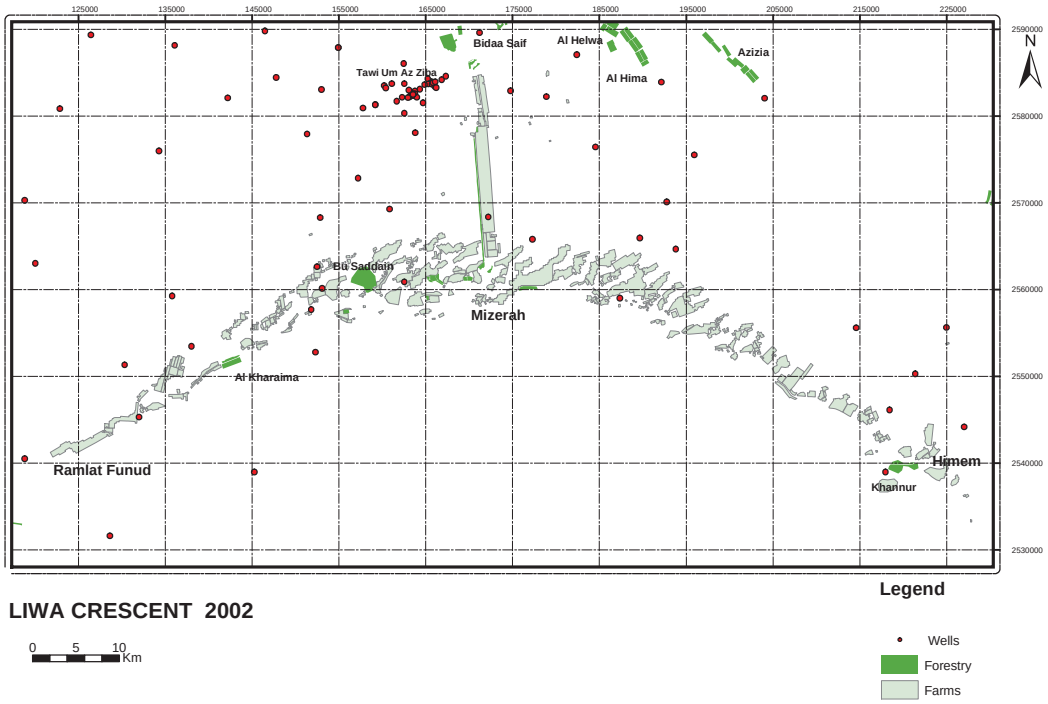
ASSESSMENT OF THE WATER SITUATION IN THE WESTERN REGION OF ABU DHABI EMIRATE

INTERIM REPORT

March, 2004



TERRESTRIAL ENVIRONMENT RESEARCH CENTRE

ENVIRONMENTAL RESEARCH & WILDLIFE DEVELOPMENT AGENCY
P.O. Box 45553
Abu Dhabi

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Team Members	Mike Brook, Mohamed Dawoud, Huda Al Houqani		

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1. INTRODUCTION

1.1 Background & ERWDA Water Resources Management Strategy Development

This interim 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 developing the Water Resources Management Plan is 5 years long, ending in mid-2008. Step 1 includes collection and collation of all pertinent water resources source and use data and information relevant for the Western Region.

The area studied in this report (Figure 1) is defined as the area which extends westwards from the concurrent consultants project which concentrates on the Administrative area of Al Ain (Eastern Region). 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.

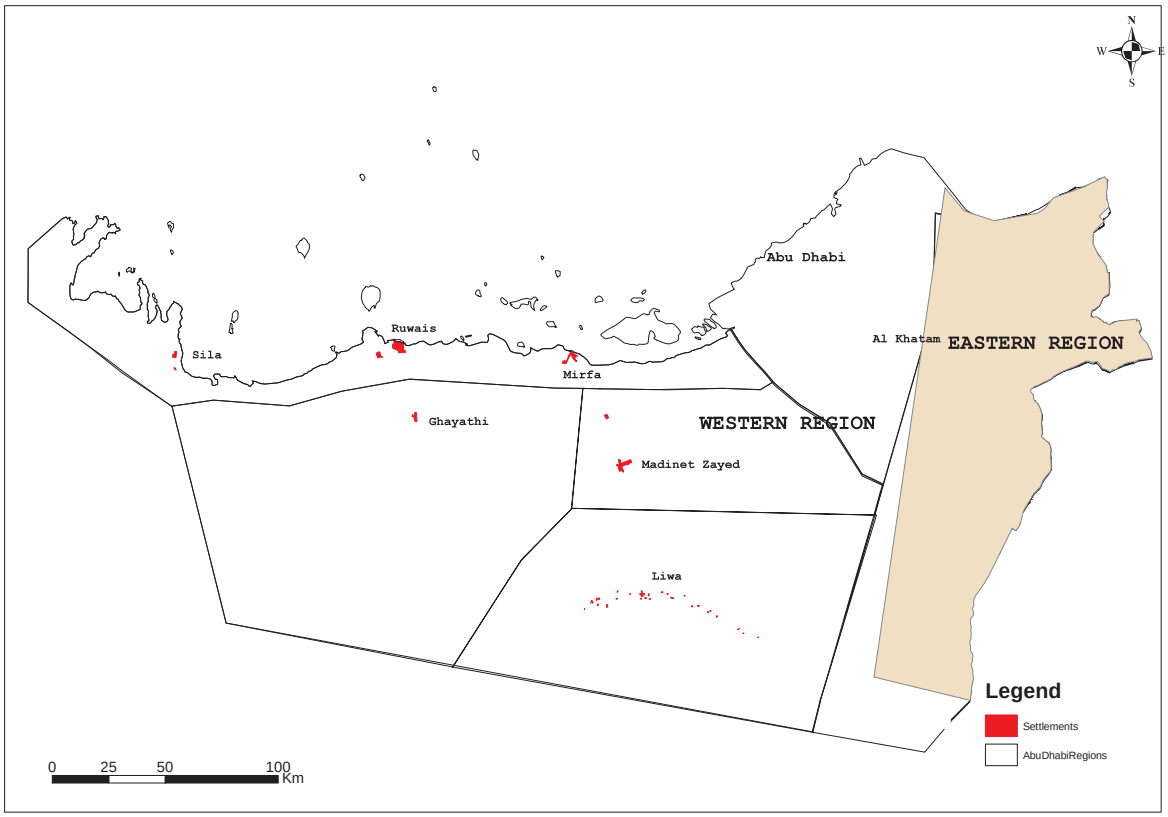


Figure 1 Location of the Western Region Studied

Based primarily on water use breakdown (essentially agricultural sector use), the whole region has been sub-divided into four areas, namely:

1) Western Region subarea 1 - Coastal belt and Islands
2) Western Region subarea 2 - Madinat Zayed
3) Western Region subarea 3 - Liwa
4) Western Region subarea 4 – Ghayathi

1.2 Scope of Report

This Interim Report covers the progress and findings of the work for step 1 of the development of the Water Management Plan for the Western Region between July 2003 and February 2004. The specific requirements of the interim report are:

- Progress report on the water resources data gathering exercise: update of water use statistics for 2002, the base year.
- Review of existing Water Resources Monitoring within the Region
- Specifications and full presentation of the GIS Database developed for the collection and analysis of water resources data and information
- Methodology for calculation of water supply – demand data
- Review of work and activities remaining for preparation of an Emirate wide Water Resources Management Plan

2. STUDY PROGRESS

2.1 Introduction

Since the submission of the Western Region Inception Report in June, 2003, work has progressed in understanding the overall water situation in this region and a GIS Water Resources Database has been established in order to store water resources information and data and to conduct various analyses and reviews, including a supply and demand model which allows for prediction of water supply shortfalls.

Water Resources data and information is now being entered into the Water Resources Database which is an integral part of the ERWDA Environmental Database. All sources of water and their use have been addressed. Groundwater is the major source of water for the region and Agriculture and Forestry are the two largest users of water (groundwater). Statistics for water sources and uses have been updated and have been published for the year 2002, the base year for this study.

2.2 Other Water Resource Studies: NDC-USGS & GTZ

Two major groundwater resources assessment projects are being conducted in the project area, namely:

1) United States Geological Survey (USGS) / National Drilling Company (NDC – ADNOC) Groundwater Research Project

2) Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) / Dornier Consulting / ADNOC Groundwater Assessment Project

Table 1 below provides a summary of wells drilled on each project and Figure 2 shows their location in the region.

Table 1 Summary of USGS & GTZ Project wells drilled up to end 2003

Total No. drilled	Total Drilled Meters (m)	Completed Well Depth Total (m)	Max Depth Drilled (m)	Min Depth Drilled (m)	Max Depth completed (m)	Min Depth completed (m)	Continuous Monitoring Wells (manual)	Continuous Monitoring Wells (data-loggers)
USGS Project								
541	101,000	58,500	894.5	11.3	804	11	70 monthly	0
							400 Annually	
GTZ Project								
699	99,990	86,880	1500	45	424	11	282 Continuous	282

The USGS project, based in Al Ain, has drilled 541 project wells between 1988 and 2003 with a total depth of 101km down to a maximum depth of 894m. The large majority of the wells have been drilled and completed into the surficial alluvium aquifer, and few have penetrated deep enough to penetrate bedrock, which has been the selected target for relatively few exploration wells that have been drilled. The average completed well depth is 108m. The latest publication which summarizes the results of the study in terms of water resources estimates and use for Abu Dhabi Emirate is 1996 (USGS, 1996).

70 wells are monitored on a monthly basis and once a year, about 400 wells are monitored for water levels during the same week. All wells are monitored manually since the collapse of the automatic monitoring system some years ago.

Despite several attempts, access to the database storing all water level and water quality data for the monitoring wells has not yet been achieved.

The GTZ project began in 1996 and to date 699 wells have been drilled. In recent years, exploration has concentrated on the western region and also the new ASR Project site near Medinat Zayed. A total depth of 99,990m has been drilled on the project with an average completed well depth of 124m. The maximum drilled depth is 1500m. 282 wells are monitored continuously with data – loggers, mostly just for water levels, however, some have water quality data loggers as well. At the beginning of the Exploration project, in 1996, drilling activities concentrated on the area of the Al Jaww plain, on the Al Ain – Buraimi border and deep wells (up to 1000m) penetrated the Um er Radhuma limestone, but no major inflows were discovered at depths greater than 300m. Only three deep wells were drilled, the remainder has concentrated on the exploration of the surficial alluvium aquifer.

Data for the GTZ project was obtained in December, 2003, comprising geophysical and lithological logs and also monitoring well hydrographs and monitoring records for salinity. All data is being compiled into a single spreadsheet and will be combined with all other relevant groundwater data obtained in order to create a series of hydrogeological maps for the Emirate of Abu Dhabi, generated from ARC GIS.

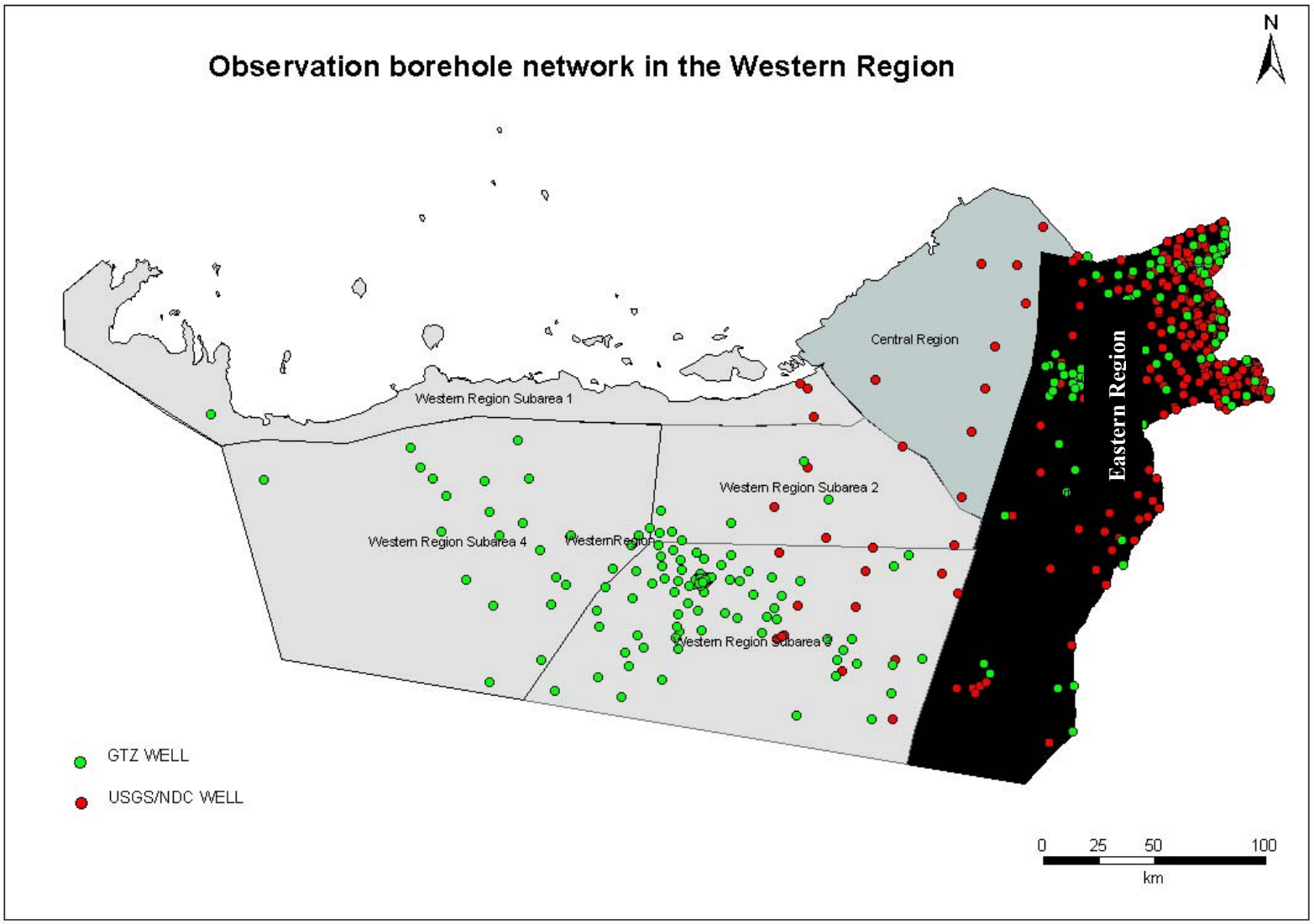


Figure 2 Location of the Groundwater Assessment Wells drilled in the Western Region

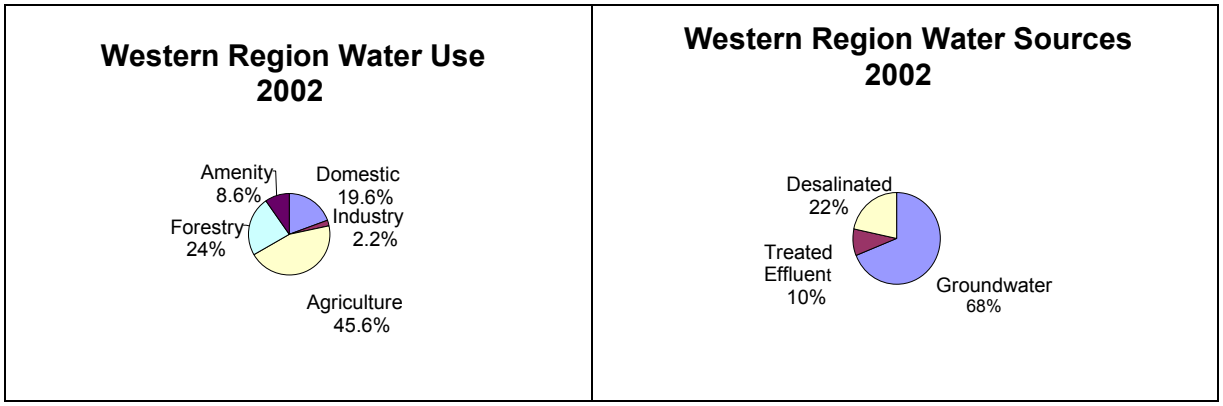
3. CURRENT UNDERSTANDING OF WATER RESOURCES DEVELOPMENT & USE

3.1 Introduction

The year 2002 has been chosen as the base year for study of Water Supply and Demands. The Inception report (ERWDA, 2003) provided a breakdown of water use according to the last major study (USGS, 1996) devoted to evaluating Abu Dhabi water use, but the statistics for the Water Production and Consumption for the Western Region reported in this interim report have been taken from the 2002 Water Resources Statistics Bulletin published by ERWDA (ERWDA, 2004) and from other work carried out by the ERWDA Water Resources Programme.

Water consumption is met from groundwater abstraction, from treated sewage effluent (TSE) and from desalination. Whilst groundwater reserves have been heavily exploited over the last 10-15 years in the region, resulting in declining water levels causing increases in groundwater salinity, groundwater still provides almost 70% of all water required in the western region and thus must be treated as the major water source, deserving increased attention with regard to its exploration, assessment and management in order to help achieve sustainable Water Resources Management. Figure 3 provides information on water use and water sources for the western region.

Figure 3 Western Region Water Use and Water Sources



Groundwater provides the bulk of water requirements, followed by desalinated water (22% from six co-generation power companies) and treated effluent from 8 main plants.

Table 2 shows a breakdown of water used in the western region.

Table 2 Breakdown of Water Use in the Western Region

Sector	Water Used (Mm^3/yr)	% of Total Western Region	% of Total for whole Abu Dhabi Emirate	% change in use since 1994
Domestic	332.8	19.6	73	90
Industry	36.9	2.2	57	1745
Agriculture	772.9	45.6	40	279
Forestry	407	24.0	21	248
Amenity	145.98	8.6	57	No 1994 data
TOTAL	**1695.58**	**100**	**-**	

The last, published detailed assessment of the water consumption in the Western Region was undertaken by the USGS/NDC groundwater research project in 1996 with an assessment of water use in 1994(USGS/NDC, 1996). There have been substantial increases in water consumption in all sectors, ranging from 90-1745%. Agriculture and Forestry, the two largest water sector uses, have both quadrupled their consumption over the last 8 years.

3.2 Domestic Water Supply & Sewage

19.6% of all water utilised in the western region is for domestic purposes. Mirfa and Sila are the only ADWEA desalination plants currently operating in the Western Region; Mirfa plant produces 27.15 Mm^3/yr and is used almost exclusively for Liwa and Medinat Zayed and Sila produces only 2.4 Mm^3/yr from two small reverse osmosis plants . The main demands for potable water are Madinat Zayed, Ghayathi, Mirfa, Liwa, Delma, Asab, Habshan and Sila.

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 where 15,000 m^3/d is produced from the multi-stage flash desalination process. The water is used by the Ruwais Industrial and residential complex, the latter comprising 42 multi-storey buildings. The irrigation requirements of the complex are approximately 3810 m^3/d met 36% by desalinated water and 54% from treated effluent. The amount of desalinated water used in irrigation has been reduced drastically with the introduction, in 2003, of a intelligent central irrigation system at the new Ruwais Housing Complex (ADNOC, 2003).

A new multi-stage flash desalination plant is being constructed at Jebel Dhana near Shweihat, in between Sila and Ruwais. The desalinated water will be re-mineralised to produce potable water which meets the Abu Dhabi standard for drinking water. Water will be delivered to the distribution networks of Sila, Mirfa and Abu Dhabi. The plant comprises six evaporator units each with a design of 16.67 MIGD and with a total capacity of 100 MIGD. Construction is expected to be completed by mid-2004.

Generally, costs of desalinated water are decreasing, brought about by a combination of two main factors, namely:

1) Greater efficiencies of production brought about by privatisation of the management of most desalination plants in the region
2) Introduction of more efficient new technologies and larger scale desalination units which, because of economy of scale, have significantly reduced general production costs from Dh 17 to Dh11 per 1000 gallons.

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.

Due to the mostly brackish nature of groundwater in areas of habitation in the western region, there are very few individual citizen wells which are operated for drinking water purposes; the only area they exist are in the fresh water groundwater mound which occurs in between Liwa Oasis and Beda Zayed (see Figure 4).

Table 3 shows the production of the eight main sewage treatment plants in the region.

Table 3 Sewage Treatment Plant Production

Sewage Treatment Plant	Production, Mm3/yr
Mafraq	95.13
Madinat Zayed	1.75
Bainoona	0.365
Mirfa	1.46
Ghayathi Ww T Plant	0.91
Delma Island	0.91
Khatam	0.5
Ghantoot	0.24
Total	**101.265**

Combined, they produce 101 Mm^3/yr and virtually all production is used in amenity irrigation for parks, gardens and other recreational/sports ground areas.

3.3 Groundwater Development

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 (nearing completion) plants. The brackish groundwater reserve is still substantial, estimated at 227 billion cubic meters (USGS/NDC,1996). By 1995, it was estimated that less than 1% of the total useable volume of brackish water had been utilised, not considering any recharge to the system.

The following main conclusions can be drawn with regards to groundwater investigation and development.

- Freshwater is very limited and is restricted to the groundwater basin immediately north of Liwa covering a surface area of about 1800 km^2. There are now no operating municipal wellfields in the project area: the 18 former Water & Electricity Dept wellfields were shut down during 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. This area is now subject to a pilot test Artificial Recharge scheme as part of an overall Aquifer Storage & Recovery (ASR) project which commenced its trail 12 month period in September, 2003 (see Figure 4).
- 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). A current deep drilling project, undertaken by the Abu Dhabi Municipality Agriculture Dept., is now on hold due to drilling rig difficulties associated with the greater depths of penetration.

- Continued development of new farms, agriculture projects and Forestry Plantations, utilising shallow groundwater resources in the Aeolian Sand and gravel aquifer, will place further local stress on this resource.

3.4 Strategic Aquifer Storage and Recovery

Groundwater is still the major source satisfying the most of the water demands in 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 for Abu Dhabi City and elsewhere in the Western Region. Such a scheme plays a very important role in the overall management of groundwater in the Emirate.

The Aquifer Storage and Recovery (ASR) project, undertaken by the Private Department of Sheihk Zayed bin Sultan Al Nahyan, with technical design and supervision by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), is located about 20km South West of Madinet Zayed in an area of remote, virgin desert at Tawi Um Az Ziba which is devoid of current groundwater extraction. Figure 4 shows the location of the ASR site which comprises 5 recharge/recovery wells and an infiltration basin measuring 50m x 25m with an infiltration capacity of about 250m³/hr. The combined well and basin recharge rate is 12,000 m³/day and a recharge / recovery cycle pilot test ASR scheme commenced in September 2003 and is planned for 12 months. Recharged water is supplied from the Mirfa desalination plant and a 9km take off pipeline from the Mirfa – Liwa main transmission line. More than 20 monitoring wells exist in the area to measure the effects of artificial recharge and to provide data with which to carry out calibration of a digital groundwater model established to predict the effects of the ASR scheme.

Supplementation of aquifer storage can be utilised in times of peak demands and also over continuous extended periods as a strategic emergency resource to satisfy domestic demands.

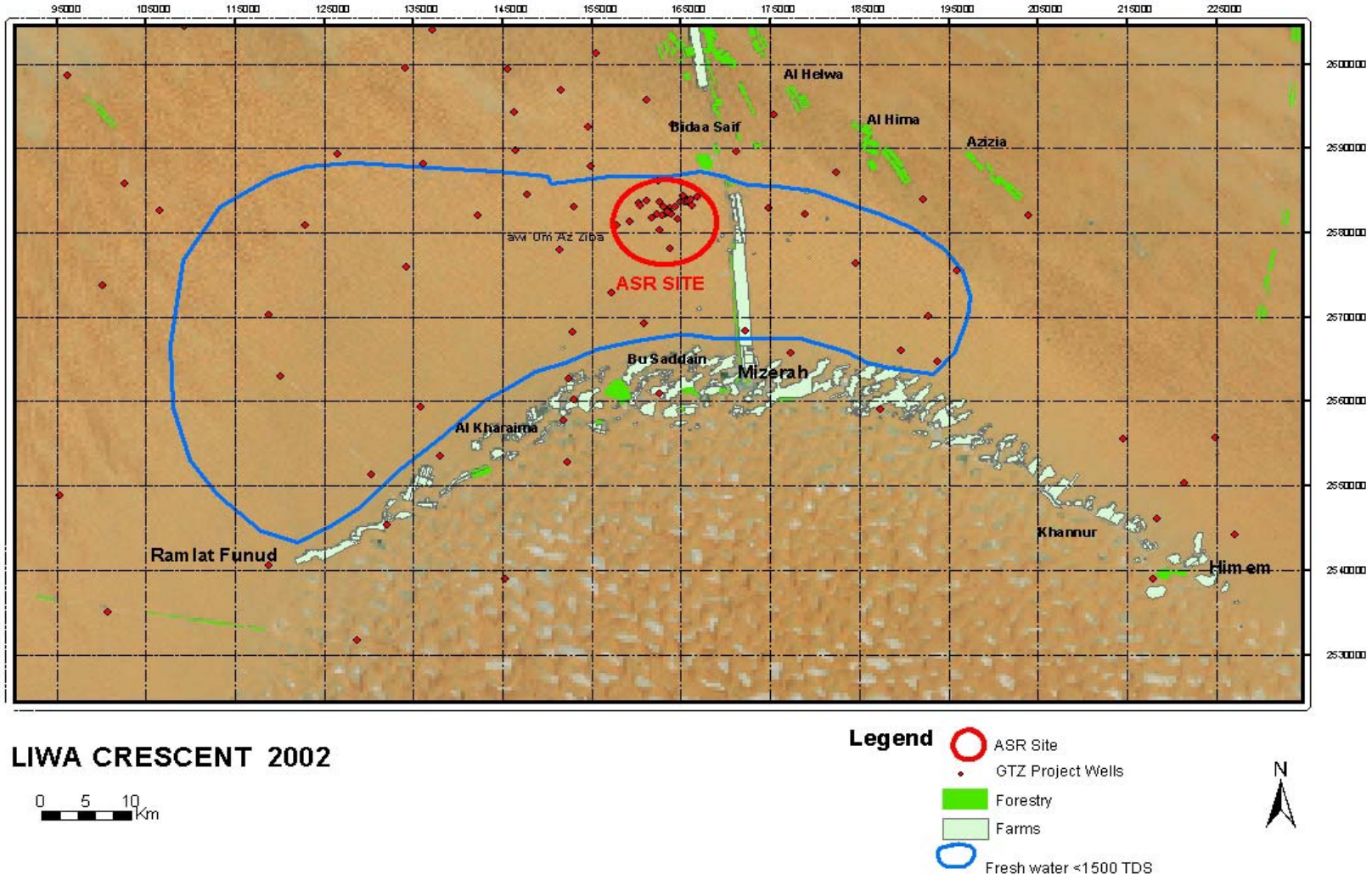
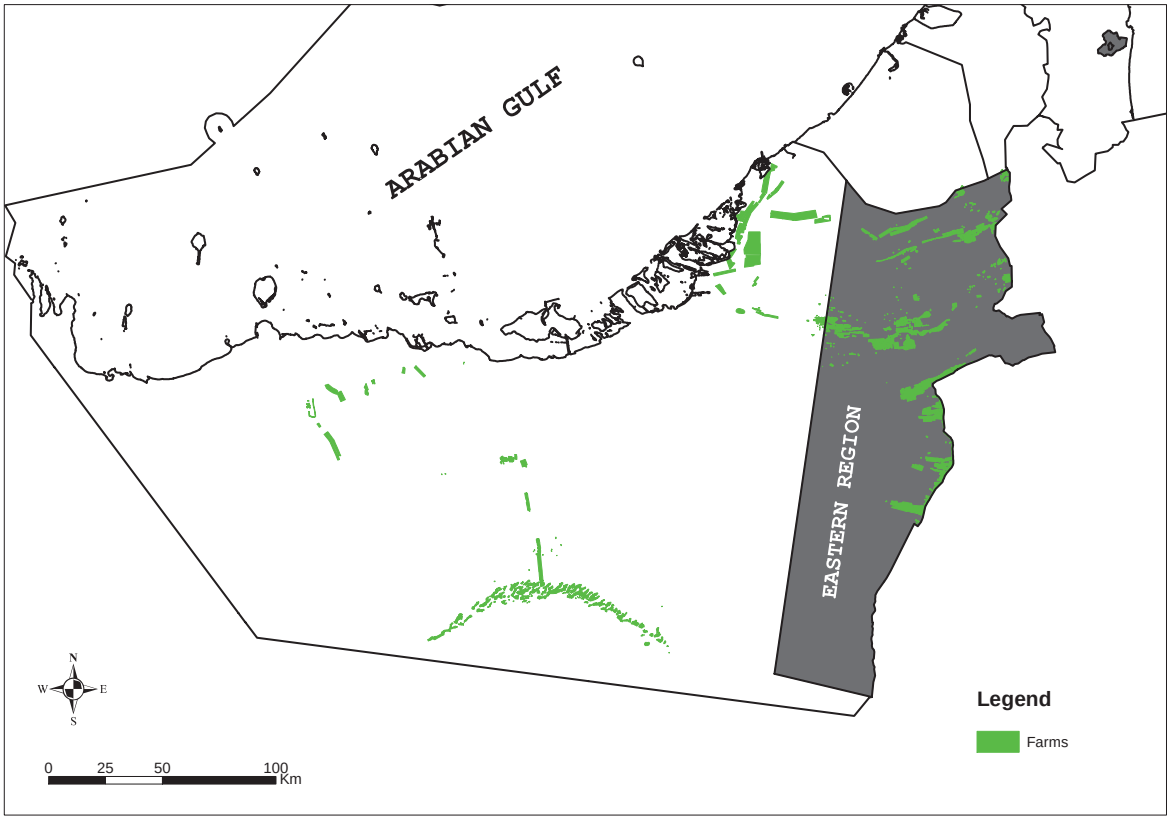


Figure 4 Location of the ASR test pilot project in the Liwa area

3.5 Agricultural development

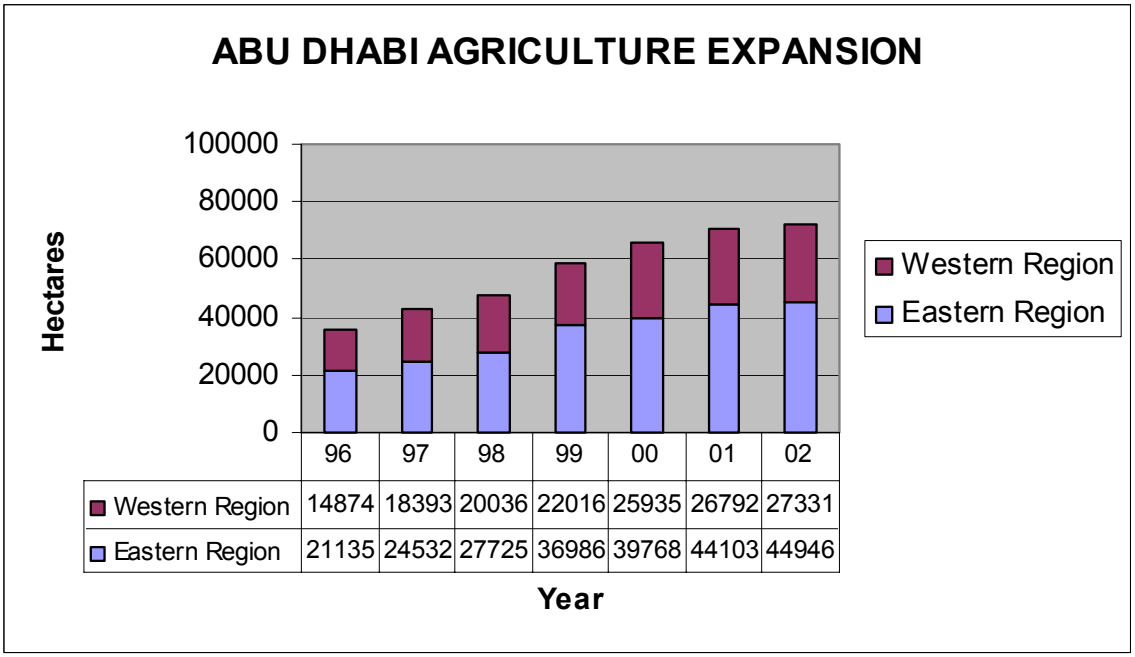
45% of all water used in the western region is for agriculture purposes. The extent of Agricultural development in the Western Region of Abu Dhabi Emirate is shown in Figure 5 and Figure 6 shows the expansion of agriculture over the last 7 years compared to that in the Eastern Region. There are now 11,443 private citizens farms occupying 27,331 ha (57% field crops, 18% vegetables, 15% fruit trees, 10% pasture) and irrigated by 41,092 wells, of which only 58% are productive.

Figure 5 Location of Agriculture Development in Western Region



The majority of the 3 ha private citizens farms are located in Liwa and Ghayathi. Liwa is the oldest development with significant farming being conducted over the last 15 years. The area under cultivation has increased from 1,000 ha in 1987 to 20,817 ha in 2002, representing 76% of the total cultivated area in the Western Region. The history and impact of agricultural development over the last decade has been studied by the USGS/NDC project (NDC/USGS,1997). As part of their investigation, 170 wells were sampled for Electrical Conductivity (EC) and Nitrate, amongst other parameters, in 1991 and 1996. All wells sampled showed an increase in EC and areas previously underlain by fresh groundwater, had brackish water in 1996 with some individual wells showing increases in salinity of more than 2000 µS/cm.

Figure 6 Abu Dhabi Agriculture Expansion 1996-2002



	96	97	98	99	00	01	02
Western Region	14874	18393	20036	22016	25935	26792	27331
Eastern Region	21135	24532	27725	36986	39768	44103	44946

In mid 2003, a rapid well inventory of the Liwa oasis showed a range in EC of 8,000 to 14,000 µS/cm, prohibiting farming of vegetables so that 90% of the cropped area seen was under Rhodes grass and dates, the two crops which are currently favoured for provision of high subsidy by the Abu Dhabi Government. The only fresh water now available for agriculture (used in glass-house farming; in 2002, there were 2146 such protected shelters in the western region, occupying 74 ha)in the Liwa area is tankered desalinated water from Mazirah, although a new distribution network throughout the Liwa Oasis will increase the amount of desalinated water presently used.

Levels of Nitrate in wells were also sampled in 1996 and varied from 5-75 mg/l. Background levels of Nitrate are measured at between 5-10 mg/l; increases are as a result of pollution from fertiliser applications.

The main issues pertaining to water use within the Agriculture Sector are as follows:

- General over-use of water brought about by prolonged periods of irrigation
- Often unnecessary over-irrigation of crops
- Irrigation using high salinity groundwater resulting in operational and crop growth problems
- Growing the right crops for the right water salinity conditions
- Extensive use of fertilizers, sometimes applied in an improper manner, causing unnecessary pollution of groundwater
- Extensive use of pesticides, sometimes applied in an improper manner, causing unnecessary pollution of groundwater
- Often large water wastage on site caused by badly leaking irrigation infrastructure, low quality plumbing fittings and fixtures, and poor maintenance of the irrigation system
- Irrigation during appropriate times of the day, in order to reduce evaporation losses.
- Continued salinization of soils through excessive use of saline / high brackish irrigation water

- Corrosion of borehole and irrigation apparatus from saline and aggressive groundwaters.
- Potential pollution to groundwater from on-site ablutions and waste landfills
- Lack of knowledge of water use – no means of measuring water used.
- Poor on site waste management

As a consequence of the above, an awareness campaign to promote water conservation and protection would be most successful if directed straight at farm owners, the farm labourers and also members of the various agriculture Depts. within the Emirates that are responsible for providing management advice to the citizens farms e.g. agriculture extension engineers from the municipalities and the Agriculture Departments.

The messages required to be delivered in water conservation / protection awareness campaign should focus on the following points:

- Avoid general waste of water. All groundwater has a price; it is not a freely available commodity and is rapidly being depleted in both quantity and quality. This is the most important message to deliver to the farmers. It should be stressed to them that their sector of activities uses twice as much water as all other users put together. Incentives could be provided to encourage water conservation e.g. spot cash awards provided to those farms which follow the guidelines below.
- All farmers should have a good knowledge of the salinity of the waters used for irrigation. Water quality should be checked at least twice a year.
- Advice of extension engineers and other government advisory agencies should be taken in order to ensure that the right crops are grown for the salinity of groundwater available. Should there be a recorded change in salinity, further advice should be sought
- Irrigation should be affected during the cooler times of day i.e. early morning, late evening at all times if possible
- In the case of brackish / saline groundwaters, which are commonly found, use of unprotected steel and other materials which are corrosive should be avoided and replaced by plastics, fibre glass, stainless steel and other non-corrosive materials
- Use of fertilizers and pesticides should be undertaken using the guidelines in place.
- Only approved Fertilizer should be used and must never be mixed in wells and boreholes. Mixing should be undertaken at ground level and in a contained environment that prevents any contamination to groundwater
- Only approved pesticides should be used and must be used according to the guidelines in place
- All leaks of water from pipes, reservoirs etc must be fixed as soon as possible after they have been discovered. Good quality plumbing fittings and fixtures should be used and the irrigation systems need to be regularly inspected for leaks and a maintenance program put in place.
- Ablutions should be linked to closed septic tanks and emptied in accordance to municipality requirements and standards
- Other waste generated on site should be properly stored and disposed of according to municipality requirements and standards. Garbage should be collected in bags and regularly taken to municipal collection sites

- Natural composting of waste organic material should be encouraged in order to produce organic fertilizer which would help to reduce the amount of artificial fertilizer used.
- Diesel and other hazardous material containers should be kept away from wellheads of boreholes and wells. Fuel systems should never leak and be allowed to pollute groundwaters.
- All used fuels and oils should be disposed of in a proper manner and not buried underground where they will ultimately cause groundwater pollution. They should be collected in appropriate containers and taken to municipality collection points
- Shallow aquifers with shallow water tables are very susceptible to groundwater pollution. Pollutants can easily pollute groundwater if there is direct access to it, for example, abandoned or dis-used wells and boreholes which are left open. It is very important that these be backfilled to ground level if they are no longer used.
- All fences around farms should be kept in good order and breakages repaired as soon as they are found in order to prevent animals from trespassing and causing on site pollution.
- All animals should be kept away from wellheads in order to prevent pollution of boreholes.
- Use of UREA, directly mixed with groundwater in the wells should be stopped. This causes direct nitrate pollution of aquifers. Use of alternative, organic fertilizers should be made.
- Only modern, efficient irrigation application methods should be used. Water flooding and unnecessary spraying should be replaced with more efficient irrigation devices.

The Municipality Agriculture Department manages 20 main projects within both the Western and Central Region of Abu Dhabi Emirate, irrigated by over 3,175 wells. The total water consumption for groundwater is estimated at 219 Mm^3/yr (table 4)

Sl. No.	Region	Area	Number of Wells	Average Depth (feet)	Production/Well (G/h)	Operation Time (h/day)	Total Production (G/year)	Total Production (Mm3/year)
1	Western Region	Bedaa Al aaried	134	300	5500	12	3228060000	14674760.76
2		Bedaa Radar	22	270	5500	12	529980000	2409289.08
3		Al Midour	113	240	5000	12	2474700000	11249986.2
4		Ghemisah	106	260	5000	12	2321400000	10553084.4
5		Bedaa Yamrah	183	300	5500	12	4408470000	20040904.62
6		Koroun Al Naam	87	250	5500	12	2095830000	9527643.18
7		Bedaa Rashed	18	200	4500	12	354780000	1612829.88
8		As Sila	8	200	4000	12	140160000	637167.36
9		Dams Al Faras and Arfaa	39	190	4500	12	768690000	3494464.74
10		Bedaa Salab	9	200	4500	12	177390000	806414.94
11		Wadi Al Rayoum	205	300	5500	12	4938450000	22450193.7
12		Bedaa Zaied	166	210	5000	12	3635400000	16526528.4
13		Liwa (East and west)	172	250	5000	12	3766800000	17123872.8
14		Ghyathi	82	220	5000	12	1795800000	8163706.8
15		Abu Hasa	210	220	4500	12	4139100000	18816348.6
16		Bedaa Ghanem	207	140	2500	12	2266650000	10304190.9
17	Eastern Region	Al Khatem	106	130	2500	12	1160700000	5276542.2
18		Aghban	130	220	4000	12	2277600000	10353969.6
19		Al ashoush	339	500	5000	12	7424100000	33749958.6
20		Al Namiraa	15	150	4000	12	262800000	1194688.8
TOTAL			2351				48166860000	218966545.6

Table 4 Abu Dhabi Municipality Agriculture Department Wellfield Developments

3.6 Forestry Development

24% of all water used in the western region is for Forestry purposes. Figure 7 shows the current extent of Forestry in Abu Dhabi Emirate. At the end of 2002 the Western and Central Region included 166 separate Forestry plantations covering a total area of 204,400 ha. 2850 groundwater wells irrigate 40.8 million trees under the management of the Abu Dhabi Municipality Forestry Department.

The objectives of the forests are to protect roads from sand incursions, especially in areas of high dunes, providing protected areas for wildlife sanctuary and, more recently, fixing / demarcating UAE's International Boundaries with its neighbours e.g. Saudi Arabia.

The target of the Forestry Dept is to have a well distribution of one per 20-25 ha of irrigated Forestry; in reality, the density is much less at one per 70 ha. New well constructions are ongoing; 221 new wells were drilled during 2002 and a total of 1004 completed over the last 5 years. Boreholes generally have uniform designs utilising maximum screened portions of pvc casing. Wellfields are located in close proximity to forests, with the exception of the coastal plantations which are established on saline sabkha soils, inundated by sea-water, where brackish water is imported from distant, inland wellfields operated by Abu Dhabi Agriculture Department.

Wells are equipped with either electric submersible (typical yields 32-38 m^3/hr) or diesel turbine pumps (typical yield 12-20 m^3/hr). All forestry plantations are irrigated using mostly brackish and saline groundwater; no desalinated water is used and there is no proposal to use it in the near future either. Fresh groundwater is utilised for irrigating the plantations between Liwa and Beda Zayed.

Details of all forestry plantations and their respective well depths and water qualities are included in Appendix A and information is summarised in Table 5 below.

Table 5 Summary of Forestry Areas and well information

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

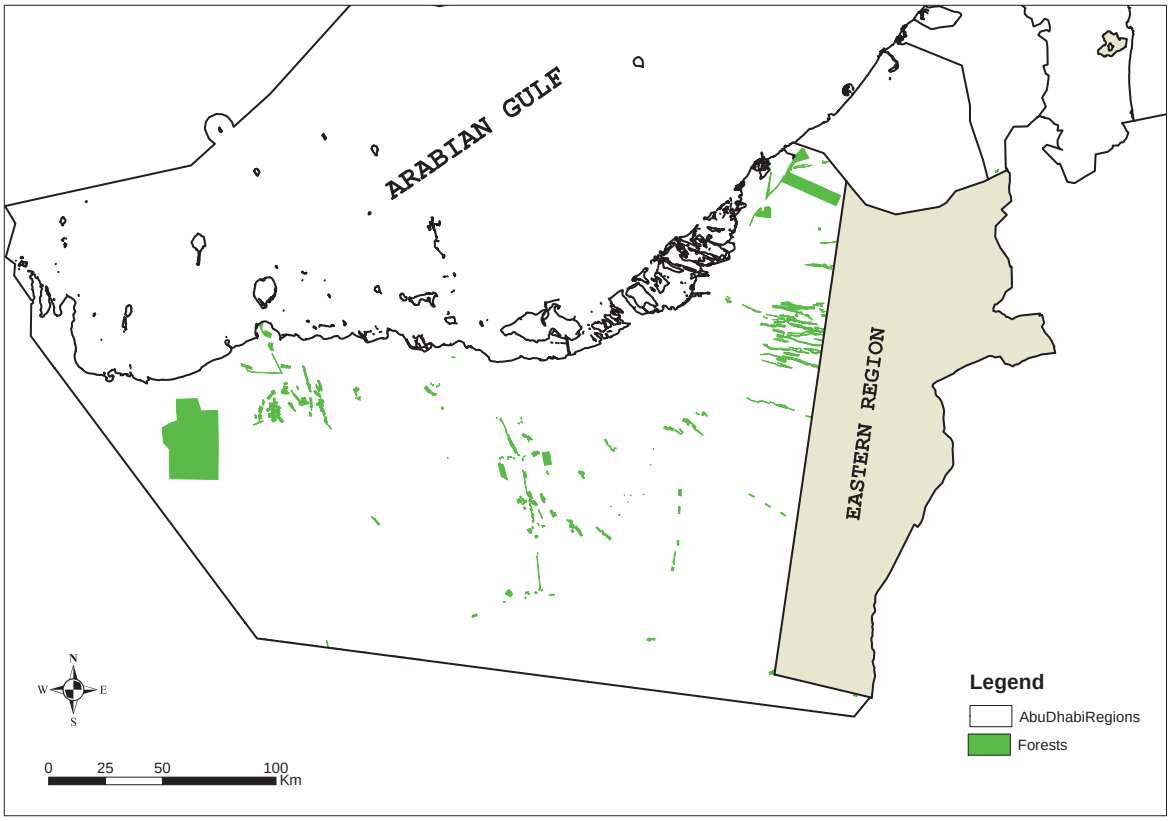


Figure 7 Location of Forestry Development in the Western Region

The majority of the forests show evidence of under-irrigation. The water requirements of wholly irrigated forest trees in extreme arid zone conditions is very poorly researched and will depend on the age of the tree and/or the extent of canopy it has grown (ground cover) *or is required to grow*. Under-irrigation will lead to the development of reduced canopies: no forests have been observed which have a full canopy, which indicates that they are young stands or that they have been under-irrigated and their growth restricted.

Estimates were made for individual tree consumption in 1988 (Sir M. MacDonald and Partners. Govt. of Abu Dhabi Inter Connection of Water Distribution Grid in Remote Areas with Abu Dhabi Water Grid.) These are as shown in Table 6.

Table 6 : Water requirements for various vegetation types

Vegetation type	Allowance	Mean requirement	Annual requirement mm/yr	Comment
Green, amenity areas	2-4.2 gall/sq m/day = 9-18.9 mm/ha/day	13.95 mm/day	5110	Probably high estimate
Date palms	Young 10-15 gall/day/tree Mature 15-20 gall/tree/day	17.5 gall/tree/day assumed with 156 trees/ha = 1.2 mm/ha/day	4550	probably very low estimate (NB Saudi research suggests mean 4mm/day Et = 14,600 cu m/ha/year)
Forest trees	4-8 gall/tree/day	Assume 200 trees/ha at 6 gall/day average = 0.54 mm/day	197-210 [assume a 400-800mm future requirement under improved irrigation regime]	Indicative of current under irrigation; maybe enough for very slow growth
Fodder and vegetables	2-4-2 gall/sq m/day = 9-18.9 mm/ha/day	13.95 mm/day	5500 fodder 1150-3850 vegetables	

In 1989 Atkins (Comprehensive Regional Development Plan of Abu Dhabi) estimated that drip irrigated forests should receive 4000 m^3/ha/year (approx. 12 gall/tree/day). Irrigation is not monitored but there is a rough target of 5-8 gall/tree/day. In practice the Abu Dhabi Forestry department indicated that 4 gall/day was more likely due to acute shortages of water. [At 200 trees/ha this equates to 0.36 mm/ha/day while the desired 8 gall/day would equate to 0.72 mm/day.] However they have no way of measuring these desired or presumed volumes. HRH Private Department in Abu Dhabi indicated that 2.5 gall/day were required per 1.5 sq m of canopy; for a forest with 20% cover this would equate to 2.25 mm/day. In the water use estimates we have used a uniform application rate of 5.45 m^3/ha/day (0.54mm/day) for the total 204,000 ha of plantations which gives an annual water use of 407 Mm^3. This represents 13% of the total water used in Abu Dhabi Emirate in 2002.

3.7 Amenity Water Supply

8.6% of all water used in the western region is for amenity purposes. Amenity plantings include parks, gardens, road side verges and recreation areas such as football pitches and golf courses, appear to receive near optimum amounts of irrigation water which is largely treated sewage effluent (TSE) of a consistent quality. Data on actual water use for amenity planting is not currently available and in the Western Region, it appears

that the Abu Dhabi Municipality Parks & Gardens Dept does not measure in any way their water use for amenity planting.

According to the Abu Dhabi Planning Department 2002 statistics bulletin, 586 donum (58.6 ha) of parks and gardens amenities exist in the Western Region, 90% public and the remaining 10% restricted to children and ladies. Amenity plantation irrigation rates have been calculated from the ERWDA study on the water situation in the Eastern and Central Regions of Abu Dhabi (Mott Macdonald, 2004). Water used for irrigation has been assumed to be applied at a rate of 0.03 Mm^3/ha/yr.

3.8 Industrial Water Use

Industrial demands in the Western Region are small and restricted mostly to the 18 group companies that comprise the Abu Dhabi National Oil Company (ADNOC). ADNOC industrial practices are located both on and off-shore. Off-shore facilities for the oil and gas sector are located on several small Islands and installation platforms with independent desalination water supplies. By far the largest demands are located on-shore, mostly at the self contained Industrial Complex at Ruwais which was inaugurated in 1982 with the commissioning of the ADNOC oil refinery.

The Ruwais Industrial and housing zone was established to develop industries and processing plants at the downstream side of the oil and gas industry. The complex, which is part of the Industrial Development plan of Abu Dhabi, overseen by the Industrial Areas Supervision Committee, comprises the following facilities:

- Oil Refinery (TAKREER)
- Natural gas liquids fractionation plant (GASCO)
- Fertilizer Plant (FERTIL)
- Petro-chemical (polyethylene) plant
- Marine terminal
- Sulphur handling terminal
- Un-leaded gasoline plant

A large housing complex at Al Ruwais comprises more than 1300 units and houses about 20% of the total population which inhabits the Western Region. The housing complex consumes 1.4 Million m^3/yr of water (57% Treated Effluent, 43% potable). Table 7 provides a summary of the water consumption and water sources for the various ADNOC group companies. Water sources for the various industrial users comprise desalinated sea and groundwater, untreated groundwater, raw sea-water and treated effluent. Produced water includes formation water brought to surface with oil & gas exploration activities and also brine reject water from desalination processes. For the western region, ADNOC Group Industries consume a total of 1,3 billion m^3/yr of water from the above sources; raw sea-water constitutes 92% of the total, produced water 5.5%, desalinated water 2.4% and the remainder from shallow groundwater and treated effluent.

Most of the total water used is for cooling and utilises sea-water. Potable water amounts to 2% of the total. Oil produced water is generally treated in order to reduce the oil in water content before it is injected into deep wells which penetrate the carbonate Um Er Radhuma Aquifer. Table 8 below provides details of oil produced water which is re-injected back into deep aquifers by the ADCO operations.

Table 8 ADCO production water re-injection

Oil Field	2002 re-injection	2003 re-injection
Asab	5100	6370
Bab	2400	2400
Buhasa	7000	3185
Sahil	160	320
Shah	160	320
TOTAL (Mm^3/yr)	5.41	4.6

Values in cubic meters per day

At present, no down hole oil-water separation takes place in the oil recovery process. By leaving the oil polluted waters in the host oil reservoirs, the potential for pollution of other aquifers is eliminated and the need for re-injection into other useable aquifers disappears. Technology for oil-water separation at source does exist and is being tested in other GCC states e.g. Oman, and ADNOC should be encouraged to follow the same path since the amount of oil produced water, although small in relation to that found in Oman for example, is still significant in terms of its contribution to polluting other aquifers e.g. Um Er Radhuma.

COMPANY / ENTITY	Desalinated Industry	Desalinated potable	Treated Effluent	Seawater	Shallow Groundwater	other (oil produced water etc)	Total
Ruwais Housing Complex	614,657	not specified	816,608				1,431,265
Ruwais Fertilizer Industries (FERTIL)	7,650	929,950		223,273,000			224,210,600
Abu Dhabi Marine Operating Co.(ADMA OPCO)	768,370					57,443,809	58,212,179
Abu Dhabi Oil Refining Co. (TAKREER)		2		505,452,000			505,452,002
ADNOC DISTRIBUTION	100						100
Abu Dhabi Gas Industries Ltd (GASCO)	823,440	795,700	344,560	219,000,000			220,963,700
ESNAAD	255,234	25,943					281,177
TOTAL ABK		22,400,000		5,332,000		5,716,000	33,448,000
ZAKUM Dvelopment Co.	237,300					3,000,000	3,237,300
Abu Dhabi Polymers Co Ltd (Borouge)	875,490	461,658		267,296,858		353,300	268,987,306
Abu Dhabi Co. for Onshore Oil Operations (ADCO)		4,440,522			3,204,262	3,605,382	11,250,166
Bunduq Company Ltd		70,000		4,833,403		1,392,577	6,295,980
TOTAL	**3,582,241**	**29,123,775**	**1,161,168**	**1,225,187,261**	**3,204,262**	**71,511,068**	**1,333,769,775**

values in cubic meters

Table 7 Summary of ADNOC group company annual water consumption (2002)

4. GIS DATABASE DEVELOPMENT & POPULATION

As part of a consultancy study for ERWDA on the assessment of the water situation of the eastern and central regions of Abu Dhabi (Mott Macdonald, 2004), a GIS groundwater database has been developed and partially populated with data from the respective regions. The database has an integral water supply-demand model which will allow the prediction of water supply – demand balances for any chosen area within Abu Dhabi Emirate.

The structure of the database is shown below in Figure 8 below.

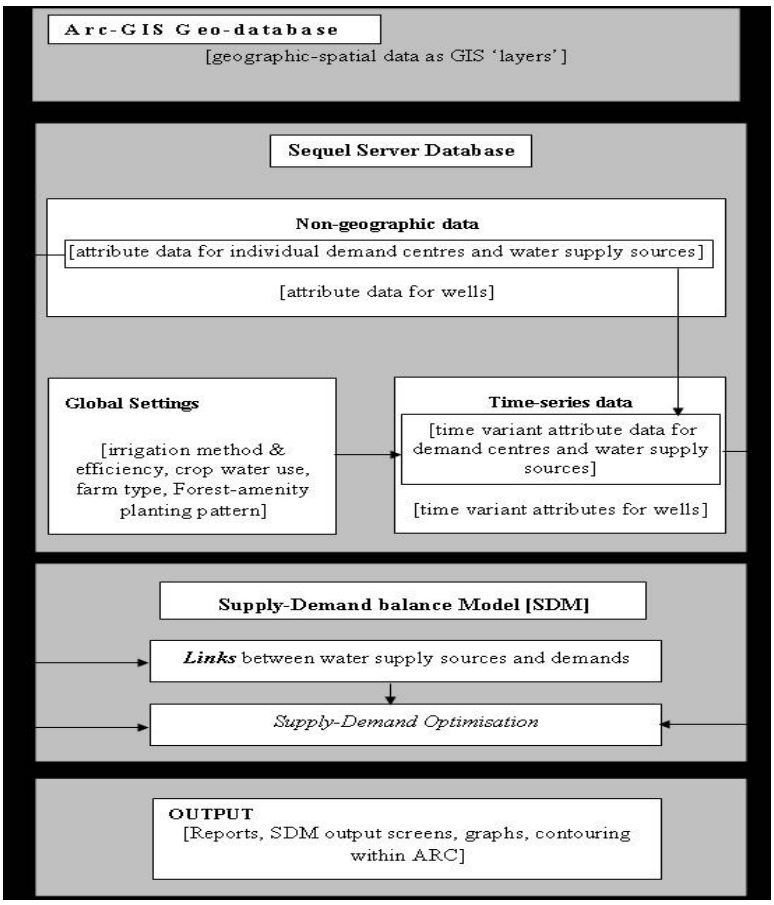
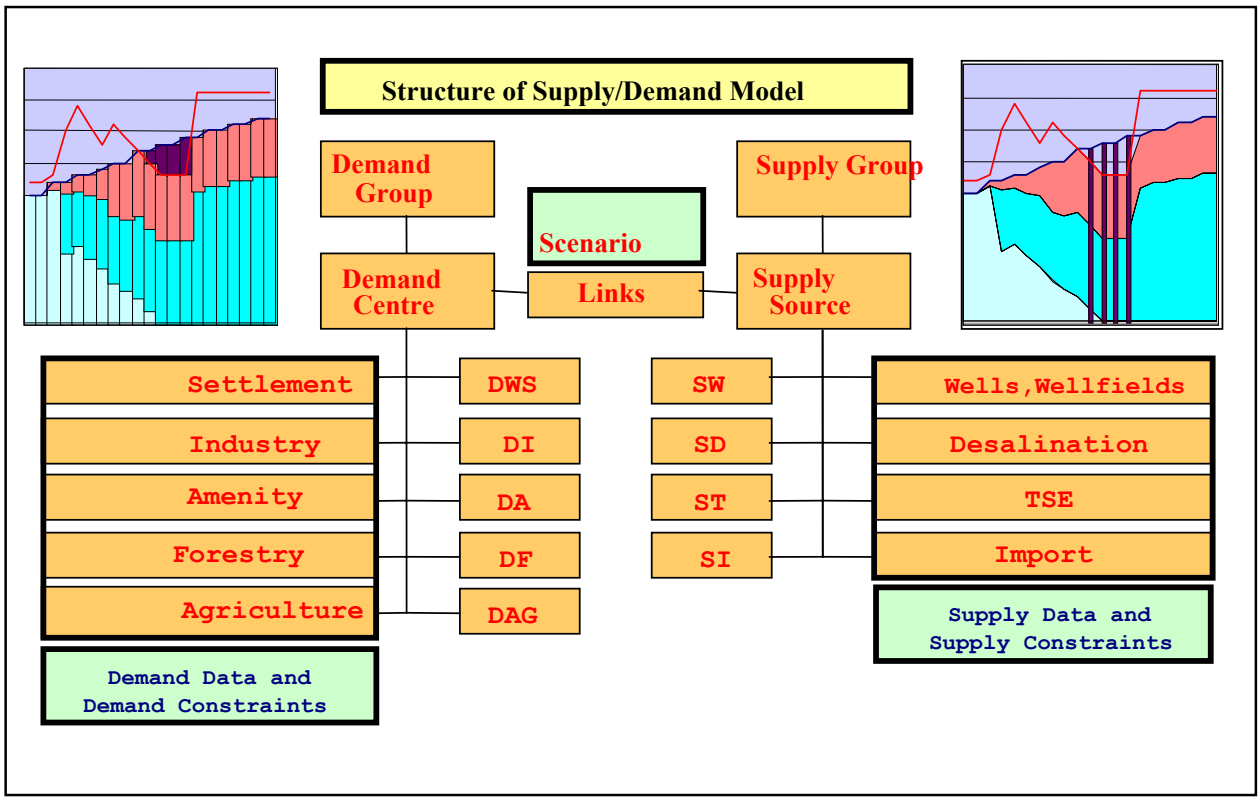


Figure 8 Structure of the Water Resources GIS Database

The database has been installed on the ERWDA server and is an integral part of the ERWDA Environmental Database.. Data entry and general population of data has not yet commenced for the Western Region. The first stage is to compile the data for the various agency sources and verify it. Data entry shall commence in the second quarter of 2004 and water supply and demand balances will be predicted up to the year 2020.

Figure 9 shows the structure of the database supply and demand model inputs with linkages.

Figure 9 Supply – Demand concept



Water Assessment Unit areas(WAUA) have already been fixed for the Eastern and Central regions; WAUA need to be confirmed for the Western region and will probably comprise of the following :

1) Western Region subarea 1 - Coastal belt and Islands
2) Western Region subarea 2 - Madinat Zayed
3) Western Region subarea 3 - Liwa
4) Western Region subarea 4 – Ghayathi

WAUA's will be confimed after verification of all water source and water use data and information.

Demand & Supply Sources:

- The physical size of demand centres and supply sources specified in the supply/demand model are user defined. Individual demand centres and supply sources may be specified or the user may aggregate supply and demand elements as demand or supply *groups.*

- In a supply group or demand group, two *different* types of supplies (e.g. TSE and desalinated water) or demands cannot be mixed. In this way, waters are distributed according to standards of quality required for each specific use

Demands:

- Water supply demand is derived from population and per-capita daily gross water demand. The 2001 Abu Dhabi population census is used as the basis for the population projections, and updates are taken from the Abu Dhabi Planning Department annual population statistics.
- Amenity water supply demand is determined from irrigated area and vegetation water demand
- Forest water demand is derived from net forest area and gross irrigation water. Landsat imagery is used to determine gross areas.
- Farm water demand is derived from net farm area and gross irrigation water requirement. Landsat imagery is used to determine gross areas.
- Each demand centre may be linked to a number of supply sources.
- Demand from human settlements must be satisfied from potable sources.
- Crop, forest and amenity demand is estimated in the SDM using Global Settings for crop water use, cropping-planting patterns and irrigation efficiency.

Sources:

- For sources, an output capacity is specified, while constraint factors may limit this capacity. Constraints may not directly relate to the source but may relate to the *links* between sources and demand centres (such as conveyance pipeline capacity and intermediate storage capacity). The user can specify both real and virtual (future unbuilt) links.
- Individual supply sources may be linked to more than one demand centre.
- Sewage effluent source (TSE) use is restricted; TSE can only supply demand for amenity planting irrigation and no other use;
- TSE output cannot exceed works treatment capacity; for individual sewage plants
- Groundwater source output cannot exceed well pump capacity and is reduced linearly with falls in well water levels.
- Except for TSE sources, no restriction applied to sources meeting demand from farms and forests.
- For desalination plants, output set at 90% of plant Design Capacity. Plant output is varied according to feed salinity.

5. WORK PROPOSED FOR FINAL STAGE OF PREPARATION FOR DEVELOPING A WATER RESOURCES MANAGEMENT STRATEGY

Over the course of the next 6 months, the following tasks are identified in order to complete the baseline survey for Water Resources to enable preparations for a Water Resources Management Strategy to begin:

- Completion of population of the GIS Water Resources Database with supply and Demand data for all regions of Abu Dhabi: Eastern, Central and Western
- Completion of water balances for supply and demands for the whole Emirate up to the year 2020
- Mapping of all Water Resources sources and users in the Emirate of Abu Dhabi (definitive set of GIS layers which will combine the results of surveys for all regions of the Emirate.
- Preparation of a Final Report defining the Water Situation of the Emirate of Abu Dhabi
- A review of all the options available in water resources management and an analysis of various scenarios for future implementation
- Preparation of a draft Water Policy document which will discuss the main issues and problems associated with the overall study of the water resources situation in the Emirate
- Determination of the Groundwater Resources of Abu Dhabi Emirate with respect to different water qualities
- The holding of a workshop with all of ERWDA's partners to discuss and finalise the draft water policy document
- Recommendations of new projects and other work related activities which are required to further Water Resources Management in the Emirate of Abu Dhabi e.g. Undertaking a National well inventory and well permitting and registration procedures, establishing a national water resources monitoring system etc.

6. REFERENCES

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APPENDIX A

WESTERN REGION FORESTRY DETAILS