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Envisioning a Comprehensive Earth Information System for Improving Water Resource Assessment in the UAE

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Envisioning a Comprehensive Earth Information System for Improving Water Resource Assessment in the UAE

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A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg Department of Geography Archaeology and Environmental Studies in fulfillment of requirement for the master degree.

August 2004

I declare

Signed

Dedication

Sheik Mansour Al Nayan

My wife and daughters

Abstract

Rapid population growth, combined with an expanding economy and tourist industry has lead to a water resource crisis in the United Arab Emirates. The water crisis includes serious difficulties in meeting basic needs, particularly in the agricultural sector, which is a dominating water consumer in the country. All economic sectors are finding it increasingly difficult meeting their water needs, which is primarily manifested by the natural scarcity of water recourses, depletion of groundwater, low efficiency of water use and low coverage of water and sanitation services.

This dissertation presents a vision for a comprehensive Earth Information System that goes beyond the limited collection of, say, meteorological data, but seeks to create a national database of past, present and future data of the many related earth system components of both natural and human origin, all of which play a role in defining the hydrologic cycle, and ultimately, the state of water resources.

This system is being motivated by the fact that most of the water resource assessments in the UAE cannot take advantage of such datasets because the data are either not collected, too fragmented, or are not part of a national archive that is accessible to the research community and the general public. This system will be developed at the highest level of the national government, through the Office of His Highness the President and the office of the Department of Water Resource Studies which will seek to provide improved water resource assessment using modern database and analytical methods, that will support the development of better studies and new, modern institutional networks and authorities.

Preface

Water Resources Assessment (WRA) is the comprehensive analysis of both the supply and demand side of the water equation, which seeks to find the balance between water resource exploitation, water conservation, water development and sound water resource management. A prerequisite to sound WRA is the need for high quality and timely data and information in support of the WRA process that consists of numerous scientific disciplines (meteorology, hydrology, geology, geochemistry, microbiology, ecology, economics, sociology, etc). These sciences can individually and corporately provide an increasing array of scientific data from a multitude of platforms and data collection systems. These include field samples, automated weather and marine stations, water monitoring stations, weather radar, airborne surveys, satellites, geophysics surveys, geochemistry analysis and others. All of these disciplines have links to water resources and the hydrologic cycle.

In Chapter 1 of this dissertation, is first to define WRA and then outline current difficulties preventing real water resources assessment for the UAE major challenges and driving forces and their impact on the water resources of the country. In addition, background material is given on the nature of the water resource situation in the UAE, and importantly the fact that the area is located in a hyper-arid Arabian Peninsula, which by definition is in a chronic water short state. So much so, that the use of climatological terms such as ‘drought’ does not even apply to this region.

Chapter 2 goes into greater detail regarding the meteorology and climatological regimes of the UAE, laying the groundwork for identifying this region as lying within a hyper-arid zone and presenting some broad climatological data. A summary of the broad sources of water for the country is then given. This includes both renewable

resources, non-renewable, and alternative sources such as desalinization and re-use. Chapter 2 concludes with a discussion on the current and future water stresses on the country, including the rapid population growth, expanding tourism trade and strongly expanding economy are putting an ever greater strain on the limited water resources.

Chapter 3, discusses the specifics of the integrated Earth Information System (EIS), which is being envisioned as a key element in better WRA for the UAE. This chapter systematically describes this system, from its meteorological core, that is based on an advanced weather forecasting and weather radar system, combined with other data sets such as local surface observations, global atmospheric models, and other data sets, to provide a state-of-the-art weather forecasting and weather analysis system. From this meteorological core, the EIS will be developed to house other data related to the hydrologic cycle. These include data such as airborne magnetic data used to explore groundwater; borehole water data used in describing groundwater aquifers, hydrologic data such as information about wadis, reservoirs, dams, and other surface hydrologic features. Geographic data sets will also be included, such as information regarding land use and land cover throughout the country, topographic features, roads, built-up areas, green areas, etc The system will house other datasets such as information on tourism, water production by desalinization plants, municipal and industrial water use statistics, etc. Chapter 3 finishes with a discussion on all relevant datasets, which are currently being pursued for inclusion into the EIS system, such as the writing of this dissertation. However other datasets could be included as they are identified or created.

Finally and perhaps most importantly, Chapter 4 asserts that the pursuit of such an advanced EIS system is pointless unless well articulated studies can be identified and pursued. This can make tangible use of the data and information that the EIS could provide. The WRA process is not limited to the assessment of difficulties preventing real WRA, but also providing practical solutions and giving recommendations on how to overcome such difficulties. Several research activities have already been pursued using components of the EIS, which are now supplying data to the core database. Likewise, the EIS also provides data in support of studies such as airborne geomagnetic surveys and experiments in rainfall enhancement. Chapter 5 concludes with a brief description of additional studies that should be pursued that would both support and make use of the advanced EIS. The final chapter provides a summary of the dissertation and a brief discussion.

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Chapter 1
Introduction and Problem Statement

Water is the most essential need of life and without it man can not survive for more than a few days. God has made every living thing dependent on water for its very existence. It constitutes two-thirds of body cell matter and 90% of all body fluids, including the blood as well as the lymphatic and spinal fluids. It is necessary for all biological processes. Furthermore, it contributes to the regulation of body temperature through perspiration.

Islam ascribes the most sacred qualities to water as a life-giving, sustaining and purifying resource. It is the origin of all life on earth, the substance from which Allah created man (25:54), and the Holy Qur'an emphasizes its centrality: "We made from water every living thing (21:30)". Water is the primary element that existed even before the heavens and the earth did: "And it is He who created the heavens and the earth in six days, and his Throne was upon the waters (11:7). " So, it is very clear that in order to understand life and living things on earth it is essential first to understand water and to unveil its secrets, creation, formation and behavior.

1.1. A Global Problem

It is estimated that the freshwater available for human consumption varies between (12,500 km^3) and (14,000 km^3) each year (Hendrickson *et al.*, 1998; Jackson *et al.*, 2001; UNU, 1996; Cosgrove, *et al.*, 2000). And due to rapid population growth, the potential water availability of Earth's population decreased from (12,900 m^3) per capita per year in 1970 to (9,000 m^3) in 1990, and to less than (7,000 m^3) in 2000 (Clarke, 1991a and b; Jackson et al, 2001; Shiklomanov, 1997; Jacobs, 2004; Clarke, 1993). This laid many countries in Africa, the Middle East,

Western Asia, and some Eastern European countries to have lower than average quantities of freshwater resources available to their populations. In densely populated parts of Asia, Africa and Central and Southern Europe, current per capita water availability is between (1,200 m^3) and (5,000 m^3) per year (Shiklomanov, 1999). The global availability of freshwater is projected to drop to (5,100 m^3) per capita per year by 2025. This amount would be enough to meet individual human needs if it were distributed equally among the world's population (Shiklomanov, 1999). It is estimated that 3 billion people will be in the water scarcity category of (1,700 m^3) per capita per year by 2025 (UNPD, 2001). The impressive amount of water, 14 trillion metric tones, and the capacity of the hydrological cycle to supply water is being outstripped by the volume of human demands, pollution of water resources and poor water management.

The distribution of water resources around the globe is highly unequal, even at the continental level. Asia has more than 60 percent of the world’s population but only 36 percent of river runoff (much of it confined to the short monsoon season). South America, meanwhile, has just 6 percent of the global population but 26 percent of runoff. Canada has in excess of 30 times more water available to each of its citizens than China. Many of the world’s largest river catchments run through thinly populated regions, these include the Amazon (15 % of global runoff but 0.4 % of global population), the Zaire-Congo that flows into the Atlantic Ocean, and the great rivers of northern Canada and Siberia that flow into the Arctic Ocean. (UNU, 2004). Meanwhile, many countries with high population density or growth rates, such as Pakistan and Egypt, are in hot, water-stressed regions where crops require irrigation. Water tables are falling on every continent. Water shortages are having an increasing

effect on global grain markets, as arid countries that rely on irrigation for crop production are switching to food imports. As a result, North Africa and the Middle East were the fastest growing import markets for grain in the 1990s. (UNU, 2004) The World Bank warns that freshwater is likely to become one of the major factors limiting economic development. At the start of the 21st century, 49 countries with around 35% of the world population were believed to have less than 2,000 cubic meters of renewable freshwater available per capita per year, implying water scarcity or chronic shortage. Major nations in the list include India, Ethiopia, Nigeria and Kenya. Northern China also faces major shortages. The crisis is likely to worsen by the deteriorating quality of water, polluted by industrial waste and sewage discharges, and spreading of water-related diseases such as cholera and schistosomiasis (Cosgrove and Rijsberman, 2000)

Many regions around the world depend on water from international rivers (Khoury, *et al.*, 1986; Inhabitants FAO, 1989; Uqba, 1992; Green, E.A. 1993; Gleick, 1993; Clarke 1993; ESCWA, 1994; ESCWA, 1995; Browning-Aitken and Richter, 2003; Lawford *et al.*, 2003; Varady and Morehouse, 2003;Browning-Aitken and Richter 2004 and Aparicio and Hidalgo, 2004) . Few agreements to share water supplies have been negotiated anywhere. On the River Euphrates, Turkey has built several large dams without prior agreement with downstream neighbours, Syria and Iraq. On the River Nile, Egypt uses 85 percent of the river's flow but has no agreement with potentially major upstream users such as Ethiopia. Unresolved disputes over riparian rights also fester within many countries.

More than 60 percent of the water used in the world each year is diverted for irrigating crops. Egypt, which must irrigate all its crops, uses more than five times as

much water per capita as Switzerland. In Asia, which has two thirds of the world's irrigated land, 85 percent of water is used for irrigation. A worldwide doubling in the area under irrigation to more than 260 million hectares underpinned the "green revolution" that kept the world fed in the late 20th century. Almost 40 percent of the global food harvest now comes from the 17 percent of the world's croplands that are made productive through irrigation (UNPD, 1994 and UNPD, 1997).

Many believe that as water becomes an increasingly scarce and valued resource, it will become a commodity. This is already true for the UAE where fresh water is produced by converting energy to water through desalination. Where it was once seen as available by right, it might be bought and sold at market prices. This offers potential benefits in its more efficient use, as water prices more closely reflect its cost, but this also holds new dangers for the poor. A thousand tons of water can produce a ton of wheat. If the price of water were to reflect its "true" cost, there is a danger that only the wealthy industrialized sector could afford it, with serious consequences for world food availability.

1.2. Water Resources in the Gulf Countries

Historically, the Gulf countries have suffered enormously from water shortages. It was the availability of water in certain regions that prompted people to settle. The local population adapted to the arid environment, the population was small and restricted to oases and better watered upland areas which could support cattle and crops, as was the case for the United Arab Emirates (UAE). Because of the rapid development and rise in population, consequent with the discovery and exploitation of oil resources, a large volume of groundwater has been used, depleting the

aquifers in the UAE. Now, the UAE faces a real water shortage problem, as neither the amount nor the quality can satisfy the ever-increasing water demands.

In spite of the harsh weather, unfavorable soil conditions, and erratic rainfall of typically less than 100 mm/y, remarkable progress has been made in the agricultural sector in the last 25 years. One negative outcome of this development success, however, has been the non-sustainable consumption of water resources for the agriculture sector which has increased dramatically over the past few decades (UAE country report, 1986; Kuwait country report, 1986; Ukayli and Husain, 1988; Bahrain country report, 1995; Qatar country report, 1995; Yemen country report, 1995; UNDESA, 2002 and UNU, 2004).

The processes of sustainable development, sustainable management and integrated water resources management, are entirely dependent on the reliability of water resources assessment studies and the message they reveal for creating sound management plans. Water Resources Assessment (WRA) is defined as “the determination of the resources, extent, dependability, and quality of water resources for its utilization and control (WMO & UNESCO, 1997).” Also, WRA is defined as the process of measuring, collecting and analyzing relevant parameters on the quantity and quality of water resources for the purpose of development and management of the existing resources. Water resources assessments (WRA) are critically dependent upon the availability, accuracy, and reliability of the necessary data for conducting such studies. Data, and their handling and analysis by qualified personnel, are key for the above mentioned processes, and when data are lacking or are of poor quality, incorrect assumptions can be made regarding the water situation in the country.

1.3. Purpose and scope of this thesis

The purpose of this thesis is to identify activities and management plans which are currently being followed in the United Arab Emirates (UAE) and which have lead to the current, unsustainable exploitation of the nation's water resources. This thesis will lay out a practical national action plan and strategy to ensure the future viability of the water resources sector throughout the UAE. The specific objectives of this study will be to:

- Assess the current difficulties which prevent real WRA in the UAE.
- Evaluate and diagnose existing and available WRA studies in the UAE.
- Envision alternative water resource assessment and management strategies and technologies (e.g. data collection platforms, information systems, integrated databases etc.) that are most appropriate and effective for WRA in the UAE.

The long term objective will be to develop a national action plan to upgrade basic water assessment and management of the UAE with an emphasis on capacity building that can be established with contributions from both internal expertise and the external support of specific agencies that can support the national action plan.

The international standard for the implementation of programs for a WRA can be divided into three main stages:

a) Basic water resources assessment.
b) The extension of networks and more detailed investigations to meet the requirements of water resources development.
c) The provision of the data and information required for the integrated management of water resources (WMO & UNESCO, 1997).

These stages define, specify and analyze the existing difficulties that prevent the implementation of these international standards, and propose definitive solutions that

can eliminate such difficulties, with the goal of creating a comprehensive water assessment program. This in turn will facilitate the pursuit of sustainable management of water resources in the United Arab Emirate.

There are two central tenants of this thesis, the first centered on *data* and the second on *process*. Tenant one states that water resource assessment must rely on high quality data, comprising all aspects of the physical hydrologic cycle and human interventions in this cycle (Figure 1.1).

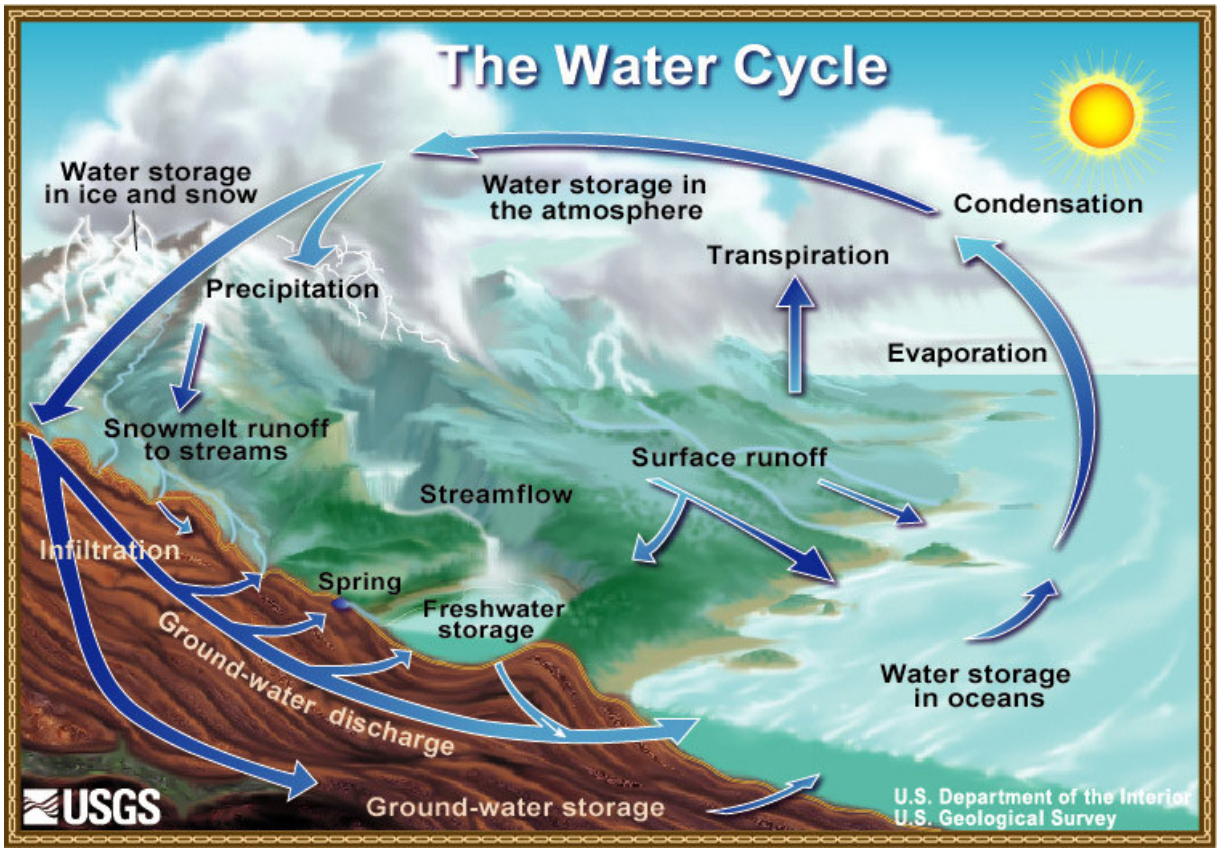


Figure 1.1 The hydrologic cycle (courtesy United States Geologic Survey).

From this tenant comes a grand vision for the UAE, namely the development of a comprehensive Earth Information System (EIS) that is based on an advanced data collection, processing, and storage system from an array of data types (geological, meteorological, hydrologic, agriculture, urban, water, infrastructure, etc.) and data

platforms (remotely sensed, radar, satellite, advanced computer models of atmospheric and hydrologic processes, etc.). The second tenant argues that while the availability of high quality and timely data of the earth system is paramount, these data are of little use without simultaneously defining problems which the data can help address. Quite simply, there must be a reason and purpose for collecting this data, and there must be qualified human resources available to articulate the problems and carry-out the appropriate research. Thus, the WRA process can be improved by developing these capabilities, which if done carefully, should lead to a more sustainable use of our most precious resource-water.

1.4. Water Resources Assessment (WRA)

Compressive water resource assessment (WRA) is the integration of water resources science, engineering and management performed in a holistic manner for the following purposes

a) Formulation of policies / strategies / legislation for water resources development and management.
b) Planning and implementation, operation, regulation monitoring and maintenance of a water resources program.
c) Decision making on water resources development proposals.
d) Research and development in water resources areas in the nation's interest.
e) Development of hydro- informatics technology.
f) International and interdisciplinary communication and exchange of water resources data, information and advances.

Water resources are defined as the “water available or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand (WMO & UNESCO, 1997)”.

WRA is defined as “the determination of the resources, extent, dependability, and quality of water resources for its utilization and control (WMO & UNESCO, 1997).”

Also, WRA is defined as the process of measuring, collecting and analyzing relevant parameters on the quantity and quality of water resources for the purpose of development and management and involves the following activities (Figure 1.2):

1. Planning and implementation of data acquisition stations and network
2. Quality control and verification acquired data.
3. Compilation of data with the best available data management systems.
4. Analysis of data to yield effective water management.

An assessment of the quantity and quality of available water is an essential prerequisite for water resources development and management, whether it is for the purpose of water supply for the population, agriculture, and industry or energy production. The United Nations water conference (Palat, 1977) recognized this fact and resolved that all efforts should be undertaken at the national level to substantially increase financial resources for activities related to water resources assessment.

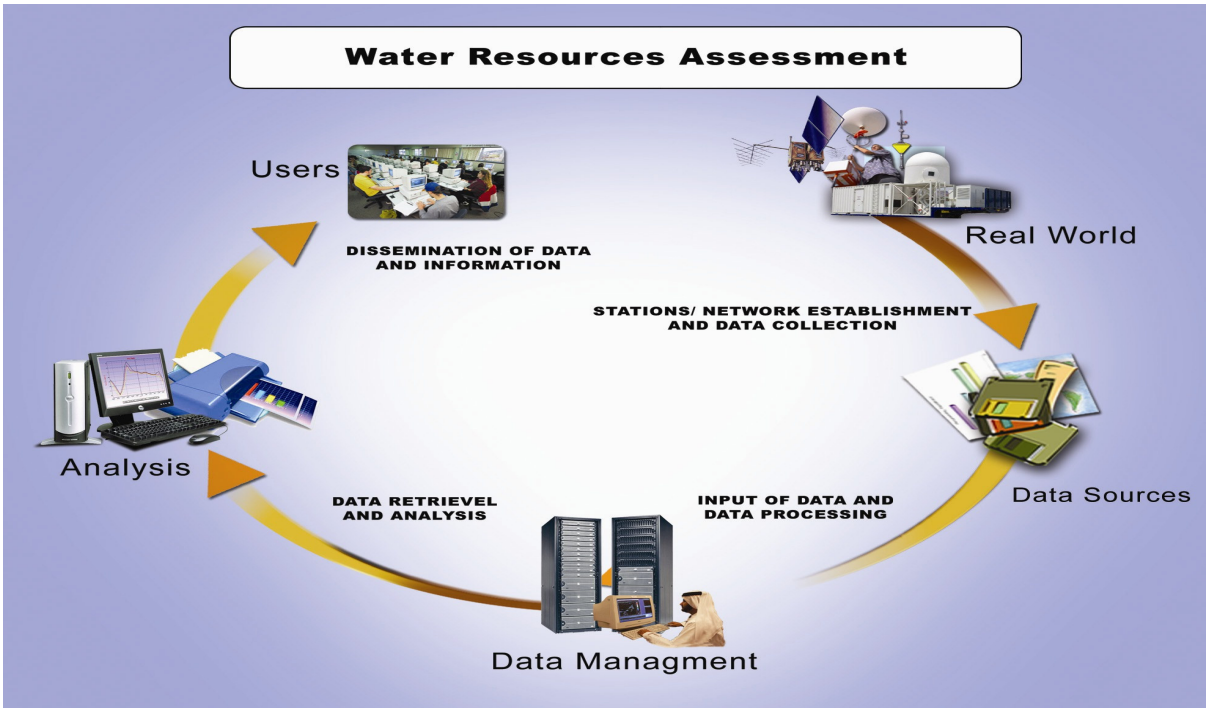


Figure 1.2 General layout of WRA cycle.

1.5. Water shortage or Drought

Water shortage is an international problem which is independent of the quantities and quality of water resources. Importantly, water shortage is *not* drought. Water shortage condition exist when sufficient water is not available to meet present or anticipated needs of persons using the water resource, alternatively when conditions are such to require temporary reduction in total water usage within a particular area to protect the water resource from serious harm.

Water shortage can be sub-divided into four categories. Each of these will be discussed independently in the following sections.

1.5.1 Natural Water shortage (water deficiency)

Deficiency here is simply a lack of natural precipitation often compounded by geographic location, topographic features and other natural conditions such as poor soil quality. This situation occurs in countries or regions located in arid and semi-arid

regions with little to no surface water resources existing (rivers and lakes) (Newson, 1992). Prime examples of this type of water deficiency are most of the Arabian Peninsula and North African countries.

1.5.2 Water Shortage due to water pollution

Not only is freshwater being over-used and wasted, it is also increasingly polluted making it impossible to use and gives rise to an effective “water shortage” situation. Each year roughly 450 cubic kilometers of waste water are discharged into rivers, streams and lakes globally (People & the Planet, 2000 – 2004).

To dilute and transport this dirty water before it can be used again, another 6,000 cubic kilometers of clean water are needed - an amount equal to about two-thirds of the world's total annual useable freshwater runoff. If current trends were to continue, the world's entire stable river flow would be needed just for pollutant transport and dilution, by the middle of this century. In developing countries, on average, 90 per cent of all domestic sewage and 75 per cent of all industrial wastes are discharged into surface waters without any treatment whatsoever. Consider the following examples:

a) Over three quarters of China's 50,000 kilometers of major rivers are so filled with pollution and sediment that they no longer support fish life.
b) All of India's 14 major rivers are badly polluted. Together they transport 50 million cubic meters of untreated sewage into India's coastal waters every year.
c) In greater Sao Paulo, Brazil, 300 metric tons of untreated effluents from 1,200 industries flow untreated into the Tiete River every day. The river contains high concentrations of lead, cadmium and other heavy metals.

d) In Thailand and Malaysia water pollution is so heavy that rivers often contain 30 to 100 times more pathogens, heavy metals and poisons from industry and agriculture than is permitted by government health standards.
e) Developed countries have polluted their surface waters as well. Two thirds of Europe's major rivers contain excessive loads of oxygen-robbing nitrogen and phosphorus from chemical fertilizers, along with pesticide residues, industrial effluents and municipal wastes.

The United States' largest river, the Mississippi, which drains 40 per cent of the lower 48 States, transports more than 1.6 million metric tons of nitrogen every year into the Gulf of Mexico. Most of the nitrogen comes from agricultural activities. The nitrogen and other pollutants carried by river have created a "dead zone" that extends some 60 miles offshore. Expanding every year, it now encompasses an area the size of Rhode Island (Newson, 1992; Sampat, 2000).

1.5.3 Water shortage Due to Political Conflicts

Water has become a very precious commodity that will probably be sold and traded internationally in the future. One example has been Turkey's ambitious proposal in 1987 for a "Peace Pipeline" project to transfer water from the Seyhan and Ceyhan river systems in south-eastern Turkey to the Euphrates basin and to other countries downstream. This project would require the construction of a series of dams, water tunnels, and the world's longest international water pipeline system, with a total length of approximately 6,550 km and a capacity of 6 million cubic meters a day (Green, 1993). The problem of circumstantial water shortage arises between countries having mutual rivers and borders. An example of this situation is the conflict between Syria, Iraq, and Turkey. Turkey, in an attempt to bolster its water storage capacity has attempted to build a number of dams. The damming of water obviously severely reduces the amount of downstream flow to Syria and Iraq.

However, the water was used as a political weapon to force Syria to curtail its support for Kurdish activists in south-east Anatolia (Green, 1993).

1.5.4 Water shortage due economics

Not all countries in the world have water shortages as a result of an actual lack of availability. The lack of resources to develop infrastructure in order to access the untapped water supply is an important impediment to many developing nations. Sudan, a country with longest part of the Nile River within its borders, suffers from severe water shortage for agricultural and domestic use. Figure 1.3 indicates that large parts of India and China suffer from similar problems (William J. Cosgrove and Frank R. Rijsberman, World Water Vision).

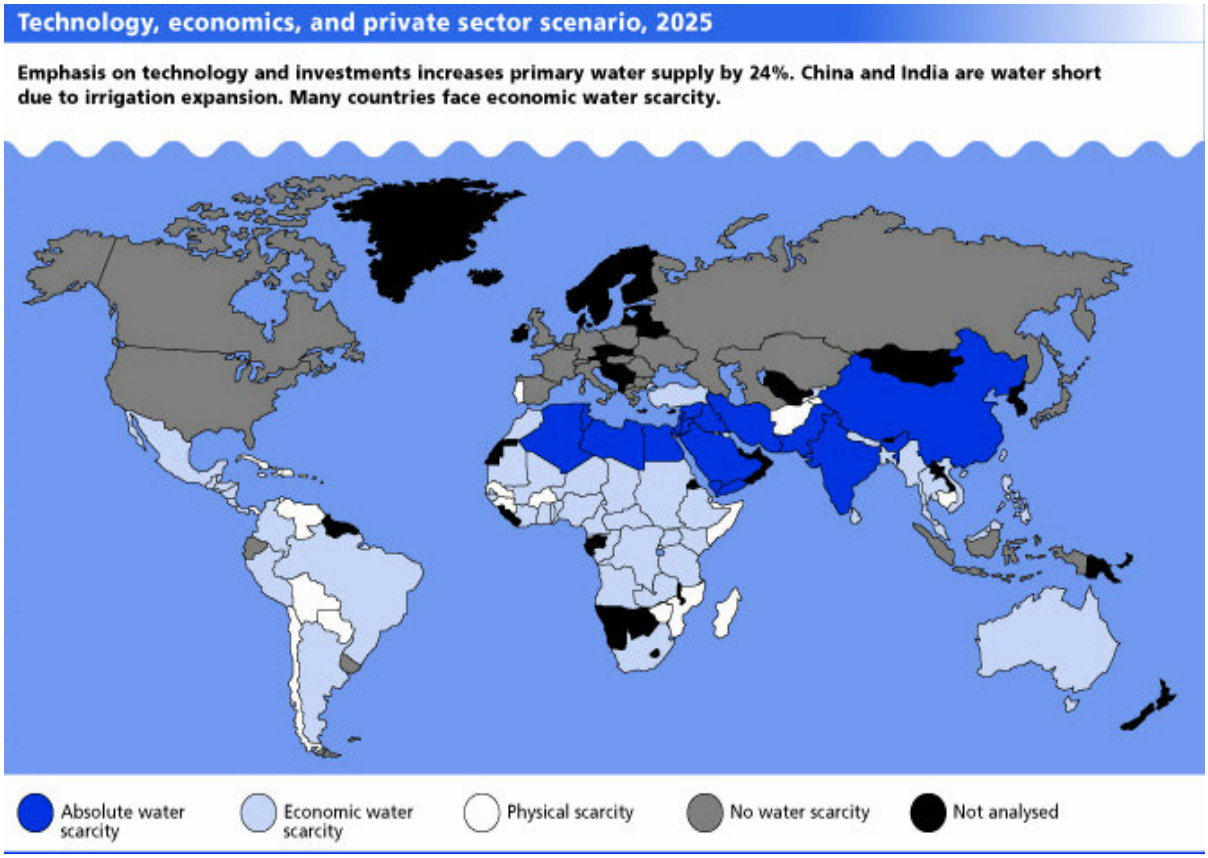


Figure 1.3 Projected water use and water stress in 2025 (Cosgrove and Rijsberman, 2000).

1.6. Drought

As mentioned, water shortage is not drought. If so, then what is drought? There are many definitions for this word. The dictionary defines drought as: *A long period of abnormally low rainfall, especially one that adversely affects growing or living conditions*. For areas which receive high amounts of precipitation, a condition of drought can develop more rapidly than in an area which doesn't receive high amounts of precipitation. Many problems can arise due to droughts, including crop damage and water supply shortage. The severity of drought depends mostly on the degree of the deficiency, the time period, and the size of the area affected. Timing is also an important factor in defining drought, such as its onset and duration, the primary season in which it occurs, delays in the beginning of the normal rainy time periods, and rain events occurring relative to the growth stage of crops are examples of this timing.

In addition to the general definition of drought described above, there are two alternative drought classification definitions. A conceptual definition is useful for a general understanding of drought, and is useful in establishing drought policies. An operational definition helps people understand things like the beginning, end, and severity of droughts. When the beginning of a drought is determined, the operational definitions help in specifying the degree of departure from average of precipitation over a time period. This can be done by comparing the current conditions with historical climatic data, usually over a 30-year period of data. This definition can also be used when dealing with agriculture and helps address drought impact on crops and the rate of soil water depletion. Drought severity, frequency, and duration for a historical period can be established operationally, but require weather data at various

time scales (such as monthly, seasonally,, or annually). This information can be extremely useful in preparing for possible future droughts. Four perspectives on drought are presented below.

1.6.1 Meteorological drought

Meteorological drought is usually defined by the measure of the departure of precipitation from the normal and the duration of the dry period. Atmospheric conditions that cause the deficiencies of moisture vary greatly from region to region. Some definitions identify droughts based on the number of days an area goes without precipitation relative to a specified “normal” level. The biggest challenges here is to define “normal” precipitation, as in certain areas, such as arid and semi-arid regions, this is particularly challenging. Often the variability of precipitation is greater than the mean. Representing meteorological drought on an annual timescale is arguably most appropriate, since it eliminates seasonal biases.

1.6.2 Agricultural drought

Agricultural drought refers to the situation in which the moisture in the soil is no longer sufficient to meet the needs of the crops growing in the area. Focus is placed on precipitation shortages, reduced ground water/reservoir levels, differences between actual and potential evapotranspiration and so on. Good definitions of agricultural drought will account for susceptibility of crops during different stages in its development. When soil moisture is lacking, this may hinder proper plant development, leading to lower final yield. The water demand of a crop depends on weather conditions (such as temperature, relative humidity), its biological make-up, what stage of growth the crop is in, and the physical/chemical make-up of the soil. If soil moisture is high enough to allow for proper early development, later lacking

moisture may not deplete final yield if the moisture can be replaced as the growing season goes on (e.g. irrigation or sufficient rainfall meets those needs).

1.6.3 Hydrological drought

Hydrological drought deals with surface and subsurface water supplies (such as stream flow, reservoir/lake levels, ground water). Extended periods of insufficient precipitation cause these water supplies to drop below normal levels. This drought definition differs from others in one significant way, Hydrological drought usually lags behind the others since the lack of moisture reveals itself in places such as ground water and surface water reservoir with a time delay. This can affect things such as hydroelectric power plants and recreational areas.

Though changes in climate and weather are the main contributors to hydrological drought, things such as changes in landscape, land use, and construction of dams also have impacts on drought. An example of this type of process occurs in the Northern Great Plains of the US. Since the Missouri River flows to the south, the lack of moisture to the north will impact the area downstream from the area receiving less precipitation. Changes in land/water use in the region will alter the hydrological characteristics of flow and runoff rates, which in turn could amplify the drought in the area downstream from the area of origin. Thus, land use changes and human alterations of the hydrologic cycle can alter the frequency and intensity of water shortages, even when no meteorological drought is observed in the immediate region.

1.6.4 Socioeconomic drought

A socioeconomic drought takes place when the supply of economic goods and services cannot meet the demand for that product, and the cause of this short-fall is

weather-related. In most cases, demand for goods and services increase due to population pressures and income effects. Improved production, technology and construction of reservoirs for water supplies may increase the supply of goods. If both are increasing, the rate of this change is crucial. If demand is increasing faster than the supply, the impact of a drought will be much more significant on the area it affects.

1.6.5 Droughts in the UAE

Many people consider droughts to be a rare event when in fact they are a normal and recurrent feature of the climate. Drought implies a lack of moisture for an extended period of time which in turns causes a deficit of moisture in the soil. This can mean different things for different areas.

Many problems can arise due to droughts, including crop damage and water supply shortage. How severe a drought is depends mostly on the degree of the deficiency, the time period, and the size of the area affected.

There are four perspectives on drought: meteorological, agricultural, hydrological, and socioeconomic. What we are concerned with in this dissertation is the meteorological drought. Meteorological drought is usually defined by the measure of the departure of precipitation from the normal and the duration of the dry period.

It is extremely important to distinguish between two types of droughts because they result from different causes and require different remedial actions when both occur.

Short Term Meteorological Drought

Nil rainfall – Few weeks/months

Dry ground – temporary lower stream flows

Long Term Hydrologic Cycle Drought

- Normal annual rainfall but drastically lowered accumulation of water in aquifers - permanently decreasing stream flows and drying up of wetlands and springs.

- Caused by over abstraction from wells exceeding recharge flows into aquifers and water resource system - lack of sufficient reservoir capacity.

Droughts are common in the United Arab Emirates (UAE). The normally meager annual precipitation causes extended periods of scant flow or no runoff at all in the UAE. Rainfall records can be used as one means to determine the duration and aerial extent of droughts.

Generally, the annual rainfall fluctuations did not show any cyclicity or trend, as seen in Figure 1.4. The rainfall over an area follows certain cyclic variation over a long period. The trend in rainfall is analyzed based on the technique of moving average. The moving average is an arithmetic average or a tool, like bar charts that can help predict when a trend is going up or down. The effect of the moving average process is to ameliorate the degree of variation within the original series by composing the new smoothed series.

A period of five years is selected for moving analysis (Figure 1.5). The annual departure from average rainfall for any year is the difference between the average rainfall for that year, which is determined from the daily, monthly or annual records, and the average rainfall for the period of record. Annual departures of rainfall for the whole UAE are shown in Figure 1.5. The curve above the average annual rainfall line is a positive departure from normal condition (wet condition), and the curve below the annual average annual line is a negative departure from normal (Dry condition). It is noticed from Figure 1.5, that the period before 1974 passed a large drought period and after this period the country passed by different wet and dry conditions where the period of wet seems to be larger than the drought particularly in the last ten years.

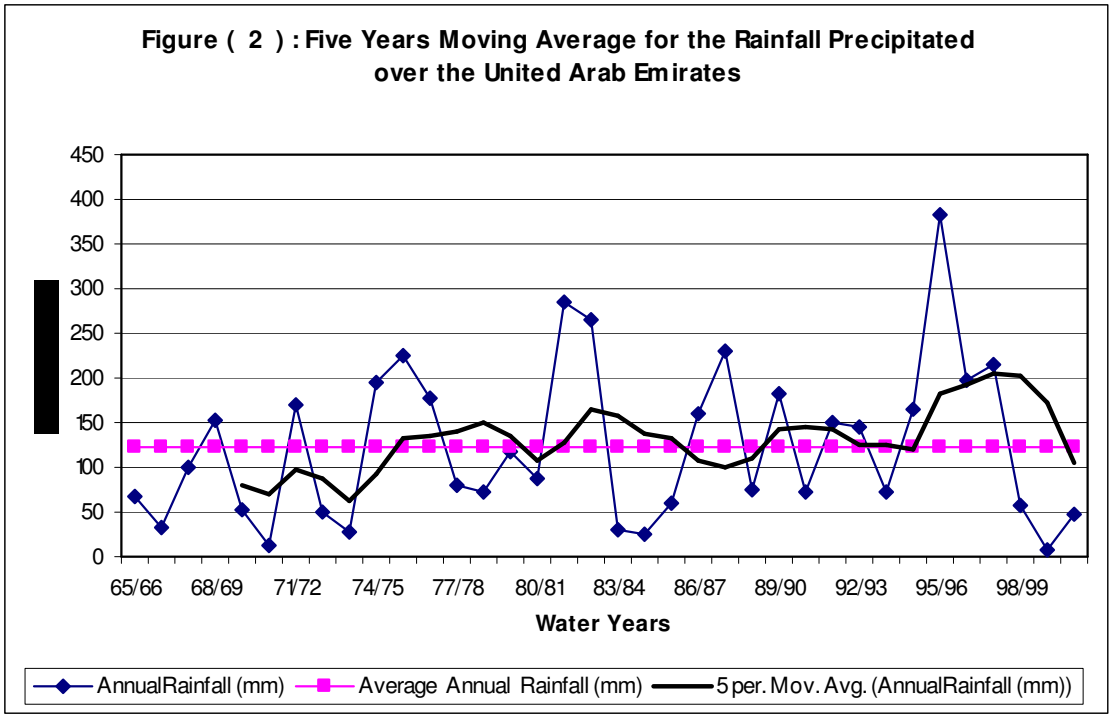


Figure 1.4. Short term drought trends over the UAE for the between 1965 and 1999 After, Ministry of Agriculture and Fishery, 2005).

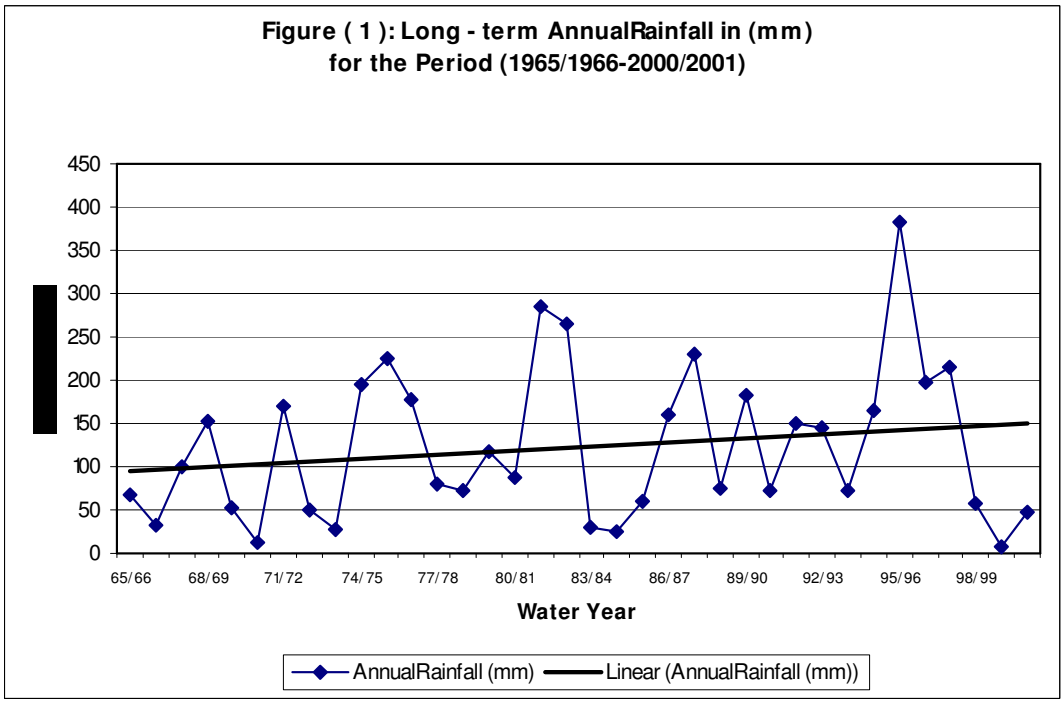


Figure 1.5. Long term trends of drought over the UAE between 1965 and 1999 (After Ministry of Agriculture and Fishery, 2005).

1.6.6 Current situation of water resources in the Arabian Peninsula

Throughout history a lack of abundant freshwater in the Arab world has affected the lives and livelihood of its inhabitants. A remarkable variety of adjustments to water supply fluctuations and deficits have been made by the indigenous people over the years. Historically, the peoples of the region were transient, largely a result of the harsh environmental conditions of the hyper-arid region. Perhaps the most important historical development was the falaj (pl aflaj). This is a local word used in both the UAE and neighboring Oman and describes an irrigation system that has been locally developed in southeast Arabia since the Iron Age, approximately 3000 years ago (Figure 1.6). The system can be described as a horizontal underground tunnel connected with surface vertical shafts. Water is drawn through this tunnel from the original source to cultivated land or a village through gravity (Burdon, 1973; Mohammed, 1986; Edgell, 1987; Shahin, 1989; Bushnak, 1992; El-Zawahry, and Ibrahim, 1992; Bushnak, 1995 and Saad, 1995)

There is no fixed length for the tunnel, which can be from 3 to 30 kilometers in length. However, a 10 kilometer long tunnel is the standard length in the region. The city of Al Ain alone has many of these aflaj, (dry and alive) belonging to different periods. The archaeological evidence shows that two of them at least go back to the beginning of the first millennium BC.

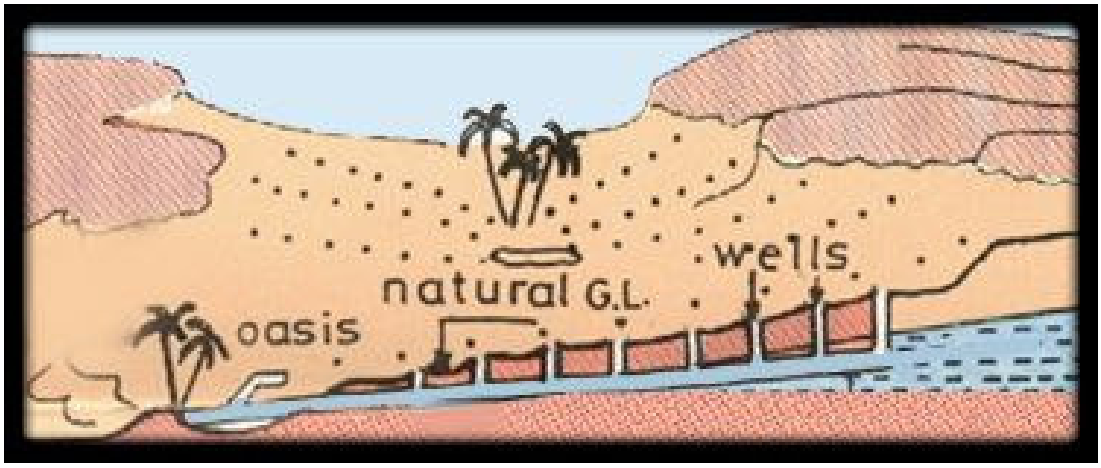


Figure 1.6 Simple schematic of a Falaj.

More recently, however, socio-economic development, high population growth, the availability of modern pumping and irrigation technology, as well as expanded urbanization and agriculture activities, have placed substantial strains on water resources. High population growth in combination with increases in per capita consumption has contributed a significant increase in water consumption. An important aspect of the region's water supply shortage is the fact that all countries on the Arabian Peninsula are situated in extremely arid zones. The intensive use of ground water resources from shallow and deep aquifers to meet rising demand has led to further exploitation of water resources in excess of natural renewability and has contributed towards water quality deterioration, especially in the coastal regions. This has compelled all countries suffering from water shortage to invest in the construction of sea water desalination plants. Rising demand is not only placing pressure on water resources, especially the most easily accessible sources, but also brings about an entirely new progression of environmental concerns and associated development costs (UNU, 1996).

1.6.7 Recycled waste water

Existing waste-water treatment facilities in the Arabian Peninsula face difficulties in handling the ever-increasing volumes of waste water generated by increased water consumption and urbanization. Waste-water discharge from major urban centers is polluting shallow alluvial aquifers and the coastline, and has caused urban water-tables to rise. The main emphasis to date in these countries has been on simple disposal of waste water, rather than on treating and reusing effluent, owing to the extensive capital investment required for the latter. Planning for the full utilization of treated effluent remains in the early stages, and the regional treatment capacity is sufficient to handle only 40 per cent of the domestic waste water generated. The total volume of recycled waste water used in the Arabian Peninsula is estimated at about 433 mcm, which is far less than the volumes treated. The reuse volumes are shown in Table 1.1, which represent approximately 25 per cent of the available treated waste water (UNU, 1996).

Table 1.1 Water resource summary in each country of the Arabian Peninsula (Abdulrazzak, 1992).

Country (area km2)	Average Annual Rainfall (mm)	Run-off (mcm)	Shallow Ground Water Reserves (mcm)	Run-off Utilizt. (mcm)	Ground Water Rchgr. (mcm)	Ground Water Use (mcm)	Desal. (mcm)	Waste Water Reuse (mcm)
KSA (2.15E6)	33-550	2,230	84,000	900	3,850	14,430	795	217.0
Kuwait (1.8E4)	30-140	0.10	182	-	160	80	240	83.0
Bahrain (652)	30-140	0.20	90	-	100	166	75	9.5
Qatar (11.6E4)	20-150	1.35	2,500	0.25	50	190	92	25.0
UAE (8.4E4)	**80-160**	**125**	**20,000**	**75**	**125**	**900**	**385**	**128.0**
Oman (2.1E5)	80-400	918	10,500	275	550	645	32	25.0
Yemen (5.28E5)	10-1E3	2,000	13,500	475	1,525	1,200	9	6.0
Total	40-363	5,275	130,772	2,700	6,360	17,611	1,628	493.5

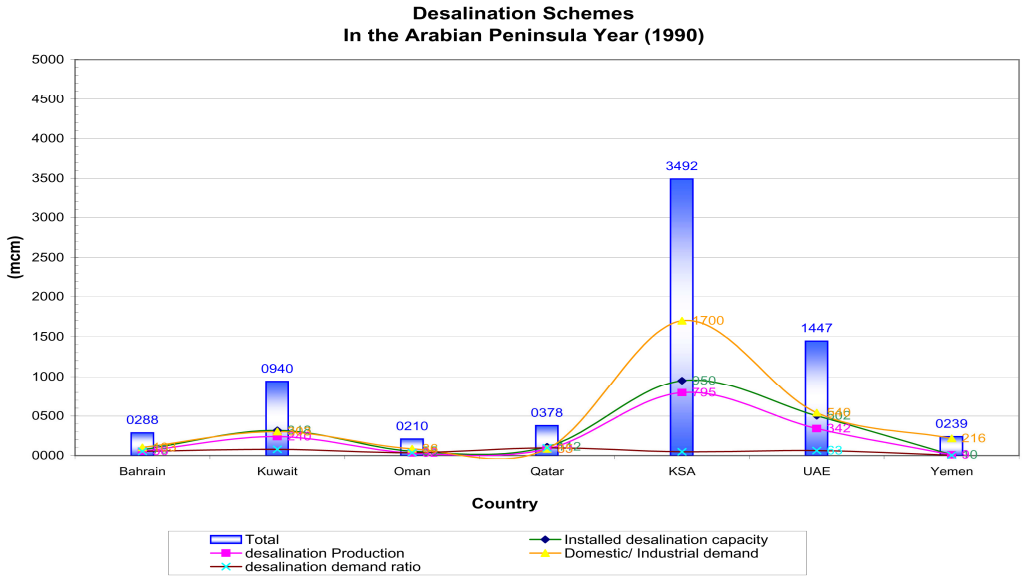
1.6.8 Desalination

During the last twenty years, many of the countries of the Arabian Peninsula have become increasingly dependent on desalination to meet their water-supply requirements (Figure 1.7). Several of the Gulf countries, however, have no option but to rely on the desalination of sea water or brackish groundwater. This is due to renewable groundwater supplies that are small and often of poor quality as a result of the limited recharge magnitude and salt-water intrusion. In addition, the deep aquifers, particularly those near the coastal zones, usually contain highly saline water, requiring desalination.

More than 80 per cent of desalinated water in the Gulf region is produced through Multi Stage Flush (MSF) distillation, while Reverse osmosis (RO) accounts for 16 %. These desalinization activities account for three-quarters of the world's capacity of MSF desalination and about one-quarter of RO production. The Gulf countries share in multi-effect distillation (MED), electro dialysis (ED) and vapor compression (VC) as well as other processes, at the respective rates of 16.4, 16.6, and 5.5 %. The rapid increase in population in the GCC countries including UAE followed by accelerated expansion in all sectors (agriculture, industry, tourism for example) has increased the pressure on water and electricity supplies. Thus it was wise to select a cogeneration technology that recovers the waste heat from gas turbine during electricity production and converts it to water by means of MSF desalination technologies which had been most widely used over the past decades. The extensive use of desalination technology has required substantial financial investments from the GCC governments. Future projections indicate that more

investments in desalination technology will be required to offset overexploitation of water resources and increased public demand.

The UAE is expected to substantially increase its desalination capacity over the coming decades, particularly for its urban centers at Abu Dhabi and Dubai (Abdulrazzak, 1992). Desalinated water will constitute a main source of water for domestic requirements for most of the countries of the peninsula, particularly Kuwait, Bahrain, Qatar, and the United Arab Emirates.



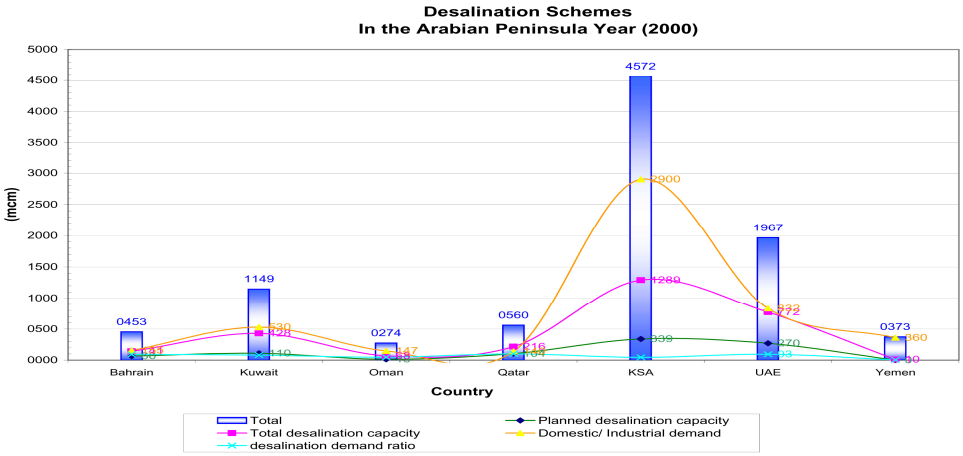


Figure 1.7. Desalination schemes in the Arabian Peninsula.

1.6.9 Aquifers Artificial Recharge

In contrast to the natural recharge, Artificial Groundwater recharge is defined as the underground storage of water in a suitable aquifer introduced through wells, galleries, trenches, channels or basins. The principle of Artificial Recharge is not new as it is applied in numerous schemes in many parts of the world, where access water (Surface water or Desalination Surplus) is introduced in the underground, mostly to sustain over-exploited aquifer systems.

Chapter 2
BACKGROUND ON THE UAE

In order to assess water resources in the United Arab Emirates, it is important to consider its geographical location and resultant climatology as well as the topographical features that influence precipitation processes and water storage and recharge.

2.1. Geographical and Topography Background

The UAE is situated between latitudes 22 and 26.5 and longitudes 51 and 56.5. The Gulf is on its northern border, Oman and the Arabian Sea are on its eastern border, Saudi Arabia to the South, and Qatar and Saudi Arabia border on the west. It covers a total area of 83,600 Km². Importantly; the UAE can be considered to lie within a hyper-arid zone (Figure 2.1).

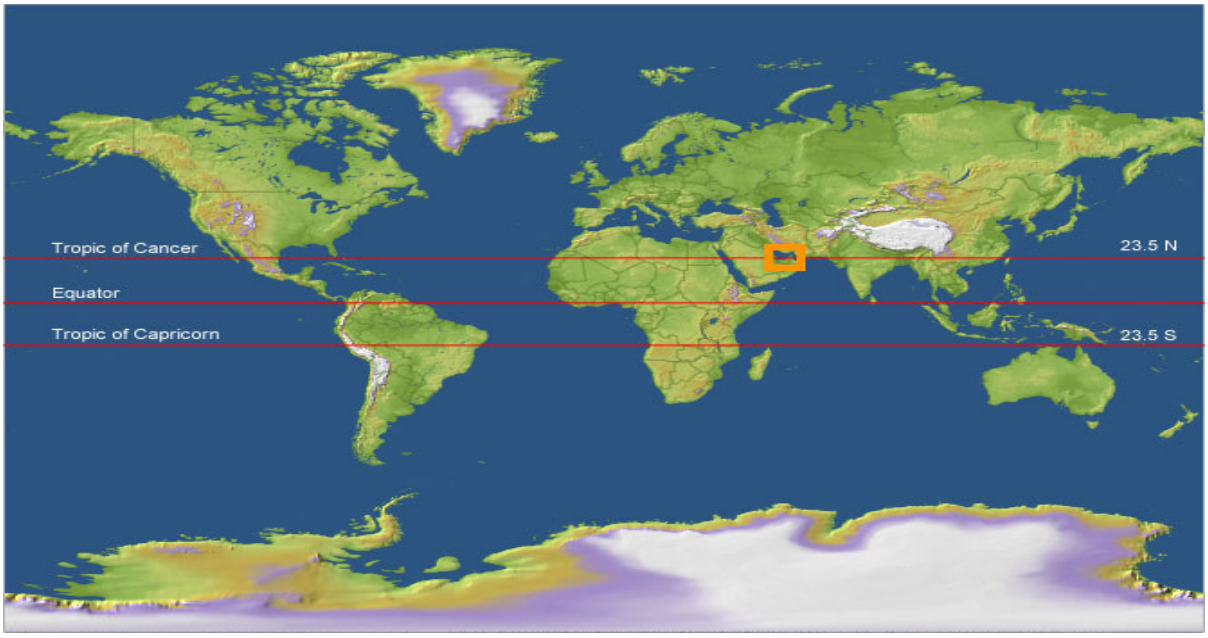


Figure 2.1 Geographical Location of UAE (Orange box indicates position of the UAE).

The UAE union was achieved on the 2 December 1971 and comprises seven emirates: Abu Dhabi, Dubai, Sharjah, Ras Al-Khaimah, Fujairah, Ajman and Umm Al Quwain.

Physiologically, the UAE is divided into three areas; a range of mountains on the North-East, a flat coastal strip to the north, and arid deserts, rich with sediments to the south (Figure 2.2). The South-Eastern part of the UAE is dominated by gravel plains covered by sand dunes formed by the strong winds. Moving to the North-East we notice diminution of the gravel plains which are replaced by semi-shifting sand dunes in the midst of the sabkha (marsh) areas. Just west of the Oman Mountains spread many vast alluvial fans associated with wadi outflows, formed long ago.

The vast low level plains and desert vary in ranging from areas below sea-level up to 300 meters above sea level. Progressively this low-level terrain gradually mingles with the range of high mountains. In between there are twisting hills lying towards the North and South. The summit of which is 1200 meters above sea level. There are also salt rocks forming saline domes in the sea, and hills on the land. Examples of this phenomenon may be seen at Jabal Al Dhanna, which is 99 meters above sea level. The range of mountains, which form a natural boundary between the UAE and Oman, extend 150 kilometers inside the UAE, while its maximum expanse to the East and West is 50 kilometers, an extension of Omani mountains with a summit that reaches 2,438 m above sea level. This variation of terrain affects the UAE climate to a great extent. In the UAE, there are many green valleys and the forestation and 'greening of the desert' policy has transformed thousands of hectares of land throughout the country into greenery.



Figure 2.2 Topographical map of UAE.

2.2. Synoptic Features of the UAE

Climatic variability and change is an important scientific, social and political topic around the world. Changing climates have important implications for many parts of the world, such as rising sea levels, and water and food resources. The location of the UAE and its characteristic land-sea distribution and the dominance of subtropical anticyclone, as a result of the descending limb of the Hadley cell, provide this region with a subtropical desert climate with several typical climatic features. The position of the UAE relative to the Arabian Gulf and the Indian Ocean also exerts an important influence on the creation of the large desert zone, which also extends over North Africa and Western Asia (DWRS, 2002). In general, the annual flow over the UAE can be classified into two main circulation fields, one in winter and the other in summer. These two circulations are separated by two transitional periods that are characterized mostly by unstable atmospheric circulation.

2.2.1 Winter Circulation

The winter (December – March) is historically regarded as being the wet season in the UAE. Rainfall may be related both to troughs over the region and the development of convective activity. The subtropical high pressure cell gets established over Northern Iran, the Caucasus region and the Anatoly Plateau in winter and the Siberian High intensifies. Low pressure over the Indian Ocean during this period also plays a role in the circulation. At the equator, during December and January, we find the 1000mb start to increase to 1005mb On the Arabian Sea. In winter, the most effective system over the region is the High pressure over Iran, which brings cool and dry northwesterly to northerly winds to the area. During this season, the Extreme Minimum temperature over the Emirates may reach a value of less than 2.0℃ in some places. This circulation would lead to a drying of the region if not for the low pressure that drifts into the area from the Mediterranean Sea, where low pressure cells form, due to the relative warmth of the seawater. These shallow lows systems have an average central pressure of 1018 hPa and are accompanied by weather disturbances such as rain and thunderstorms.

Once this low is formed, it is accompanied by a front called the "Mediterranean Arctic Front". Hence, when the tropical warm air currents (coming from the south) meet the Arctic cold currents coming from the north, the low-pressure systems form and move towards the east. It was noticed that the lows which drift to the east, start forming over the Island Cyprus and thus it is called the “Mediterranean Low”.

2.2.2 Summer Circulation

The summer circulation brings heat waves and sandstorms to the area but is usually not accompanied by any rain except for thunderstorm development over the mountains. The extreme maximum Temperature over the Emirates during summer

may reach 52°C in some places. During this period, the Euro-Asian High disappears due to the heat and is established over the Azores Islands in the Atlantic Ocean. Over Northern Africa, and West, Central and South Asia, a series of seasonal thermal low pressure systems form, the most effective of which is the one established over the Pakistan plain and North-West India. This is known as the “Indian Seasonal Low". The ITCZ is between 22° and 24°N latitude, i.e., it is just over the Emirates. The atmospheric pressure over the Indian Ocean during this period is weak but relatively high when compared with the low pressure over the Arabian Peninsula. It is for this reason that this ocean is considered as an effective source of rain over the Emirates during this season. The subtropical high variance in the upper atmosphere is an important factor contributing to the lack of precipitation in summer as the air subsides and reduces the chance for the development of clouds and rainfall.

The first transitional period

This period starts at the end of March and ends in May (spring), when the high pressure cells over Central and West Asia weaken because of the heat and low pressure systems start to appear over North-East India and the South-West of the Arabian Peninsula. The weather activity during this period is strong over the Eastern part of the Mediterranean Sea and the plains to the south of it, which help in the formation of the low systems that give heavy rain showers in spring. These showers intensify with the arrival of the Arctic Air in the upper layers of the Troposphere, which creates a condition of instability. Starting mid-April, the surface becomes hot enough to help the uprising air currents to ride and meet the Arctic Air in the upper levels, forming local thunder activity cell. This is accompanied by sudden heavy rainfalls. Wind direction during this period is not as steady as in winter or summer. The North-

Westerly winds decrease, somewhat, where as the northerly winds increase, as do the south-easterly winds. These winds usually bring hot air, which gives the period some of the characteristics of the hot season where the temperature reaches a little below 40℃, and represent an early summer period located between two relatively less warm periods.

The second transitional period

Occurs between September and November (autumn), when the low-pressure systems over Asia start to weaken because of the drop in the temperature. At the same time the Siberian high pressure comes back to its old position, and the pressure quickly increases over Siberia and Central Asia. Low pressure, as in the spring transitional period re-appears and increases in November and brings rain accompanied by thunderstorms. During this period, the north westerly winds decrease to less than in summer and winter, but prevailing northerly winds increase as do the southerlies (DWRS, 2002) .

2.3. Climatologically Background

During the years (1966-2001), UAE has been affected by many synoptic patterns such as, the Siberian high pressure, the Mediterranean trough, the Red Sea trough, the Indian Monsoon trough and the Thermal low over the Arabian Peninsular. The combined effects of the geographic, topographic and physiographic settings are responsible for shaping the general climatic features, particularly in respect to the distribution of rainfall in the region.

2.3.1 Precipitation

The rainfall distribution in the UAE region is directly related to the prevalence of the atmospheric circulation. Due to the effect of many troughs and the formation of

some cumulus clouds over the mountainous regions, especially during the spring season, there were several records of precipitation, of which the mean monthly total rainfall was between 37.9 mm during February and 0.3 mm during June. The maximum total monthly rainfall, was 286.6 mm during February 1988 (Figure 2.3).

2.3.2 Evaporation and Evapotranspiration

In the Arabian Desert and the gulf region, the evaporation rate reaches 2500 mm/year (This value is calculated by Penman Equation for the measured annual potential evapotranspiration) along the coasts and rises considerably towards the interior. Evaporation capacity usually denotes the maximum possible evaporation from the underlying surface with unlimited moisture reserves under given meteorological condition. The minimum amount of evaporation over U.A.E occurs in January (4.2 mm/day), and the maximum in June (13.9 mm/day), (Figure 2.4).

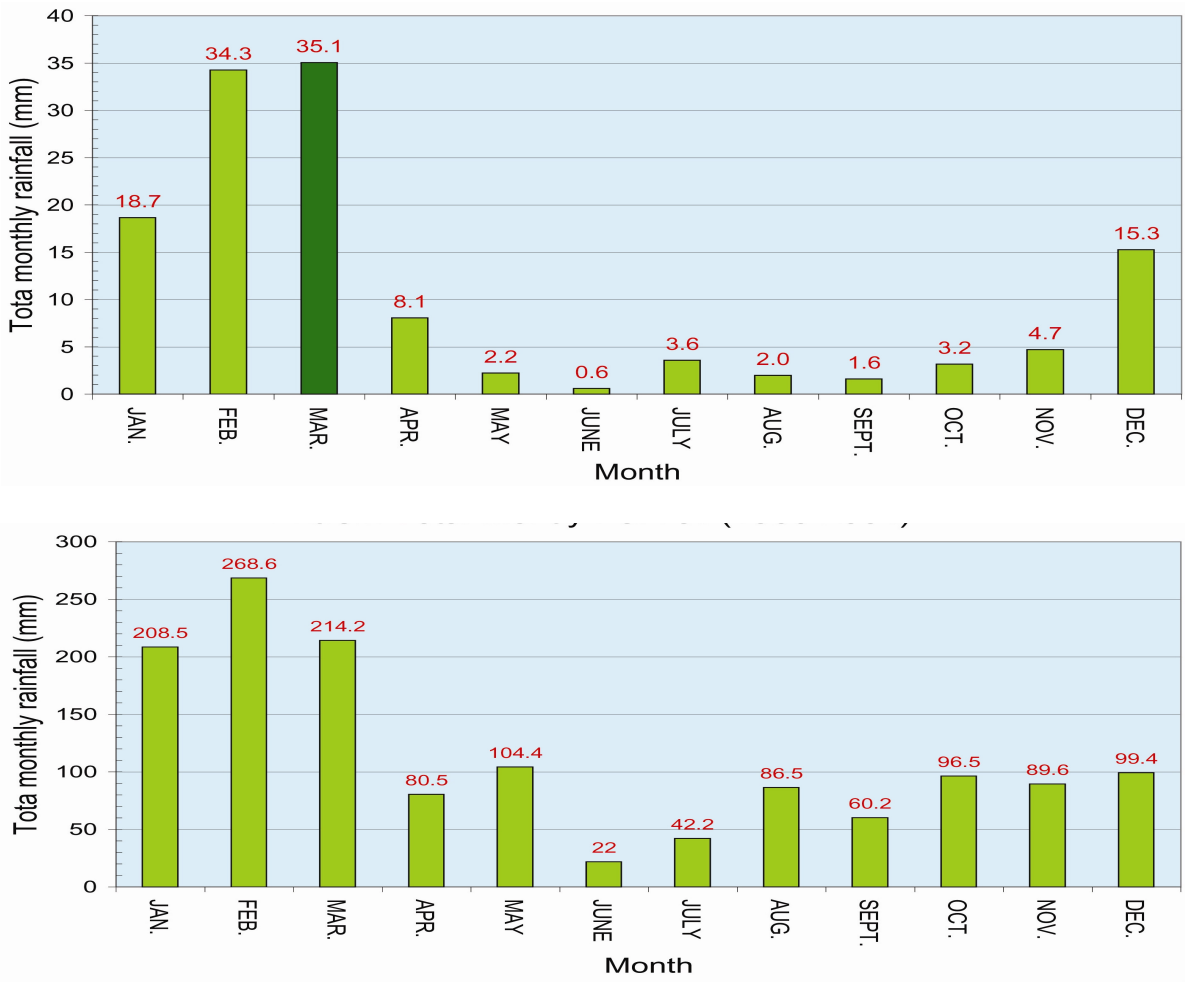


Figure 2.3 Total monthly mean (top) and extremes (bottom) rainfall between 1996 and 2001 (Ministry of agriculture records).

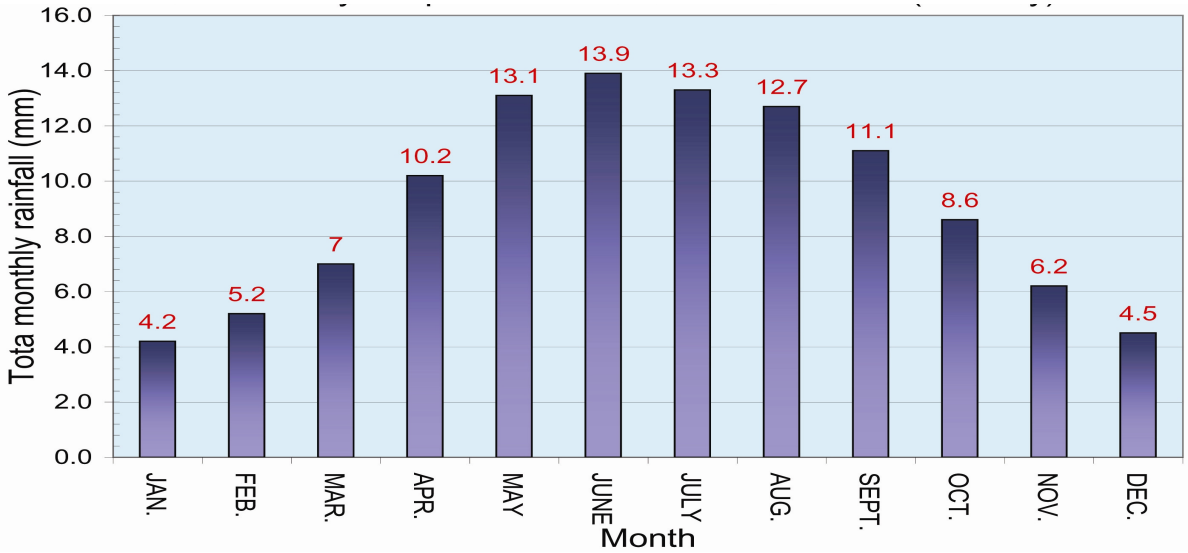


Figure 2.4. Mean monthly Evaporation in mm.day^{-1} over UAE between 1996 and 2001 (Ministry of agriculture records).

2.3.3 Surface Dry Air Temperature

The average measured temperature ranged from 18.3 ℃ during January to 35.1℃ during July, The maximum mean temperature ranged from 24.2℃ during January to 41.8℃ during July. The minimum mean temperature for the years 1969-2000 was between 12.4℃ during February and 28.3℃ during August. Furthermore, the highest maximum temperature recorded was 50℃ during July 1992, whereas the lowest minimum temperature was 2.9℃, recorded during February (Figure 2.5), (Ministry of Agriculture).

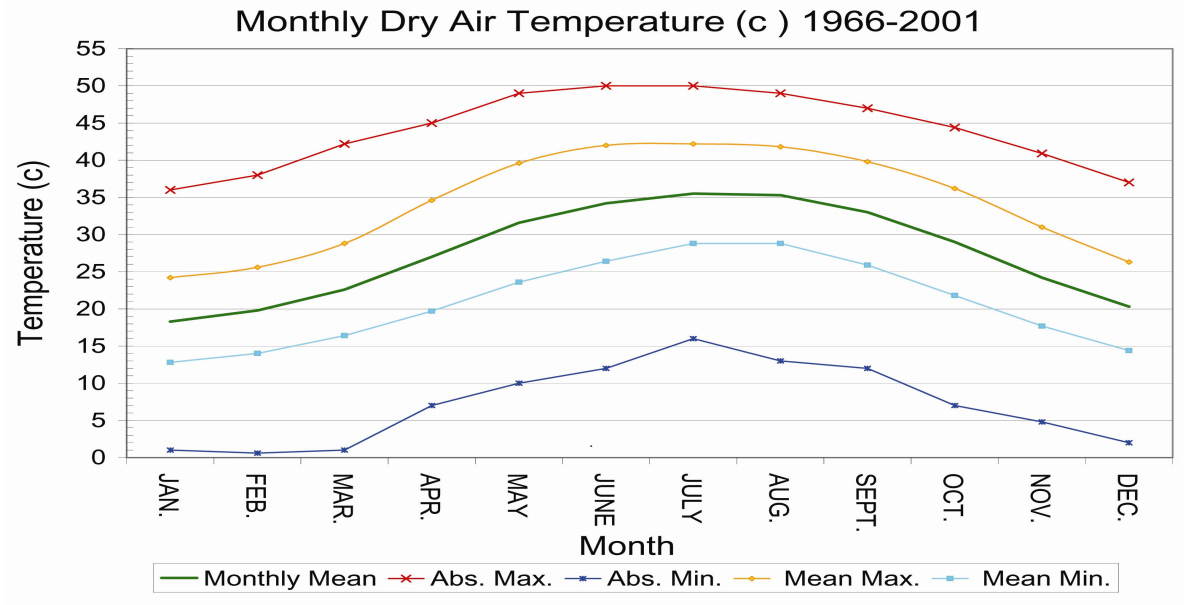


Figure 2.5 Monthly measured dry Air Temperature Cº 1966 – 2001 (Ministry of agriculture records).

2.3.4 Relative Humidity

The average monthly relative humidity varies between 51% during June and 64% during September. Whereas, the mean maximum relative humidity varies between 89% during January and 76% during May (recorded at many parts of the country), and the mean minimum value was between 39% during January and 17% during May (Figure 2.6).

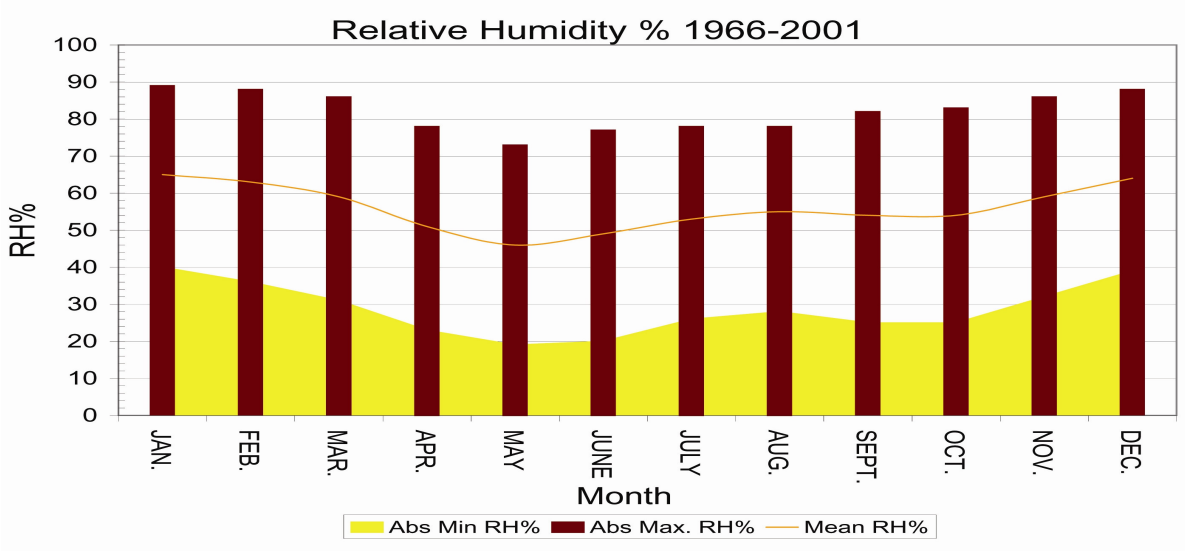


Figure 2.6 Relative Humidity % 1966 – 2001 (Ministry of agriculture records).

2.3.5 Wind Speed

North-westerly winds dominated the northern, western and central parts of the U.A.E, while north-easterly winds prevailed over the rest of the country. The highest wind gust recorded a value of 70.0 Kt during the month of February. The annual average wind speed was between 3.5 Kt during November and 4.8 Kt during February (Figure 2.7).

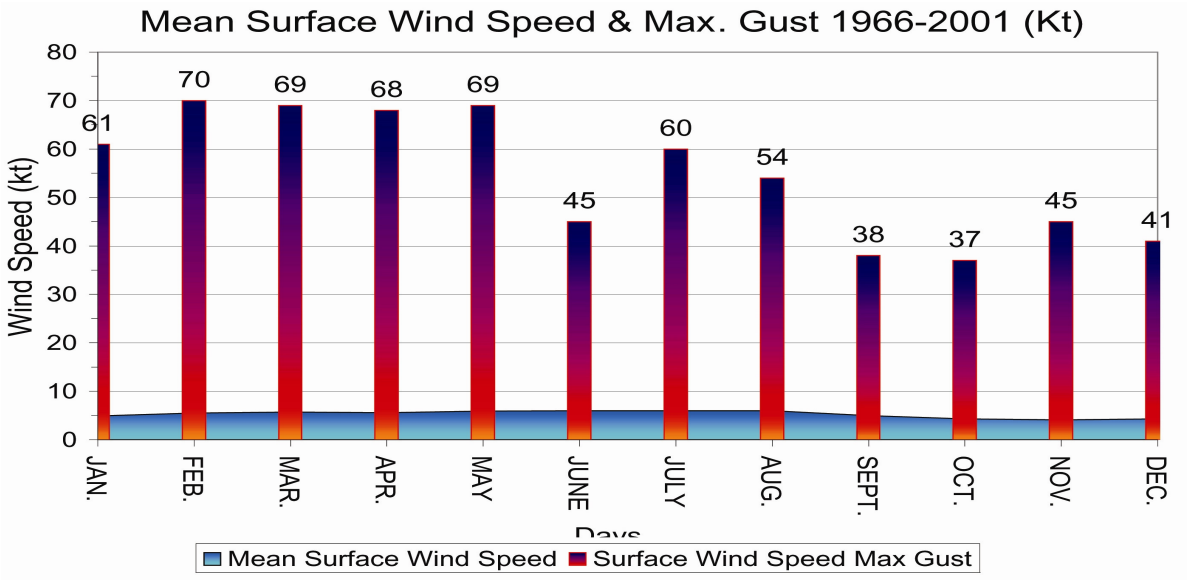


Figure 2.7 Mean surface wind speed & Max. Gust (kt) in UAE (Ministry of agriculture records).

2.4. Water resources background in the UAE

Renewable water resources in the UAE are limited. The United Nations Environment Program ranks the UAE only behind Kuwait as the country with water use as a percentage of renewable resources at an astonishing 1500%!

Water sources for the United Arab Emirates generally include the following:

a) Alluvial Groundwater (including aflaj).
b) Deep Groundwater.
c) Surface water.
d) Desalinated water.
e) Waste water treatment (Recycled water).

Each of the aforementioned sources of water contribute to the total re-usable fresh water supply in the UAE. An analysis of the contribution of each of these showed that Ground water and water derived from desalination account for 88 % of the total supply (Figure 2.8a). Desalination's contribution has increase steadily

and is almost equivalent to the ground water supply. Agriculture and forestry is the single largest consumer if fresh water in the UAE (Figure 2.8b)

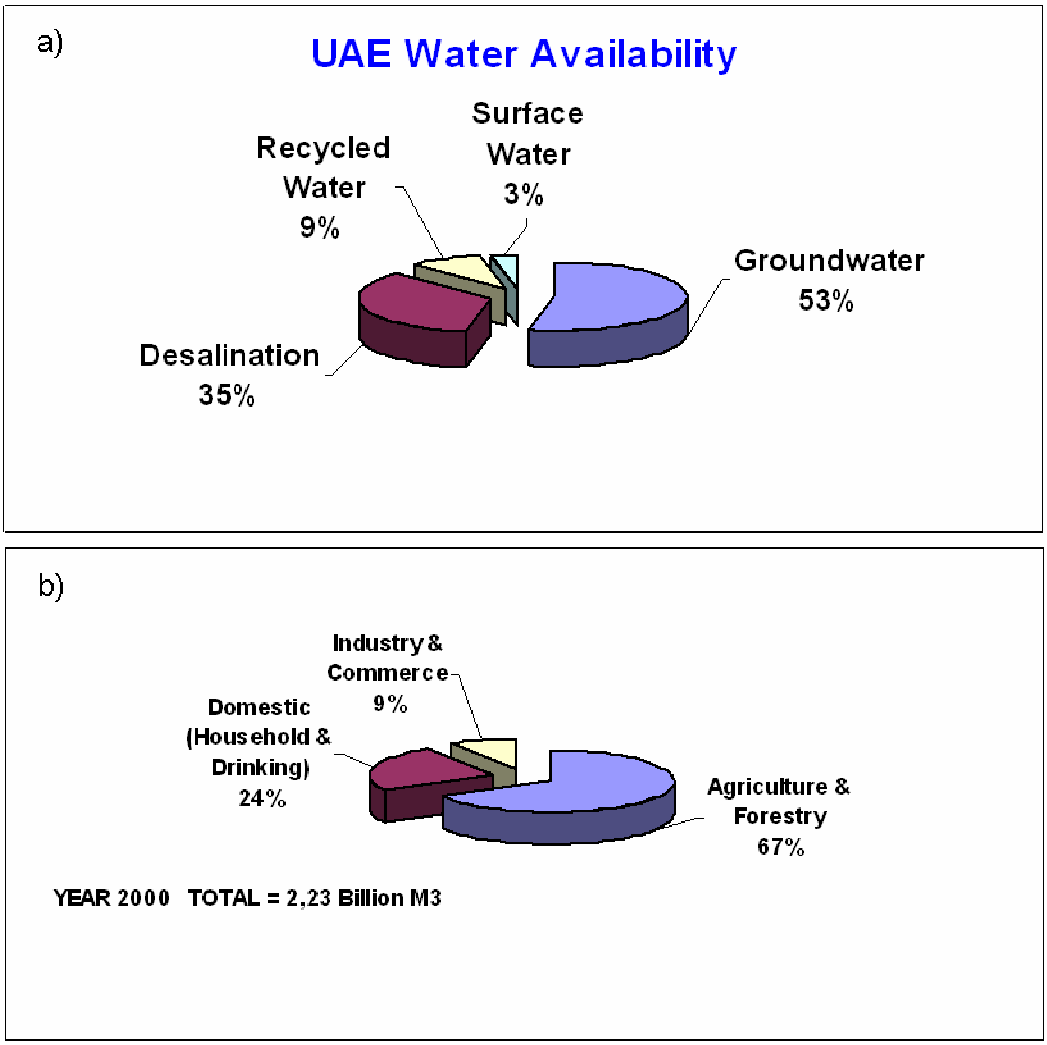


Figure 2.8. a) Sources of fresh water and its b) usage in the United Arab Emirates.

The nature of these resources and their use in the UAE are described below:

2.4.1 Groundwater

Shallow alluvial aquifers

Alluvial deposits along the main wadi channels and flood plains of drainage basins make up the shallow groundwater system in the Arabian Peninsula. Groundwater in the shallow aquifers is the only renewable water source for the Arabian Peninsula countries. The shallow aquifers in the eastern part of the peninsula, particularly in the UAE and Oman are generally thicker and wider than in the west, while alluvial thickness in the inland basins is greater than in those of the coastal basins (Abdulrazzak, 1992 and Abdulrazzak, 1995). In general the shallow aquifers in the UAE can be classified as:

a) The limestone aquifers in the north and east,
b) Opiolitic aquifer in the east,
c) Gravel aquifers flanking the eastern mountain ranges,
d) Sand dune aquifer in the west and south west (Figure 2.11 illustrates the main aquifers in the United Arab Emirates.

Quaternary alluvium of the western gravel aquifer is composed of about a 60 m sequence of sand and gravel with thin interbeds of silt and clay. Most of the alluvium was derived from the opiolitic Oman Mountains. In the north and west of Al Ain, present day wadis are located between NE-EW trending sand dunes.

Aquifers associated with the prolific sand dunes are perhaps the least studied in the UAE. Fresh water aquifers in the quaternary sand dunes were discovered between Liwa and Madinat Zayed only recently. The continuation of exploration projects is expected to lead to similar fresh water lens discoveries of usable freshwater. The Sabkha deposits occur between dunes, and are composed of thin

sand and silt deposits. The thickness of this formation is highly variable; varying between 50 m and 150 m. The term "Sabkha" is a transliteration of an Arabic word meaning "Salt Flat". Physiographically, Sabkhas are very flat, through not necessarily level areas.

Field measurements show that the depths to groundwater are < 5 m in the Liwa, Diba, Khorfakkan, Kalba, Sbaam, and Khatt areas, 10-25 m in the Al Shuayb, Madinat Zayed and Madam Areas. 25-50 m in Al Wagan, Al Hayer, Jabal Hafit, Al Faiyah, Al Jaww plain, Hatta and Masafi areas, 50-100 m in wadi Al Bih and Al Ain areas and > 100 m in Al Dhaid area (Figure 2.9 and Figure 2.10).

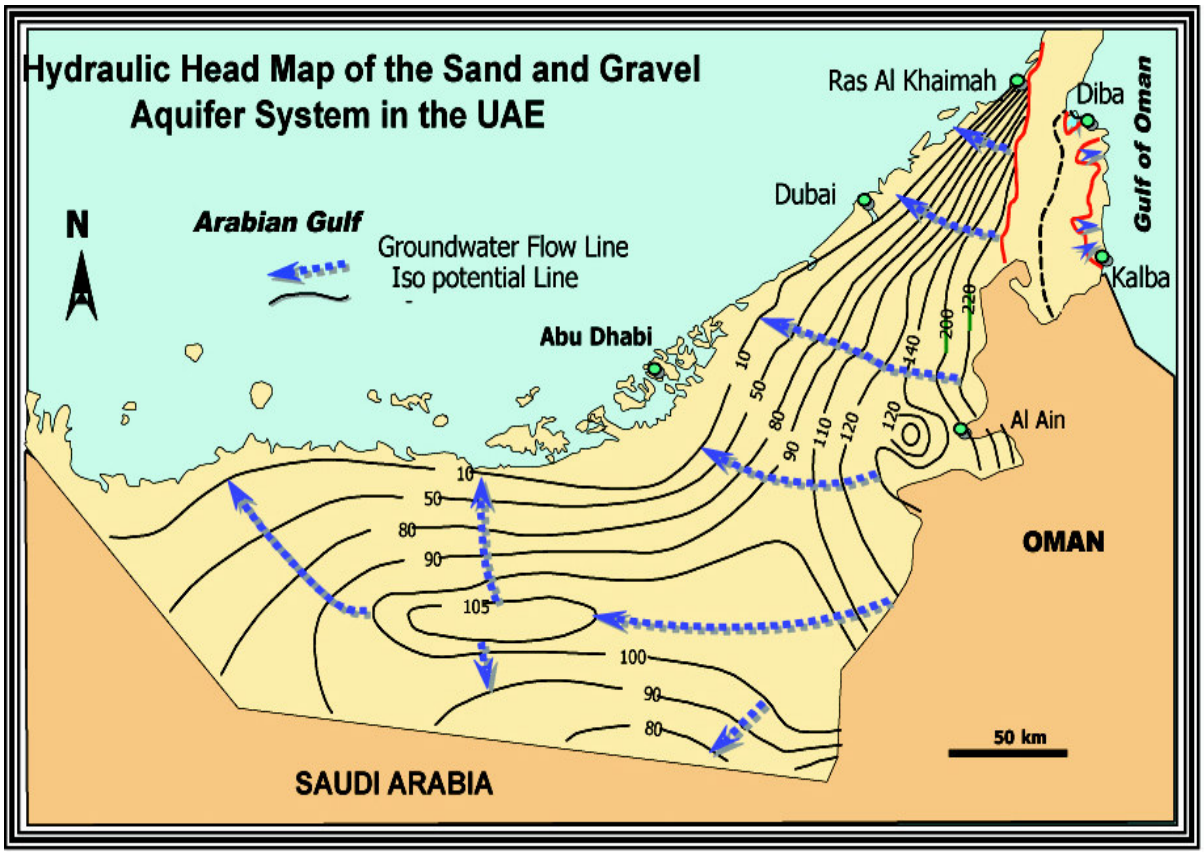


Figure 2.9. Groundwater resources of Abu Dhabi Emirate by GTZ (Hutchinson, 1996).

Local discharge areas are encountered west of Al Ain, Liwa and western coastal sabkha. The coastal alluvial aquifers are subject to salt-water intrusion, especially on

the northern coast or Gulf side of the country. This is believed to be due mostly to the extensive groundwater withdrawals that have occurred over the past decade. Shallow aquifer water quality is generally good. Groundwater from the shallow alluvial is sometimes used for domestic and irrigation purposes. (Modified from Hutchinson, 1996).

Fossil ground water aquifers

The other main source of water for the countries of the Arabian Peninsula is the non-renewable fossil groundwater stored in the sedimentary deep aquifers. Figure 2.11 shows the sandstone and limestone geological formations of the Arabian Shelf. These features store significant amounts of groundwater that are thousands of years old (Burdon 1973; Edgell 1987). The sedimentary aquifers have been classified as either primary or secondary, based on their aril extent, groundwater volume, water quality, and development potential (MAW, 1984).

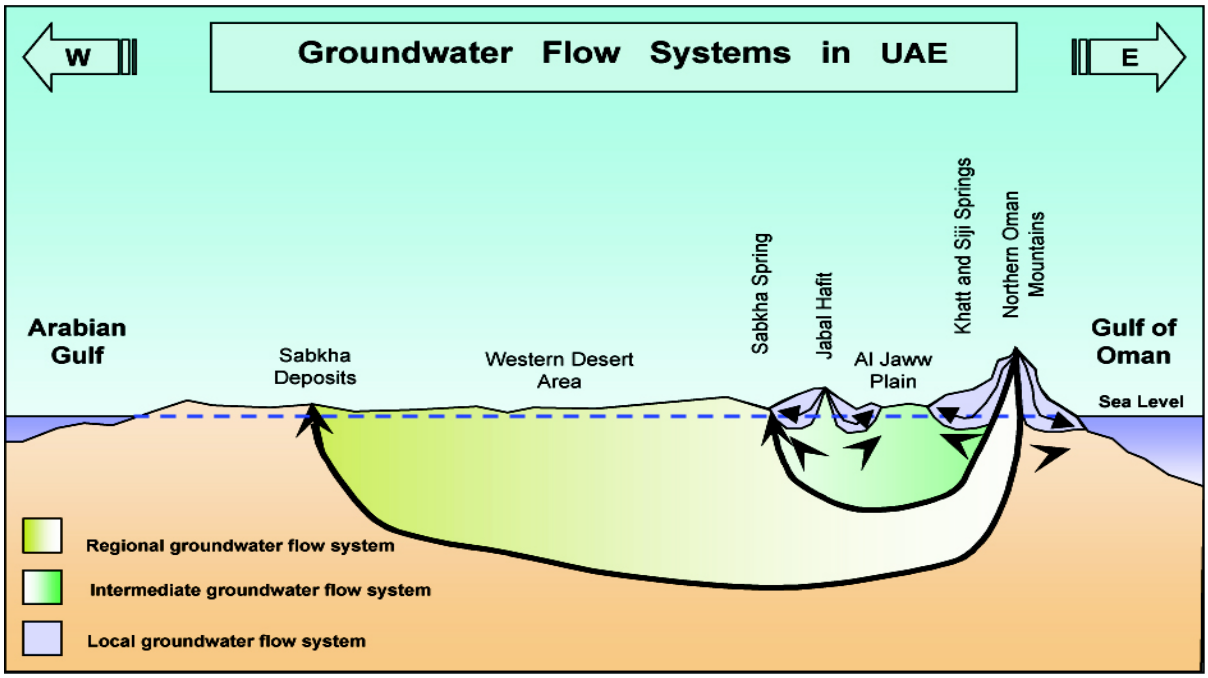


Figure 2.10. Groundwater flow systems in UAE (Rizk et.al, 1998).

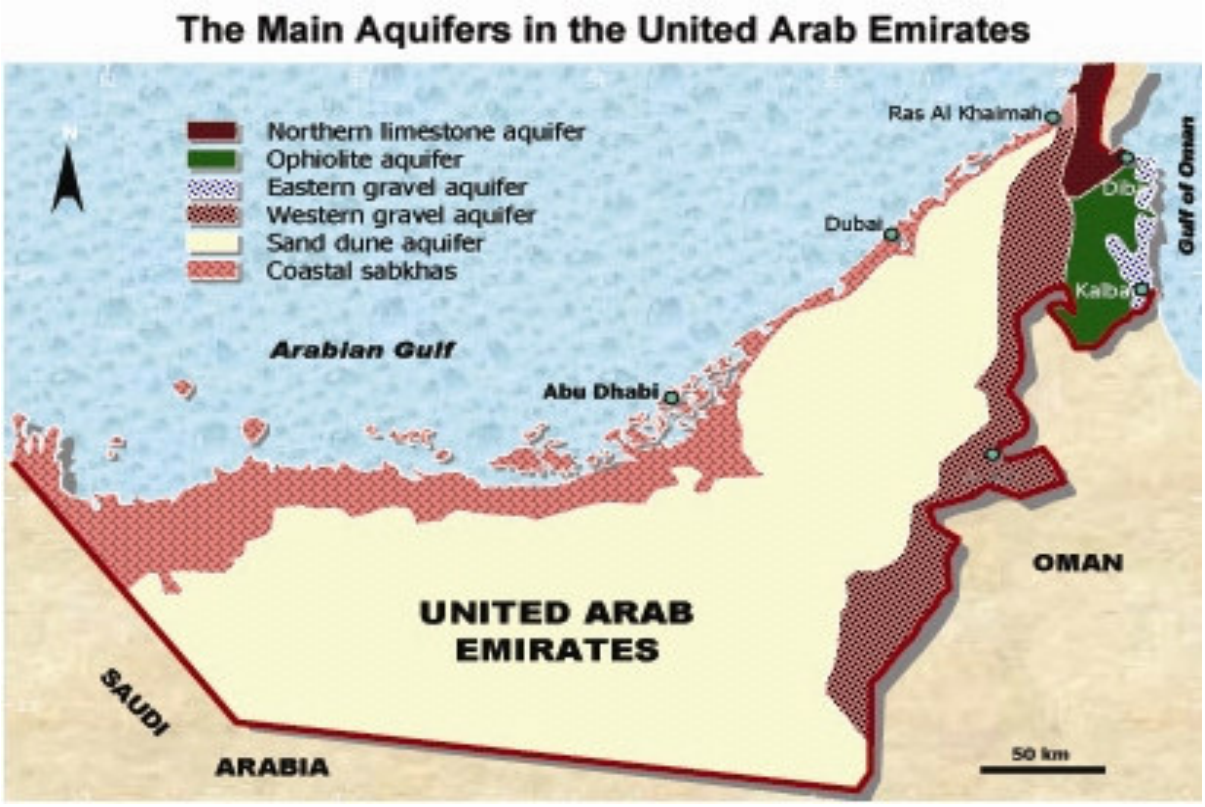


Figure 2.11 The main aquifers in the UAE (Rizk et.al, 1998).

The primary aquifers are the Saq, Tabuk, Wajid, Minjur-Druma, Wasia-Biyadh, Dammam, Um er-Radhuma, and Neogene. The latter two are carbonate aquifers while the remainders are sandstone. Secondary aquifers are Aruma, Jauf, Khuff, Jilh, Sakaka, the upper Jurassic, the lower Cretaceous, and Buwaib. These aquifers cover two-thirds of Saudi Arabia and some of them extend into Kuwait, Bahrain, Qatar, the United Arab Emirates, Oman, and Yemen, as well as into Jordan, Syria, and Iraq.

The Dammam aquifer

This aquifer possibly extends in the subsurface over most of Abu Dhabi Emirate. There is an increase in thickness and major changes of the lithology of the aquifer east of Al Ain; mostly this aquifer is not productive. Near the western border of the northern Oman Mountains, the alluvial deposits which construct the Um er Radhuma

aquifer in the UAE outcrops in Jebel Hafit in connection with Dammam outcrops. A thickness of 300-550 m in the southern part of the UAE, top of this layer (Um er Radhuma) at 985m below surface at Liwa, and the water quality is highly saline. Figure 2.12 shows a conceptual model of the different water-bearing zones in the Jabal Hafit area: fresh water zone replenished by meteoric water; a mixing zone where fresh water mixes with brackish water, and a deep saline water zone. The model supports a mixture of two different sources: fresh water from rains falling on the Jabal Hafit and saline water moving upward from a depth of 2000m, by gas or temperature drive. Brackish water forms as the two types of water mix together (Khalifa, 1997).

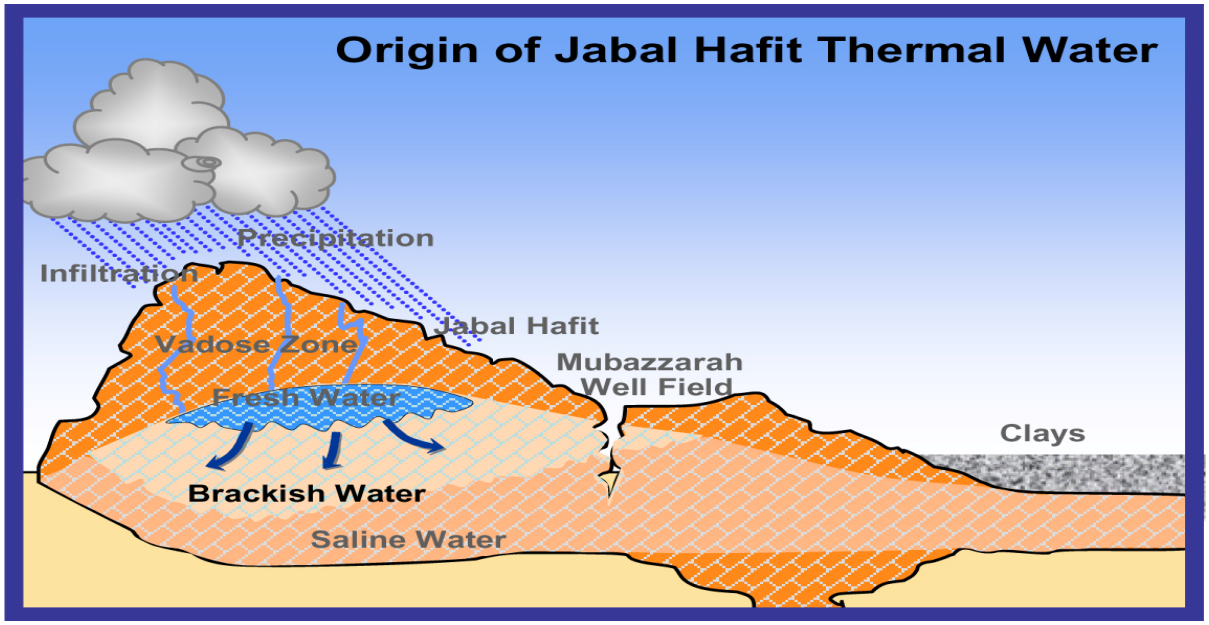


Figure 2.12 The different water-bearing zones in the Jabal Hafit (Khalifa, 1997).

The Dammam aquifer which is covered by clastic deposits of Oligocene-Miocene age in the UAE is still in the exploration stage and the initial findings show that, in the south western areas (Liwa area), the Dammam aquifer occurs at about 400 m below ground surface and has a thickness of 280 m. while in the southern

areas the Dammam aquifer occurs at about 600 m below ground surface and has a thickness of about 500 m. Towards the north, the depth of the aquifer is about 1300 m below ground surface. The aquifer has been shown to contain very saline water, except in Al Ain area, where some wells penetrated the Dammam aquifer at depths of about 210 m, containing slightly brackish water.

Although water in the deep aquifers is ample in quantity, the quality varies greatly and is not always suitable for domestic consumption. Total dissolved solids range (TDS) from 400 to 20,000 ppm. The Environmental Protection Agency of the United States (EPA-USA) guideline for consumable water TDS is at 500 ppm Max. (www.epa.gov), while the World Health Organization (WHO) and European Union (EU) currently have no guidelines (www.who.int). Water from these deep aquifers tends to be saturated with calcium and magnesium salts and has high concentrations of sulphate and chloride ions. The water in the deep aquifers also contains relatively large quantities of hydrogen sulphide and carbon dioxide gases. The brackish water from some of these deep aquifers is usually used without treatment for agricultural purposes. The groundwater of most of the deep aquifers requires treatment such as cooling, aeration to remove hydrogen sulphide and carbon dioxide gases, and lime soda processing.

2.4.2 Groundwater as a water supply source by Emirate

The Emirate of Abu Dhabi

The management of underground water is led by the Abu Dhabi Water and Electricity Authority (ADWEA) and the Abu Dhabi Municipality. The total number of usable underground water wells is about 40,000, distributed in the Al Ain region, the Central region and the Western region. Under ADWEA, the quantity of water

abstracted from underground wells in year 1999 is 38.8 mgd as fresh water (UAE water demand forecast, 2000– 2001).

The Emirate of Dubai

The current underground water abstracted from wells in Dubai is about 10 mgd. Most of the water is abstracted from Al Aweer and Al Wohoosh underground water wells. The quantity of water is continuously decreasing due to continuous abstraction and limited recharge. (ADEWA, 2002). There are no substantial surface water resources in the emirate of Dubai.

Emirate of Sharjah

The Emirate of Sharjah depends mainly on underground water for its domestic water supply. It forms approximately 50% of the total water resources. The underground water supplies about 28 mgd abstracted from many wells in Sharjah City, Kalba, Khorfakkan and Al Hamriyah areas. Some quantity of the abstracted water is being desalinated through RO process in Kalba and Al Hamriyah areas due to high salinity of these underground wells. (ADEWA, 2002). There are no substantial surface water resources in the emirate of Sharjah (ADEWA, 2002).

Northern Emirates

The Emirates of Ras Al Khaimah, Fujairah, Umm Al Qaiwain and Ajman form the northern emirates. Al Dhaid, which is a part of the emirate of Sharjah, is also under the northern emirates region. The main water resources are underground water and desalinated underground water using RO plants. The total underground water production is about 28.6 mgd, produced from 366 underground water wells distributed in the northern emirates Table 2.2). The salinity levels of under groundwater are increasing, due to the increase in water abstraction from

underground well, which also led to decreasing in the number of usable wells in the recent years (UAE water demand forecast, 2000– 2001). Table 2.1 illustrates the TDS levels in the northern emirates groundwater wells.

Table 2.1 TDS Levels in the Northern Emirates Groundwater Wells (ADEWA, 2002).

Emirate	TDS Levels (mg/l)						No. of wells
	0-500	501-1000	1001-1500	1501-2000	2001-2500	> 2500	
Ras Al Khaimah	8	35	23	25	17	44	152
Fujairah	21	44	12	1	0	0	78
Ajman	2	8	6	18	15	60	109
Umm Al Quwain	0	0	0	0	12	15	27
Total	**31**	**87**	**41**	**44**	**44**	**119**	**366**

Table 2.2 Table Groundwater Water Production in the Northern Emirates, Year 2000 (UAE water demand forecast, 2000– 2001).

Sr. no	Ground water source	Quantity (mgd)
1	Western area (Ajman and Umm Al Quwain)	11.8
2	Northern area (Ras Al Khaimah)	12.5
3	Eastern area (Fujairah)	2.7
4	Central area (Al Dhaid)	1.6
Total		**28.6**

2.4.3 Surface Water

The mean annual runoff on the main Wadis in the United Arab Emirates is 125Mm³. A large volume of runoff water is now harvested by 35 recharge dams with a total storage capacity of 75 Mm³. A few dams are under construction at present and several others are planned in the future. Springs provide about 3.0 Mm³ of water per year. Springs discharges range from 0.6 Mm³ / yr to 2.50 Mm³ / yr, with little change over the years. Discharge of some springs is directly related to rainfall, whereas the discharge of others is not directly related to rainfall, because the recharge area is far away and the catchment's area is too large. Also the confined aquifers are not affected sharply. During the 1984 – 1991 period, spring salinity has increased by 10 % (Khatt South in Ras Al Khaimah) to 50 % (e.g. Bu Sukhnah in Al Ain) as a result of

low rainfall and heavy ground water pumping in the recharge areas. Despite their limited discharge, Falaj water is a renewable resource which is directly related to rainfall. During 1978 – 1995, the total Falaj discharge in the UAE varied between 9 Mm^3 / yr in 1994 and 31.2 Mm^3 / yr in 1982 (Al Adrous, M.H,1990), which represents 2.8 to 9.7 % of the total water use in the country.

The annual recharge for groundwater in United Arab Emirates is estimated at 120 Mm^3 (Kahlifa, 1995). This low recharge rate in combination with high levels of extraction leads to a highly unbalanced situation of aquifer depletion in many areas such as Al Ain and Al Dhaid, dryness of many shallow wells, and intrusion of saline water. Due to excessive ground water pumping, cones of depression ranging from 50 to 100 km in diameter now exist in the Al Dhaid, Hatta, and Al Ain and Liwa areas. The volume of desalinated water has increased from 7 Mm^3 in 1973 to 694 Mm^3 in 2000. In 1985, the desalination plants in the United Arab Emirates produced 204 Mm^3 of water, which represents 60 % of the domestic water needs. In 1998 the production of desalinated water reached 526.6 Mm^3 (Rizk, Z.S, 1999), which is 76 % of the water used for domestic purposes. In 1997, the United Arab Emirates production of desalinated water was 57 % in Abu Dhabi, 35 % in Dubai, 5 % in Sharjah, and 3 % in the northern Emirates.

There are many surface water resources in the northern emirates due to the many valleys and mountains. About 45 dams had been built to prevent rain water disposal to the sea. Currently, 27 dams are under construction with a total design storage capacity of 5 million m3 (Ministry of Agriculture and Fisheries, 1993). The total storage design capacity of these dams is approximately 100 million m3. Water

stored by the dams is being used to recharge the underground water aquifers and to satisfy the increased agricultural water demand.

In spite of the absence of permanent streams in UAE, there are numerous dry drainage basins that can carry water during occasional heavy rain storms. Streams drain either eastward into the Gulf of Oman, or westward in the direction of the Arabian Gulf in the north and the sand dune fields in the southwest (Figure 2.13).

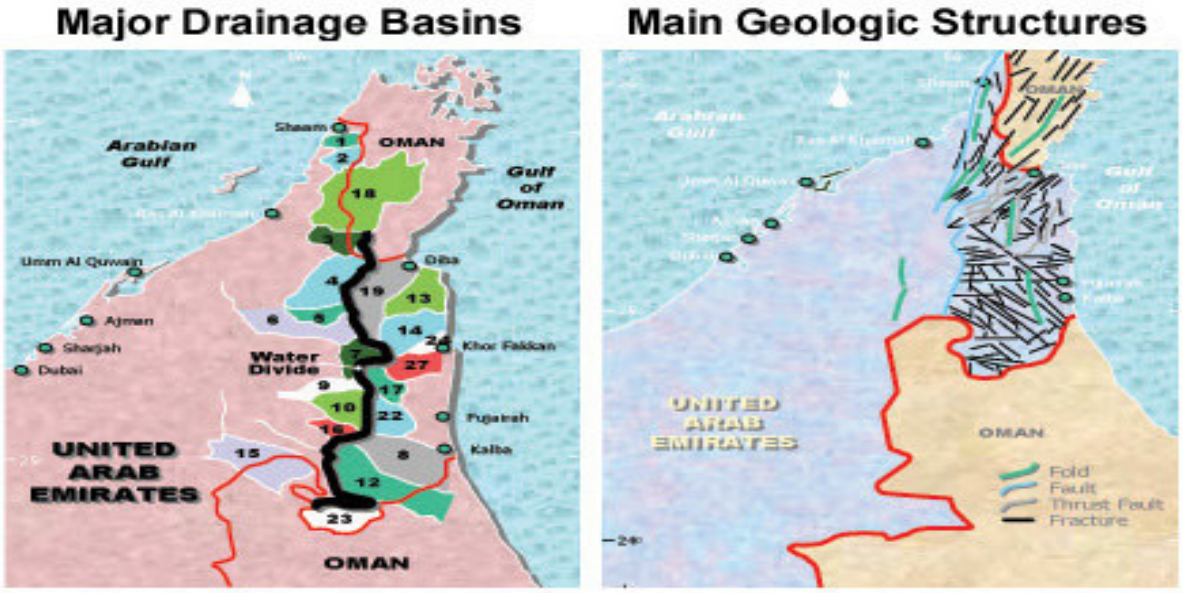


Figure 2.13. Major drainage basins and geologic structures of the UAE (Rizk *et al.*, 1998).

The drainage basins can carry large amounts of water over a very short period of time and also support the aflaj systems (Table 2.3). Run-off occurs mainly in the form of intermittent flash floods, and is governed by rainfall patterns and topographic features over the UAE. The area of these basins vary from 5km² (Wadi Dhanna) to 5000 km² (Wadi Al Bih). The annual run-off volume generated in the United Arab Emirates is estimated to be approximately 125 mcm (Abdulrazzak, 1992). These drainage basins need more detailed studies for estimation of their water budgets and calculations of their run-off capacities during heavy rain storms (see Methods).

Table 2.3 Aflaj of the UAE (Rizk *et al.*, 1998).

Falaj No.	Basin Name	Area (km^2)	Predicted Runoff Volume (mcm)	Rank of Flash Flood Risk	Length of Overland Flow	Rank of Infiltration Rate
1	Ajran	98.3	1.35	4	0.26	6
2	Muraykhat	32.5	0.45	1	0.22	8
3	Saah	1.5	0.21	8	0.20	9
4	Mudabbah	67.1	0.92	6	0.24	7
5	Lihast	44.1	0.61	9	0.22	8
6	Shik	32.8	0.45	10	0.26	6
7	Ghayl	18.5	0.25	6	0.28	5
8	Musayliq	133.7	1.83	7	0.29	4
9	Sidr	16.9	0.23	10	0.29	4
10	Masah	17.1	0.23	5	0.29	4
11	Bu Qalah	118.7	1.63	9	0.28	5
12	Khubayb	39.7	0.54	3	0.36	1
13	Khuqayrah	84.7	1.16	2	0.31	3
14	Saad	136.3	1.87	8	0.33	2
15	Al Ain East	149.5	2.05	8	0.20	9

Under the pressure of population growth and economic expansion, natural water sources have become either reduced in quality and/or quantity. In an attempt to overcome the associated problems, the UAE has undertaken a massive project to construct 43 dams in 15 wadi's in the eastern and northern parts of the country to conserve scarce water resources. Among those dams the major nine dams are the following: Ham Dam, Wurayyah Dam, Zikt Dam, Basseirah Dam, Bih Dam, Idhm Dam, Gulfa Dam, Tawiyaeen Dam, and Hadf. These dams act as recharge mechanisms for the adjacent underground water aquifers e.g. the main goal of constructing the Tawiyaeen dam is to slow down the run-off which spreads in the gravel plain (see table 2.4). The capacity of this dam is 18.5 mcm, and the total capacity of the nine dams is approximately 45 mcm.

Table 2.4 Main dams in the UAE and there annual average volumes (Al Asam, 1996).

Main Dams In UAE							
Dam	Bih	Ham	Idhn	Gulfa	Hadf	Zikt	Tawiyain
Year	2.02	0.96	10.79	(1984)	(1991)	(1991)	(1991)
1982	3.29	1.72	0.76				
1983	1.03	0.21	2.00				
1984	2.27	--	0.89				
1985	2.37	--	1.55	--			
1986	8.21	10.22	9.88	--			
1987	4.26	23.65	6.51	14.35			
1988	4.94	10.09	5.24	21.14			
1989	0.49	20.27	0.76	12.76			
1990	0.57	5.73	19.02	19.36			
1991	5.85	5.65	14.93	20.73			
1992	2.00	1.90	13.00	36.61	8.47	18.52	0.42
1993	0.62	15.95	6.43	8.88	10.84	1.50	9.64
1994	2.92	8.76	7.06	24.90	7.61	17.09	5.76

2.4.4 Emirate of Abu Dhabi.

Desalinated water is the major water resource in Abu Dhabi Emirate. The majority of desalinated water is produced from Umm Al Nar and Taweelah desalination plants, while the remaining is produced from a desalination plant in Mirfa and small plants in Sila, Delma Island, Jebel Dhana and Sir Baniyas Island. Refer to Figure 2.14 for the desalination capacities.

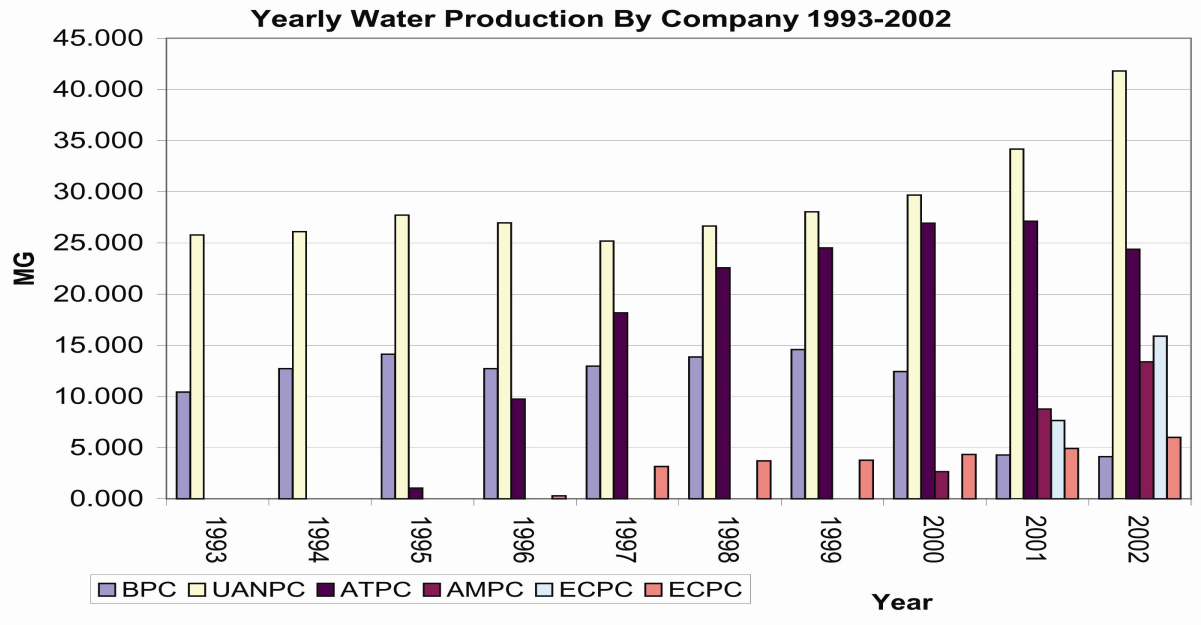


Figure 2.14. Yearly Water Productions by Company 1993-2002.

The Al Shuweihat project, when completed by the year 2004, will provide about 93 mgd to the Abu Dhabi Emirate, a capacity that will help boost development along the Gulf coast. The recycled water in Abu Dhabi Emirates is mainly produced from Al Mafraq waste water treatment plant, which is under the jurisdiction of Abu Dhabi Municipality. The total quantity recycled water from Abu Dhabi and Al Ain Municipalities is about 54.6 mgd (ADEWA, 2002). The overall water production of desalinated water, recycled water and well field water from ADWEA and non ADWEA administration is tabulated in Table 2.5.

Table 2. 5 Existing Water Production in Abu Dhabi Emirate

Authority	Type of production	Water production (mgd)
ADWEA (Beginning of 2000)	Desalination	220.8
Al Ain Municipality (2000 data)	Recycled	11
Abu Dhabi Municipality (2000 data)	Recycled	43.6
ADWEA, Abu Dhabi, Al Ain Municipalities, private wells and others (1994 data)	Well field domestic (fresh)	42.2
	Well field agriculture (fresh)	40.4
	Well field (brackish)	330.9
	Well field (saline)	63.9
	Total	**752.8**

The firm capacities of existing ADWEA desalination plants and Wellfields water utilization in the Emirate of Abu Dhabi are shown in Figure 2.15.

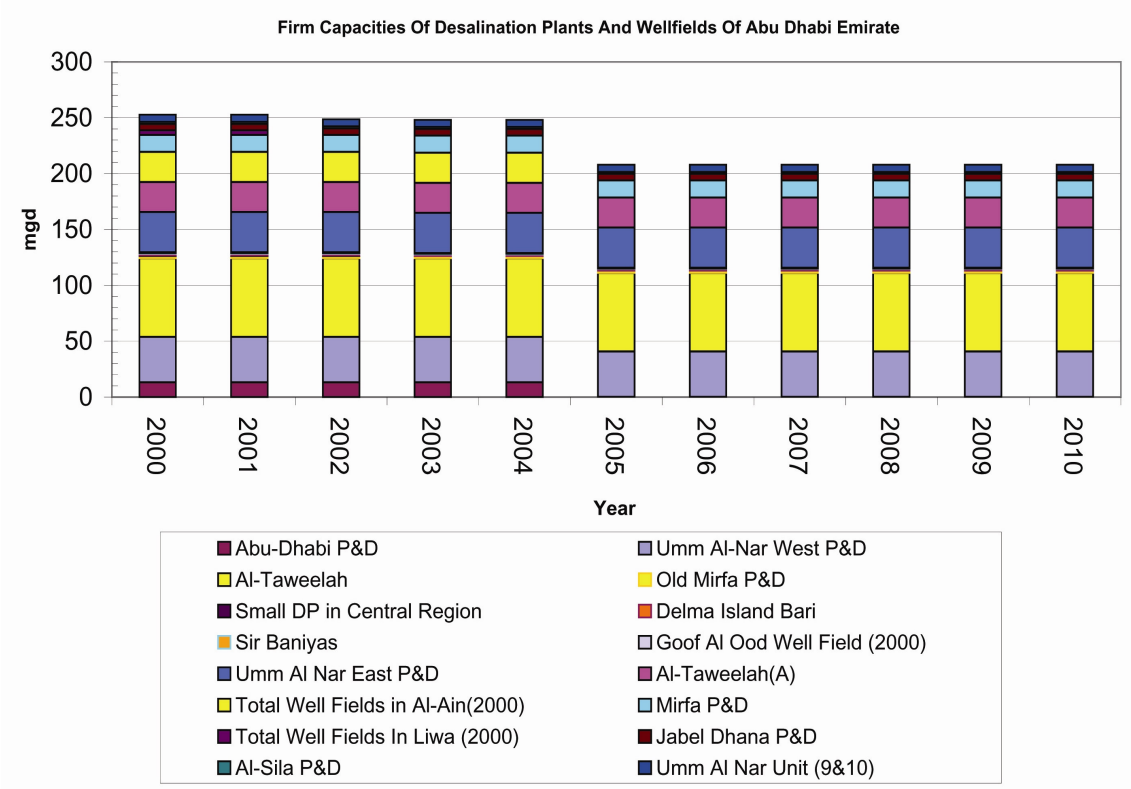


Figure 2.15 Firm Capacities of Existing Desalination Plants and Wellfields of Abu Dhabi Emirate (Al-Hosani, *et al.*, 2002).

Emirate of Dubai

The emirate of Dubai depends mainly on the desalinated water produced from desalination plants located in the Jebel Ali area. The total capacity of the produced water is about 147 mgd. Refer to Table 2.5 and Figure 2.14 for the desalination capacities. (ADEWA, 2002)

Emirate of Sharjah

A quantity of abstracted groundwater is desalinated through the RO process in Kalba and Al Hamriyah areas due to the high salinity of these underground wells (Source: SEWA), while desalinated sea water is the other basic resource of water of the Sharjah Emirate. The production capacity is estimated at 31 mgd. The majority of produced water is from the desalination plant in Layyah, while the remaining is produced from RO desalination plants in Kalba, Al Hamariah and Abu Mussa. Refer to Tables 2.7 and 2.8 for the desalination capacities.

Northern Emirates

The desalinated water in the northern emirates is composed of RO and MED plants. Some of the RO plants are utilized to desalinate some of the saline groundwater. The majority of desalinated water is produced from MED plants due to their integrity with power generation. The total quantity of water production is about 15.4 mgd. Tables 2.6 and 2.7 show the desalination water production in the northern emirates in the year 2000, while Figure 2.16 is an estimate of the percentage of freshwater supplied through desalinization for the entire country.

Table 2.6 Desalination Water Productions in the Northern Emirates, Year 2000, (FEWA, 2000)

Sr. No	Source	Quantity (mgd)
1	Desalination	28.6
2	Sea water RO plants	3.1
3	Ground water RO plants	5.2
4	MED plants	7.1
Total		**15.4**

Table 2.7 Desalinated Water Productions in the UAE (Year 2000) (ADEWA, 2002)

Emirate	Capacity
Abu Dhabi	242.3 mgd
Dubai	147.0 mgd
Sharjah	31.1 mgd
Northern Emirates (UAE)	15.4 mgd
Total	**435.8 mgd**

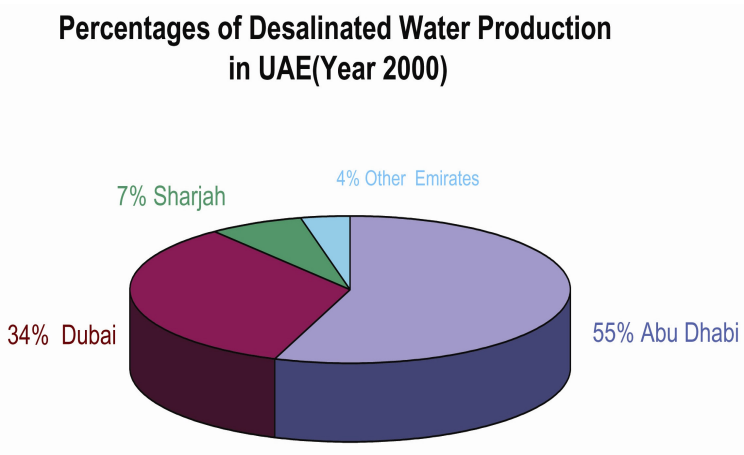


Figure 2.16. Percentages of Desalinated Water Production in UAE (Year 2000)

2.5. Causes of water shortage in the UAE

As reviewed in Section 1.5, “Water shortage or drought”, there are many definitions of water shortage. Clearly, since the UAE is situated in a hyper-arid zone, water deficiency as measured by a lack of natural precipitation is the primary culprit of the water shortages faced by the UAE. However, one should not overlook the others issues that compound this problem, which is the large human and economic growth that has occurred throughout the region over the past few decades. Thus, the UAE has two confounding problems: the desire for high economic growth, which will attract external migration to the country as well as tourists, and a water scarcity that in the short-term can only be made up through desalinization. Of course the other major “hidden” source of water is that which is “virtually” supplied in terms of major food imports!

Some water master planning has tried to project future water demands. Figures 2.17 and 2.18 illustrate briefly the water demand forecast and forecasts of desalination needs for the Abu Dhabi Emirate, respectively.

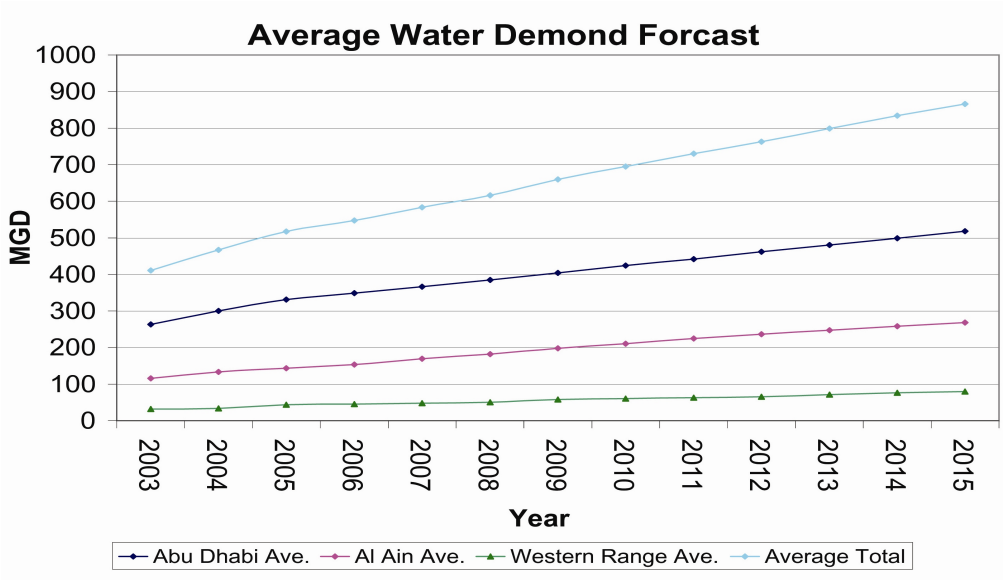


Figure 2.17 Average water demand forecast (ADWEC, 2002)

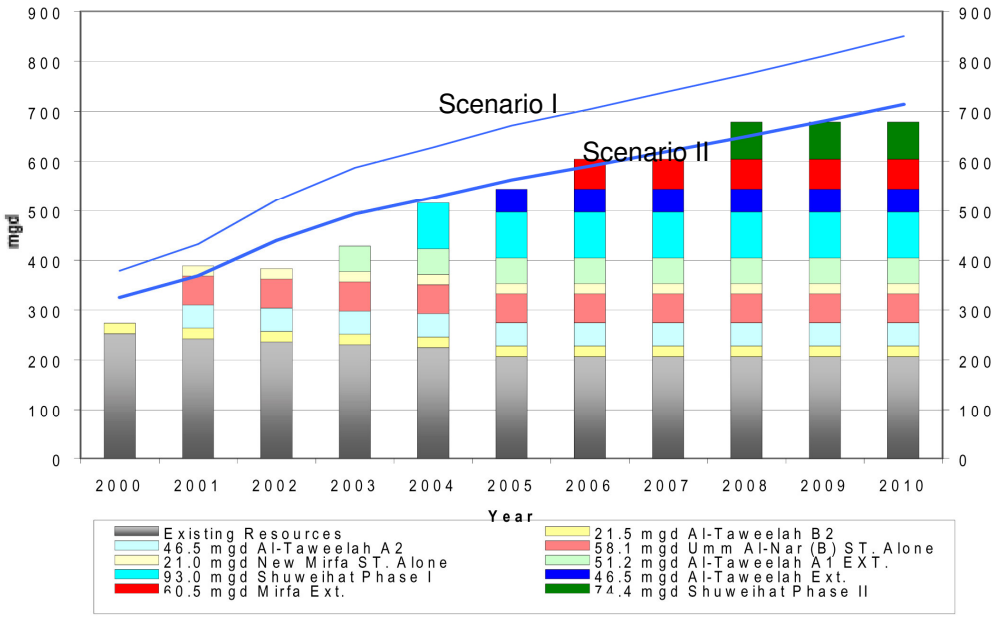


Figure 2.18. Firm Capacity Desalination Plants Existing, Committed and Planned for Abu Dhabi Emirate.

Water shortages are pervasive throughout the UAE, and may be subdivided into two categories 1) Localized water shortage (concentrated in certain area) and 2) General water shortage (like the general arid and semiarid character of the UAE). Despite the intensive efforts that have been made by the UAE Government to meet the increasing water demands for the different sectors and applications, the gap between water demand and supply is large and continues to expand. The water crisis in the UAE has developed over time and it is useful to investigate the root causes of this situation and how these may have changed over time. These include:

a. Geographical location, topographical features and the climate.
b. Underground water overdraft.
c. Rapid expansion in, agriculture, tourism, Industry, inhabitants, and foreign labor.
d. Growth in Non-skilled labors especially in the field of agriculture.

2.5.1 Population Growth

The great increase in population in the UAE in addition to the enormous expansion of economic and industrial activities has meant that underground water is insufficient to cover the present needs for human activities and the rapid development. Figure 2.19 illustrates the population growth in the UAE over the past 30 years at five year intervals.

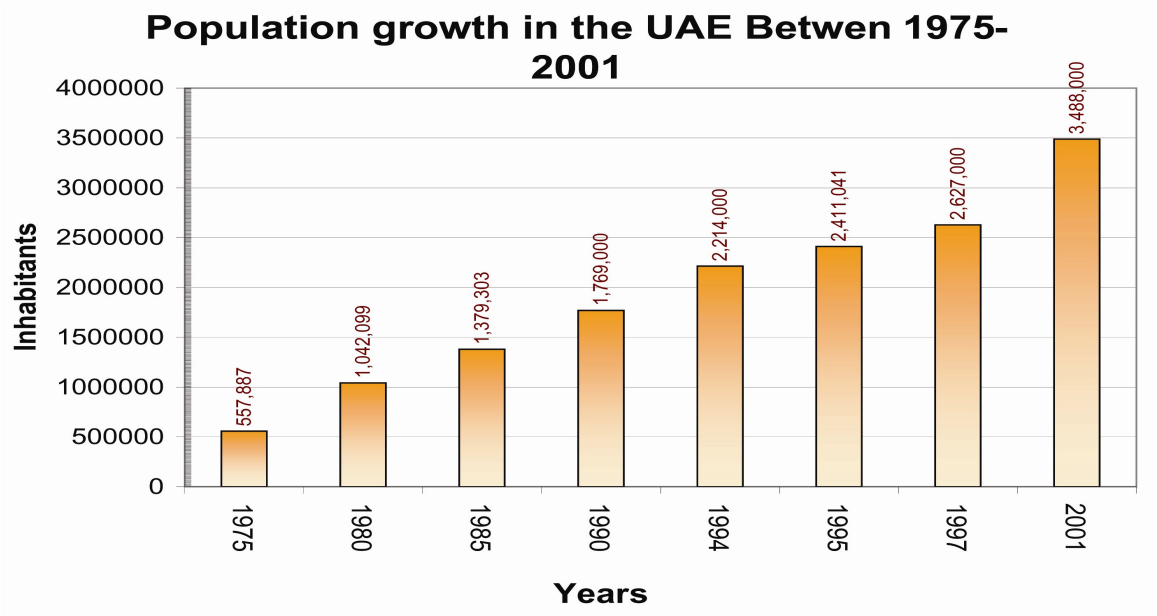


Figure 2.19. Population growth in the United Arab Emirates between 1975 and 2001 (Ministry of planning, 2002).

According to the most recent National assessment, the United Arab Emirates had a mean annual growth rate of 7.7 % between 1950 and 1995. In addition, according to the United Nation medium variant population projection, the UAE will have the highest global rate of population growth for the period 1950 to 2050 as illustrated in Table 2.8.

Table 2.8 Average Annual Population Growth Rates (UNPD, 1997)

Past population Growth, 1950 – 1995		**Centennial population Growth, 1950 - 2050**	
Population Growth Rate (in %)		**Population Growth Rate (in %)**	
	Average Annual 1950 – 1995		Average Annual 1950 – 2050
United Arab Emirates	7.7	United Arab Emirates	4.0
Qatar	6.9	Western Sahara	3.7
Western Sahara	6.4	Qatar	3.5
Kuwait	5.4	Djibouti	3.2
Djibouti	5.0	Oman	3.2
Brunei	4.0	Kuwait	3.1
Saudi Arabia	3.9	Saudi Arabia	2.9
Libyan Arab Jamahiriya	3.7	Libyan Arab Jamahiriya	2.9
Cote d'Ivoire	3.5	Gaza Strip	2.9
Oman	3.5	Niger	2.7

2.5.2 Domestic, Industrial, and Agricultural Water Use

Imbalances between increasing water demand and existing water resources are being experienced by the UAE. During the last decade, water demand in all sectors has increased dramatically as a result of high population growth, improvement in the standard of living, efforts to establish self-sufficiency in food, and promotion of industrial development. The deficit is being met through sea-water desalination and mining of groundwater resources. Currently, agriculture is the primary water consumer in the UAE. Industrial water demand is very small in comparison to the domestic sector.

Over the course of the last few decades, the UAE government has focused its efforts in water development to the inter-emirates, comprising water transfers, wadi-basin development, identifying and exploiting natural groundwater reservoirs, and creating desalinization systems which has led to a more interconnected water system across emirate borders.

Domestic and industrial water requirements for the UAE are satisfied through desalination and a limited amount of groundwater from both shallow and deep aquifers. Likewise, agricultural water demand has sharply increased where groundwater reserves are being mined. This agricultural development is a direct result of government policies encouraging self-sufficiency in food production. Government incentives and subsidies have made it possible for large areas to be cultivated, placing great strain on the existing groundwater resources.

Total water demand for agricultural, industrial, and domestic purposes for the UAE increased during the period 1990-2000 from 1.49 to 2.18 bcm, an almost twofold increase, due to high population growth and the need for food production. Water requirements are expected to reach 3.2 bcm by the year 2025 (Figure 2.20). Agriculture accounts for the majority of water use, followed by the domestic sector. For the UAE, the agricultural water requirements are estimated at 1.4 bcm in 2000 and are expected to reach 2.05 bcm in the year 2025.

Industrial activities in UAE are limited and have contributed to only small increases in total water requirements, when compared with the domestic and agricultural sectors. Industrial water demand in 2000 reached 30 mcm. Industrial demand is projected to reach 50 mcm in the year 2025.

Industrial production structure in the UAE is geared towards consumer goods and petroleum refinement. Major industries in the United Arab Emirates consist of petrochemicals, cement, and limited food and beverage production.

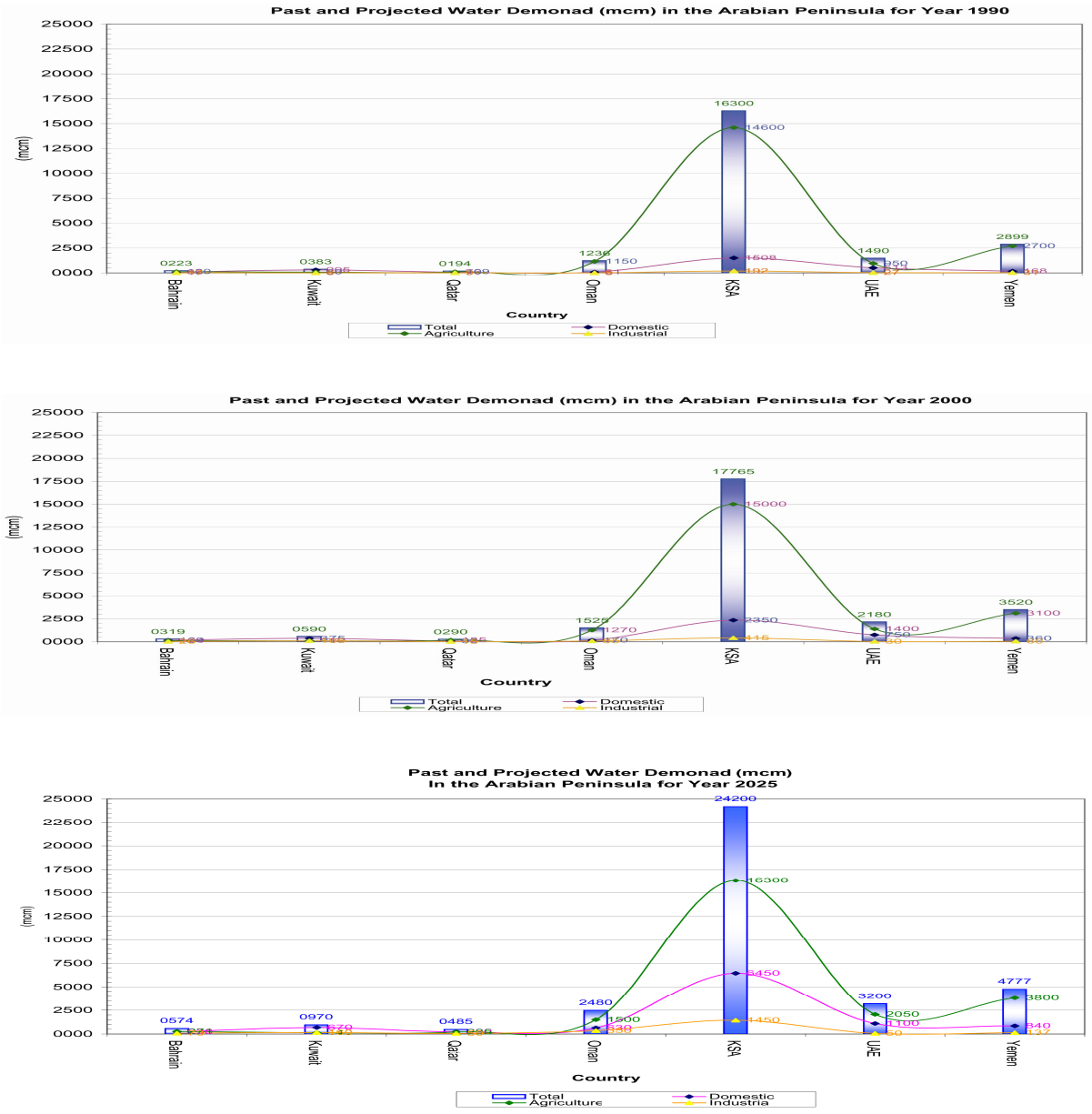


Figure 2.20 Past and Projected Water Demand (mcm) in the Arabian Peninsula for the Years 1990, 2000, and 2025 (ESCWA, 1994 – 1995).

2.5.3 Tourism Expansion

The growing attention given to the tourism industry in the UAE by both governmental and private sectors has resulted in significant growth in the UAE. This is reflected in the establishment of a number of governmental departments and organizations devoted to tourism promotion. In addition, a large number of private companies and travel agencies specializing in receiving tourist groups and organizing tourist tours have been established, Figure 2.21 represents the increase in the number of guests (in 1000) in the UAE from 1994 to 2002.

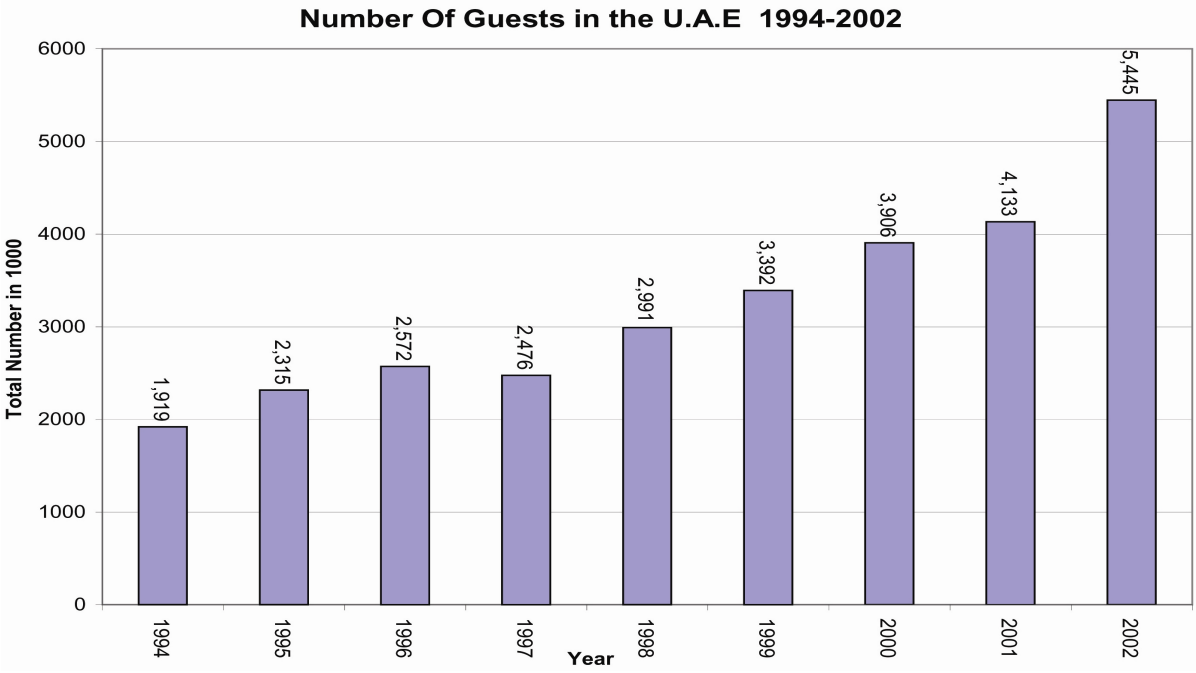


Figure 2.21 Number of Guests in 1000 in the UAE 1994 – 2002 (Ministry of Planning, 2003).

The tourism sector has expanded significantly over the past ten years and has become an important contributor to the countries gross national product. The increase in hotels revenues from 3.115 billion dirham in 1998 to 3.275 billion dirham in 1999 in conjunction with the accompanying rapid promotion of trade activities are a

good representation of the growing contribution of the tourism sector to national income in the UAE. The implication of the rapid expansion of tourism has implications on the sustainability of water, as it can lead to enhanced soil erosion, increased pollution discharges into the sea, habitat loss, pressure on endangered species and strains on water resources.

2.5.4 Water losses from transmission pipelines

Water losses from transmission pipelines have a negative impact on the water supply capability, and contribute to the increase in the gap between water supply and demand in the country. Therefore, while performing the assessment of the water budget for the country, water losses from transmission pipelines must be included in the calculation of the water budget. Also, transmission and distribution pipelines must undergo continuous rehabilitation, replacement and cleaning in order to reduce those losses.

Chapter 3
The Vision of a National Earth Information System to Support Water Resource Assessment

A primary hypothesis, which forms the genesis of this thesis, is that advances in water resources assessment (WRA) is severely constrained in the UAE due to the non availability of reliable data in support of WRA, and as long this problem persists, planning and development of water programs and water assessments will continue to remain a guess work. Likewise, there is no compatibility in the data bases in the many organizations and institutions that are involved in the collection of water related data because each one uses its own procedures and formats.

3.1. Defining a National Earth Information System

Collection and assessment of all existing data on water resources, water uses and water re-uses in UAE in terms of quantity and quality is a first phase towards a fully integrated approach to water resources conservation and management within the UAE. A priority has to be given to a scientific and centralized knowledge of the country's water resources with the building of a national earth information system (EIS). The DWRS has begun to establish the UAE national water resources data bank which in turn will integrate with the UAE national data bank in the near future (Rogers, 1986; Helsel, 1992 and McPhee and Yeh, 1994). The DWRS has been mandated to collect basic information, for disseminating central findings, and for transforming conclusions in policy proposals for decision makers at the highest level. Indeed many of the necessary meteorological data are becoming available through

the DWRS, with hydrology data, very soon becoming integrated into the EIS, as well as other none conventional water resource data which will also join the EIS.

The current difficulties and challenges that the UAE faces with regards to freshwater are due to the tremendous fragmentation of the institutions and data which are scattered throughout the country. The absence of a national data bank in the UAE can be identified by the following attributes:

a) The absence of a central authority that deals with water related studies, research, and planning.

b) An Insufficient number of weather and water monitoring stations.

c) An inadequate expertise in data collection systems and processes.

d) Scattering of available hydrologic data, making it nearly impossible to create a comprehensive picture of the water resource situation in the UAE.

In fact, the UAE does not currently have a national governing authority that is overseeing water resources development, as this development process is currently done piecemeal. Therefore as needs arise, institutions, the private sector and even individuals identify their own water needs and pursue means of acquisition. This is perhaps nowhere more evident than in the groundwater drilling and pumping process, where there is no major legislative control in the form of permitting and monitoring, which is a central reason why water resources assessment is currently inadequate in the UAE. Without proper assessment of groundwater resources, permitting of drilling and pumping activity and monitoring of climate and pumping rates, it will be impossible to determine to what extent, our current practices will be sustainable.

With these facts in mind, the vision of a comprehensive earth information system is based on the idea of developing a computer-based modeling and database

system that utilizes cutting-edge hardware, software, and engineering development techniques for all manner of scientific disciplines related to the management of water resources. This means the inclusion of data from the physical sciences, including: Meteorology, hydrology, geology, ecology and geography; and from the social sciences (GIS and Remote Sensing): economics, socio-economic development, human behavioral data (tourism, water use, water saving, etc.), and industrial data (desalinization capacity, heavy industrial water use rates, light industrial water use rates, etc.).

3.2. An Earth Information system for the United Arab Emirates

The integration of these disparate datasets requires innovative thinking as to how to bring them together in the most useful and constructive manner as possible. It is one thing to store an abundance of data, while it is quite another to integrate them into a useful set of information that a decision maker will find useful.

The system is centered on a computerized relational database that can house terabytes of data. There is nothing particularly special about a relational database in this context, but what is important, is realizing that such a database would need to store, retrieve and display many different kinds of data, develop means too retrieve them, and then find the most effective means of analyzing the results and summarizing those results for decision makers. Therefore, there are four critical elements to the data identification, acquisition, and storage process which are summarized below:

a) Identifying *Sources* of data.

b) Determining the *Reliability* of the data.

c) Ensuring complete temporal and spatial *Coverage* of the data.

d) The ability to articulate the *problems and issues* that need to be addressed with this data.



Figure 3.1 The organizational structure of a UAE water resources and environmental Earth Information System database.

3.3. Components of the Earth Information System

As can be seen in Figure 3.1, the vision for the EIS is quite comprehensive; comprising a number of disciplines that would be coordinated into a central database system and whose data could not only be accessible internally, by the staff of the Department of Water Resource Studies, but also through the Internet via web-browser based computing environments. Users of the system will be able to make queries to the database, visualize data via advanced graphical representations and have the ability to download select datasets that would be compatible for further

analysis using such analytical tools such as commercial Geographical Information Systems, Excel, Etc. Each component is described in more detail below.

3.3.1 The Meteorological Component

Over the past few years, the DWRS has pursued the development and deployment of an advanced, automated weather observational station (AWOS) comprised of over more than 50 AWOS, that cover the whole UAE, with real time data acquisition every 15 minutes. Parameters such as rainfall, temperature, humidity, wind speed and direction, solar radiation, etc. are included. In addition to AWOS towers, the system also is comprised of:

a) More than 10 automatic monitoring marine stations that covers most of the UAE costal zone, with real time data acquisition every 15 minutes.
b) Six weather radars covering the whole UAE.
c) Implementation of an advanced meso-scale weather forecasting model, the Mesoscale Model-Version 5 (MM5).

All of the above mentioned projects are very vital to the estimation of groundwater recharge, and the scientific analysis of the potential contribution of rainfall enhancement in increasing groundwater recharge rates.

The meteorological components of the EIS are perhaps the most advanced part of the system, and drive its development requirements due to the fact that many of the datasets are real-time and require sophisticated control. Figure 3.2 shows all elements of the meteorology sub-components, including the data collections platforms: 1) Land-based Automated Weather Stations; 2) Marine-based Automated Weather Stations; 3) A weather radar network; 4) Satellite and other remotely sensed data products; 5) Upper air data from a network of lidar (Light Detection And

Ranging, which uses the same principle as weather radar); 5) Data from global weather models such as the European Center for Medium Range forecasts; 6) The World Meteorological Organizations Global Telecommunications Systems (GTS) data feeds for upper air (sounding) data.

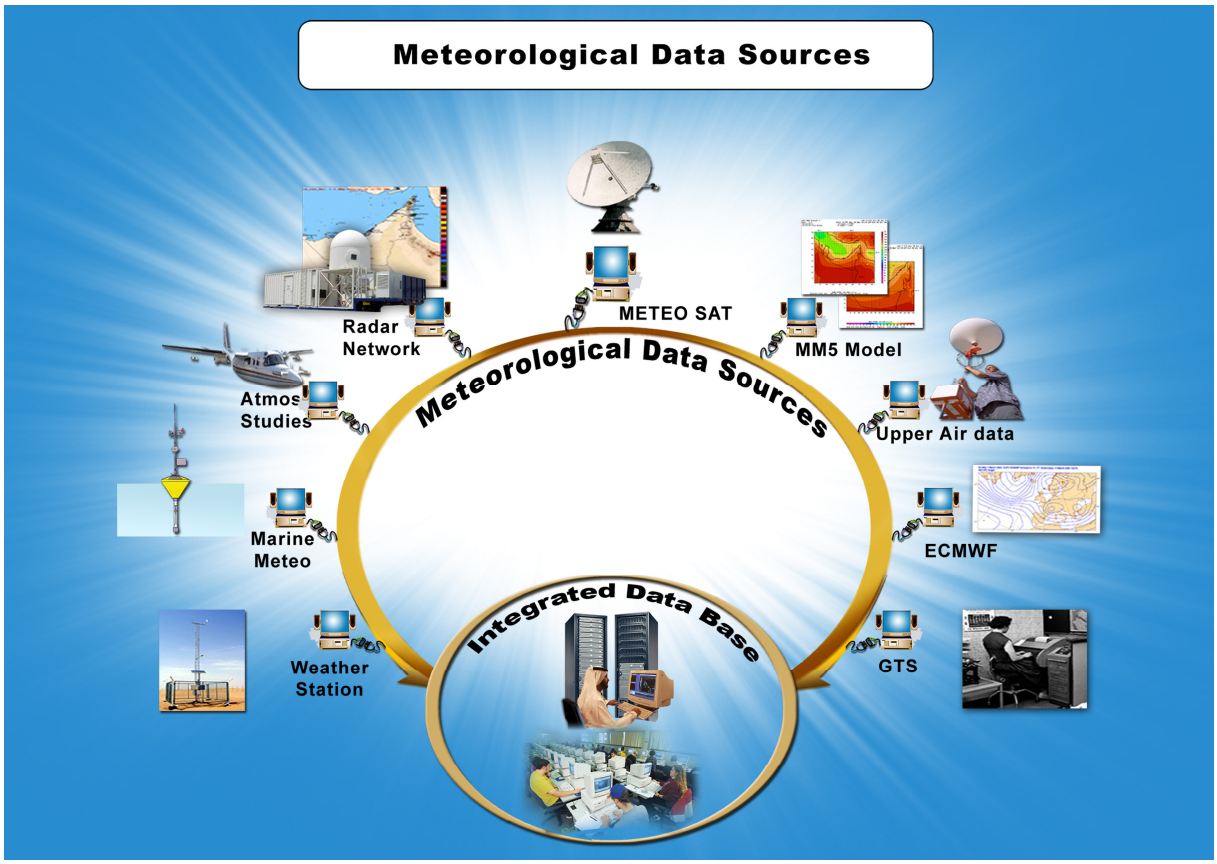


Figure 3.2 The meteorological components of the EIS system.

In addition to the real-time data, collection platforms are derived data sets and datasets computed as Climatological statistics from the raw data. For example, data derived from the network of weather radar can be used to develop 'radar climatology' datasets, which would be useful for studying seasonal rainfall patterns or in support of rainfall enhancement programs, or other such studies. Data from the automated weather stations can be used to compute Climatological statistics such as high and low temperature extremes, precipitation totals and maximums and many others.

The system also includes an advanced meso-scale weather forecasting system. This component of the EIS requires sophisticated hardware and software and generates a tremendous amount of data in real-time, as it generates weather forecasts on a daily basis. The weather forecasting model integrates many of the real-time observations (Automated Weather Observational Stations (AWOS), Global Telecommunication System (GTS), and European Center of Medium Weather Forecast (ECMWF)) to help improve its forecasts.

An overview of the system is given in Figure 3.3, and shows the system centered upon the “The Model Application Cluster” (MAC) which is comprised of a linked set of 48 individual computers networked together to execute the weather forecast model. The MAC runs a Real-Time Four-Dimensional Data Assimilation (RT-FDDA) weather forecasting model, which is then supported by and supplies data to the database system commonly referred to as the Data Application Cluster (DAC). The DAC controls the main geospatial database for the system. Networked GIS workstations function as independent analysis tools, which can directly link to the DAC database via customized software or via Open Data Base Connectivity (ODBC) Drivers such as the Windows-based MySQL ODBC 3.5.1.

In addition to these components, meteorological data are also being collected from other agencies throughout the UAE, who collect similar types of meteorological data. For example, the Ministry of Agriculture and Fisheries has several AWOS stations that collect the full compliment of meteorological data as well as a network of rain gauges whose data archives extend back to the 1970’s. These data are being collected and incorporated into the EIS system. Daily rainfalls from nearly 30 rain gauges dating back to 1980 have been inserted into the database.

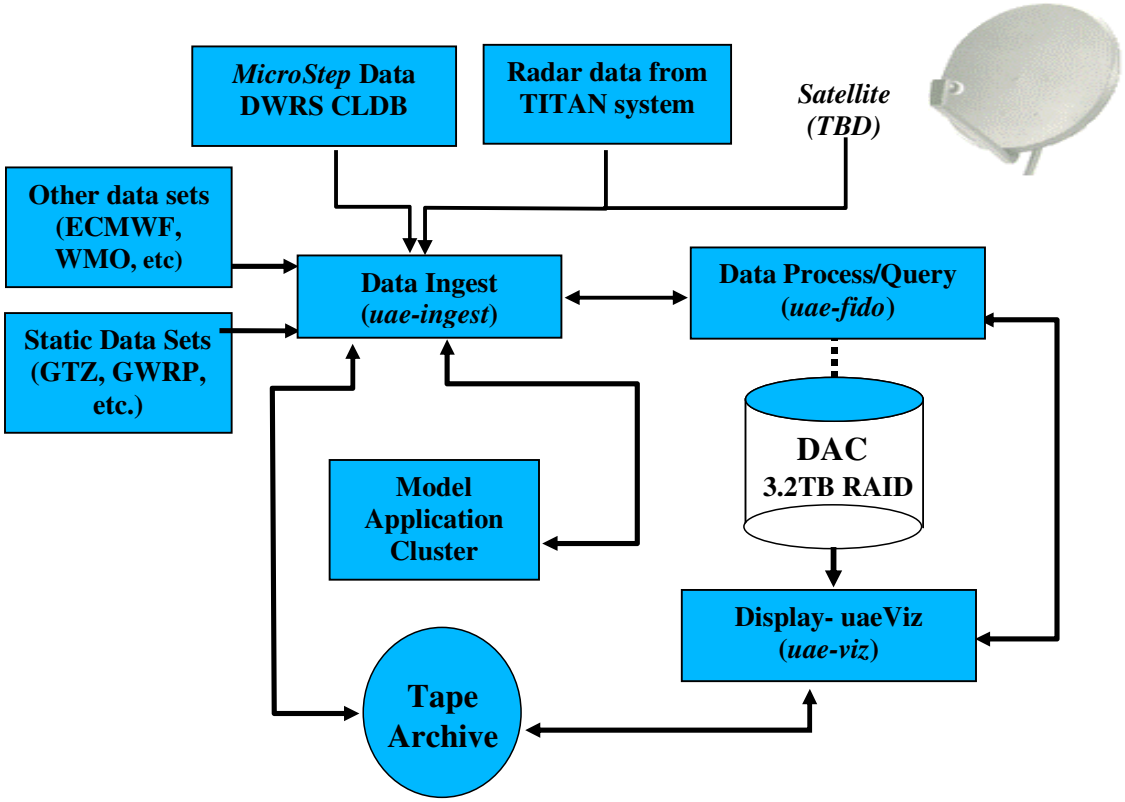


Figure 3.3 UAE-4DEiS System Hardware and Functional Process Description.

3.3.2 The Hydro-Geologic Components

The hydro-geologic component of the EIS system includes all manner of data associated with the terrestrial part of the hydrologic cycle. This includes data about wadis, the geography of wadis, dams and reservoirs, alluvial groundwater aquifers, deep groundwater aquifers, digital elevation data; digital land use and land cover data, etc. Figure 3.2 summarizes all hydrologic components while Figure 3.3 summarizes the current geologic components that are being considered in the EIS system under the 'hydrogeology' category.

Mapping geology with geophysics has the power to extend geological knowledge into areas where the geology is covered by transported sands (as in UAE case). Unfortunately, only recently, a few foreign companies in cooperation with

some national companies or institutions started hydrological exploration projects with the aim of water resources assessment. These companies used expensive ground geophysics techniques. Combining geophysical methods enhances the accuracy of the maps generated.

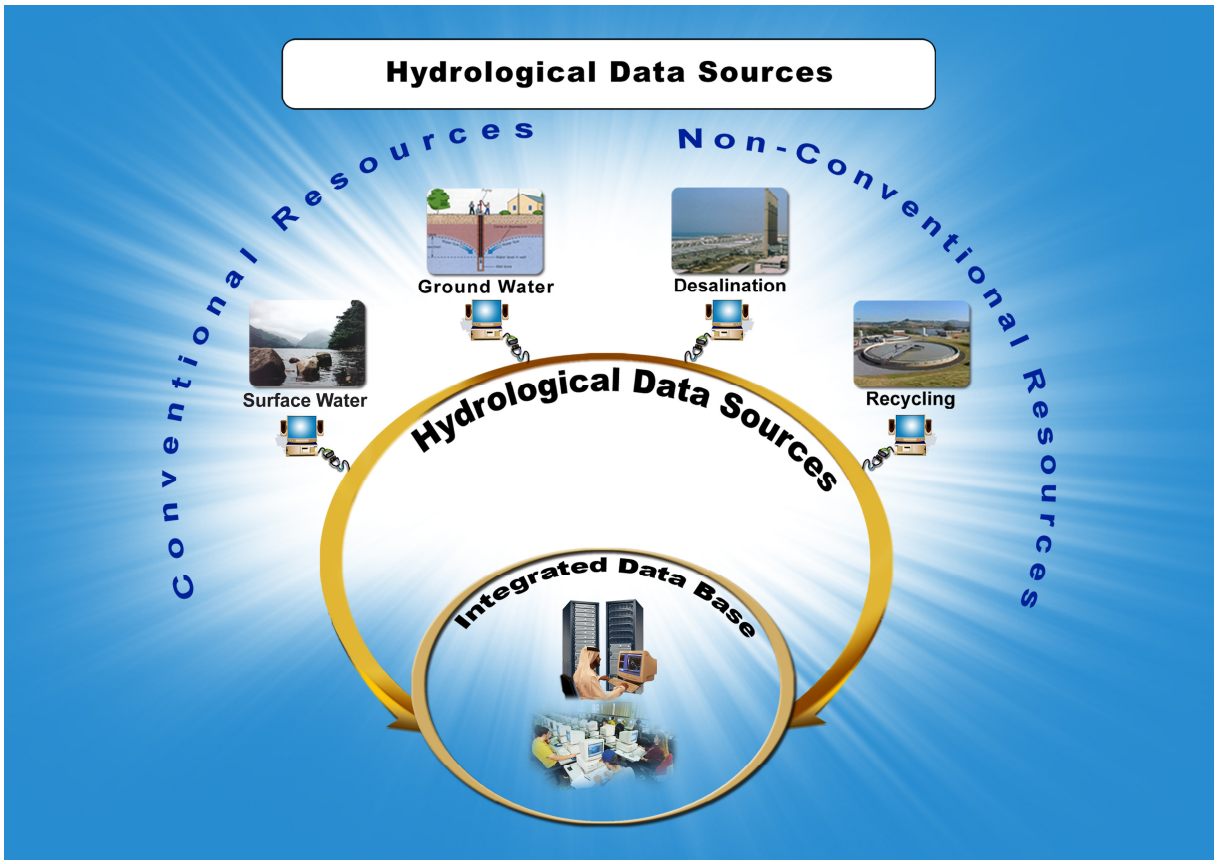


Figure 3.4 The hydrologic components of the EIS system.

Airborne geophysical techniques have been employed since the 1960's to characterize the subsurface. A high-resolution airborne geophysical survey is a rapid and cost effective technique, and an invaluable tool for the national resources exploration. Geophysical airborne survey will support the DWRS on the implementation of its strategic plan regarding sustainable water management.

The focus is to identify and quantify existing water supplies in the UAE to support critical decisions on future water management. The purpose of this is to eventually provide a comprehensive suite of specialized geophysical services within the UAE to study and evaluate existing water assets and natural water aquifers. It is recognized that better understanding is required of the existing fresh groundwater resources within the UAE for effective water resource management. This process will serve to inform water resource management in the UAE in the foreseeable future.

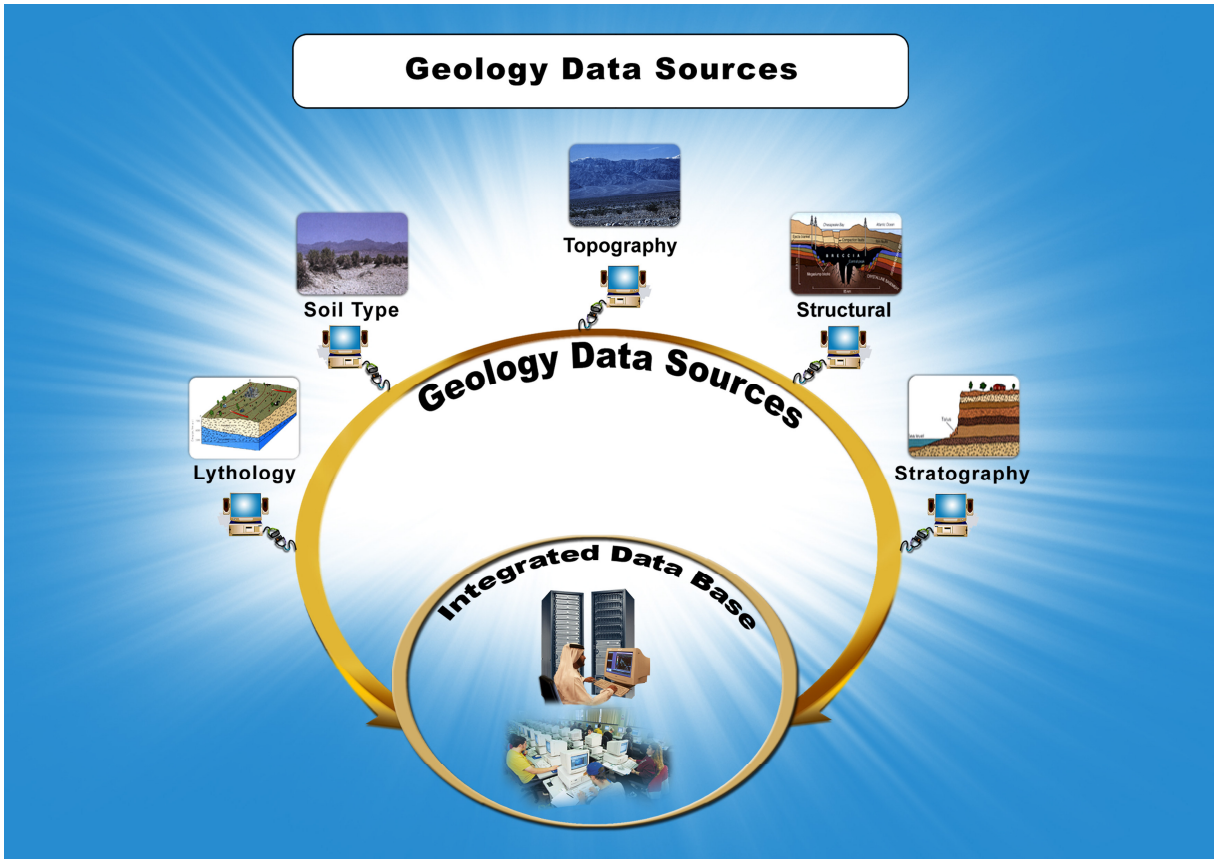
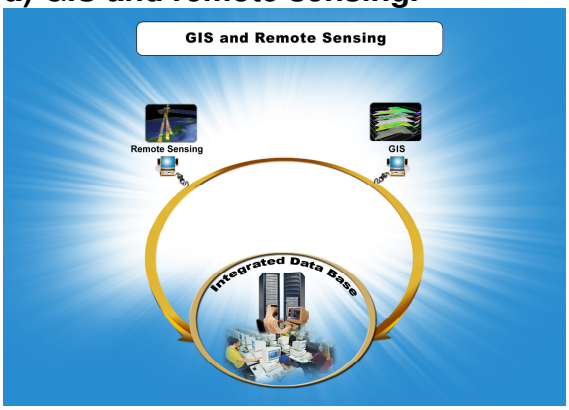


Figure 3.5 The geologic components of the EIS system.

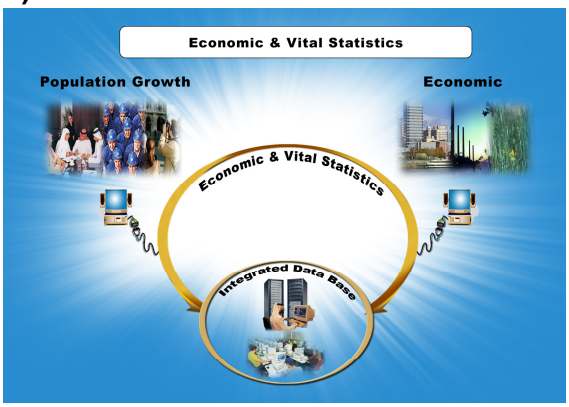
3.3.3 Other Components

Figure 3.5 references the other data elements that are being included in the EIS system, which are summarized in Figure 3.6. These include geographic data which are common to commercial the geographic information system (GIS), such as the Environmental System Research Institute's (ESRI) ARCGIS© software. These can include all manner of geographic data, such as: Country Borders/Land and Ocean, Cities, Populated Areas, Wadis, Roads, Urban Areas, Green Areas. Gridded data, including topography, land use and land cover, all manner of geologic data (soils, minerals, tectonics); national census data (population, housing, tourism, and infrastructure such as water, electricity and telecommunications, etc.); environmental data (pollution, waste water production, etc.).

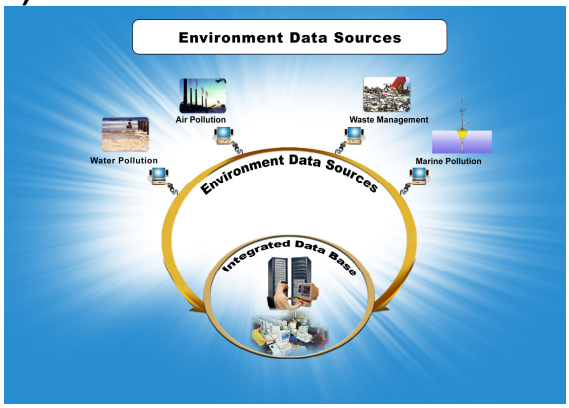
a) GIS and remote sensing.



b) Economic and vital statistics.



c) Environmental Data.



d) Other sources.

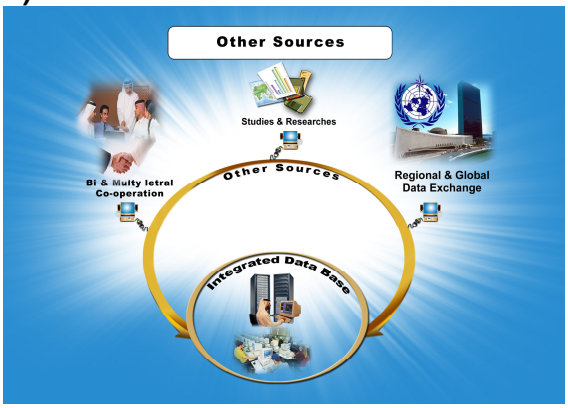


Figure 3.6 Detailed geologic components of the EIS system.

3.4. Data Resources in the UAE

As part of the EIS, all the major supporting datasets that are housed in different institutions spread throughout the country are being gathered for inclusion into the Earth Information System. However, it is impossible, impractical and nonsensical to include all data. The first priority is to identify the most important data elements for WRA, the current sources of water related data in the country, and identify the necessary requirements to meet the upcoming data needs first, the institutional authorities, both public and private, are identified throughout the UAE (which are responsible or have an interest in water related data). Next, the data that these institutions require or collect are identified and finally they are gathered and inserted into the database.

3.4.1 Public Authorities

There are four major authorities responsible for the urban and rural water and domestic water supply. They are responsible for producing and distributing water and electricity, according to geographic distribution:

a) Abu Dhabi water and electricity authority (AWEA) for Abu Dhabi Emirate.
b) Dubai electricity and water authority (DEWA) for Dubai emirate.
c) Sharjah electricity and water authority (SEWA) for Sharjah emirate.
d) The federal electricity and water authority (FEWA), located in Dubai, for the emirates of Ajman, Ras AL Khaimah, Umm AL Quwain and Fujairah and the rural area of Sharjah.

The data collected from these authorities includes:

a) Desalination plants locations, types, capacity, production, consumption, etc.

b) Desalination plants under construction.

c) Groundwater well numbers, types, production capacity, water quality, sustainability.

3.4.2 Governmental Ministries

Data will be continually collected from different ministries including:

a) Ministry of planning.

b) Ministry of agriculture and fisheries.

c) Ministry of industry.

d) Ministry of electricity and water.

The data collected from these authorities include the following:

a) Population by emirate and year.

b) Population in main cities.

c) Average annual growth rate.

d) Estimates of population by Emirate.

e) Actual and estimated population.

f) Labour force.

g) Tourism.

h) Agriculture expansion & growth.

i) Industrial expansion & growth.

j) Additional weather and climate information.

k) Information on wadis and dams.

In addition to the aforementioned it will be important to conduct studies, research to gather the necessary and statistics that relate to water consumption in the domestic, agricultural and industrial sectors.

3.4.3 Companies working on water projects inside the UAE

Data are under collection from several foreign companies including but not limited to the following:-

a) United States Geologic Survey as part of the Groundwater Research Program.
b) NDC (National Drilling Company).
c) ADNOC (Abu Dhabi National Oil Company)
d) GTZ.
e) Schlumberger.

Data available from the above mentioned companies are entirely related to ground water aquifers locations, types, volumes, productivity, recharge rate, sustainability, water quality and quantities, etc. So, listing or giving a list for all the available scientific researches with regard to the groundwater resources in the UAE will assist in making the available information available for research and management decisions.

3.4.4 Other Resources

Data from universities, research centers, and other available studies related to water resources in the UAE, concerning both past and current situations, will be sought after. In addition, there are many international and regional data resources concerning water related subjects such as, hydrogeology, water resources, etc,

especially those related to water resources in Arid and semi-Arid regions including the Arabian countries & Arabian Peninsula such as:

a) World Water Vision – Arab countries Vision Consultations.
b) Geo 2000 (Global Environmental Outlook).
c) WWAP (World Water Assessment Program).
d) UNESCO Data base.
e) UNEP Data Base.
f) ESCWA (United Nations Economic & social Commission for Western Asia).
g) CSAD (Arab Centre for the Studies of Arid Zones and Dry Land).

3.5. Data Classification and sorting

Data will be classified and sorted according to the above mentioned categories and sub-categories. Also, the reliability of the data must be evaluated so that only reliable data will be taken into account. In addition, the coverage of the data is very important for the evaluation of the country water budget.

Data must be processed independently in order to figure out the effect of each parameter on the water supply and demand of the country After that the general water budget of the UAE will be calculated.

Chapter 4
Supporting the Information System through Research

The importance of an Earth Information system for integrated water resources assessment has led to the vision and implementation of a number of systems and projects initiated by the Department of Water Resources Studies (DWRS) of the Office of His Highness, The President. This system should enhance data collection, processing and interpretation in the UAE, which in turn will help researchers in conducting real water resources assessment and management using real and reliable data. In the next few pages, a summary of some initial research priorities that the UAE can pursue. This is a sample list of the projects achieved:

4.1. Advanced Airborne Survey Technology In Ground Water Resource Assessments

Over the past several years, different airborne geophysical technologies have been applied to great effect, to groundwater resource exploration and management around the world. The UAE (DWRS) is investigating whether these technologies may help in the search and management of fresh groundwater resources in the Emirates, where thousands of boreholes have been drilled over the past eight years. The DWRS recently invited some airborne geophysical survey companies to fly a variety of technologies over a known groundwater resource near the Al Khazna Palace to demonstrate the speed and quality of data acquisition and show how the data could be integrated with existing datasets to provide the most value for water, minerals, agriculture and environmental industries.

A combination of airborne technologies was flown, including Time Domain Electromagnetic (TEM), magnetic, Gamma Ray Radiometric, and laser altimeter

systems. The HoistEM was mounted on a UAE Army helicopter using an in-loop configuration. The low flying height of the transmitter allows stronger signal strength into the ground over a smaller footprint. This means that the HoistEM system is capable of resolving conductors as narrow as 30 meters. Furthermore, the symmetric geometry of the transmitter and receiver configuration produces a clean symmetric response, independent of the flying direction (Figure 4.1)

The interpretation of the data took advantage of additional information supplied by institutions that are carrying on work of groundwater exploration, such as bore holes and groundwater geophysical data, to show how these data could be applied, to add value to the identification and management of water resources.

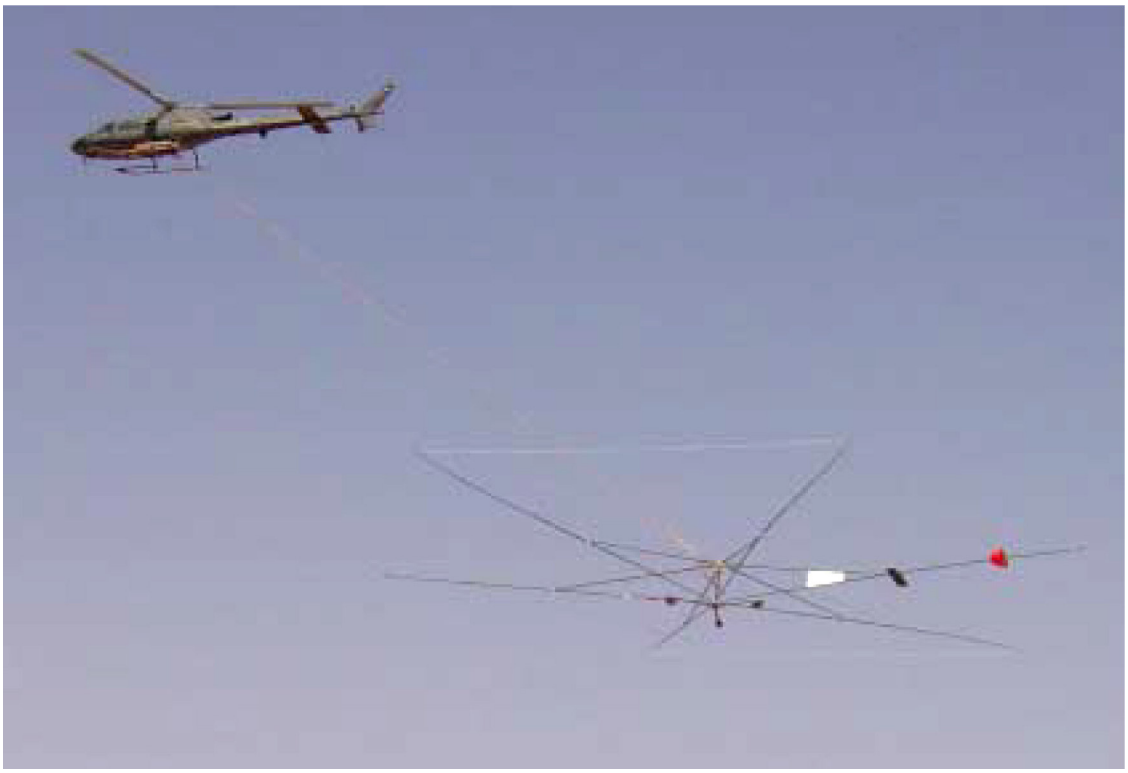


Figure 4.1 The actual helicopter hoist mounted EM system with transmitter (TX) and receiver (Rx) coils on a UAE Army helicopter.

The Al Khazna area (Figure 4.2) was chosen for the trial because the hydrogeology has already been investigated from historic drilling exploration by GTZ consultants. These drilling results suggest that the shallow to medium deep seated stratigraphy beneath the area (down to a depth of approximately 200 meters) comprises three main sedimentary sequences (Figure 4.3):

a) Recent wind blown sand deposits.

b) Pleistocene to recent distal fluvial fan deposits, intercalated with inland sabkha.

c) Tertiary continental and evaporate deposits of the Fars Formation.

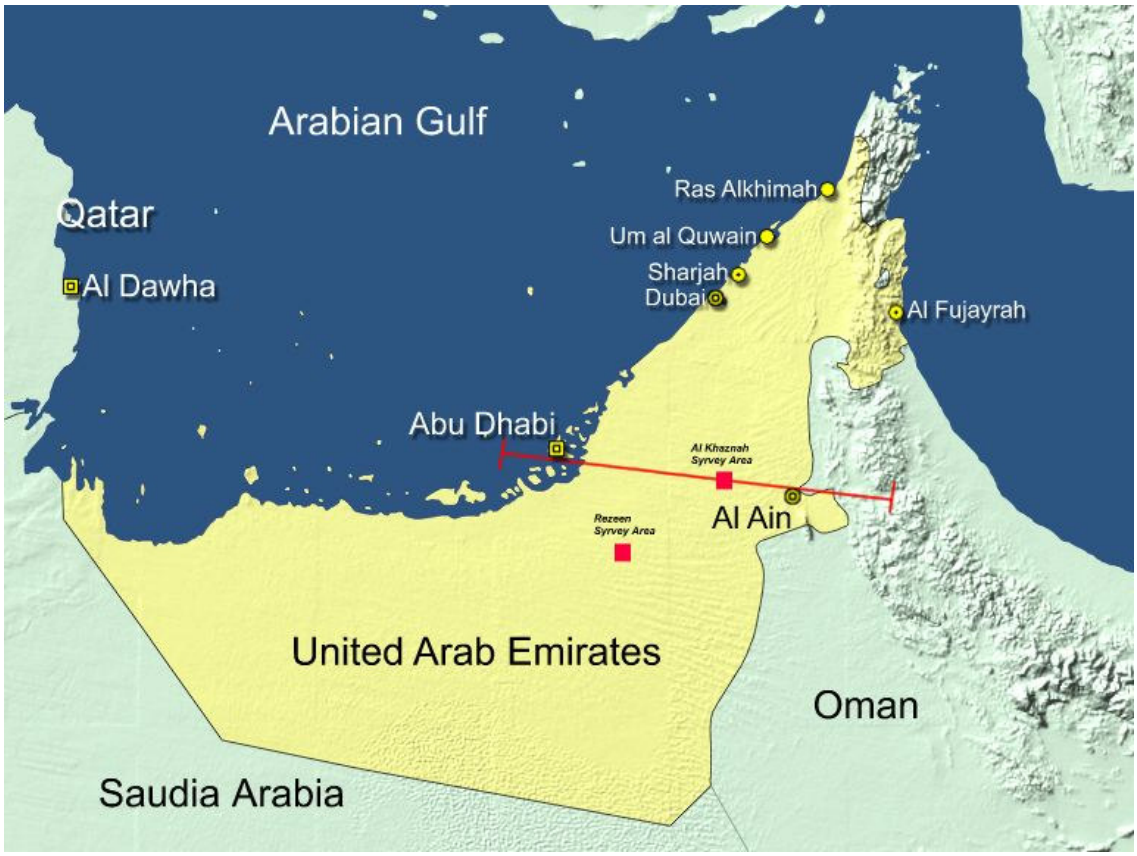


Figure 4.2 Location map showing the Al Khazna survey area.

The survey area is covered by Quaternary sand dunes which form in broad sand ridges several kilometers wide and spaced several kilometers apart. The surface of these ridges is covered by loose fine grained light brown dry sand that is readily remobilized by the wind into high choppy asymmetric dunes or low sand sheet areas (Figure 4.3). The sand cover is underlain by up to 50 to 100 m of fluvial conglomerate, gravel, clayey silt and fine sand. The conglomerate contains clasts of ophiolite, chart, dolomite and shale cemented with calcrete, gypsum and manganese oxide.

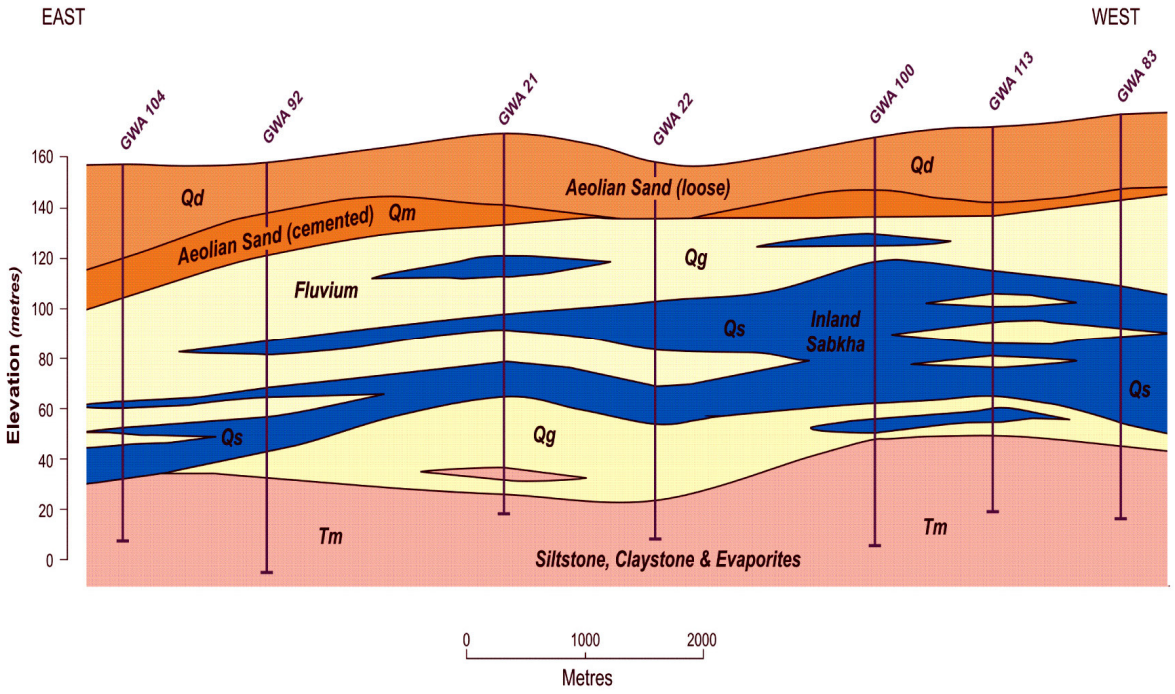


Figure 4.3 EW Geological section of Al Khazna based on GTZ drilling logs.

Fresh groundwater mainly occurs in the sand and conglomerate lenses between a depth of 10 and 100 meters. The Tertiary clay stones tend to have very little permeability or storage and the salinity tends to be higher due to the presence of evaporated deposits. Figure 4.4 shows a water quality map produced by GTZ

Consultants based on bore-water quality samples collected from numerous scattered private and exploration boreholes in the fluvial deposits.

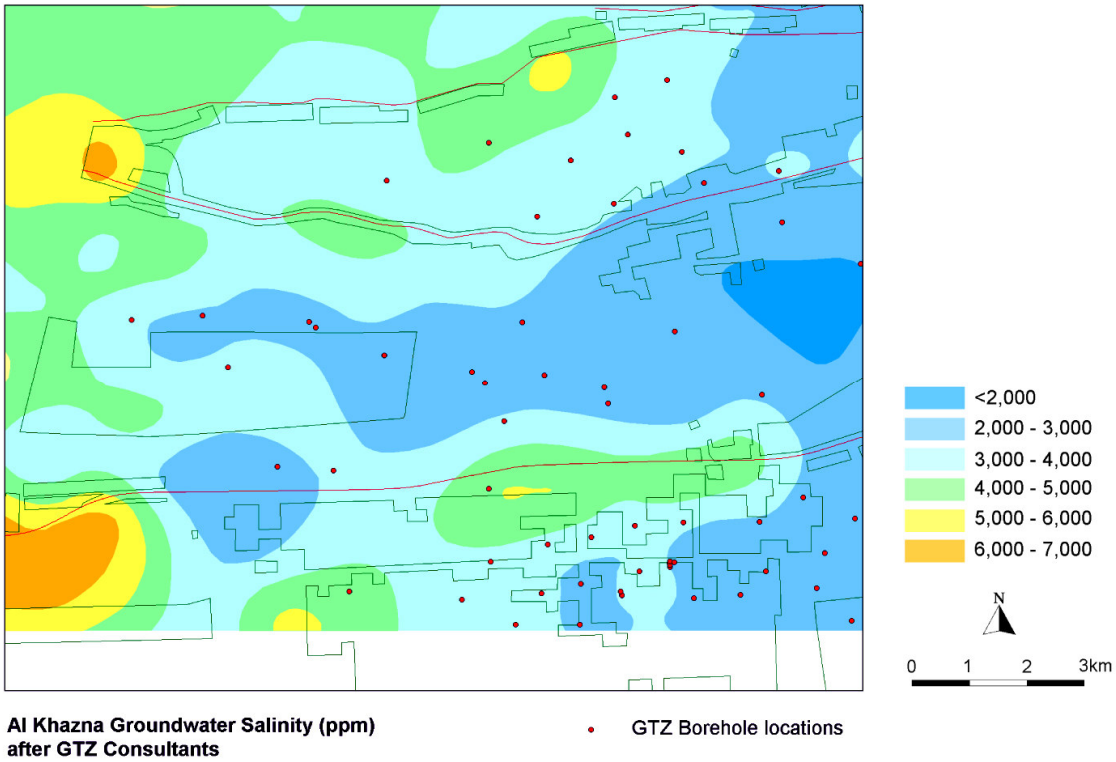


Figure 4.4 Groundwater qualities in the fluvial gravel aquifer at Al Khazna, (reproduced from GTZ consultants).

From the results of the survey trials, it is clear that rapid, high quality airborne data acquisition surveys are feasible in the Emirates. When airborne data is integrated with existing datasets, it provides a powerful tool, not only for the rapid search and management of fresh groundwater resources, but also in mineral exploration, agriculture and environmental management.

Never before has a “whole of country survey” been undertaken and the challenge for the DWRS will be to manage the quantity, integrity and security of the data acquisition, as well as how the data is integrated with other users to provide meaningful value added products.

4.2. Water Demand Forecast

Despite the increases in water demand and accompanying increases in the supply infrastructure, water remains scarce in many localities in the UAE, yet there is still no national understand regarding the nature of these demands, how they are being met, and how they can be sustained in the future. Well formulated and planned research is necessary to address these issues.

The scarcity of water is enhanced by the rapid increase in irrigation water requirements for farming and landscaping. The UAE government has recently decreed a large increase in the number of farms that fully depend on desalinated water. The decree is part of the government policy for distributing the farms to the citizen population in order to reach self sufficiency in most items of food production. However, the agricultural sector is heavily subsidized by the government.

The percentage growth in citizen population is high in comparison with other countries. Additionally, economic growth has resulted in an increase in non-citizen population. An average population growth of 5.8% is forecasted by the ministry of planning. In addition, the population growth in rural areas is approximately twice the growth in urban areas. High per capita consumption is caused by the climatic conditions prevailing in the UAE, high standard of living and low tariff structure for water.

4.3. Rainfall Enhancement

For the reasons detailed in this thesis, namely the impeding water crisis and the fact that the UAE is in a perpetual state of water scarcity, the UAE government through the DWRS office has explored the possibilities to augment water resources via methods such as cloud seeding to enhance rainfall.

The potential for such man-made increases is strongly dependent on the natural microphysics (e.g. the size and concentration of water droplets and ice inside clouds) and dynamics of the clouds that are being seeded. These factors can differ significantly from one geographical region to another, and even between seasons in the same region. In some instances clouds may not be suitable for seeding or the frequency of occurrence of suitable clouds may be too low to warrant the investment in a cloud seeding program. Therefore, the following two questions are critical to answer before proceeding:

a) Does the frequency of occurrence of clouds warrant the investment in a cloud seeding program?

b) Would the clouds in UAE, based on our current knowledge of cloud seeding techniques, be amenable to seeding in order to enhance rainfall?

As part of the UAE program that included flights over the Oman Mountain region from 2001 through 2003, research suggested that the frequency of occurrence of clouds during the summer was sufficient to warrant a randomized cloud seeding experiment and that those clouds were amenable for seeding with hygroscopic flares to enhance rainfall. Measurements conducted with the new Al Ain radar in the UAE during the 2003 summer supported the earlier results. During the winter, insufficient cloud opportunities occurred to warrant a cloud seeding program.

With respect to the second question, microphysical observations of cloud droplets and aerosols show continental conditions in both the UAE and Oman during the summer. More varying conditions exist during the winter, mostly due to weaker cloud conditions (higher clouds and lower updraft speeds). The consistency of the measurements across the region indicates that during the summer, convective storms could be amenable to seeding with hygroscopic flares in the vicinity of the Oman Mountains.

Based on the results mentioned above, the UAE government through the DWRS is evaluating and quantifying the increases in precipitation due to seeding, using a randomization procedure to demonstrate statistically that the seeding method works, and to quantify the increase achieved. This approach is similar, for example, to what is commonly done in medical trials with a new drug. The data from these experiments, particularly radar and weather forecasting, will be incorporated into the EIS system.

4.4. Water Budget Analysis via Hydrometeorology Observatories

Here, water budget analysis refers to studies related to the physical hydrologic cycle. There is a fundamental question that is yet unanswered with regards to renewable water resources in the UAE, namely: What is the primary mechanism of recharge to the alluvial aquifers, and does their rate of extraction far exceed their replenishment? The study of wadi hydrology, while tackled by many in the UAE has been too geared around fragmented research. What is needed is a clear vision that seeks to understand the physical hydrology of these systems. The EIS can help this process by providing an integrating framework for conducting studies and a central repository for storing new data.

These kinds of studies could also address issues such as:

a) Quantify and qualify existing water resources within the UAE through use of new airborne geophysical data acquisition in conjunction of existing data.
b) Identify and map saline/fresh water interfaces and intrusions along the coastline.
c) Map saline water migration pathways into agricultural areas.
d) Identify and map prehistoric water aquifers in desert areas.
e) Interpretation of integrated data to produce new water resources maps.

The DWRS is envisioning the development of a hydro-meteorological observatory, centered upon one or two ideal wadis located in the UAE. The idea is to heavily instrument with all necessary equipment, the wadi bed and the surrounding watershed contained within it, with a dense network of strategically placed rain gauges, surface flux towers that could measure heat and moisture fluxes from the land surface. Also, dense network of soil moisture sensors both normal and parallel to the wadi bed, placed at multiple depths, to determine the penetration depth of soil water following rainfall and wadi flow. Until we know the nature of rainfall that leads to sufficient runoff and recharge, we will still not fully understand the mechanisms of groundwater recharge, particularly in the alluvial aquifers associated with wadis.

Chapter 5
Summary and Conclusion

The UAE have limited renewable freshwater supplies, which have been nearly fully developed, with fossil groundwater reserves the only dependable source in many areas and a tremendous reliance on desalinization to meet growing urban and tourist demands. In some regions, depletion of these non-renewable groundwater resources is taking place at an alarming rate, owing to over pumping in order to meet agricultural and other requirements.

Improvements in the standard of living and urban migration, coupled with the absence of conservation programmes, have brought about high domestic water consumption, which itself increased, for example, three times from 1980 to 1990. Programmes currently in force have focused mainly on the development of water resources rather than management, in order to meet rising water demand. To overcome water shortages, the UAE have come to rely on desalination and mining of groundwater resources. Conservative forecasts indicate that demand during the period 1995-2025 for all sectors is expected to increase almost twofold.

As mentioned before in the preliminary findings, there are a major challenges and driving forces which have a negative impact on the water resources in the UAE, starting with the highest population growth in the world and ending with, but not limited to, multiplicity of authorities, lack of comprehensive national water policies and inadequacy of public awareness.

It is important to stress water management and acceptance that water is a commodity in short supply, and therefore has distinct value and cost and is not something available on demand in any quantity at virtually no cost. To achieve this

goal, there is a growing need for an awareness programme of the problems involved in the conservation and rational use of water, and the protection of groundwater to support what may prove unpopular economic policies. The awareness programme should target all educational levels. It should cover the relevant parameters grouped as below:

a) Conservation of resources.
b) Special, well controlled education programmes on the best methods of exploitation.
c) Drilling, modern techniques of water distribution and continuous maintenance.
d) Scales of charges for fresh water.
e) Establishment of agricultural guidelines for the use of Sea and Brackish water in Irrigation.
f) Monitoring the usage of modern irrigation techniques, which reduce water demand and enhance production, like drip and sprinkler irrigation techniques. Concentrate on trees resistant to drought & salinity, and encouraging the use of greenhouses.
g) Development of database for all the UAE which preserves all the hydrological cycle data beside wells information data.
h) The water resources and their conservation are essential for the country for both present and future generations.
i) Finally, we have to work together to protect the future of our children because **we did not inherit the world from our parents – we borrowed it from our children** (Mohammed A Abu Zeid, president of the world water council)

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