ASSESSMENT OF THE WATER SITUATION IN THE WESTERN REGION OF ABU DHABI EMIRATE

INCEPTION REPORT

June 2003

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1. INTRODUCTION

1.1 Background & ERWDA Water Resources Management Strategy Development

This inception report describes the progress to date on Step 1 (Western Region) of the development of ERWDA's strategic goal of developing a Water Resources Management Strategy and Action Plans for the Emirate of Abu Dhabi. The overall programme, of which baseline information and ambient monitoring is the first part, is described in Table 1.1 below.

Table 1.1 ERWDA Approved Action Plan for Strategic Goal No. 4 "A Management Regime for Water Resources"

STEP	ACTIVITY	TIME FRAME
1	Baseline Information & ambient monitoring	2003 – mid 2004
2	Planning & Development of Water Resources Management Scenarios & Options	Mid 2004 to end 2006
3	Develop Water Resources Management Strategy – objectives, principles, guidelines,	2006 – 2007
4	Develop Implementation Plans (action plans) & Implementation Capacity	2007
5	Implement & Monitor Programmes & projects to achieve the strategic plan goals	2007

The overall Goal is Conservation of the Emirate's Water Resources and rationalisation of water use.

The objective of the Water Resources Programme in ERWDA is to develop a Water Resources Strategy & implement a plan which will help to manage the overall water resources of the Emirate of Abu Dhabi in a sustainable, economically viable and environmentally sound way that will allow the long-term socio-economic development of the Emirate

At present there is no single authority responsible for managing the Water Resources of the Emirate and no Government Water Resources plan exists. Water Resources are extremely scarce in the Emirate and their protection and conservation are vital for long term socio-economic development and for the sustainability of the environment generally.

To assist ERWDA in completing Step 1 of the Action Plan, the UAE Offsets Group (UOG), in co-ordination with the Environment and Wildlife Development Agency (ERWDA) and through its Water Resources Department, has appointed Consultants Mott Macdonald International(Mott Macdonald, 2002 & 2003) to undertake a similar assessment of the overall Water Situation in Abu Dhabi's Eastern and Central Regions, and the development of a database and linked GIS to allow the display of

water features and derivation of water resource balances. Both projects will essentially complete step 1 of ERWDA's action plan. The project areas covered by this and the concurrent project are shown in Figure 1.

The study focus is upon the acquisition and verification of water related data, and its input to a linked Database-GIS, and its use as a tool in water resources appraisal, monitoring and management. Major elements are as follows:

- Review of previous and recent studies.
- Collection, compilation and analysis of all relevant water resources data; in particular, the project will utilise all available existing data provided by the relevant agencies;
- Comprehensive inventory of all available well data.
- Comprehensive inventory of all water production, demands and use within the study area, covering all types of water sources and their respective qualities e.g. Desalination, Groundwater, Treated Wastewater etc as well as their use e.g. Domestic, Agricultural, Industrial, Amenity and Forestry etc.
- Development of a database-GIS with capacity for resource and water balance modelling (concurrent with the aforementioned Consultancy Study)
- Data verification and input to the database
- Identification of the major issues, concerns and problems related to Water Resources Management in the Project Area

The study area comprises the Western Region of Abu Dhabi (Figure 1); it extends westwards from the concurrent consultants project which concentrates on the Administrative area of Al Ain (Eastern Region) and the Central Region including Abu Dhabi. The study area falls entirely under the jurisdiction of the Abu Dhabi Municipality and the Office of the Rulers Representative for the Western Region. The study area occupies 52,048 km² (77% of the total 67,340 km² terrestrial area of Abu Dhabi) and also includes offshore islands.

FIGURE 1 PROJECT LOCATION MAP

1.2 Scope of Report

This Inception Report covers the progress and findings of the work between February 2003 and June 2003. The specific requirements of the inception report are:

- Summary of literature review with description of trends in water resources usage and general water situation.
- Progress report on the water resources data gathering exercise, stating any difficulties/problems and data gaps.
- Review of existing Water Resources Monitoring within the Region
- Specifications and full presentation of Computer Database proposed for the Project
- Methodology proposed for calculation of water balances and groundwater resources evaluation

2. GENERAL INTRODUCTION TO THE WATER SITUATION IN THE WESTERN REGION OF ABU DHABI EMIRATE

2.1 Climate, Landforms and Urbanisation

The study area has an arid desert climate with a rainfall which is most irregular, typically between zero and 30mm/annum. The mean winter rainfall varies form 0-30mm and the mean summer rainfall is less than 5mm across the entire project area. In a wet year, the annual rainfall averages from 20mm – 160mm across the project area. Mean maximum temperatures range from 39-43ºC and mean minimum temperatures from 13-17ºC. There is no perennial surface water flow in the whole of the project area. The area may be classified into the following landform types:

a) Sand Dunes (linear, small barchan, Mega barchan, transverse)
b) Sand & Gravel Plains
c) Coastal Sabkha & khors
d) Ancient inland Sabkha, closed depressions and ancient wadis (Sabkha Matti)
e) Salt Domes (islands)
f) Islands & Peninsulas

By far the largest area is covered by Dune sand and paleodune deposits. Dunes range in size from mega barchans found in the dune field directly south of the Liwa crescent where the average relative dune heights are 103m to small barchans south east of Baynunah which have an average relative height of less than 10m (UAE University, 1993). The dunes are a common north – eastern extension of the well known sand sea “Ar Rub Al Khali” which lies mainly within Saudi Arabia. Topographic elevations in the project area range from 0m (offshore Islands) to 259m above mean sea level (mega barchan dune field south of Liwa). Inland sabkha is found within the depressions of the mega barchan dune field. Several other ancient land forms are also developed in the project area under different climatic conditions e.g. ancient sabkha at Sabkhat Matti, paleolakes in the Liwa and Al Sila areas and fans & deltas also near Al Sila.

The coastal sabkha extends all the way along the northern project boundary and comprises dominantly carbonate sands and muds together with varying amounts of evaporitic minerals. Much of this Sabkha plain is supratidal, but the seaward parts adjacent to lagoons are occasionally covered by sea water during stormy weather. Several secondary landforms are developed along the coastal belt, e.g. salt dome hills, flat topped hills at Jebel Az Zannah, ancient raised sand beach ridges and low dunes found at the landward margins of the coastal plain marking the beginning of the internal sand dune region. Offshore, there are three kinds of Islands; barrier, salt dome and submerged hill. Table 2.1 lists 24 islands and offshore installations within the project area. The largest is Abu Al Abyad with a maximum length of 35km and a maximum width of 12km. Ras Khumays at the far western part of the project area is a good example of a peninsula landform.

Settlement is sparse in the Western Region study area. The total 2001 population is 116,177, just 10% of the total for the whole of Abu Dhabi Emirate. The major mainland settlements are Ruwais, Madinat Zayed, Al Mirfa, Ghayathi and Liwa and the main Island settlements are Dalma, Das and Zakum. The island list also includes permanent

settlements associated with oil & gas installations offshore e.g. oil rigs etc Table 2.1 shows all the settlements in the project area which are recorded in the 2001 Census. (Abu Dhabi Planning Dept, 2002).

Table 2.1 2001 Project Area Population Distribution

MAINLAND		ISLANDS	
Name	**Population**	**Name**	**Population**
Ruwais	19925	Dalma	5609
Madinat Zayed	17869	Das	3594
Al Mirfa	12325	Zakum	1060
Ghayathi	11377	Abu Al Abyad	829
Liwa Oasis (west)	7088	Sir Ban Yas	819
Liwa Oasis (east)	6691	Zarku	708
Ba'yah	6262	Al Mubraz	357
Muzair'ah	4147	Um Al Sheef	129
Bu Hasa	3451	Arzana	101
Asab	2435	Al Bunduq	95
Jabel Dhana	2389	Al Waheel	60
Baynunah	2321	Haniora	52
Habshan	1377	Al Saadiat	50
Bida Al Mutawah	1194	Quareen Alush	19
Tarif	1006	Ghagha	18
Arjan	881	Balghaleem	17
Al Sila	827	Ajej	15
Sahil	489	Um Al Birk	12
Al Ghoufat	297	Maseera	8
Al Barir	156	Tafah	8
Mukhairez	61	Mushairib	4
Wasit	14	Bu Al Shoom	4
Al Khirza	8	Qusar Bu Saeed	4
Qumra	7	Khamis	4
Al Shubook	4		
Totals	**102601**		**13576**

2.2 Shallow and Deep Geological Formations

2.2.1 Shallow Geology

The surficial geology of the Western Region of Abu Dhabi Emirate comprises five main quaternary deposits, namely, sabkha, dune sands, carbonate beach sand deposits, dune sands with inter-dunal sabkha deposits and paleodune deposits. The only other non – quaternary surficial geological formation is the Baynunah Formation which is of Miocene Age. (USGS/NDC, 1996).

The majority of the area is Aeolian sand. Aeolian sand is widespread and comprises medium to very fine grained, sub-rounded to well rounded particles of quartz, carbonate, heavy minerals and evaporite minerals. The deposits are generally clay and slit free and thus have moderate to good permeability. Layers of calcareous and

dolomitic clay occur in the sands of a lower unit and are thought to represent cemented zones associated with a paleo water table. The overall unit has an average thickness of about 40m.

Sabkha (salt flats) deposits occur at the coast and also inland. Coastal sabkhas have both seawater and groundwater ingression and are restricted to a thin belt along the Arabian Gulf. They are areas of groundwater discharge and are often overlooked as forming an aquifer, albeit of very poor groundwater quality and productivity. Brine is usually found within 1m of ground surface. (Sanford & Wood 2001). Inland sabkhas are mostly inter-dunal and are produced by evaporation of shallow, saline groundwaters.

Generally, sabkhas comprise thin layers of sand, silt, marl and evaporite minerals. The depth to water table and wind deflation processes are the two principle factors which control the topography of sabkhas.

Alluvium (gravel) and sand plains are quite rare in the area and occur only as very localised sheets close to low lying resistant hills.

Paleodune deposits (aeolianite) are ancient consolidated sand dunes. They comprise fine to medium grained, rounded to well rounded quartz sand and grains of foraminifera, coral, red algae, ooids, shell fragments, evaporate minerals, heavy minerals and micritic carbonate cement. The quartz component of the dunes increases progressively from north – south so that in the Liwa area, it can comprise up to 90% of the overall paleodune deposit.

The Baynunah deposit comprises poorly consolidated fluvial sand of late Miocene age and outcrops over an area of about 3000 Km². Sediments are horizontally bedded and form relatively high topography up to 60m amsl. The Formation can contain thin sandstone, conglomerate, clayey silt and gypsiferous sandstone beds. Sediment source is from the west in Saudi Arabia.

2.2.2 Deep Geology

Underlying the surficial, quaternary and Miocene Formations are four other important formations which are all water bearing, namely, Lower Fars Formation, Oligo-Miocene Clastics unit, Dammam and Umm er Radhuma Formation (UeR).

The main structural features of the above Formations are gentle and simple folding. Karstifcation of the limestone Dammam Formations has produced considerable secondary permeability and good aquifer potential in this regional aquifer system that extends across the Arabian Peninsula.

The Dammam Formation is a marine carbonate and has an average thickness of 270m. It is unconformably overlain by Oligo-Miocene Clastics of continental origin which have an average thickness of 105m. It comprises siliceous sand, sandstone and minor interbedded shale layers.

The Lower Fars Formation is a shaley deposit which unconformably overlies the Oligo-Miocene Clastics unit and has an average thickness of about 100m. This

Formation comprises shallow marine mudstone, claystone and shale with inter mixed carbonate and gypsum.

2.3 Summary of Water Resources

2.3.1 Hydrogeological Setting

No surface water resources exist; the project area is remote from the occasional active wadis which flow from the Al Hajar Mountains of Oman into the Eastern Region of Abu Dhabi Emirate. In the Eastern Region run-of from the mountains is a major source of recharge and at Shwaib, a recharge dam has been constructed to capture run-off and infiltrate it for aquifer replenishment. Generally, Abu Dhabi Emirate's low- lying relief and lack of topography makes it unsuitable for recharge dam feasibility. Therefore it is the various groundwater systems that are of interest hydrogeologically. Sediments of Quaternary age contain the most important aquifer systems in the study area, while recent deep drilling has investigated carbonate aquifers. Water Resources of the shallow quaternary aquifers are fairly well understood whilst those of deeper, bedrock aquifers still require considerably more exploration and assessment before the same level of confidence can be placed on their evaluation. The Main hydrogeologic units present in the project area are:

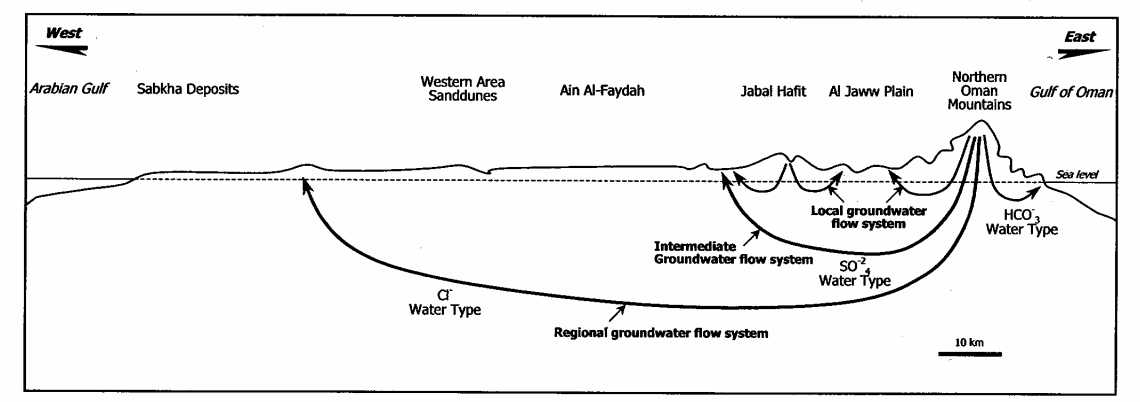
- a shallow, unconfined sand dune (Aeolianite) aquifer which covers about 90% of the surface of the project area and can attain an average thickness of about 150m; used mostly for irrigation, oil well drilling and desalination plant feed water.
- Lower Fars Unit (approx 160m thick); poor aquifer properties and none or little abstraction
- Oligo-Miocene clastics aquifer, with approximate thickness of 100m; receives injected oil – feed brines
- Dammam Limestone Aquifer (approx. 265m thick) produces brackish groundwater, often injected into oil reservoirs to stimulate recovery.
- Umm Er Radhuma (Simsima Limestone) Aquifer; used as source injection water for oil reservoirs

Specifically in the Al Sila area, at the far western part of the project area, the surficial, unconfined aquifer comprises approximately 40m of fluvial sands, clay and sandstone, representing delta and paleolake remnants of the Baynunah Formation, and withdrawals are for local irrigation.

The most important, and most heavily utilized aquifer is the Aeolian sand deposits in which permeability decreases with depth due to an increase in clay and intergranular cement content. The base of this aquifer marked by the onset of the Lower Fars Formation.

In the project area, a regional flow system can be demonstrated, from the Oman mountains and the mountain front recharge areas, westwards to the Gulf and to discharge points within the coastal sabhka; USGS work (USGS/NDC, 1996) suggests that a significant flow component also moves to the SW into Saudi Arabia. Westwards towards Abu Dhabi City and the Gulf, progressive increases in groundwater salinity. Figure 2 (Alsharhan et al, 2001)

Figure 2 Groundwater Flow Systems in Abu Dhabi Emirate



shows a schematic of the various groundwater flow systems in Abu Dhabi Emirate; the lower and middle regional groundwater flow systems are the most dominant in the project area. The intermediate system is of the Sulphate type and accounts for most of the brackish water quality in the project area. The lower regional system is of the Sodium Chloride type and has its end point at both inland and coastal discharge sabkha areas.

The USGS/NDC Groundwater Research Project (USGS/NDC,1996) has classified groundwater quality into three main types, namely: fresh: 0-2400 mS/cm (0-1500 mg/l), brackish: 2400-24,000 mS/cm (1500-15,000 mg/l) and saline: greater than 24,000 mS/cm (>15,000 mg/l). [WHO Drinking Water Standards, quote slightly different class boundaries and describe fresh as 0-2500 mS/cm (or about 0-1600 mg/l) and brackish >2500 mS/cm. The Extension Service of Abu Dhabi Municipality, Agriculture Dept have adopted a salinity class system as follows: Class 1 0-4,000mS/cm, Class II 4,000-8,000 mS/cm, Class III 8,000-12,000 mS/cm and Class IV greater than 12,000 mS/cm.

The Forestry Department of Abu Dhabi Municipality use a different classification system for groundwater, namely: fresh 0-1500 mg/l, brackish 1500-10,000 mg/l, saline 10,000-20,000 mg/l and very saline greater than 20,000 mg/l.

For the purpose of this study, the USGS/NDC general groundwater classification shall be adopted, however, the brackish unit shall be further sub-divided into low and high brackish with the boundary being 8,000 mg/l.

The only fresh groundwater in the project area occurs as a remnant basin of fossilised water immediately north of the Liwa Oasis (USGS/NDC, 1994). This basin occupies an area of 2,400 Km² with an average thickness of about 30m, although the unconfined “Liwa Aquifer” has a maximum thickness of 120m. The average transmissivity of the unconsolidated fine sand aquifer is 300 m²/d with an average specific yield of 0.22 (22%). The southern margins of the fresh water mound have been heavily exploited for irrigation over the last 10-15 years with a rapid expansion in the agriculture sector e.g. between 1987 and 1996, the combined area of farms and forestry more than doubled from 6,000 to 12,500 hectares. (NDC Fact Sheet,1997). Fresh and low brackish waters comprise about 40% of the total groundwater storage in the Liwa Aquifer.

The remainder of the groundwater is of high brackish or saline quality. Brackish groundwater occurs in both surficial sand aquifers and deep carbonate aquifers, as does saline groundwater. All offshore islands have saline groundwater, with the exception of occasional shallow hand dug wells which are fed by rain-harvesting techniques e.g. local catchment basin recharge at Marawah Island.

2.3.2 Review of Literature & Previous Studies

The project area has been subject to several significant groundwater investigations over the last 20 years, as follows:

Year	Investigation Title	Scope & Summary Conclusions
1985 (March)	Fresh Water Resources Development & Rationalization of use in UAE	Seminar at UAE University Faculty of Engineering, including overview of Regional Aquifer Geology of Abu Dhabi
1985 (June)	Geoconsult & Bin Ham Drilling Est.	A deep water well drilling investigation commissioned by the Ministry of Agriculture & Fisheries, UAE in 5 different areas of UAE, including Liwa in the Project area. Borehole LW 1 drilled to a depth of 1035m. Uer Formation reached at 985m.Three aquifers identified; Fars (0-97m), Oligocene – Miocene clastics (97-413m) & Dammam (413-685m), EC respectively 100,000, 15,000 & 38,000µS/cm. Uer and surficial sand aquifer not tested.
1986 (Dec)	IWACO & Bin Ham Drilling Est. for UAE Ministry of Agriculture & Fisheries, Water & Soil Dept. Groundwater Study Project 21/81; Drilling of Deep Water Wells at Various Locations in the UAE	Main Report Volume Text; Regional report Volume 5 Groundwater Development in the Western Agricultural Region. Final report and geo-logs for above investigation at Liwa.
1988 (Jan)	ADCO Geology Dept. Hydrogeological Study of the shallow aquifers of the Shah Oilfield, south of Liwa	An internal ADCO investigation into hydrogeology of the Shah Oilfield, also using Liwa well data. 10 out of 17 water wells drilled for water supply for oil operations tested in aeolian sands, with Transmissivities ranging from 0.8 to 41m²/d tested at yields of between 0.07 – 2.6 l/s. TDS ranges from 15480m – 48874 mg/l, thus all saline. Isotope analysis conducted for 9 wells, with calculated apparent ages for groundwater ranging from 10,000 – 28,000 years
1994	USGS.NDC Groundwater Resources of the Liwa Crescent Area, Abu Dhabi Emirate	Comprehensive hydrogeological study of the fresh water basin at Liwa, including drilling and aquifer testing of 18 wells over an area of 14,560 km². Investigated unconfined aquifer comprising fine grained sand and silt with max. Thickness of 120m. Includes estimate of fresh water of 16,000 Mm³ and brackish groundwater of 101,000 Mm³ and recommendation on production well spacing of 200m and limiting yields to 500 m³/d.
1996	USGS-NDC Groundwater Resources of the UAE	Compilation of studies within a comprehensive groundwater research programme which was started in 1987 for the whole of Abu Dhabi Emirate; investigations focussed upon Liwa area of Project area(called ' the Blue Book')
On-going since 1987	USGS-NDC Groundwater Resources of the UAE	Major groundwater investigations which have continued for over 17 years with this Joint USGS/NDC project reporting to ADNOC. First detailed assessment of the Groundwater Resources of Abu Dhabi Emirate, incl. summary maps for aquifers, piezometry, Aquifer parameters, water quality.
On-going since 1995	GTZ for ADNOC: Groundwater Assessment Project, Abu Dhabi	This major, well funded project has the objectives of (1) creation of a sustainable water resource management system (2) assessment of the shallow-deep groundwater resources in the entire Emirate (3) development of central water database and GIS and (4) investigations into water consumption in agriculture & forestry. Project elements have included a large well drilling and testing programme (88 deep wells of greater that 300m), 390 shallow-medium wells and 188 monitoring wells), well census (over 13500 wells), production wellfield development in Al Khazna and SW of Al Ain, and installation of groundwater monitoring network with follow up monitoring of water levels and conductivity. In addition, GTZ have carried out isotopic analyses as part of recharge investigations. Project is currently supervising a recharge well pilot study north of Liwa utilising desalination sources water from Mirfa plant

Year	Investigation Title	Scope & Summary Conclusions
1999	Balfours –Tebodin Bu Hasa Irrigation Project	710 wells drilled & tested for irrigation of Forestry plantations. Yields range from 32-54 m³/hr and EC from 1500 - 4760µS/cm.
2000 (July)	Tebodin - Bida Yamra drilling, implementation & maintenance of 200 wells and installation of pumps	Contract completed for Abu Dhabi Municipality Agriculture Dept for Government Agriculture projects – most wells for irrigation of forest plantations
2001 (March)	Investigation into the Hydrology of the coastal sabkhas of Abu Dhabi, United Arab Emirates	Separate USGS project as part of overall Groundwater Resources Assessment study. More than 500 shallow wells (<5m) dug to collect brine samples and 22 piezometers installed along 300km coastal belt. Hydrological study of the behaviour of sabkhas – Estimates within a rectangular volume of sabkha, defined as 1m wide, 10km long & 10m deep are 1 m³/yr input by lateral groundwater flow, 40-50 m³/yr by upward leakage and 640 m³/yr by direct recharge from rainfall.

Most of the investigations carried out to date have concentrated on the surficial sand aquifer and there has been very little investigation into the potential of deep, carbonate aquifers Deep aquifer exploration has commenced in 2003 and this is currently being conducted by both Abu Dhabi Municipality Agriculture Dept and by Sheikh Zayeds Private Department (new work for drilling to depths of >1000m presently being put to tender).

Investigations to date have concluded as follows:

- The shallow, Aeolian sand aquifer, especially in the Liwa Oasis area, is being over abstracted, a process that is leading groundwater level fall, increasing salinity and increasing problems in farming activities with a restriction on products that can be grown due to increasing salinities of both water and soil.
- Few deep test boreholes have so far been drilled to investigate the oligo-miocene aquifers and deeper still carbonate aquifers of the Simsima, Dammam & Umm er Radhuma Formations; to date, no fresh water aquifers have been encountered at depth and the potential for fresh water finds is negligible; however, low brackish groundwaters are feasible and can be utilised for irrigation.
- There has been little resource monitoring and water resource regulation and water resources management has been seldom applied.

2.3.3 Current Understanding of Water Resources Development & Use

Although estimates of current and projected demand do vary across the various agencies concerned with water production and distribution, it is certain that water demand in Abu Dhabi is increasing remorselessly due to high population growth, economic and industrial growth and policies which actively encourage agricultural and forest development. Current demand estimates (source: Tebodin 2001 Master Plan & ADWEC 7 year Statement) are between 400-450 MGD (excluding demand from forest and agriculture), and assumes, if demand remains unrestrained, an average annual growth of 10.6 percent over the period 2002-2010. It is the agriculture and forest sector which is mainly responsible for the high and increasing demand. Recent estimates of water use in the whole of Abu Dhabi Emirate are as follows:

Water Use Type	**(percent of total)**		
Public Water Supply	23		
Industry	10		
Irrigation:	**67**	*of which farm & amenity*	*47*
		& Forest	*20*

(Estimates given at a Seminar on Water Resources Management, 19-20 October 2002, in Al Ain; quoted by the Program Advisor to the USGS-NDC Groundwater Project).

This consumption is met from groundwater abstraction, from treated sewage effluent (TSE) and from desalination; approximate estimates of the relative contribution from these sources is as follows:

Source	**Percentage of Water Production**		
Desalination	29.0		
TSE (Al Ain & Abu Dhabi)	7.2		
Groundwater	63.8		
		Of which Wellfield domestic fresh	5.6
		Wellfield agric fresh	5.4
		Wellfield brackish	44.0
		Wellfield saline	*8.8*

While for desalination, TSE and domestic wellfields, these estimates are considered reliable, estimates of water production for farms and forests (wellfield agricultural fresh-brackish and saline) maybe less reliable. One objective of the current project is to attempt an estimation of these demands, using cropped areas and crop water use estimates taken from current landsat imagery and utilising land classification methods of remote sensing.

The groundwater resources of the Western region, and their likely development potential, is considered to have reasonable expectation for meeting demands for brackish groundwater although future potable supply demands can only be reasonably met from desalinated seawater e.g. Al Mirfa and Shuweihat plants. The brackish groundwater reserve is still substantial. The following main conclusions can be drawn with regards to groundwater investigation and development.

- Fresh water is very limited and is restricted to the groundwater basin immediately north of Liwa. There are now no operating municipal wellfields in the project area however; the existing 18 former Water & Electricity Dept wellfields were shut down by 2001 because of levels of chromium in groundwater that were above permissible levels and deemed to be a significant health risk.
- Little or no active recharge, either direct from rainfall, or indirect from other means, is occurring in the project area. The groundwater sources are therefore fossil and non-renewable.
- despite major groundwater exploration efforts (in particular by the USGS and GTZ), it appears that no significant undeveloped fresh water aquifers have been detected in the study area, other than the fresh water basin immediately north of Liwa Oasis.
- Exploration and assessment of deep aquifers has to date been very limited. There still remains substantial scope for deep (500m – 1500+m) drilling projects to investigate Dammam, Umm er Radhuma & Simsima Formations. All Formations are present throughout the Project area and have considerable thickness; coupled with secondary permeability they have significant potential for new groundwater resources (most likely to be brackish or saline though).

- Continued development of new farms, agriculture projects and Forestry Plantations, utilising shallow groundwater resources in the Aeolian Sand Aquifer, will place further local stress on this resource.
- Groundwater is still the major source satisfying the total water demands of the project area; its conservation and rational use should be a high priority; at present, the potential for aquifer storage & recovery projects is being assessed with a pilot study to inject desalinated water into the sand aquifer in the Liwa area via recharge wells and to build up a substantial strategic reserve of groundwater for emergency drinking water supply.

(1) Agricultural Development

Agriculture development is controlled under the management of the Abu Dhabi Municipality Agriculture Department and comprises both Government and private farms and Forestry. The Dewan of the Western Region also manage a relatively small area of farms

The Municipality Agriculture Department manages 28 different Government projects within both the Western and Central Region of Abu Dhabi Emirate, irrigated by over 3,175 wells. Irrigation of forestry is undertaken mostly, with a small number of farms (total No. in 1999 was 211 – Abu Dhabi Municipality, 1999) and parks, gardens and road verge projects. Based on an 8-hour/day pumping regime, the combined water requirement is about 64Mm³/d. Salinity of groundwater ranges from 2500 – 17,000 mg/l. Complete details of the operations will be reported at a later date in the interim report. Between 2000- 2002, 1480 wells were drilled on 4 large central wellfields at Bu Hassa (Project 1 & 2), Bida Yamra (2), and Saih al Khasob.

As an example of the scale of these irrigation developments, Bu Hasa Project 2 comprises 350 wells, drilled & tested between Feb – August 2000. Drilled depth ranges from 44m – 93m and all wells were completed with standard design, about 28m screen and rest is 8-inch casing. Total drilling = 26485m, total completed = 26184m, total screen = 32144m, total gravel packing = 7142m3 and all wells were pump tested for 24 hrs. The static water level in the wells varies between 19m to 67m. Yield varies between 32.5 m3/hr to 53.5 m3/hr and drawdown between 1.4m and 5.4m. EC at the end of test varies from 1500µS/cm to 4760µS/cm.

Development of private citizens farms is undertaken by the Agricultural Extensions and Marketing & Livestock section (Agricultural Guidance) at Abu Dhabi Municipality. Private farm developments are mostly in the Liwa and Ghayathi areas. Farms are typically 2-3 hectares in area and generally are supplied by two water wells drilled at opposite corners of the farm plot.

The last decade has seen considerable expansion in the private farm sector, largely encouraged by generous subsidies and soft loans paid by the Agriculture Guidance Section. Free services presently offered to farmers include well drilling and pump installation & maintenance, establishment of an irrigation network, levelling, soil importation, ploughing and hoeing, erection of fences and supply of seeds, vegetable seedlings and fertilisers. The amount of soft loans offered to farmers has reduced however in recent years; between 1996 and 1999, loans offered have reduced from Dh 51 Million to Dh25 Million and there has been a steady increase in the magnitude of free services offered to farmers during the same period . According to Municipality statistics (Abu Dhabi Municipality, 1999), the total number

of private farms in the central and Western Regions in 1999 was 8968 occupying 29,000 hectares, a 70% increase in area compared to that of 1995. The total number of farms developed in 2002 is greater than 10,000 (exact numbers will be confirmed later). Between 1995 and 1999 the number of water wells drilled by the guidance section increased from 20237 to 27480. Only 63% of the wells in 1999 were actually producing compared to 94% in 1995.

Other agricultural activities are carried out by the Dewan, under the Rulers Representative of the Western Region, based at Beda Zayed. A small number of farms cultivate dates, fruits and vegetables; details of abstractions and irrigated areas are not known at this stage, follow up is required at interim report stage.

(2) Forestry Development

Afforestation projects are undertaken by three different organisations; ranked in order of size of projects undertaken, they are:

1. Abu Dhabi Municipality Forestry Department
2. Abu Dhabi Municipality Agriculture Department
3. Dewan of the Western Region

Abu Dhabi Municipality Forestry Dept

Up to the end of 2002, the Forestry Dept of Abu Dhabi Municipality managed 166 projects covering 204,400 hectares with over 40 million individual trees. The Department divides its activities into three regions, namely Madinat Zayed, Al Wathbah and Ghayathi. The table below provides details:

Region	No. of Projects	Area (hectares)	Total No. Trees
Madinat Zayed	54	45200	9,043,400
Al Wathbah	72	40800	8,160,000
Ghayathi	40	118,400	23,690,000
Total	**166**	**204,400**	**40,883,400**

The first Forest, Al Bab (“Father”) was established at Beda (Madinat) Zayed in 1971 in order to provide an improved habitat for the local Bedouin and their animal husbandry and to attract Bedouin settlement to Beda Zayed. By the end of the 1980’s, reasons for establishing forests had changed to protecting roads with forest belts, providing protected areas for wildlife sanctuary and, more recently, fixing / demarcating UAE’s International Boundaries with its neigbours e.g. Saudi Arabia.

A general lack of water, and salinisation problems of water & soil have hindered the establishment and management of Forests. Groundwater is used for irrigation; wells are developed in central wellfields pump to elevated reservoirs which then irrigate the individual trees by gravity from efficient drip irrigation. A total of 2852 wells irrigate the 166 plantations,

with a general distribution of one well per 20-25 hectare of forest development. In 2002, 221 new wells were drilled and 1004 wells have been drilled or dug over the last 5 years. The distribution of wells drilled is given below:

Region	No. Wells	Well Depth Range (m)	Groundwater Salinity Range (mg/l)
Madinat Zayed	500	12-91	1500-18,000
Liwa*	143	15-91	800-13,000
Ghayahthi	392	13-46	4,000-15,000
Al Wathbah	1817	9-61	3,500-51,000

* Liwa falls in the Madinat Zayed Forest Administration Region

Fresh groundwater is only available in the Liwa region; brackish to saline groundwater is used in the Madinat Zayed , Ghayahthi and Al Wathbah regions and very saline water is also used in the Al Wathbah region.

The table below provides details of salinity tolerances of trees which are grown in the plantations.

Plant species	Local Name	Common Name	Max Salinity Tolerances (mg/l)
Acacia ehrenbergiana Hayne	salam		7,000-8,500
Acacia nilotica (L.)Delile	garath	arabian gum tree	8,000-10,000
Acacia victoriae Benth.			8,000
Acacia tortilis (Forssk.)Hayne	samar		2,500-6,000
Acacia cyanophylla			1,500-40,000
Prosopis cineraria (L.) Druce	ghaf	umbrella thorn	8,000-14,000
Prosopis juliflora (Sw.)DC.	ghawaif	Mesquite	35,000
Prosopis chilensis (Molina)Stuntz			8,000-10,000
Ziziphus spina- christi (L.) Willd.	sidr	jujube	4,500-5,500
Salvadora persica L.	arakh	tooth brush tree	9,000-16,000
Phoenix dactylifera L.	nakhil	date palm	25,000
Eucalyptus camaldulensis Schlecht.	keena	eucalyptus	9,000-12,000
Azadirachta indica (L.)	neem	neem tree	up to 8,000
Cassia italica (Mill.) F.W. Andrews	senna		1,500-5,000
Conocarpus lancifolius Engl	dammas	land mangrove	15,000-25,000
Atriplex spp.	atriplex		8,000
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	rimth		8,000-10,000
Simmondsia chinensis (Link.)C.K.	jojoba	goatnut	6,000-7,000
Calligonum comosum L'Her.	arta		5,500-6,000
Leptadenia pyrotechnica (Forssk.) Decne.	markh		4,500-5,500
Haloxylon persicum Bunge	ghada		4,000-5,000
Zygophyllum qatarense Hadidi	harm		32,000-35,000

Generally, trees tend to be under-irrigated and salinity levels of groundwater are in conducive to growth. Many trees, despite being 20-30 years, are less than 3m high, show stunted growth and suffer from soil salinization due to lack of irrigation water for leaching of salts in the root zone. Forests developed along the Abu Dhabi – Sila road are located in areas of

Sabkha; consequently, soils and irrigation waters are imported. Imported soil thickness is less than 1m. Groundwater of brackish quality is pumped considerable distance from wellfields developed in the central part of the Western Region in order to irrigate the trees along the Abu Dhabi – Al Sila highway.

Despite under-irrigation of trees, the 161 projects use significant quantities of groundwater. Landsat imagery classification will be used in the next stage of the study to determine irrigated areas and water requirements.

Over 50 of the forest plantations, which were originally created to help combat desertification, now also serve another purpose as wildlife reserves. These protected areas are found at Al Waheehi, Wadi Al Ghozlan, Hima Forest, Haloota, Bab, Jahilia, Beda Hazza, Jebel Dhana Forest, Abu Arnab, Ghayathi, Nasasa, Butouf Forests, Majhoula, Yawaldibsa, Yulqadar, Fuweilat and elsewhere. The reserves provide a protected shelter for gazelles, oryx, ostrich etc and are fenced and have security guard patrols.

Abu Dhabi Municipality Agriculture Department

The Agriculture Department are also responsible for drilling wells to supply irrigation water to various Afforestation Projects in the Western Region, varying from thin strips of verge plantations to protect roads to large scale projects up to 20,000 hectares in size (Baynoonah). These developments will be captured within GIS and their water requirements determined within the supply-demand model of the project database.

Dewan of the Western Region

The Rulers Representative of the Western Region (Dewan Office) also manage some Forestry Projects and water requirements for the developments are provided by wells drilled by the Dewan's own drilling rigs. Quantification of water requirements will be undertaken using analysis of landsat imagery and a study on individual well capacities.

(3) Public Water Supply

In the western region, all public water supply is provided from desalinated water produced by plants at Mirfa and Sila. Mirfa plant produces 22.3 Mm^3/yr using the Multi stage flash distillation method and Sila only 2.4 Mm^3/yr from two small reverse osmosis plants. The Abu Dhabi Distribution Company (AADC) has responsibility for supplying water of potable quality which meets the Regulation & Supervision Bureau's drinking water quality standards of 2000 (Appendix A).

Other small plants with a typical capacity of up to 10,000 m^3/d are operated privately on islands e.g. Sir Baniyas, Delma, Abu Al Abyad etc and by ADNOC at Ruwais Industrial Estate. Wellfields in the Liwa area, previously operated by AADC, have been closed down in the last 2 years because of high chromium values in groundwater which pose potential carcinogenic risks to human health. However, AADC continue to operate 30 wells from wellfields at Busaddain, Liwa, Jawalood and Ghayathi with a total annual production of less than 1 Mm^3/yr; water is utilised for irrigation only. The main demands for potable water are Madinat Zayed, Ghayathi, Mirfa, Liwa, Delma, Asab, Habshan and Sila. The table below gives weekly and annual consumption figures for the main centers.

Western Region Potable Water Consumption from Mirfa & Sila Desalination plants (2003)

Center	Weekly Consumption gallons	Weekly Consumption Cubic meters	Annual Consumption* Cubic meters	% of total
Ghayathi	7727620	35130	1826748	6%
Delma	9917000	45083	2344299	8%
Mirfa	4786470	21759	1131483	4%
Liwa	46147640	209787	10908933	37%
Madinat Zayed	32675000	148541	7724109	26%
Habshan	9629000	43773	2276219	8%
Asab	2500000	11365	590980	2%
Sila	10536300	47898	2490697	9%
TOTALS	**123919030**	**563336**	**29293467**	

* based on weekly consumption for last week April, 2003

A new, 166 Mm^3/yr Multi stage flash Desalination Plant is presently being constructed at Shuweihat and will be commissioned in 2004 to supply additional water to the Western Region.

Analysis of all water production and consumption data in the domestic sector and data entry to the ERWDA database will be undertaken at the interim report stage.

(4) Amenity Water Supply

Amenity water supply includes irrigation for public parks and gardens, road side beautification and both public and private sports grounds and recreational facilities. In the database supply and demand model being developed, amenity demands also include private palaces. The sources of water for amenity supply are three-fold; primarily treated effluent for parks & gardens and recreational facilities, supplemented in some areas e.g. Sila, by groundwater supply and exclusively public water supply (desalinated water) for private palaces.

In 1977 there existed one public garden in Abu Dhabi. Between 1995 and 1997, the area of public parks and gardens increased from 328 to 346 hectares and in 1999 the total number of facilities in the Western Region was 94 compared to 303 in the Abu Dhabi district.

Data collection and identification of current amenity areas in the Western Region is ongoing. Where possible, land classification by remote sensing will be utilised to determine areas of development and water use.

(5) Industrial Water Use

Industrial development in the Western Region is small and largely restricted to the Ruwais Industrial Estate, managed by ADNOC and to both onshore and offshore oil & gas installations. ADNOC have been requested to provide data on the water requirements of all 17 of their Group companies. ADNOC operate desalination plants for their operations both at Ruwais and their oil & gas facilities. Further research into Industrial water use will be undertaken during the interim stage of the study.

2.4 Existing Water Resources Monitoring

2.4.1 General

The 5 year objectives of TERC within ERWDA include (1) the development and implementation of a water resource management strategy and (2) the monitoring of compliance. Strategy development typically requires regional resource data, derived from hydrogeological investigations and from groundwater monitoring, to give overall characteristics of the resource and its potential; frequency of monitoring will normally be based on the rate of change of the parameter being monitored. A regional view is likely to indicate parts of the resource system which are stressed (through over abstraction and/or salinisation) or polluted (an example in the study area is nitrate pollution from agriculture).

Subsequent monitoring of appropriate frequency, will need to be expanded, to observe 'stressed' or polluted areas. Such data will allow ERWDA as the regulating agency, some warning indications of non-compliance with resource management rules, in particular unauthorised well development and abstraction, and pursuit of activities which are aquifer polluting.

A comprehensive groundwater monitoring system will include water level or piezometric level measurement and salinity-conductivity measurements; depending on the perceived target of monitoring, it could also involve a groundwater sampling program with periodic full chemical analyses of natural chemical parameters, of heavy metals or of pesticides and hydrocarbons.

2.4.2 Current Monitoring Status

There is no established national water resources monitoring programme for the Emirate of Abu Dhabi. Such a programme will be recommended as part of the Water Resources Management strategy being developed by ERWDA.

The NDC/USGS groundwater research project (Groundwater Resources of Abu Dhabi Emirate) is presently conducting monitoring as part of their project activities. In addition to weather data monitoring, they monitor the following in the whole of Abu Dhabi Emirate:

No. of Boreholes	Parameter	Frequency
53-70	Static water level (SWL)	Monthly
400	Static water level (SWL)	Annually
1800	Water Quality; full chemical analysis for all wells drilled by USGS (>430)	Once/intermittent [but regular measurements to be started]

In addition, some monitoring is carried out at specific sites (perhaps as part of an hydrogeological investigation) and in areas where resources are developed by other agencies; such activities include:

- observation wells/piezometers set outside the boundary of afforested blocks, to detect water level impacts of pumping;
- as part of a project to study nitrate build up as a result of the application of fertilisers on farms, observation wells/piezometers near to agricultural areas, and in areas where no agricultural development has yet taken place, are monitored for water level & water quality changes;
- The NDC-USGS project has a current objective of creating a water quality monitoring network, to indicate hydrochemical trends with time.

All this monitoring data is available in a database maintained by the USGS-NDC project in Al Ain, and as yet, no access has been provided to ERWDA.

The GTZ Groundwater Assessment Project current monitoring activities support the projects general assessment program. Full details of the monitoring programme are not available but of the 88 deep wells and 390 shallow wells drilled and tested by GTZ, 188 wells are monitored; of these 100 are observed monthly in the Eastern and Western Region for water level and conductivity; for others, frequency maybe continuous or periodic. It is also expected that a new monitoring system will be established as part of the pilot study for artificial recharge near Liwa. The data is stored within an ARC INFO database, but as yet, no access has been provided to ERWDA.

The Dept of Agriculture of the Abu Dhabi Municipality is responsible for developing groundwater resources for both Government Projects (Agriculture Dept) and private citizens farms (Agriculture Guidance Dept). Occasional water study investigations are conducted by the Agriculture Dept in problem areas and additional monitoring for water levels and salinity is undertaken. No routine monitoring is undertaken in areas developed for citizens farms.

The Abu Dhabi Municipality Forestry Dept has jurisdiction over 2852 wells in 166 forest areas; the Dept can quote average pump unit well yields and salinity ranges for groundwater in each forest area. No regular monitoring of water levels or water quality is undertaken.

ADNOC is likely to be operating a substantial number of water supply wells for their oil & gas exploration camps and for other oil/gas related installations. Monitoring status is unknown at this time.

The Department of Water Resources Studies within the Office of H.H The President manage 47 automatic weather monitoring stations throughout the UAE, 35 of which are located in the

Emirate of Abu Dhabi, 15 specifically in the Western Region. The following parameters are recorded on an hourly basis:

- Dry Temperature
- Wind speed
- Pressure
- Relative Humidity
- Dew Point
- Rainfall
- Solar radiation
- Soil Temperature & moisture

Data is readily available on –line for the full length of records. The majority of the weather stations have been installed only in the last 2-3 years.

3 DATA COLLECTION, COMPILATION & APPRAISAL

3.1 Data Sources

The agencies and other organisations which are sources of water resource and water related data and information have been identified and are listed below, in Table 3.1. Appendix B provides the names of technical staff within each organisation that have been contacted in obtaining various water resources data and information. Some of the staff have been officially nominated to assist ERWDA in their task of developing a Water Resources Management Strategy.

In addition, much of the demographic/infrastructure, national boundary data and farm-forest boundary data required for the project is held by Abu Dhabi Municipality and Utility companies and in a series of Master Plans carried out for these agencies, in particular:

- Abu Dhabi Municipality Forests dept: sketch of forest areas
- ADWEA: complete GIS mapping for potable water/services/pipes and tanks for Western Region
- TRANSCO: Master Plan
- ADWEC: planning data

The major source of groundwater data in the Project area are the two ongoing groundwater assessment projects, namely the United States Geological Survey (USGS) / National Drilling Company (NDC) joint Groundwater Research Project based in Al Ain and the Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ) / Dornier Consulting/ ADNOC joint Groundwater Assessment Project based in Abu Dhabi. With regard to the water resource studies conducted by these projects we can conclude that:

- both are well-resourced studies which have accumulated a huge amount of water resource related data of all types [USGS-NDC started in 1987; GTZ in 1995];
- both studies have been biased towards groundwater assessment and evaluation of groundwater quantities and qualities; there has been little involvement in aspects of water management;
- these data have been extensively validated, organised and input to databases with some GIS links; both Oracle and ARCINFO software are used as databases.
- although the USGS-NDC study was originally largely restricted to the east of Abu Dhabi Emirate, and the GTZ study to the west, there has been significant work overlap in the same geographic areas;
- there appears to have been little or no technical level contact between the NDC-USGS and the GTZ studies;

In general, the work of these two major projects is not accessible. None of the GTZ studies are known to have been published in international journals and we have not gained access to any data collected from this project to date; in 1996, the USGS produced a Groundwater Resource Evaluation of the Emirate which provides summary information but only a very small amount of data has been obtained, despite numerous requests.

Table 3.1: Contacts for Data Acquisition

Organisation/Company	Department	Job Title
Abu Dhabi Distribution Company	Water Network Division	Manager
ADCO	HSE Division	Environmental Engineer
Abu Dhabi Municipality & Town Planning	Sewerage Projects Committee	Head of Irrigation & Utilities Division
	Sewerage Directorate	Head of Operation & Maintenance Section
	Town Planning Dept (GIS)	Head of GIS Center
	Forestry Dept	Head of Department
	Agriculture Dept	Head of Department
	Extension Services Department [includes Drilling Section]	Director
Abu Dhabi Industrial City	Planning	Planning Engineer
Abu Dhabi Government	Planning Dept	Chief Statistical Researcher
ADCO	Health Safety & Environment Division	Environmental Protection Engineer
ADNOC	Petroleum Resources Division – Offshore Production Directorate	Manager
	HSE Division	Manager
ADWEA	Power & Water Desalination Research Centre	Director
	Projects Department	Director
	Planning & Development	Head, Digital Systems Dept
ADWEC	Management	Managing Director
Abu Dhabi Emirate Dewan	Western Region	Rulers Representative
Emirates Centre for Strategic Studies and Research	Studies	Director
Ministry of Agriculture & Fisheries	Water & Soil Dept	Assistant Deputy Minister of Water and Soil
NDC-USGS	Groundwater Research Program	Director
Private Department for HH Sheikh Zayed bin Sultan Al-Nahyan	Agriculture	Consultant Expert
Regulation and Supervision Bureau for the Water & Electricity Sector in the Emirate of Abu Dhabi (RSB)	Management	General Manager
The Office of HH the President	Water Resources Studies Dept	Director
	Meteorological Section	Head of Meteorological Section
TRANSCO	Planning & Projects Division	Manager
UAE University	College of Engineering	Professor of Water Resources

- free access to the reports and database-GIS systems held by the above studies would be extremely helpful and would reduce work involved in data acquisition and processing and the GIS-build processes.

As a bare minimum, the following groundwater data is required from the two projects in order to undertake an updated groundwater resources evaluation for the Emirate:

a) Time series (yearly) groundwater levels in all monitored wells from the two projects across the Emirate of Abu Dhabi (levels to be surveyed to mean sea level). Time series data end with current day levels and quality
b) Time series (yearly) groundwater quality data (including field measured parameters e.g. electrical conductivity (EC) in all monitored wells from the two projects across the Emirate of Abu Dhabi
c) Depth versus EC data for all wells included in the two projects (levels to be surveyed to mean sea level)
d) Aquifer thickness and types at all project wells (levels to be surveyed to mean sea level) and as many other sites as the project as investigated (main aquifer types are shallow alluvium and aoelianite, Upper Fars, and deeper (carbonate) aquifers
e) Aquifer type with parameters of Storage, Transmissivity etc at all tested project wells and as many other sites as the project has investigated.
f) Detailed Description of both projects groundwater, surface water and meteorological monitoring networks, including exact location, type and detail of information recorded and range of recording dates.

Further requests for this invaluable groundwater data, at ERWDA Deputy Chairman level, are now being prepared to The Office of the President, Water Resources Studies Department and from ERWDA Secretary General to ADNOC CEO.

The project also has access to May/June 2002 Landsat data which is being used as a base layer for the GIS. In addition, we are digitising from Landsat, infrastructure features and water resource demand areas (farms & forest etc).

4. DATABASE AND GIS DEVELOPMENT

The original terms of reference for the Mott Macdonald Consultancy Water Study for the Eastern & Central Region of Abu Dhabi Emirate called for:

i) Formulation, in association with the client, of a centralised computer database, capable of storing, evaluating and analysing all data collected, linked to a Geographical Information System and to input all data into the database.

ii) Projected Water Demands & Balances – The Consultant shall use projected water demands and prepare projected water balances for the various Water Assessment units. A model for predicting balances will also be developed and a digital copy provided to the client.

iii) Groundwater Resources Evaluation stating given quantities and quality per assessment unit of study area.

The above terms have been accommodated by developing a Sequel Server database, linked to ARC GIS and incorporating both a supply – demand model, capable of predicting future water balances, and a groundwater resources evaluation model.

4.1 Database

The ERWDA data management standards have Microsoft SQL Server (SQL) as the prime data storage system. SQL will be the main storage base for the water resources geo-databases, and other data not required by ArcGIS but important for the water supply/demand model. The database is being designed so that current and future balances between water supplies (or sources) and demands can be calculated for any specified geographical area within the Emirate. Database development using SQL Server and visual basic is being carried out by Mott Macdonald International, ERWDA's consultants on the Project entitled "Assessment of the Water Situation in the Eastern and Central Region of Abu Dhabi Emirate (Mott Macdonald, 2002, 2003).

4.2 Development of GIS within the Water Resources Study

4.2.1 Introduction

The main objectives of the GIS can be summarised as follows:

1. To provide a simple and flexible information system to store, analyse and display available information relating to water resources, with a minimum of customisation, so that the system can be readily modified in the future.
2. To provide a user-interface and data output system for a supply/demand water balance model for water resources planning.

The geographical information system is being developed using the ArcGIS software. The standard user interface will incorporate some basic customisation to enable the most routine analysis and display attribute information in the form of tables, graphs and contours. Figure 4.1 shows a flow diagram of the relationship between the water supply-demand model to be developed within the database, and GIS. The GIS is currently being developed by ERWDA's Consultant, Mott Macdonald International and will be developed to produce a simple, flexible system, containing all available information which is directly relevant to water resources planning activities.

4.2.2 GIS Outputs

Table 4.1 summarises the proposed main outputs from the GIS, which comprises information either displayed directly from the database or produced as a result of performing certain GIS analyses on this data. The outputs will be displayed through the ArcGIS user interface, in the form of tables, graphs, images, reports or maps.

The testing of the proto-type database & GIS functions will take place during the interim stage of the project with input of water resources data & information collected to date.

Figure 4.1 Components of Database-GIS Structure (From Mott Macdonald)

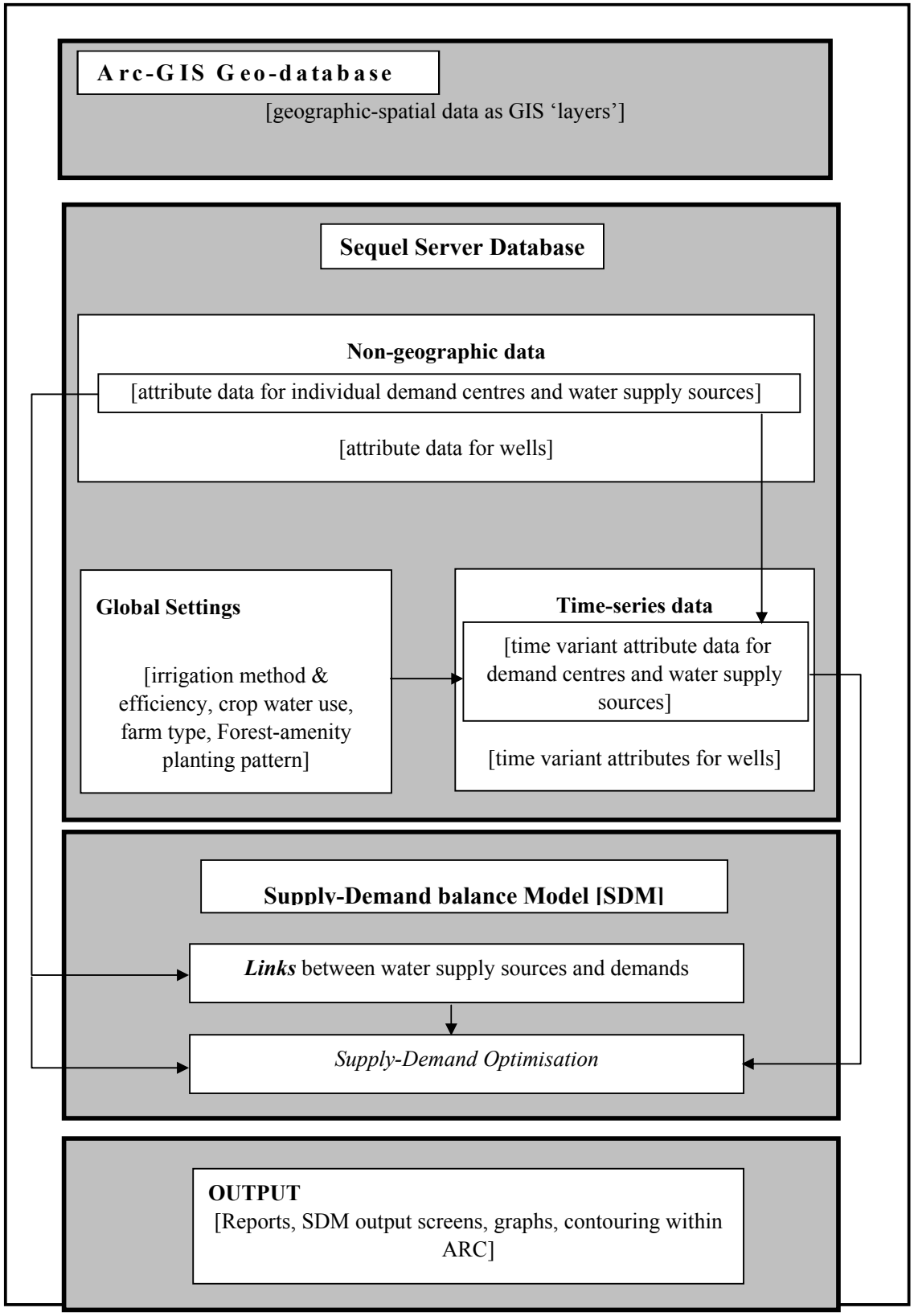


Table 4.1 GIS Inputs and outputs

Spatial data	Related database	Spatial/ Non	Feature Class	Data Capture	Data Source
Primary Spatial Data					
Wells		s	point	spreadsheets/manual entry/digitising	Research projects, ADWEA etc.
Observation Wells		s	point	spreadsheets/manual entry/digitising	Research projects, ADWEA etc.
	Well time series data (10%)	n		databases/manual entry	Research projects, ADWEA etc.
Wellfields		s	polygon	draw on-screen based on wells	Research projects, ADWEA etc.
Desalination Plants		s	point	manual entry/direct import	Mott MacDonald/ADWEA GIS
	Future capacities of desal/TSE	n		spreadsheets/manual entry	ADWEA Masterplan/Municipalities
TSE Plants		s	point	spreadsheets/manual entry/digitising	Municipalities
	Future capacities of desal/TSE	n		spreadsheets/manual entry	ADWEA Masterplan/Municipalities
Aflaj		s	arc	manual entry	USGS/ADWEA GIS/AL AIN MUN.
Settlement Areas		s	polygon	direct import/on-screen digitising	ADWEA GIS/landsat in conjunction with population data
	Future population/industry/park	n		spreadsheets/manual entry	ADWEA Masterplan/other organisations
Agricultural Areas		s	polygon	direct import/on-screen digitising	ADWEA GIS/landsat
Forestry Areas		s	polygon	on-screen digitising	landsat in conjunction with forest maps
Water quality classification		n		manual entry	National standards
Per capita consumption (present and future)		n		manual entry	ADWEA & Mott Macdonald
Crop/forestry water consumption		n		manual entry	Crop requirements expert
Background Spatial Data					
Country Boundary		s	polygon	digitising/direct import	maps and existing coverages
Roads		s	arc	on-screen digitising	landsat
Topography		s	arc	direct import	ADWEA GIS
District Boundaries		s	polygon	direct import	ADWEA GIS
Additional Data for Supply/Demand Balance					
Major Transfer schemes		s	arc	direct import	ADWEA GIS/ ADWEA Masterplan
Major Reservoirs and tanks		s	point	direct import	ADWEA GIS/ ADWEA Masterplan
Major Pump stations		s	point	direct import	ADWEA GIS/ ADWEA Masterplan
Supply-demand link		s	arc	manual entry linking demand/supply cent	To be decided
Demand Centres		s	polygon	manual entry	To be decided
Supply Centres		s	polygon	manual entry	To be decided
Study units		s	polygon	merging district boundaries	ERWDA Standards
Secondary Spatial Data					
Major Recharge Dams		s	point	digitising/manual entry/existing data	maps
Aquifer information		s	point/raster	manual entry	
Major Wadis		s	arc	digitising/on-screen digitising	landsat/maps

5. WATER BALANCES

5.1 Introduction

There are two types of water balance being investigated by the project:

1) water resources balance

2) Supply/demand balance.

The first relates mainly to the water balance of the groundwater resource system and includes components such as sub-surface groundwater flows, recharge and discharge components and changes in groundwater storage. The second relates to the interaction between demand centres, such as agricultural areas, forest areas, population centres and industries, and supply sources. The supply sources include wellfields, groups of individual wells, aflaj, desalination plants, treated sewage effluent (TSE) and imports from outside the Emirate. Each demand centre is linked to one or more supply sources (see section 4.2.1).

The project will use the database-GIS to examine the current and future balance between water supplies and demands, by means of a linked supply-demand model (SDM). It will also allow the user to make a study of water resource balances in any specified part of the Emirate of Abu Dhabi.

A water resources balance model concerns the water balance of the groundwater resource system and includes components such as sub-surface groundwater in-flows and out-flows, recharge and discharge components and changes in groundwater storage. The project will make simple resource balances for several elements of the study area. Table 5.1 shows the various links between the Supply – Demand Model and the Water Resources Model.

Table 5.1 Links between SDM and WRM

Supply – Demand Model	SDM Source	Water Type	Water Use	WRM component	Water Resources Model
	Wellfields/ Wells	Groundwater	Water supply	Groundwater discharge	
			Irrigation	Urban recharge Irrigation return flow	
	Desalination plants	Desalinated water	Water Supply Irrigation	Urban recharge Irrigation return flow	
	Sewage treatment works	Treated sewage effluent	Irrigation	Irrigation return flow	
	Imports	Generally desalinated water	Water supply Irrigation	Urban recharge Irrigation return flow	

After Mott Macdonalds

For example, wellfields abstract groundwater and the actual quantity abstracted is a discharge component in the water resources balance. Demand centres receive water from the supply sources and part of this will return to the groundwater systems. These return flows are recharge components in the water resources balance. They include urban recharge, comprising leakage losses from supply network and from sewage systems, and return flows from irrigation application to agricultural, forest and urban amenity areas.

5.2 Water Resources Balance

5.2.1Introduction

Providing sufficient and representative hydrogeological data is available, then a comprehensive water resources balance can be derived to incorporate for example, multi-layer aquifer systems and all aquifer recharge, discharge and storage components.

This optimum data condition does not exist for the Emirate of Abu Dhabi. Most of the available data is restricted to the shallow sand or clastic deposits with little known about the deeper, carbonate aquifer systems. The main groundwater balance will be performed for the shallow aquifer. Estimates only can be provided for the deeper aquifer systems.

5.2.2Water Balance Components

The components of the water balance include the following:

- Sub-surface inflows and outflows across the boundary of the considered area, specified for individual aquifers.
- For individual aquifers, the vertical exchange, in the form of leakage, between the aquifer units.
- Groundwater discharge components, which include:
  - Groundwater abstraction from wells.
  - Capillary losses from areas (mainly sabkhas) where the groundwater table is in close proximity to the ground surface.
  - Capillary contribution to the root zone of plants and trees in areas where the groundwater table is in close proximity to the base of the active root zone.
  - Infiltration of groundwater into sewers where these are located below the groundwater table.
- Recharge components, which include:
  - Deep percolation of rainfall to the groundwater table (not expected in the study area).
  - Wadi bed infiltration during wadi floods, including infiltration from reservoirs & recharge dams (not present in the Western Region).
  - Return flow from applied irrigation in cultivated and forest areas.

  - Return flow of applied irrigation water to amenity areas in urban areas and along roads.
  - Leakage losses from water supply distribution networks, including losses from main transmission lines between supply sources and demand centres
  - Leakage losses from sewerage systems.
  - Artificial recharge via wells or infiltration ponds (e.g. Liwa pilot project).
- Aquifer storage changes, both confined and unconfined.

6. WORK PLANNED FOR THE INTERIM STAGE OF THE PROJECT

The following work is planned for the next stage of the project and will be reported in an interim report:

- Continued water resources data & information collection and compilation (especially groundwater data & information from the two Emirates Groundwater Research projects from which very little information has been forthcoming to date)
- Digitising of both spatial and non-spatial information as layers within ARG-GIS. In most cases, these layers will need to be merged with the GIS layers already created by Consultant Mott Macdonald for the Eastern & Central region of Abu Dhabi Emirate.
- Installation of the Sequel Server database and proto-type testing at ERWDA. This will be conducted in association with the Consultant. A pilot study area will be chosen and tested with real data being entered via the various data entry screens.
- Entry of all water resources data and information via their respective data entry screens into the Sequel Server Database
- Analysis of missing data and infilling of gaps; it is proposed that a series of well inventories will be required to be undertaken for Forestry and Agriculture Projects
- Further assessment (pending availability of information from the two ongoing groundwater research projects) of the existing water resources monitoring network
- GIS-Remote sensing image analysis studies pertaining to classification of land and water use within vegetated areas (Agriculture, Forestry, amenity plantations etc)
- Detailed assessment of industrial water use
- Assessment of Water supply, production and water use in the oil & gas sector

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APPENDIX A

ABU DHABI WATER QUALITY STANDARDS

2000

APPENDIX B
PROJECT DIRECTORY