource management makes the difference between efficient and wasteful systems. The utilities providers as well as the individual users can be classified in this level. As a water-stressed city state, Singapore has developed an exemplary system for water management. The PUB is a national water agency and at the same time a local service provider because Singapore is not a big country. The achievements of the PUB are expounded by Tortajada [6], with emphasis on certain aspects such as the human resources, corruption and autonomy in comparison with other Asian utilities. It is indeed notable that the entire water supply system is 100% metered and the unaccounted for water (UFW) is only 5.18% in 2004 [6]. A table, included in the appendix, provides evaluation criteria and parameters to use in assessing water utilities.

The framework of a unified national water institution such as the Public Utilities Board has been conducive, in the case of Singapore, to an efficient provision of water in accordance with national goals for water conservation. The framework in Kuwait is different. Two ministries, Ministry of Energy (under which former Ministry of Electricity and Water is subsumed) and Ministry of Public Works, are in charge of water provision and used water disposal. The publication surveying optimization of water management measures in that region [21] refers to a prior publication in Arabic which addresses this explicitly: "The Enhancement of Institutional Measures Arrangements for Water Legislation Enforcement and the Improvement of Institutional Functions in Selected ESCWA Member Countries". A table comparing different institutional frameworks is reproduced here from [21].

Type of institution	**Advantages**	**Disadvantages**
Separate Ministry for water resources, responsible for water resource management and planning	- Development of specialization and concentration of expertise on water-related matters within a single institution; - A separate ministry serves in itself to reflect the State's or Government's concern for water issues; - Equal status in dealings with other sectoral ministries	- Water-related issues may be sidelined instead of being integrated into economic development; - The fact that the ministry is separate from other ministries may impede coordination, oversight, enforcement and policy implementation generally; - Water issues will probably be neglected in other ministries because they are the concern of a separate ministry
Water-related matters, including water resource planning and management and water utilization, handled by one of a number of departments within a single ministry (irrigation/ agriculture/energy)	Water issues can readily be taken into account in the development of policies relating to irrigation, agriculture, electricity/energy, and the like	- May lead to limited scope for water-related activities (since they are not comprehensive activities as in the case of a separate ministry); - The interests of water resource planning and management may conflict with those of water utilization handled by other departments. Planning and management may be

		neglected in favour of utilization projects (irrigation, agriculture, and so on); - May reflect a low level of concern with water-related issues
Ministry of Electricity and Water responsible for drinking water (with specialized bodies for desalination, urban water supply and rural water supply)	This type of institutional arrangement is common in States that rely mainly on desalination (also in Yemen, despite its limited use of desalinated water)	Poor coordination with water resource planning authorities, and inadequate concern with water resource management (tendency to concentrate on utilization and extending water and sanitation services)
Water authority or inter-ministerial committee responsible for integrated water policy development	- Same advantages as in the case of a separate ministry (concentration of expertise within a single institution, indication of Government's concern), but does not have equal status in dealings with other ministries; may be of lesser status than a ministry; - Representation of all relevant bodies facilitates policy coordination; - Representation of all relevant bodies means that all aspects can be discussed before policy is settled	- Same disadvantages as in the case of a separate ministry (problems arising from the fact that water issues are isolated from economic development, coordination difficulties, neglect of other water related bodies, difficulties in policy application and water resource management; - No representation in Council of Ministers, little influence; - Low-level representatives on the authority or committee; - Other practical difficulties (e.g. infrequent meetings) that complicate timely decision making
Advisory councils that are established expressly to prepare integrated water resource development and water planning policies	- Participation by volunteer organizations, the private sector and national organizations is facilitated by the fact that the institution is advisory in nature; - Assorted viewpoints can be taken into account in policy preparation; - Creates channels of communication with the popular sector	- The council is advisory in nature, and consequently its recommendations may not be taken into account in policy development; - Council has no powers/ jurisdiction and consequently may find its role reduced to little more than raising public awareness about water issues

Table 2-2. Comparison of different institutional frameworks at the national level, reproduced from [21]

Noting the disadvantage of the institutional arrangement in Kuwait, it is not clear that a ready made solution which emulates Singapore may be best for Kuwait. Rather, Kuwait can learn from the principles of good water governance at the local authorities level from successful cases such as Singapore and work to solve its specific challenges as may be needed, whether through an overhaul of the system or through incisive corrections.

2.6 Overall Comparison of Kuwait and Singapore: Recommendations

Considering all the observations we have made in this chapter we may make certain concrete recommendations for Kuwait's water institutions. Firstly, we recognize that Kuwait and Singapore, although both considered as water scarce, have different water challenges and therefore focus on unique solutions suited to them. For example, as much as Singapore is aiming to phase in desalination and deemphasize importation, Kuwait, we propose, should aim to consider importation more seriously. Secondly, the institutions responsible for water will necessarily mirror the technology and the infrastructure that is dominant in the provision of water. Therefore, the primacy of desalination in Kuwait and especially of the distillation method has meant that water and electric power production go well together, perhaps in cogeneration plants and the management of energy and water may very well proceed synergistically as in the Ministry of Electricity and Water.

The recent restructuring in both Kuwaiti and Singaporean water institutions is important to consider. Kuwait merged the Ministry of Electricity and Water with the Ministry of Oil in 2003 to form the Ministry of Energy. This brings the advantages and disadvantages cited in table 2-2. We may add that this framework does not highlight the importance of the water sector in the public eye or in government. In focusing only on potable water production in coordination with the energy sector, the managed water cycle discussed in the first chapter is not completed. Infrastructural developments for wastewater and stormwater systems are the responsibilities of a different institution, the Ministry of Public Works. In Singapore, on the other hand these responsibilities were transferred in 2001 from the Ministry of the Environment to the Public Utilities Board, allowing it to manage "the entire water cycle" and to [6]

> develop and implement a holistic policy, which included protection and expansion of water sources, stormwater management, desalination, demand management, community-driven programmes, catchment management, outsourcing to private sector specific activities which are not core to its mission, and public education and awareness programmes.

In 2004, the Ministry of the Environment became Ministry of the Environment and Water Resources, allowing the PUB to focus on the mentioned activities while the Ministry oversaw regulation and other legislative activity as well as bringing a national and regional goal to bear on the specialized and streamlined PUB. We summarize a few points of comparison between Singapore and Kuwait in the following table and suggest some proposals for change in Kuwait.

Kuwait	Singapore
Water supply and demand considered separately. Demand management underdeveloped as a tool.	Water supply and demand management conjoined in successful and holistic approach, resulting in conservation achievements.
Supply of water and used water/sanitation managed through different institutions. Re-use of treated wastewater not significant.	Unified water agency for supply of water and treatment/re-use of water. Efficiency of delivery (minimum unaccounted-for-water).
Water provision highly subsidized by government. Institution financially dependent on government and other sectors.	Financially independent institution. Emphasis on performance, good governance, human resource development, visibility.
Internal water storage enhancement required; urban centers served by water towers	Internal storage enhanced in continuous developments [7], 0.142 km^3 in 2005, in protected and semi-protected catchments covering 50% of the land area and increasing

Table 2-3 Institutional comparison of Kuwait and Singapore

Kuwait may benefit from the following changes to its water institutions:

- MEW and MPW should merge into one body emphasizing the managed water cycle.
- The merged Ministry of Water should be distinct from the Ministry of Energy despite their interdependence, especially in the context of desalination. The increased autonomy, clear mandate for all water related issues, visibility to the public, and unified front for water using sectors as well as regulating government bodies are few of the advantages.
- The new ministry should emphasize financial independence from other sectors. Incorporating demand management as a way of generating funds and as an essential tool for conservation should be considered.
- The new ministry should work with other development sectors in addressing the water needs and problems of the whole nation. Standing alone as a Water Ministry gives it a better standing to make a contribution and to lead national policy change
- The new ministry should apply the concepts of IWRM to sustainable water resources development, not leaving any options unconsidered. In the case of Kuwait, enhancing storage capacity and a renewed commitment to further study proposed importation projects is timely.

Chapter 3
Water Resource Development in Kuwait

3.1 Overview

The storage enhancement options for Kuwait reviewed by Murtaugh [24] recognize the natural advantages of the drainage depression near the Rawdhatain basin. Ruwaih and Al-Hadi [4] give the approximate geographical area of this basin as between longitudes: 47.3333 and 47.7333 degrees and latitudes: 29.6666 and 29.9833 degrees. The depressions in this area collect rainwater in shallow aquifers and provide the limited amount of fresh groundwater for the country. Therefore losses from storage facilities (surface or aquifer storage) would go back into recharging these shallow aquifers. Moreover, this is a site of extensive water and oil extraction facilities and development with the attendant infrastructure. Potential water suppliers Iran and Iraq are close to the northern border and the Gulf coast is also nearby to the east. A major disadvantage with this particular location is its greater distance from desalination and wastewater treatment plants in the center of the country which are also potential suppliers to water storage. This option would allow a production or water treatment schedule optimized for efficiency instead of depending on the temporal fluctuations of demand and supply.

Our main tool for analysis for this section will be ArcGIS, an ESRI (Environmental Systems Research Institute) geographic information systems software. We will use ArcGIS in site selection as well as to delineate desired storage areas, alter the geographic data according to specifications and analyze the resulting changes. The data sets that we use include:

1. Shuttle Radar Topography Mission (SRTM) digital elevation models (DEM) at 90 meter resolution,
2. Earth Observation Satellite Company (EOSAT) Landsat images captured in 2000,
3. Digital Chart of the World (DCW) based on the U.S. Defense Mapping Agency's 1:1,000,000 Operational Navigational Charts, focusing on a subset of the land use and land cover features which are of interest at the site selection stage:

    non-perennial, intermittent streams and inland water bodies, buildings, quarries, oil wells and oil fields, water wells, major roads, power lines, overland pipes, grasses and shrubs.

3.2 Innovative Storage Design: Adapting a Solution from Low-Impact Urban Development as an Artificial Surface Aquifer

The suitability of the general area around the Rawdhatain basin for storage enhancement facilities has already been discussed. Before we proceed to delineate the exact locations for the proposed storage areas, let us discuss what type of storage design will be sought. As a standard for comparison, we will refer to Murtaugh's [24] proposal for a surface reservoir in the main depression in this basin. Covering an area of 143 km^2 and maximum depth of 11 meters, the reservoir would hold a maximum of 1 km^3 of water, enough to supply 3 years worth of Kuwait's current demand. The reservoir would only require damming in the Southeastern face, where there is a natural outlet from the depression. Murtaugh also reviewed artificial aquifer recharge efforts which have already been under investigation by Kuwait.

The main setback facing the proposed surface reservoir is evaporation loss. It is technically impractical to cover such an area with roofing or sheeting, which in any case cannot completely prevent losses [24]. In terms of volume capacity and design and maintenance ease, the surface reservoir is more attractive than aquifer storage. However, neither of these strategies nor the design we will propose here addresses the security vulnerability of an extensive water storage facility on which the country may come to rely. The security concerns may be valid but do not justify inaction because the status quo does not address these concerns or solve the long term water resource development needs of the country.

Professor Elfatih Eltahir proposes a storage structure adapted from a low-impact development (LID) urban design solution. Low impact development is "a new, comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds." [34] Some of the major applications of LID is stormwater detention (delayed release) or retention (indefinite storage time) and rainwater harvesting. In highly developed urban areas, paved surfaces cause stormwater runoff to occur with little delay of rainfall events and with high peaks. Stormwater detention is therefore important to alleviate risk of floods and to prevent capacity overflow of stormwater systems. Rainwater harvesting is important in arid areas where the water can be put to direct use in homes, buildings and for landscaping or irrigation. It is a key method for conserving water which is highly value added by treatment and delivery via pipelines to the user. The traditional designs for such storage facilities range from above ground or buried vaults, arched chambers, or pipes of various materials. With the increasing awareness of the benefits of "green design" and such industry standards as the LEED rating system (Leadership in Energy and Environmental Design) more innovative design solutions have emerged. Invisible Structures, Inc. [28] is a company which has worked in the field since 1982, and designed *Rainstore3,* a product for subsurface stormwater storage on which we will be focusing.

Rainstore3 units, made from injection molded plastic, come in modular panels of 36 vertical columns which can be stacked up to 2.5 meters high using in-built compression fittings. Laboratory and in situ experiments determined a load capacity of 112 psi, which satisfies the H-20 road vehicle load standards in the USA with minimum top cover. Several applications have therefore been carried out in extensive parking lots. In developed land, prime real estate area is therefore saved by allowing underground storage. Vegetation cover can also be recovered in irrigated lands, for example in tree nurseries and green houses. Light development, such as we will encounter in the desired storage areas in Kuwait, namely pipelines, power lines, roads, and grass cover can be restored to the original state. Figure 3-1 shows a pictorial overview of the earliest installation of Rainstore3 by Invisible Structures for Multnomah Elementary School in Los Angeles, California. By harvesting rain water with the Rainstore3 installation, the school was able to increase its green areas and reduce the heat island effect of the paved areas and thus reduce discomfort of their students and air conditioning costs. Figure 3-2 shows an individual Rainstore3 unit in closer detail. Table 3-1 provides a comparison of this design with more common designs for underground water storage.

Figure 3-1:A. Storage - Excavate for sand bed, 40 mil PVC liner, and Rainstore3 units.
B. Access Port - Cut away two columns of Rainstore3 for the access port. Any size of pipe can be accommodated.
C. Assembly - Simple block shapes work in any direction and are easy to place. These Rainstore3 units were set on their heads, utilizing the smooth side against the filter fabric padding placed over a 40 mil PVC liner. (photographs and text description from project profiles [28])

Figure 3-2 : Rainstore3 unit 1m by 1m by 0.1 m, stackable up to 2.5 m from Rainstore3 brochure [28].

Performance Criteria	**Rainstore3 2.5 meter height**	**Arched Chambers 34"x75"x16"**	**Corrugated Metal Pipe 60" diameter**	**Corrugated Metal Pipe 72" diameter**	**Concrete Pipe 72" diameter non-perforated**
% of excavated volume available for water storage	~75%	~40%	~60%	~53%	~38%
% of storage volume occupied by stone	0%	~59%	~60%	~70%	0%
Maximum water storage volume/surface area	8.2 ft^3/ft^2	~1.4 ft^3/ft^2	3.8 ft^3/ft^2	4.7 ft^3/ft^2	3.2 ft^3/ft^2
Chamber depth design flexibility	4" min., 98" max., in 4" increments	12" min. 30.5" max	12" min., 60" max., 6" increments	12" min., 240" max., 6" increments	12" min., 240" max., 6" increments
Cover depth required	12"	18"	12" – 30" based on diameter	12"-24" based on diameter	6"
On site handling and manual installation	Easy	Easy	Difficult	Difficult	Difficult
Maintenance, inspection, clean-out	Moderate	Moderate	Easy	Easy	Easy
% if chamber surface available for infiltration	100%	~75% including side cuts	~15% based on perforation area to pipe surface area	~15% based on perforation area to pipe surface area	0%

Table 3-1 Product Performance Analysis [28]. Note that Rainstore3 has a void capacity of 94 %.

We propose using Rainstore3 or similar adaptations as a water storage solution for Kuwait. Instead of excavating earth to place the storage units underground, we take advantage of the natural topographic low areas and build the structure up on the surface and thereafter cover with earth to restore original land use and land cover. We will call this concept an artificial surface aquifer (ASA). The main challenge in this adaptation is that of scale. We will return to this problem in a quantitative way after we delineate the proposed ASA areas. However, a brief discussion on the practicality of such a project is merited from the outset. The main argument for a water development project of this scale is the magnitude of the water problem if not currently then with some foresight, the magnitude it would reach if unchecked. The main costs would be the initial manufacturing or purchase of the storage units and installation. The main ingredient is polypropylene co-polymers for the structural units, and polyvinyl chloride (40 mil PVC liner) for the impermeable lining. These have lifetimes of 70 years and 40 years or more respectively [28]. With Kuwait's economy already tied to the hydrocarbon industry, it is conceivable that manufacturing would be a sound option and even a boost to the economic activity of the country. The strategy that was adapted to ASA can also be used in the urban setting of Kuwait City in its original LID context. This may alleviate the groundwater rise problem in Kuwait City because of excessive landscape irrigation. Rain in Kuwait also occurs in infrequent and high intensity bursts, stressing the capacity of the stormwater system. Stormwater retention and rainwater harvesting can be accomplished in tandem and meet the water conservation goals that the urban centers need to achieve. It is hoped that this study engenders further analysis of the feasibility and possibly a scaled down demonstration or pilot program.

3.3 Artificial Surface Aquifer (ASA) delineation

Reiterating the desired features of the ASA:

1. natural topography suitable for water accumulation
2. proximity to existing facilities
3. proximity to Gulf Sea and to Northern border with Iraq, Iran potential water exporters
4. least disruption of existing facilities, with the knowledge that most if not all land use and land covers can be restored to the original.

The GIS data sets that we use are first of all projected from "geographic projection" into the correct "projected coordinate system" which, in the case of Kuwait is "WGS_1984_UTM_Zone_38N". This converts spatial extents according to 1 meter for 0.017453292519943299 degrees, and positions the map geographically according to a datum and projection specified. The projection of all data sets which come from different sources is important to make proper spatial comparisons. The Digital Chart of the World and Landsat images serve as a starting point to make a general survey of the conditions we set above. The map in figure 3-3 shows key features of interest in Kuwait. The non-perennial or intermittent streams show a larger concentration in the Rawdhatain basin. We will also process the DEM in order to find the patterns of this paleo-drainage networks. Oil wells, water wells and sand and gravel quarries are concentrated in this area.

We then focus on a smaller area in the North by cropping the SRTM DEM of the whole of Kuwait. The smaller extent of this DEM will allow us to make computations faster and focus attention at the desired scale. The DEM raster has a cell size of ~90 x 90 (3 arc second) with a vertical resolution of ± 16 m and horizontal resolution of ± 20 m (circular error) [29]. Figure 3-4 shows the DEM map of Northeastern Kuwait in stretched grayscale showing the general trend of high to low elevation going from Southwest to North and East to the coast, with maximum elevation of 219 m and minimum 28 below sea level. The totally white patches indicate areas where no reliable elevation data could be obtained.

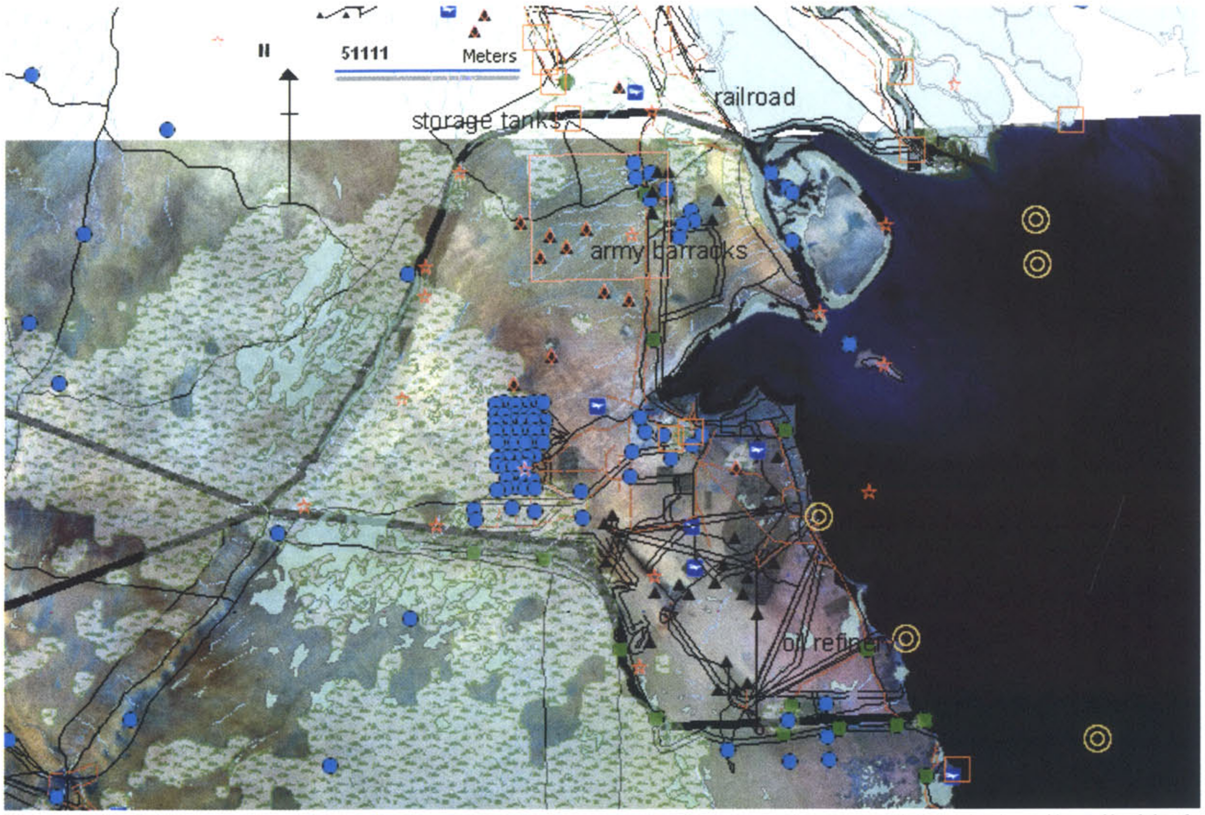


Figure 3-3: Map of Kuwait (LandSat and DCW data sets) showing water wells-blue circle, oil wells-black triangle, quarries-red diamond, roads-dark line, pipelines (overland and underground)-double line, power lines-red dashed line, pipeline terminals-concentric circles, telecommunication and power substations-green circles, airports and airfields-symbol, key buildings-red star, grasslands-symbol, paleo-drainage network-intermittent blue line, inland water (non-perennial)-pale blue patches. Rawdhatain basin approximate area according to [4] in shown as pink rectangle.

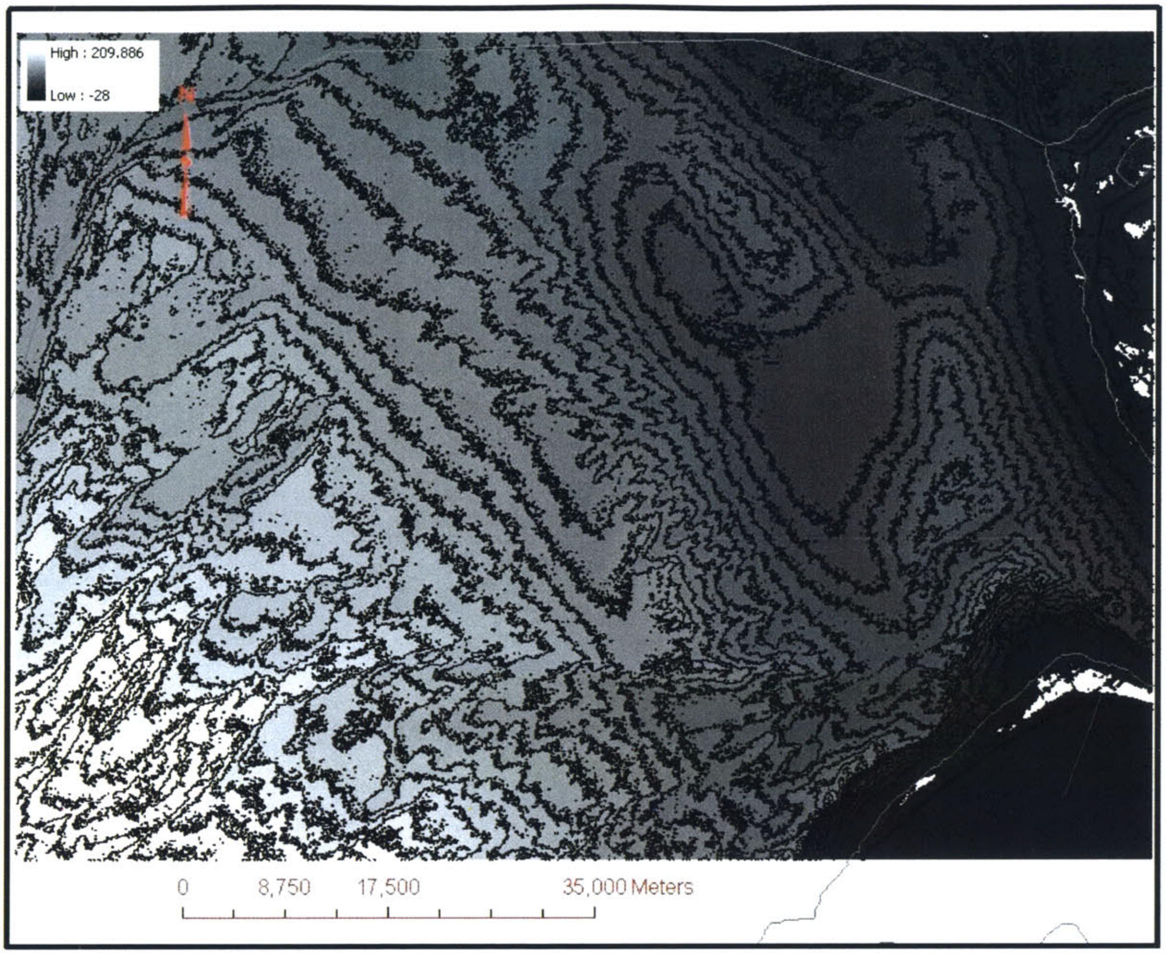


Figure 3-4: Showing a smaller area DEM in Northeastern Kuwait, with contours at 8 meter interval, with inner contour of 40 m around the Rawdhatain and Umm Al-Ahish. Further analysis will be carried out on this area.

Our next step is to analyze the DEM to identify the low lying flat areas. In Spatial Analyst tools, we compute neighborhood statistics, finding the minimum value of the elevation in a 3 by 3 rectangular grid (~0.0729 km^2 area) and displaying this value in each grid cell. In Raster Calculator, we then find the areas of the DEM which have values equal to the neighborhood minimum. After the depressions identified thus, showing three major areas which will be of interest which we will call ASA 1, 2 and 3 as shown, we overlay these areas with the land use and land cover map to make sure that there is as little disruption of the surrounding buildings and water and oil facilities as possible.

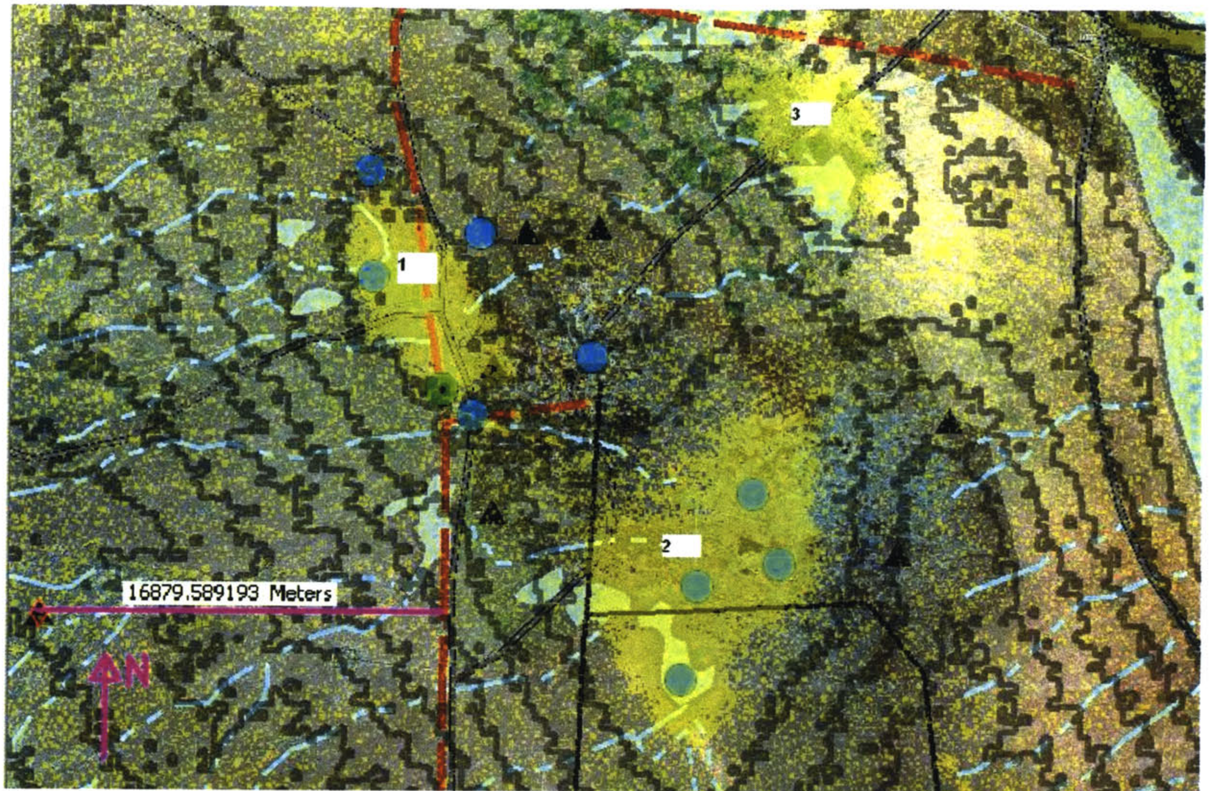


Figure 3-5. Showing the depressions, numbered as ASA 1, 2, 3 overlain with land use and land cover features, discussed in the text. 10 m interval contours help to locate these features with respect to the larger region shown in figure 3-4. ASA 1 and 2 are encircled by 40 m contour and ASA 3 by 20 m contour.

Land Cover and Land Use: A survey of the features that could possibly interfere with the construction of main artificial surface aquifer ASA numbers 1 to 3. Referring to figure 3-5 we see that ASA 1 is crossed by 3 forking roads and a power line (red broken line) as well as a power substation or transformer yard (in green). There is one water well and one oil well in this same area (Rawdhatain well field). ASA 2 has four water wells and is crossed by a road and a pipe line below the surface (Umm al-Ahish well field). ASA 3 only intersects a road, but it is a greener grassland as shown with a larger water accumulation area. ASA 1 and 2 flank a major developed area as seen from the Landsat image. This may be a compound of buildings in which the water and oil facilities are managed. The freshwater bottling plant is off the main road to the west of the ASA's. Although the mentioned features can be recovered back after the construction of the ASA, the power line and buried pipelines may cause an undesired disruption. The option of temporarily or permanently relocating these features should be considered in the feasibility and cost-benefit analysis.

We proceed to delineate ASA 1 to 3 and to analyze the storage capacities as well as the alterations that would be caused to the natural water flow pattern. Figure 3-8 shows the stream delineation obtained from the original DEM without added elevations from the ASA's. The stream delineation is computed using a convenient tool in ArcGIS called ArcHydro Tools. ArcHydro was developed by the Center for Research in Water Resources of University of Texas at Austin and is available for download from their website through the GIS Water Resources Consortium (http://www.crwr.utexas.edu/giswr/). The computation procedure to delineate streams is as follows using tools in ArcHydro under Terrain Processing menu; the input and output rasters are shown in square brackets in the beginning and end of each description; also included is a small (zoomed into the ASA area) accompanying figure of the output at each step:

1. [DEM]: Fill Sinks. This removes sinks in the DEM (whether actual, such as sinkholes or data errors) because hydrology tools in ArcGIS have a difficulty in dealing with them. [Filled] (DEM shown in figure 3-4)

2. [Filled]: The flow direction is assigned to each cell by computing the slope of the filled DEM, and determining the direction of steepest slope, which water would follow. The information is carried in each cell as eight discrete numbers 1, 2, 4 up to 128 in a geometric progression according to East = 1, Southeast = 2 and so on in clockwise steps up to Northwest = 128. [Flow_Direction]

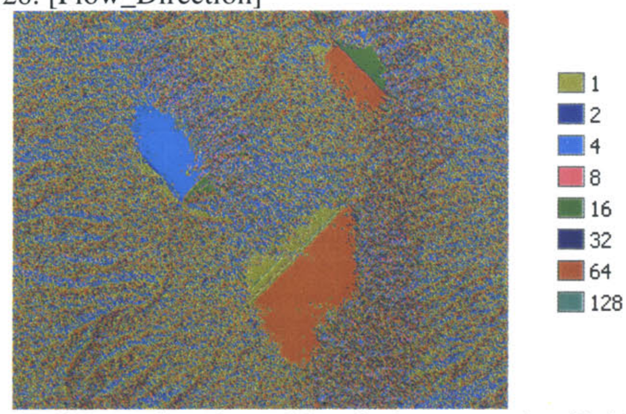


Figure 3-6. Notice in the different directions of flow in the proposed artificial aquifers ASA 1 (South), ASA 2 (North from the Southern side and East from the Northwestern side), ASA 3 (North from the Eastern and Southern Sides and West from the Northern Side)

3. [Flow_Direction]: The next step computes a Flow Accumulation by taking the flow direction as a guide and compounding the number of cells that would drain into any given cell according to the upslope conditions. The values range from zero at the edge of the watershed (the DEM map), to maxima of around 74,000 cells (600 km^2) for our DEM (Northeast Kuwait DEM total area: 449,472 cells ~3,371.8 km^2). The cells showing maximum accumulation are likely going to be streams or in the case of the Kuwaitis climate, paleo-drainage stream networks. [Flow_Accumulation]

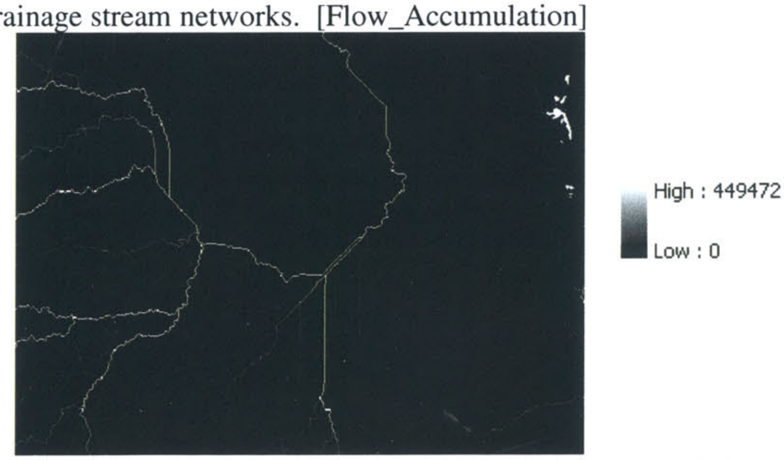


Figure 3-7. Flow Accumulation (flow accumulated from number of cells given in key)

4. [Flow_Accumulation] is used in the final step to delineate the stream network according to a stream threshold, which is 1% of the Total Drainage Area (4495 cells or 33.7 km^2). Therefore in our case, the stream network is defined as those area of the raster with a flow accumulation greater than 4495 cells. The stream threshold can be altered to match observed paleo-drainage networks more closely if this data were available as a digital map. In general, the stream threshold would depend on the climate and landcover. For wet climates, we would expect smaller areas to contribute to streams because of saturation excess runoff. In dry climates, however flow accumulation from a larger area is needed to contribute to streams, although when storm events occur in low frequency but high intensity we can expect to see infiltration excess runoff contributing to flash-flood phenomena and we would observe more stream networks than expected. [Stream_Network]

Natural Drainage. Figure 3-8 shows the final product of the stream delineation, and the proposed depression areas for the three ASA's. Although these ASA's are chosen to be in flat low lying areas, figure 3-6 shows that ASA 2 and 3 will have definite boundaries over which water stored in the ASA units will tend to flow and accumulate in different directions, as long as the topography is not altered through preliminary earth work. What this may signify is the need for multiple water extraction points and the need for slightly higher earth bank and top-fill in some areas, or alternatively a variable thickness of the ASA units with a maximum of 2.5 meters. Analyzing the elevation profiles across the three ASA's enables us to determine a suitable regional connection between the three units, namely from 1 to 2 to 3. See figure 3-9 showing the elevation profile across a path closely following the stream delineation as shown. A piped connection network between the three ASA's can make use of this regional path that most closely follows a downward sloping elevation and hydraulic gradient. The gradient are approximately: ASA 1 to 2, 5 meters drop over 5 km distance and ASA 2 to 3 , 16 meter drop over 10 km distance.

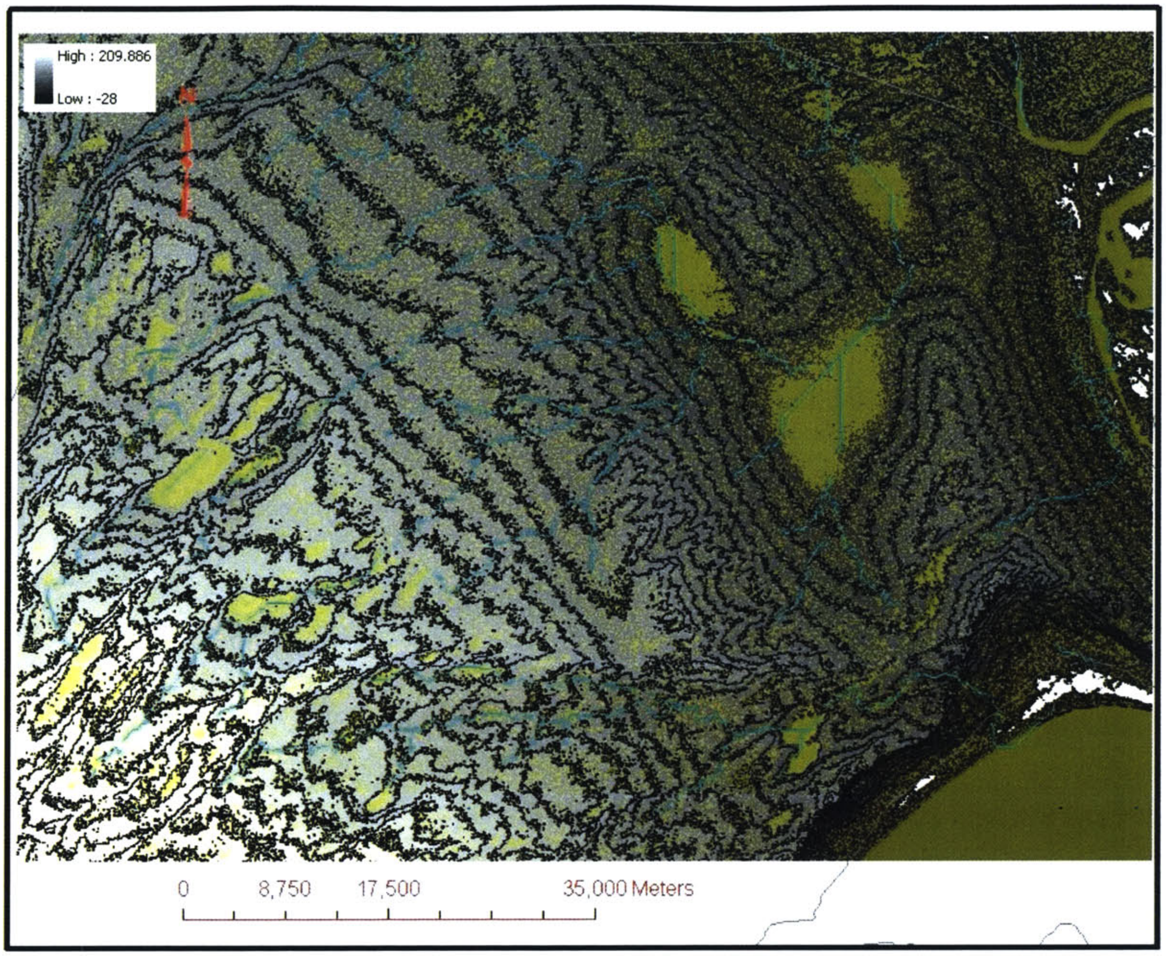


Figure 3-8. Showing the stream delineation and the depression areas of ASA 1 to 3, and the Northern border with Iraq several kilometers from ASA 3.

We delineate ASA 1 by following the 40 meter contour, ASA 2 by following the 33.5 meter contour and ASA 3 by the 17.5 meter contour lines. The 33.5m and 17.5m contour lines most closely circumscribe the second and third depressions, but are not shown in the 8 m contour maps displayed in previous figures. They are easily created using the spatial analyst "Create Contour" radio button. We draw polygon shapefiles slightly inside the contour lines to avoid the up-sloping edges and build up those polygons, after converting them to rasters, to 2.5 meter elevation additional to the original elevations. The three aquifers together provide a storage capacity of 0.32 cubic km, as summarized in table 3-2. The edges will have to be built up in terrace or staircase structures to maximize the storage capacity of the ASA units.

ASA	Number of cells	Total Area km^2	Volume km^3	
1	4962	37.22	0.09	
2	9778	73.35	0.17	
3	3452	25.89	0.06	0.32 **Total Volume**

Table 3-2. Showing the area and volume of the ASA's 1 to 3, based on cell dimension 86.1 m, aquifer height 2.5 m, and porosity 94%.

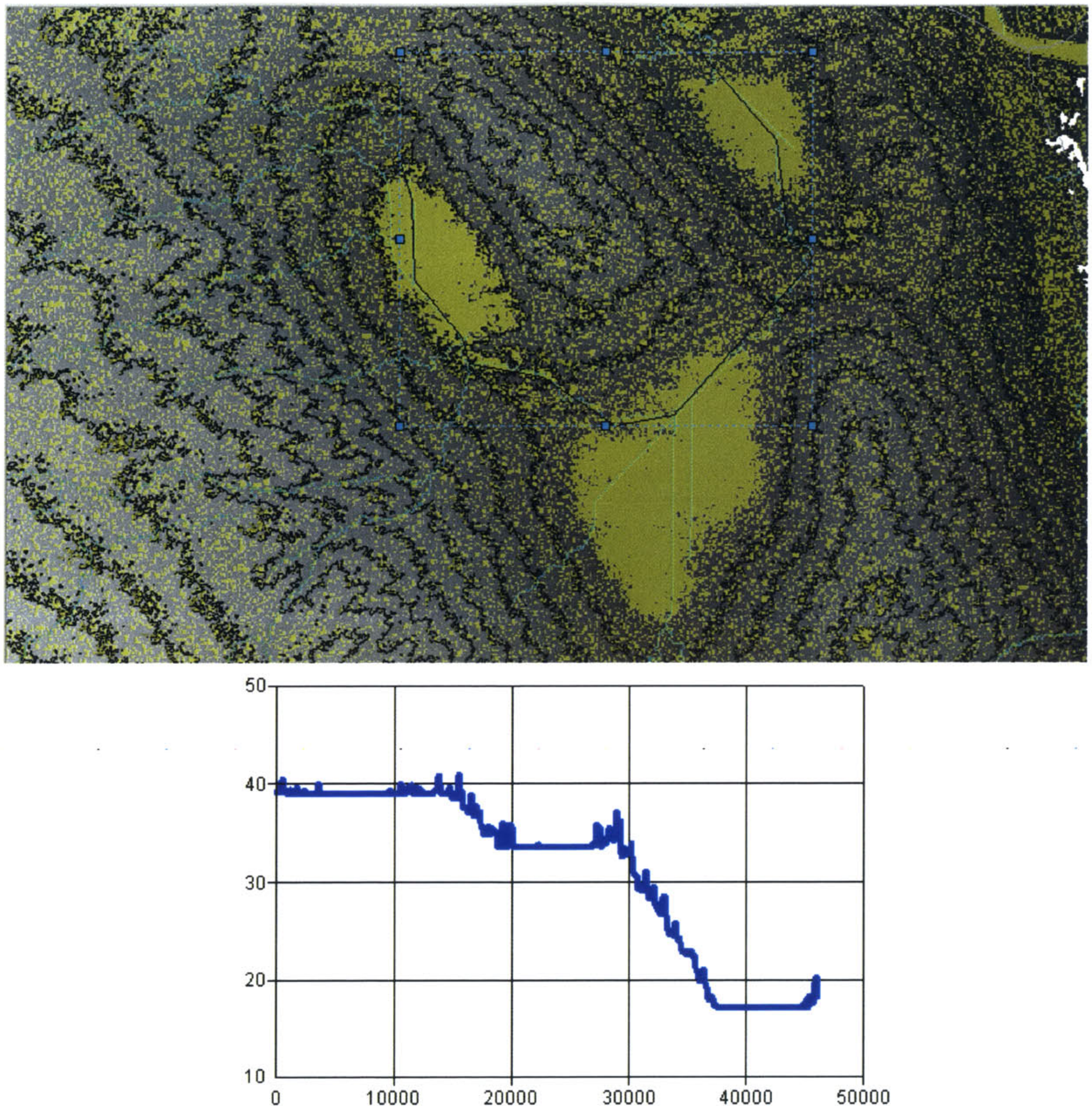


Figure 3-9. Showing the regional elevation profile across ASA 1 to 3 obtained by following the stream delineation. Both axes in meters.

We consider the edges separately as we aim to expand the storage of the original three ASA's through ASA 4 to 6 as shown in figure 3-10. The terraced structure is necessary to maximize storage by avoiding the lost wedge of storage volume which can be visualized as a slanting cube reservoir (side length s, slanting angle θ), with the water level to the regional horizontal [28]. After the water fills up to the height s on he downslope side it will overflow out leaving a triangular prism of volume $s^3/(2*\tan\theta)$ empty. Each boundary of the ASA's will need to be studied closely through accurate surveying in order to minimize the earth movement and leveling while at the same time maximizing the distance laterally (in between the contours) over which the ASA units can be interconnected. An internal head gradient of 1m may be tolerable as long as compensating top-fill is distributed accordingly, and the natural gradients are exploited in the pumping (injection and abstraction) locations and schedules.

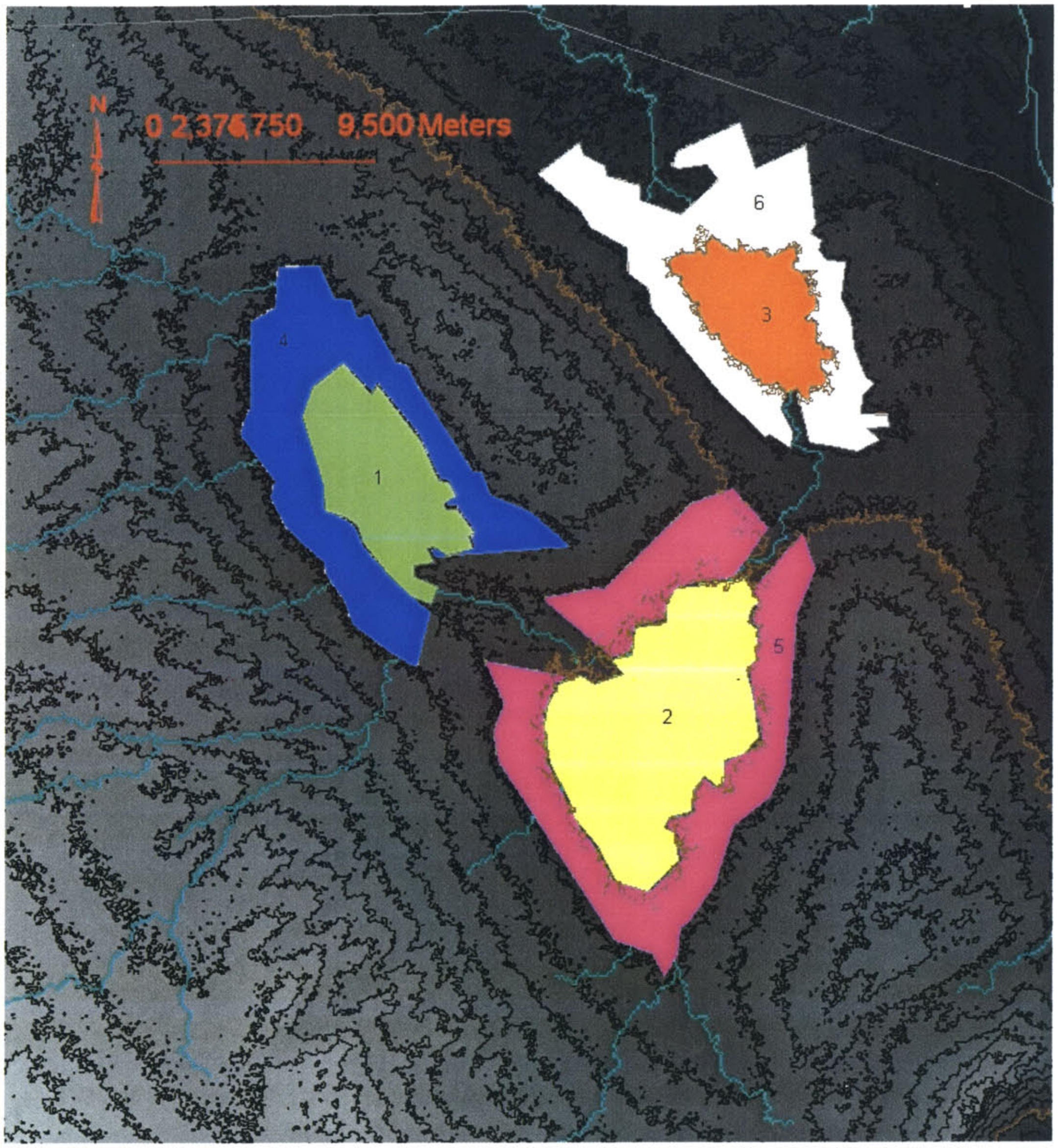


Figure 3-10. Showing the delineation of the 6 ASA's fulfilling criteria discussed in the text.

Assuming a high vertical (elevation) resolution, the lateral circular error of ± 20 m propagates to produce a high error in the volume computed. The delineation of the ASA's by drawing polygons visually also contributes to the error. Despite the error variability in the volume computed for the first three ASA's, in comparison with our 1 km^3 standard of comparison, it is clearly necessary to add ASA's 4 to 6. In order to determine the specifications for the terrace structure of these ASA's, a detailed survey of the area is required to yield much more reliable data than the current DEM. However, we will focus on ASA 4 to illustrate the concept, and make a generalized assumption to compute the added volume capacities of the three additional ASA's. Figure 3-11 and 3-12 show the elevation profiles across two lines crossing ASA 4.

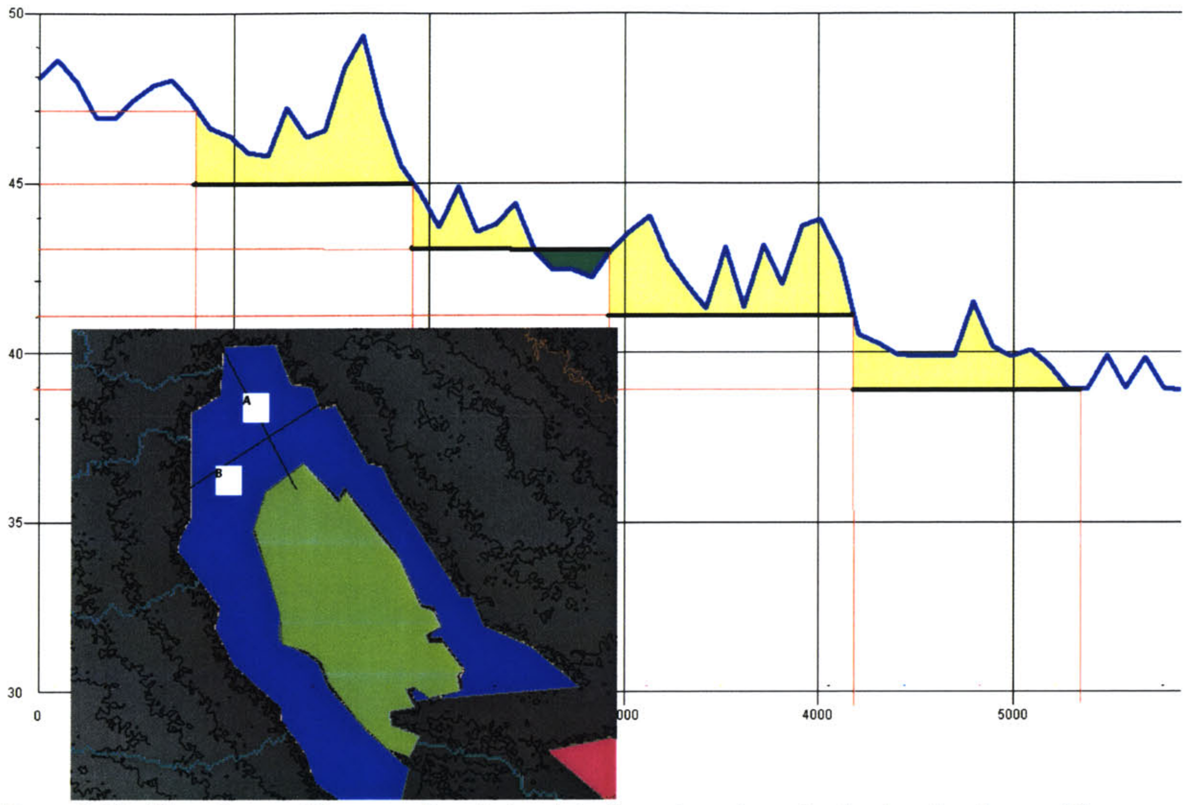


Figure 3-11. Elevation profile across line A, top to bottom, (axes in meters), showing the need for terraced structure and indicating the earth redistribution that would be necessary. Heavy dark line would be the horizontal level base for the terraces. The elevation excess of this base is shown in yellow and deficit in green. After the earth is leveled the terraces can be built up with ASA units according to design heights.

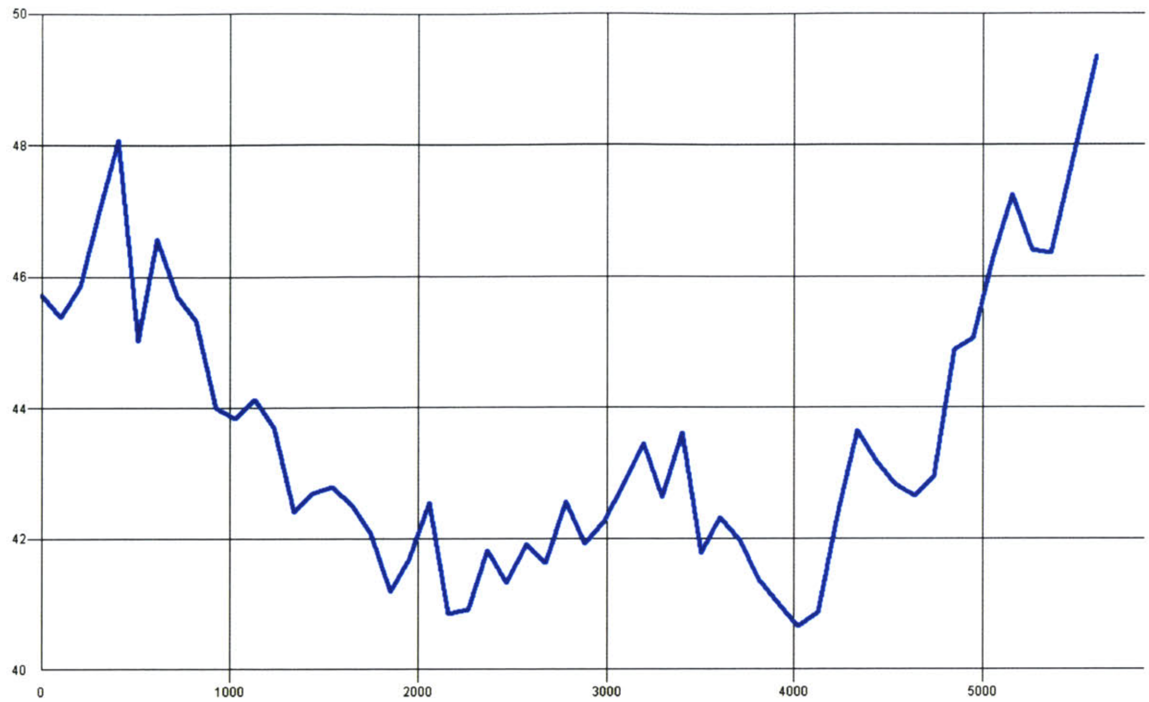
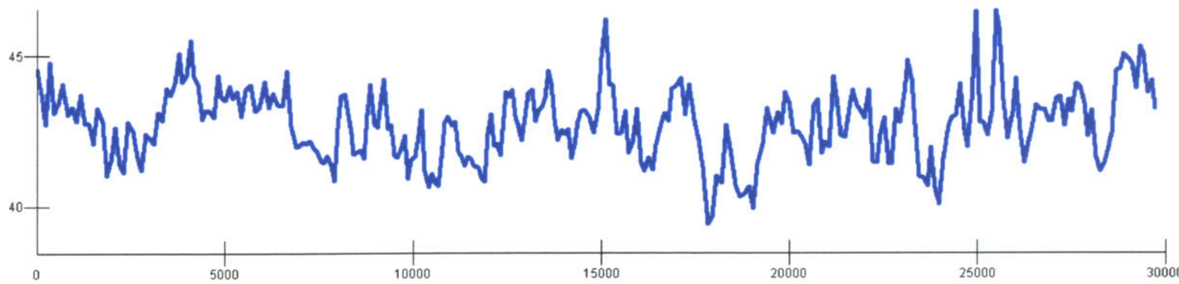


Figure 3-12: Elevation profile across line B, left to right, (refer to figure 3-11, axes in meters) showing the need for careful surveying in order to find the optimal direction in which interconnected ASA units will run parallel to contours or as semi-annular structures.

Figure 3-11 and 3-12 show that with the available data, only a qualitative indication of design features can be given. A DEM of higher accuracy can be used to compute 1 m interval contours which can be very useful at the design stage. Site surveys will be indispensable to find optimum arrangements of the ASA units in the ASA's 4 to 6. Semi-annular interconnection of the units in terraced structures parallel to the contours is suggested. As the profile of line A in figure 3-11 shows, terraces can span 1 km or more in width and if carefully interconnected up to 30 km in length or circumference. We may impose a design criteria such as no more than 1 m hydraulic head difference between any two points in an interconnected unit. The balance needs to be made between the cost of implementing complicated ASA geometries that closely follow the terrain with lest disruption (allowing for terracing) and the cost of earth movement that may be required to simplify the geometry and contain the stored water in the ASA units with sufficient top-fill and earth dams for the peripheries. The profile across the length of ASA 4, shown in figure 3-13 illustrated this point clearly. The elevation difference can be more than 1 meter, for example, in the steepest gradient, an approximate change of 5 meters occurs over a distance of 1 km. This is comparable to the gradient encountered in crossing between contours in profile line A, for example. This suggests that a second degree of terracing, parallel to contours, would simplify the design.

In order to compute the storage capacities of the three additional ASA's, we will propose a unit height of 2 meters, and assume that areas are fully covered by the terrace structure. This may be a simplification which does not allow for free areas that would be needed to make piped hydraulic connections between terraces, or in case the interfaces are left free, the head difference across terrace units which would reduce the storage capacity in the upper terrace unit. However, given the error margins we deal with, the simplification is justified. Table 3-13 summarizes the storage capacities.



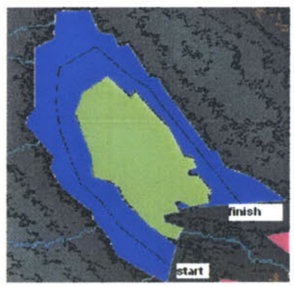


Figure 3-13. Showing the elevation profile in ASA 4 across a line approximately half-way between the boundary of ASA1 and ASA 4 and the outer boundary of ASA4.

ASA	Number of cells	Total Area km²	Volume km³	
4	8829	66.23	0.12	
5	10959	82.21	0.15	
6	8960	67.21	0.13	0.41 **Total Volume**

Table 3-3. Additional storage capacity of ASA 4 to 6. 2m unit heights, same efficiency of storage assumed.

We will proceed to analyze how the added elevations of 2 m to the outer ASA's and 2.5 meter to the inner ASA's will affect the flow patterns in the region. The proposed development project would increase the storage capacity of Kuwait by 0.73 km^3. It remains for us to discuss how this storage capacity would be used in a revamped water management scenario in Kuwait as discussed in chapter 3. This will be the topic for the final chapter.

Before we apply the analysis steps using ArcHydro tools, we add the specified elevations to each of the ASA's. The first step is to convert the polygon shapefiles we delineated into rasters. We then perform raster calculations to assign the original elevations of the DEM to the new ASA rasters and add the ASA heights on top. We can call these the ASA DEM's. Finally, we mosaic each of the ASA DEM's with the original DEM to obtain a new DEM which we can proceed to process using ArcHydro tools. Figure 3-14 shows the new flow patterns which can be compared with figure 3-8. The main difference can be seen in the flow pattern around ASA 2 and 5. In the original stream network the depression (Umm al-Aish well field) was a point of convergence of a few streams which in the new development scenario would skirt around ASA2. As part of the storage development, a rainwater harvesting strategy can be devise so that the natural accumulation of runoff in these depressions is not curtailed. The flow directions under the new scenario give an indication of the need for managing the surface of the ASA's through pumping and extraction points with a more detailed knowledge of the hydraulic head distributions.

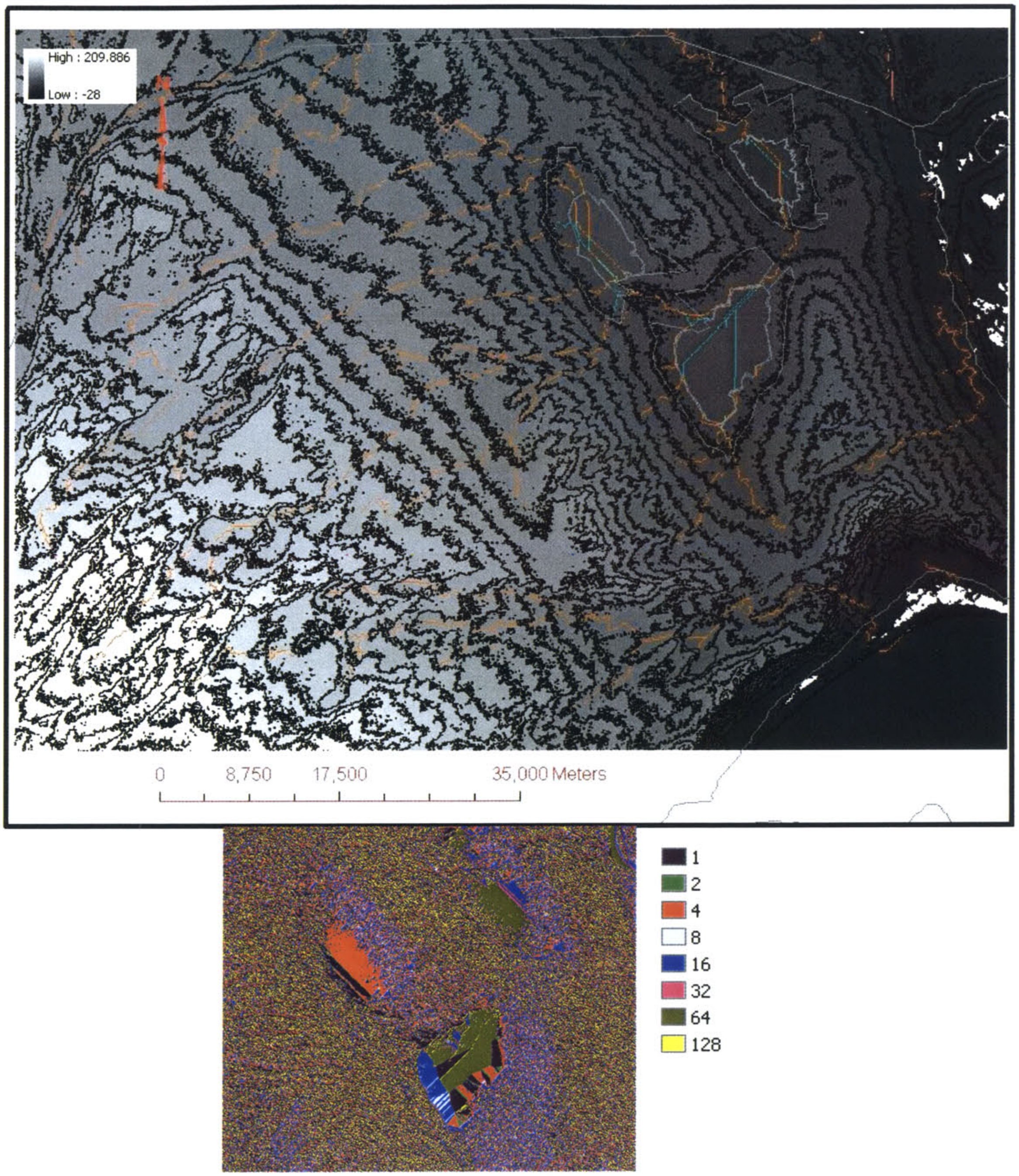


Figure 3-14. Showing the altered flow patterns in orange compared with the original flow pattern in blue. The ASA's are shown as outlines. The accompanying flow direction chart, zoomed in on the ASA's shows some alteration to the flow directions indicating the need for hydraulic control.

Chapter 4
Conclusions

Although we contend with a large margin of error barring a ground site survey, we can make a positive conclusion that a storage enhancement scheme as proposed in Chapter 3 goes a long way in alleviating the water problem in Kuwait. Considering the projected annual water demand for 2010 of 1.02 km^3 [3], our computed additional storage capacity of 0.73 km^3 amounts to approximately 72% of the nations water needs. Such a large capacity for storage addresses the inherent insecurity of water importation by giving the water authority a margin of safety in case water supplies were to suddenly be discontinued. The risk associated with large storage facilities of strategic resources such as water is not unique to any nation. The proposed sites are in close proximity to existing water and oil facilities and would benefit from the infrastructure as well as the security protection that would go hand in hand with these facilities.

In conjunction with institutional capacity building and a focus on demand management, storage enhancement should be a primary focus for sustainable water resources development in Kuwait. The comparison with the case of Singapore affords lessons to be drawn in all of these areas, although we propose that Kuwait give importation increased consideration while Singapore is aiming to reduce its reliance on imported water completely. The regional and international level of water resource management is similar in both cases, with the exception that Asia Pacific regional bodies seem to be a few years ahead in their implementation of good governance principles. Western Asia regional bodies, on the other hand are at a formative stage but proceed with the required care in examining the best institutional structures that are suited to their circumstances. The national water authorities in Kuwait could be served well by emulating the streamlined and unified structure of the Public Utilities Board in Singapore. The best balance needs to be struck between independence, clear mandates, visibility on the one hand and integration with national development goals and synergistic operation with other sectors on the other. Although lessons must be drawn from all applicable cases, and in particular from the successes of Singapore, the institutional frameworks most suited to Kuwait will in the end be unique to it.

We have examined how our proposed storage facilities will affect the land use, landcover and regional water drainage patterns. To a large extent the existing features offer advantages to the proposed project, such as the water and oil facilities and the infrastructure surrounding them. The main advantage of the ASA structures proposed in this thesis is that land use and landcover can be recovered back to their original state after construction. The natural drainage can be managed to provide the storage units with a source of harvested rainwater. The alterations to the drainage pattern as a result of the storage units will indicate the best locations for water accumulation. The ASA's are located close to Northern neighbors Iraq and Iran, potential suppliers of water, as well as being an ideal destination for the Turkish Peace Pipeline already mentioned. The proximity to the Gulf promotes the consideration of other potential supply routes as well as the advantage of the area for future desalination plants. The distance from population centers in the middle of the country, however, discourages the option of purified wastewater as a potential source for storage at these sites.

Although cost of desalination is the most competitive, and is dropping with the advent of new technology, water importation can be advantageous in the bigger picture, and of general economic value as an option for sustainable development. As compared to $\$1/m^3$ which is a feasible cost for sea water desalination with available technology [34] [1] (compare $\$2/m^3$ distillation in Kuwait [3], and $\$0.51/m^3$ in Singapore[6]), the Turkish Peace Pipeline [18] would deliver water at around $\$1.75/m^3$. The Iranian pipeline would be of similar or less cost. Desalination, at worst will be as economic as other non-conventional sources, notwithstanding the dependency on the oil market. However, degradation of the environment from oil power generation, disposal of hot brines, and coastal degradation can be allayed by slowing down the development of desalination as the major source of supply enhancement in the region.

References

[1] I. Bremere, M. Kennedy, A. Stikker, J. .Schippers, "How water scarcity will affect the growth in the desalination market in the coming 25 years", *Desalination* 138 (2001)

[2] M. Al-Rashed, M. Sherif, "Water Resources in the GCC Countries: An Overview", *Water Resources Management* 14 (2000)

[3] A. Fadlemawla, M. Al-Otaibi, "Analysis of the Water Resources Status in Kuwait", *Water Resources Management* 19 (2005)

[4] F.M. Al-Ruwaih, K.M. Hadi, "Water quality trends and management of fresh groundwater at Rawdhatain, Kuwait" *European Journal of Scientific Research* 11,#3 (2005)

[5] A. Mukhopadhyay, A. Akber, E. Al-Awadi, N. Burney, "Analysis of Freshwater Consumption Pattern in Kuwait and its Implications for Water Management", *Water Resources Development* 16,#4 (2000)

[6] C. Tortajada, "Water Management in Singapore", *Water Resources Development* 22,#2 (2006)

[7] L.P. Onn, "Water Management Issues in Singapore", paper presented at Water In Mainland Southeast Asia, 29 November—2 December 2005, Siem Reap Cambodia, conference organized by the International Institute for Asian Studies (IIAS), Netherlands, and the Centre for Khmer Studies (CKS), Cambodia

[8] Draft Program Proposal: Kuwait Climate, Water and Vegetation, MIT-Kuwait Center for Natural Resources and the Environment (2006)

[9] M.A. Darwish, "On electric power and desalted water production in Kuwait", *Desalination* 138 (2001)

[10] L.P. Onn, "The Water Issue Between Singapore and Malaysia: No Solution in Sight?", *Economics and Finance* No.1 (2003) Institute of Southeast Asian Studies

[11] Y. Al-Wazzan, F. Al-Modaf, "Seawater desalination in Kuwait using multistage flash evaporation technology — historical overview", *Desalination* 134 (2001)

[12] M. Abdel-Jawad*, E.E.F. El-Sayed, S. Ebrahim, A. Al-Saffar, M. Safar, M. Tabtabaei, G. Al-Nuwaibit, "Fifteen years of R&D program in seawater desalination at KISR Part II. RO system performance", *Desalination* 135 (2001)

[13] D.P. Loucks, E. van Beek, Water Resources Systems Planning and Management - an introduction to methods, models and applications, UNESCO Publishing 2005

[14] J. Thomas, B. Durham, "Integrated Water Resource Management: looking at the whole picture", *Desalination* 156 (2003)

[15] Eds. A.C. McIntosh, C.E. Yñiguez, Second Water Utilities Data Book: Asian and Pacific Region, Asian Development Bank, 1997

[16] Water: a shared responsibility. The United Nations Word Water Development Report 2, Executive Summary, World Water Assessment Program, UN Water http://www.unesco.org/water/wwap (2006)

[17] "Implications of Groundwater Rehabilitation on Water Resources Protection and Conservation: Artificial Recharge and Water Quality Improvement in the ESCWA Region", ESCWA, United Nations, New York, 2001

[18] "The Role of Desalinated Water in Augmentation of the Water Supply in Selected ESCWA Member Countries", ESCWA, United Nations, New York, 2001

[19] "ESCWA Report: Fifth Session of the Committee on Water Resources", Beirut, 30 Octrober—Novermber 2002, ESCWA 2003

[20] "Sectoral Water Allocation Policies in Selected ESCWA Member Countries: An Evaluation of the Economic, Social and Drought-Related Impact", ESCWA, United Nations, New York, 2003

[21] "The Optimization of Water Resource Management in the ESCWA Countries: A Survey of Measures Taken by the ESCWA Countries During the 1990's for the Optimization of Water Resource Management and Capacity Building in the Water Sector", ESCWA, United Nations, New York, 2004

[22] Asia Water Watch 2015: Are Countries in Asia on Track to Meet Target 10 of the Millennium Development Goals, ADB, UNDP, UNESCAP, WHO, Asian Development Bank 2006

[23] M. Milutinovic, "Water Demand Management in Kuwait", DCEE MIT thesis 2006

[24] K. Murtaugh, "Analysis of Water Supply Options for Kuwait", DCEE MIT thesis 2006

[25] J.M. Trondalen, "A Pre-Feasibility Study: A Regional Mechanism for Building Capacity to Manage International Water Resources" (UNESCWA date unspecified, inferred from content and references to be 2006)

[26] M. Solanes, A. Jouravlev, "Water Governance for Development and Sustainability" UN Cepal, Santiago, Chile, June 2006

[27] "Guidelines on Strategic Planning and Management of Water Resources" ESCAP, United Nations, 2006

[28] Invisible Structures, Inc. (http://www.invisiblestructures.com/index.html accessed May 2007) project profiles, product brochure and white papers

[29] USGS Seamless SRTM "finished" (3 arc sec) data desrition and downloads
http://seamless.usgs.gov/website/seamless/products/srtm3arc.asp (accessed through 2006, 2007)

[30] GIS for Environmental Engineering Class notes, Daniel Sheehan, 2006

[31] UN-Water, http://www.unwater.org/about.html accessed January, 2007

[32] Capacity Building for Integrated Water Resources Management, http://www.cap-net.org/ accessed May 2007

[33] Gulf Cooperation Council (GCC) http://www.gcc-sg.org/index_e.html,
http://www.gcc-sg.org/cooperation.html accessed May 2007

[34] Low Impact Development Center, http://www.lowimpactdevelopment.org/ accessed May 2007

[35] Y. Zhou, R.S.J. Tol, "Evaluating the Costs of Desalination and Water Transport", *Water Resources Research*, Vol. 41, 2005

[36] BBC News Story "Iran-Kuwait Water Plan Unveiled"22 February, 2001
http://news.bbc.co.uk/2/hi/middle_east/1184501.stm accessed May 2007

Association of Southeast Asian Countries (ASEAN)
http://www.aseansec.org/64.htm

United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP)
http://www.unescap.org/about/subprog.asp

United Nations Economic and Social Commission for Western Asia (UN ESCWA)
http://www.escwa.org.lb/

Global Water Partnership (GWP)
http://www.gwpforum.org/servlet/PSP

Asian Development Bank (ADB)
http://www.adb.org/

International Food Policy Research Institute
http://www.ifpri.org/

UNESCO Water, sustainable development and conservation of freshwater resources in the world
http://www.unesco.org/water/

UN Water
http://www.unwater.org/flashindex.html

AQUASTAT – FAO's information system on water and agriculture
http://www.fao.org/AG/AGL/aglw/aquastat/main/index.stm

World Water Council/World Water Forum
http://www.worldwatercouncil.org/index.php?id=1&L=0

International Water Association
http://www.iwahq.org/templates/ld_templates/layout_632897.aspx?ObjectId=632922

Ministry of the Environment and Water Resources, Singapore
http://app.mewr.gov.sg/home.asp?id=M1

Appendix
Additional Tables and Figures

SUGGESTED EVALUATION CRITERIA FOR UTILITIES

Consumer Satisfaction		**40%**
Coverage	10%	
Water Availability	10%	
Service Level	10%	
New Connection Fee	10%	
Water Resources Management		**20%**
Water Production/Population	5%	
UFW/Metering	10%	
Consumption	5%	
Financial Resource Management		**20%**
Grant Financing	5%	
Operating Ratio	10%	
Accounts Receivable	5%	
Human Resource Management		**10%**
Staff/1,000 Connections	5%	
Management Salaries	5%	
Accountability		**10%**
Annual Report	10%	
Total	**100%**	**100%**

Notes

Coverage (House Connections)		**10%**
100%	10%	
>50%	5%	
<50%	0%	
Water Availability		**10%**
24 hours	10%	
>12 hours	5%	
<12 hours	0%	
Service Level		**10%**
(a) No public Taps	5%	
Public Taps	0%	
(b) 100-200 l/c/d	5%	
<100l/c/d or >200 l/c/d	0%	

New Connection Fee		**10%**
Reasonable Cost	5%	
High Cost	0%	
Installments to Pay	5%	
Total Fee upfront	0%	
Water Production/Population		**5%**
<0.5 m3/day/person	5%	
>0.5 m3/day/person	0%	
UFW/Metering		**10%**
Full Metering	5%	
Partial Metering	0%	
UFW < 25%	5%	
UFW > 25%	0%	
Consumption		**5%**
<200 l/c/d	5%	
>200 l/c/d	0%	
Grant Financing		**5%**
Nil	5%	
Any	0%	
Operating Ratio		**10%**
<0.75	10%	
0.75 - 1.00	5%	
> 1.00	0%	
Accounts Receivable		**5%**
<3 months	5%	
>3 months	0%	
Staff/1,000 Connections		**5%**
<10	5%	
>10	0%	
Management Salaries		**5%**
Above Government Level	5%	
Government Level	0%	
Accountability		**10%**
Annual Report Available to Public	5%	
Annual Report Unavailable	0%	
Timely Report (within 12 months)	5%	
Reporting after 12 months	0%	

Table A.1 Evaluation Criteria for Water Utilities, reproduced from [15]

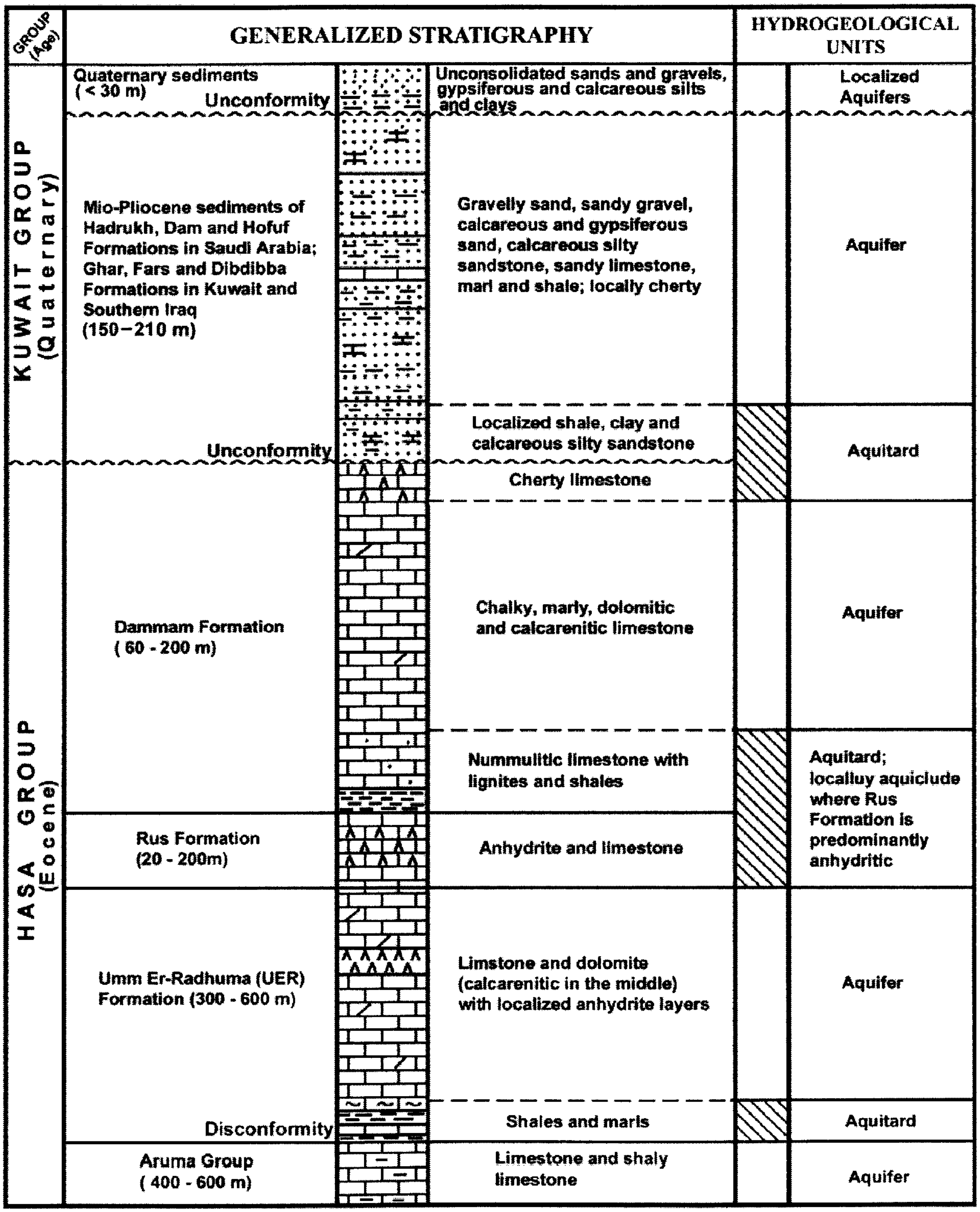


Figure A-1. Stratigraphy and hydrogeological subdivision in the Kuwait aquifer system [4]

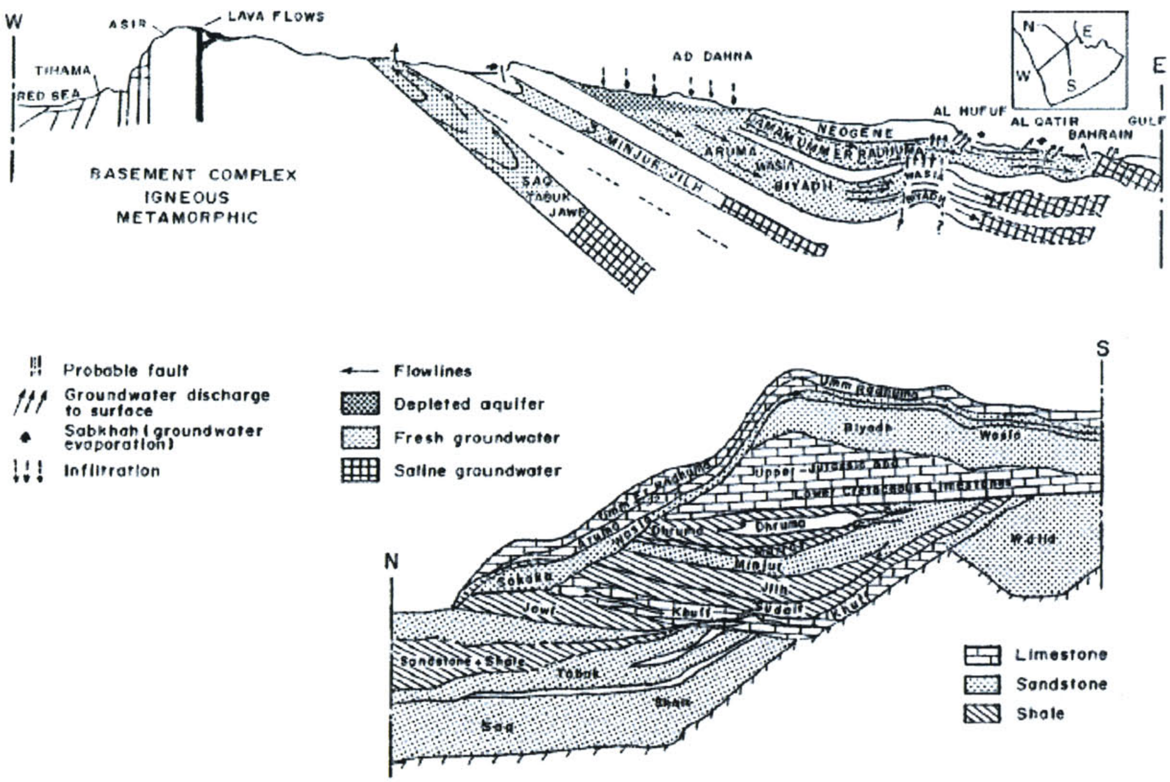


Figure A-2 Two geological cross sections in the Arabian Peninsula [2]

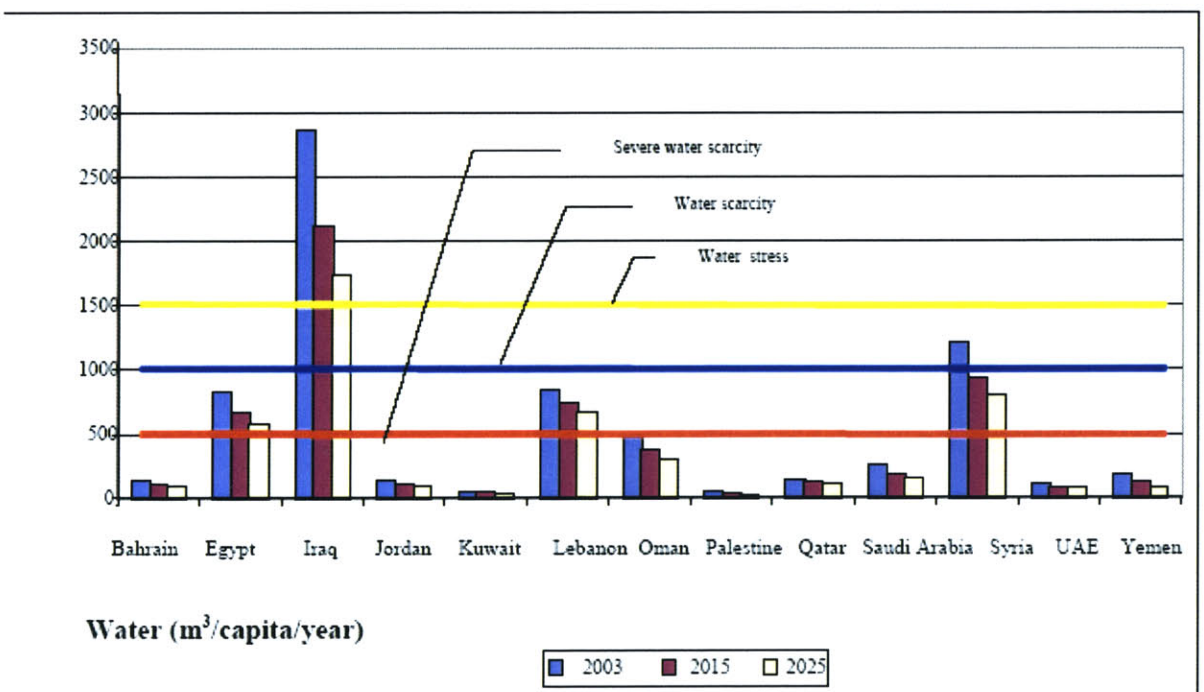


Figure A-3: Per capita water share in the ESCWA region [20]

Country/area	Conventional water resources[b] Surface water	Groundwater recharge	Groundwater use	Non-conventional water resources Desalination	Wastewater and drainage reuse[c]
Bahrain	0.2	100.0	258.0	75.0	(3.0) 17.5
Egypt	55 500.0	4 100.0	4 850.0	6.6	(4 920.0) 3 800.0
Iraq	70 370.0	2 000.0	513.0	7.4	1 500.0
Jordan	350.0	277.0	486.0	2.5	61.0
Kuwait	0.1	160.0	405.0	388.0	30.0
Lebanon	2 500.0	600.0	240.0	1.7	2.0
Oman	918.0	550.0	1 644.0	51.0	23.0
Palestine	30.0	185.0	200.0	0.5	2.0
Qatar	1.4	85.0	185.0	131.0	28.0
Saudi Arabia	2 230.0	3 850.0	14 430.0	795.0	(24.0) 131.0
Syrian Arab Republic	16 375.0	5 100.0	3 500.0	2.0	(1 270.0) 1 447.0
United Arab Emirates	185.0	130.0	900.0	455.0	108.0
Yemen	2 250.0	1 400.0	2 200.0	9.0	52.0
Total	150 710.0	18 537.0	29 811.0	1 925.0	8 322.0

Source: 'Shared groundwater resources in the ESCWA region: the need, potential benefits and requirements for enhanced cooperation,' paper presented at the Expert Group Meeting on Legal Aspects of the Management of Shared Water Resources, Sharm El-Sheikh, Egypt, 8–11 June.

a/ Note that the totals do not reflect the figures in the columns owing to rounding errors.

b/ The flow of the Tigris and Euphrates rivers can be reduced by abstraction upstream in Turkey.

c/ Values in brackets are drainage water reuse.

Table A-2 ESCWA Water Resources in 2000 in million cubic meters [20]

Country	Annual Renewable Water Resources: Total[4] (km^3)	Annual Renewable Water Resources: Per Capita (m^3)	Annual Water Withdrawals: Total (km^3)	Annual Water Withdrawals: Per Capita (m^3)	2000 GDP Per Capita (US$)	Population 2000 (millions)
Cambodia	**476**	**32,876**	**4.1**	**311**	**274**	**12.2**
Indonesia	**2,830**	**12,749**	**82.8**	**391**	**750**	**203.5**
Laos PDR	**334**	**57,638**	**3.0**	**567**	**328**	**5.2**
Malaysia	**580**	**23,316**	**9.0**	**392**	**3,870**	**23.2**
Myanmar	**1,046**	**20,870**	**33.2**	**699**	**142**	**49.0**
Philippines	**479**	**5,884**	**28.5**	**377**	**981**	**76.3**
Singapore	**1**	**139**	--	--	**23,071**	**4.0**
Thailand	**410**	**6,459**	**87.1**	**1,429**	**1,963**	**62.4**
Vietnam	**891**	**10,805**	**71.4**	**914**	**403**	**77.7**

Table A-3: Water Resources of ASEAN Countries, GNP Per Capita, and Population: 2000 [10]