GROUNDWATER USE AND POLICIES IN ABU DHABI

IWMI Project Report No.13

Groundwater governance in the Arab World

Rachel McDonnell, Stephen Fragaszy

December 2016

ICBA AGRICULTURE FOR TOMORROW
IWMI International Water Management Institute
USAID FROM THE AMERICAN PEOPLE

This is an IWMI project publication – "Groundwater governance in the Arab World – Taking stock and addressing the challenges"

This publication was made possible through support provided by the Middle East Bureau, U.S. Agency for International Development, under the terms of Award AID-263-IO-13-00005.

Cover photo: Rachael McDonnell.

TABLE OF CONTENTS

Figures

Tables

1 Introduction

The United Arab Emirates presents a fascinating case study for any investigation into water resource governance in the Middle East North Africa (MENA) region. From a government/governance view, it is a federal country comprising seven emirates each with its own monarchy, so is unlike any other in the world. It also has a high per-capita GDP of $63,181 (2013) relative to many other countries in the region, and is on a rapid development track which brings both opportunities and challenges to water governance in this most arid of areas.

This report takes stock and outlines the issues and challenges of water and specifically groundwater governance in the Emirate of Abu Dhabi, the largest emirate of the seven, which has the highest percentage of groundwater use (Figure 1). The Emirate occupies an arid region sloping west from the Omani Mountains and north from the Rub Al Khali desert of Saudi Arabia to border the Gulf, with most of the area sand and stony desert, with sabkhas in the coastal strip. The emirate is divided into three administrative regions. It was chosen as an area of study because of the complex waterscape that has developed over the last forty years, with new non-conventional water (desalinated and treated sewage effluent) supplies making up an ever-increasing water budget deficit. Thus the lessons learned from the approaches used in both groundwater and non-conventional water governance and policy development may be salient for other countries as they too develop under arid conditions in the coming years.

This report is divided into two main parts. The first reviews the groundwater management systems and their use over time and for the present day. This gives insight on changes of the state of the resource and the changing frameworks of water policy and management over time. In the second part, the groundwater governance developments and policies are examined.

Figure 1. Map (a) showing the seven emirates that make up the country of the United Arab Emirates and (b) the three regions with Abu Dhabi, Al Ain, and Western (aka Al Gharbia)

a) b)

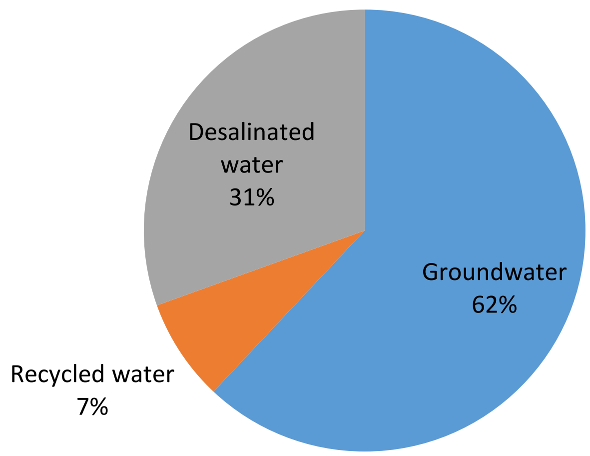
Source: (a) http://2012books.lardbucket.org/books/regional-geography-of-the-world-globalization-people-and-places/index.html; (b) Wikimedia.

2 Overview of groundwater resources in Abu Dhabi Emirate

Abu Dhabi's water consumption rate often makes international headlines as one of the highest in the world, with an estimate of 575 liters per capita per day (Pitman et al., 2009). This consumption rate reflects a major shift in social practice in a country where just two generations previously frugal water management was essential for survival. With the discovery of oil in the 1950s, traditional water management practices were replaced by a drive to green the desert and because of population expansion resulting from economic development. Extensive capabilities were developed to pump groundwater from the substantial freshwater lenses in Liwa and Al Ain to support many new areas of farming and forestry beyond the traditional oasis systems. At the same time the population grew exponentially through a combination of migrant labour needed to support the economic development as well as natural increase from the Emirati citizens.

This report will examine groundwater resources in the context of all water supply and demand systems in the Emirate. It is by considering the total resource base context that the status of groundwater can be better understood. Today water supply totaling 3,568 Mm^3/year is based on three main sources, known as the three taps (see Figure 2) (Government of Abu Dhabi, 2013). Groundwater continues to provide the lion's share but desalinated and recycled water (treated waste water) contribute 38 % of total supply and are important for the sectors they serve, respectively domestic supplies and landscaping (Pitman et al., 2009; Pitman et al., 2010; Government of Abu Dhabi, 2013). This percentage is increasing as rapid urban development continues, particularly in Abu Dhabi city, with concomitant increases in desalinated and recycled water production capacity from new plants.

Figure 2. Total water supply sources in Abu Dhabi Emirate (%) in 2012



Source: Government of Abu Dhabi, 2013.

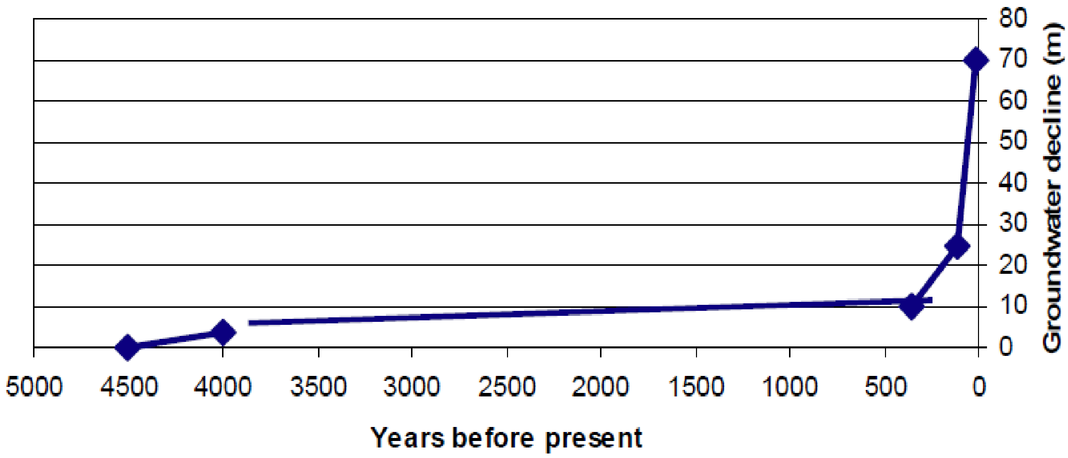
2.1 Natural water resources

Rainfall is sparse and erratic in both time and place with mean annual rainfall declining from east to west across the Emirate, varying from 119 mm at Al Wigan, to 96 mm in Al Ain and only 46 mm at Jebel Dhana in the Western Region. Mean annual rainfall of Abu Dhabi Island is only 87 mm, and annual potential evaporation of more than 2,000 mm ensures precipitation is often lost before contributing to water resources or crop production (Ministry of Environment and Water, 2010).

The general aridity and unreliability and limited extent of rainfall ensure that surface water is little considered as a resource. High intensity isolated rainfall often causes sporadic *wadi* floods that quickly infiltrate and recharge aquifers. Volumetrically, net rainfall contributes about 24 million cubic meters (Mm3) a year (Brook, 2005; Moreland et al, 2007). About 16 Mm3 is from rainfall over the Emirate and 8 Mm3 is from cross-border flows from Oman.

Groundwater has been the main source for water supply for thousands of years. From the archaeological record it is known that shallow hand dug wells were constructed both onshore and on offshore islands. Examples of late Stone Age (c. 5,000 BC to 4,000 BC) and early Islamic period (620 AD to 1800 AD) dug wells are found at the present site of Abu Dhabi International Airport and also on Marawah Island respectively (Brook, 2005). In areas of shallow water tables in the superficial, alluvial and sand aquifers, hand dug wells and open pits for water abstraction are still constructed today. Jorgensen and Al Tikriti (2002), from a hydrologic and archaeological study of climate change in the Hili area of Al Ain, have shown that trends of increased well depths and declining water levels for the past 4,500 years correlate with an increase in aridity of climate. Figure 3 shows a 4,500 year hydrograph with a slow groundwater decline from 2,500 BC to ca. 1650 AD, an increased rate of decline then to around 1900 AD, after which there is a very rapid decline that is largely anthropogenic. The increase in aridity experienced in Abu Dhabi Emirate represents a trend which existed over all or most of the Middle East, eastern Mediterranean and northern Africa which had an immense impact on the development of civilizations. In the Al Ain area, non-irrigation farming could not successfully be sustained at the end of the Bronze Age. This hindered economic development until the aflaj systems were introduced in the Iron Age (Brook, 2005).

Figure 3. Changes in groundwater levels at Hili Al Ain over the last 4500 years (



Source: Brook, 2005, Jorgensen and Al Tikriti, 2002.

These groundwater resources, in the absence of significant recharge, are essentially a large reservoir of ancient water laid down during previous wetter periods (Woods and Imes, 1995; Woods and Imes, 2003; Woods et al, 2003). Explorations over the last 30 years have shown that the *fresh* groundwater area available before the major developments in pumping extended in the northeast of the Emirate over about a 1,600 square kilometre area and covered around 2.7 % of the Emirate. Most of this fresh water, accounting for approximately 8% of total fresh groundwater reserves, occurred within about 15 to 25 km of the Oman Mountain front from

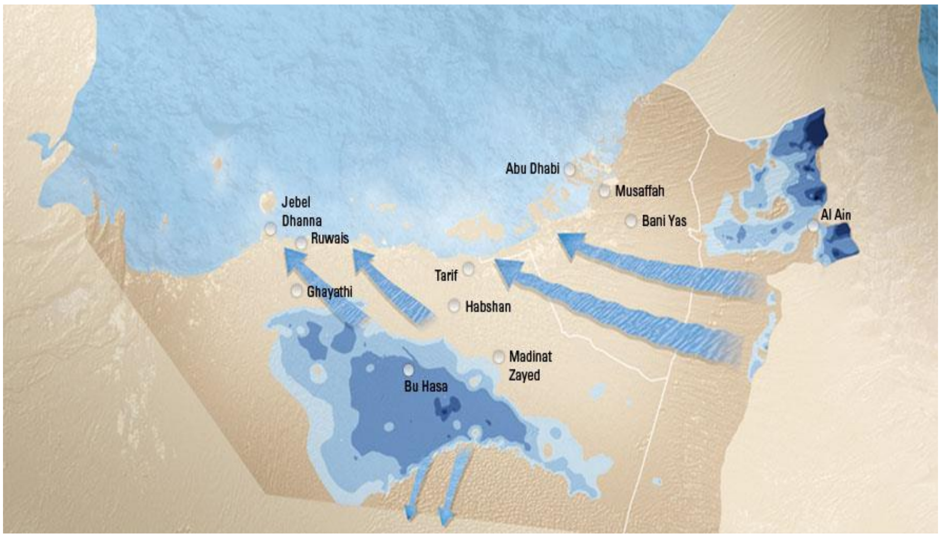
Mezyad to Al Shwaib in the Al Ain region (USGS/NDC, 1996; Moreland et al, 2007). The source of the fresh groundwater in the Eastern Region was primarily episodic storm runoff and underflow through the alluvial sediments in wadis that drained the Oman Mountains (Symonds et al, 2005). A narrow band of fresh water extended about 30 km west of the Oman border through Al Ain to Al Saad (Figure 4).

In the second major area of fresh groundwater, accounting for 84% of total reserves, the total predevelopment fresh groundwater area beneath the Liwa Crescent in the western Emirate was about 3,800 square kilometres or 6.5% of the total area of the Emirate which had reduced to 2,199 kilometres by 2005 (Moreland et al., 2007) (Figure 4). The source of this fresh water was paleo-recharge thousands of years ago during wetter climatic periods than the present arid climate (Woods and Imes, 1995). Several studies have indicated that virtually no recharge occurs in the Western region under present climatic conditions so any abstractions are effectively mining of the resource.

With annual abstraction estimated at 2,174 Mm3 and maximum recharge rate around 140 Mm3, the estimated usable groundwater reserves would be depleted within 55 years if 'business-as-usual' abstraction rates continued (Pitman et al, 2009).

Given the importance of salinity in determining the usability of the resource, it is useful to consider the volumes for each category as given in Table 1. The values highlight that little of the available groundwater is fresh, and whilst brackish can be used in some crop production systems, the majority of the resource is unusable.

Figure 4. The two major freshwater aquifer systems of Liwa and Al Ain



Source: www.environmentalatlas.ae/resourceOfLife/ecologyOfWater (Last accessed 27th June 2016).

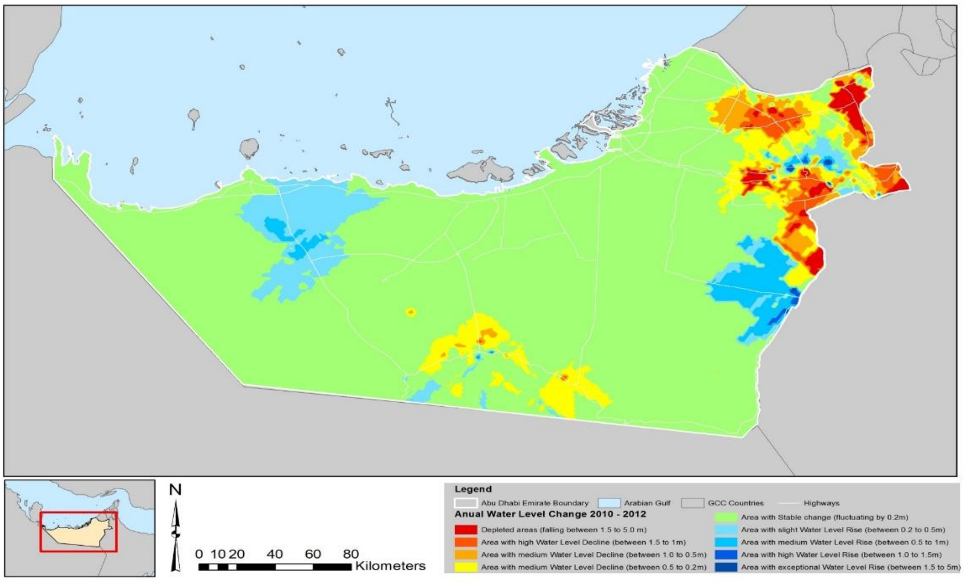
At the current rates of extraction both fresh and brackish groundwater resources will be exhausted in the next 50 years (Moreland et al, 2007). The rate of recent falls in groundwater levels is illustrated spatially in Figure 5 with the areas of greatest declines found in the Al Ain area as a result of agricultural practices. The picture however is much more complex than one of uniformly falling water table levels. In some areas aquifer levels are increasing bringing different hazards. In parts of Al Ain, rising water levels as a result of treated wastewater disposal and irrigation of landscaping using desalinated water have led to flooding of housing foundations, and near-surface water logging. In the areas of Al Baynunah near the coast, rising water levels are a result of forest irrigation with water abstracted from deep aquifers leading to superficial water table rises.

Table 1. Groundwater reserves estimate

Salinity Zone Fresh (<1500 mg/l)	Area (m^2x10^6)	Avg. Saturated Thickness (m)	Average Specific Yield	Volume in Storage (Mm^3)
Fresh – Eastern Region	1440	20	0.14	4,000
Fresh – Western Region	2400	26	0.23	14,000
Fresh – Emirate	**3840**			**18,000**
Salinity Zone Brackish (>1500 and <15,000 mg/l)				
Brackish below Fresh Water – Eastern Region	1440	40	0.14	8,000
Brackish below Fresh Water – Western Region	2400	69	0.23	38,000
Brackish – Remaining Areas	29,983	42	0.15	189,000
Brackish – Emirate				**235,000**
Total Fresh and Brackish Groundwater				**253,000**

Source: Moreland et al., 2007.

Figure 5. Average annual change in groundwater levels in Abu Dhabi 2010-2012



Source: Government of Abu Dhabi, 2013.

2.1.1 Physical Status of Groundwater Resources

Groundwater in Abu Dhabi may be categorized into two groups: the first are the unconsolidated/superficial aquifers that have been the main sources of water to date; and the second are the bedrock aquifers that are found in predominantly carbon-rich rock formations (Figure 6).

2.1.1.1 Bedrock Aquifers

Bedrock aquifers occur throughout the Emirate and are mostly carbonate deposits laid down in shallow marine seas. They occur generally at significant depth and have not been explored or exploited like the shallow unconsolidated aquifers. The main water bearing formations are as follows (Pitman et al, 2009):

- The Asmari Formation (Whittle and Alsharhan, 1994);
- The Karstic Limestone Formations (Khalifa, 1997; Bright and Silva, 1998);
- The Dammam and Rus formations;
- The Rus Formation (Al Amari, 1997);
- The Umm er Radhuma Formation (Hassan and Al Aidarous, 1985); and
- The Simsima Formation (Hamdan and Anan, 1989).

2.1.1.2 Unconsolidated/Shallow Aquifers

The sand dunes and alluvial deposits comprise the most common and productive aquifers in the Emirate (Rizk et al., 1997). The shallow unconfined aquifer is present throughout the Emirate and about 80% of the Emirate has Quaternary sand and gravel aquifers (Figure 6). In the Eastern Region the main aquifers are Quaternary sand and gravel aquifers underlain by the Upper Fars Formation which continues eastward into the Sultanate of Oman, the Lower Fars Formation in the southeastern Umm Al Zamoul area, the Dammam and Simsima limestone bedrock aquifers, and discontinuous carbonate units north of Al Ain. In the Western Region the Quaternary sand aquifer is directly underlain by the Lower Fars Formation as a basal unit which acts as a regional aquiclude (Wood et al., 2003).

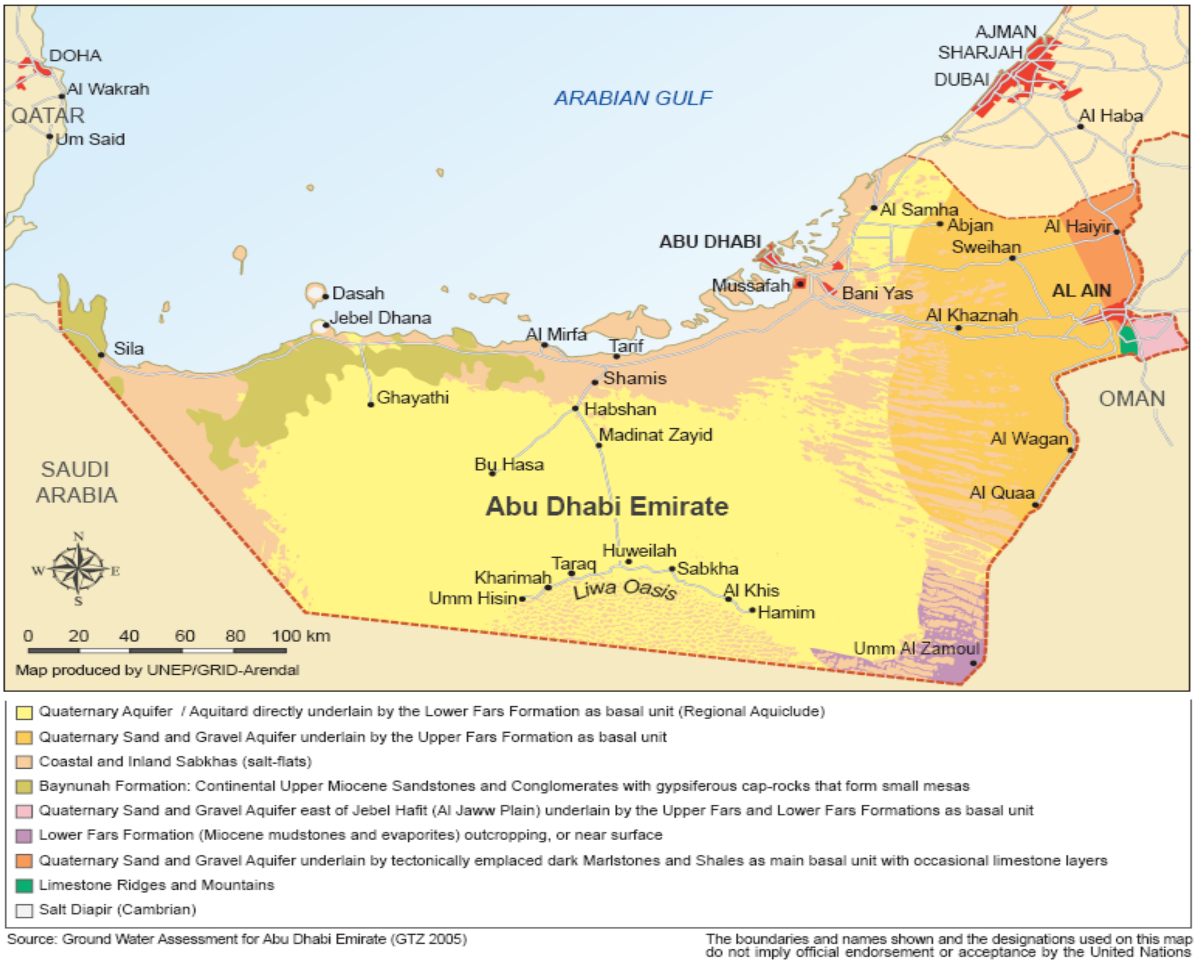
There are also thin coastal sabkha[1] aquifers and the Baynunah Formation comprising of Upper Miocene sandstones and conglomerates with gypsiferous cap rock that form numerous low-lying shallow and uneconomic aquifers. Both formations are underlain by the regional Lower Fars aquiclude (Hutchinson et al., 1996). The recharge of these aquifers spans from 46 millimetres (mm) at Jebel Dhanna in the Western Region to 119 mm at Al Wagan, south of Al Ain. Given that most of the landscape of the Emirate is flat consisting of sandy soil with scattered sand dunes and some low elevation sabkhas, there is little runoff from these areas and any rainfall infiltrates the surface quickly. The recharge is thus negligible and is only locally boosted by wadi flows originating from the east (Woodward and Menges, 1991).

In the Eastern Region, on the escarpments of the Al Hajar Mountains, rainfall produces runoff that drains into the wadis that flow westward crossing Abu Dhabi borders into the inlands with an average annual surface water flow of about 7.6Mm3 annually (Table 2). This runoff produces a natural recharge of groundwater estimated to be around 31 Mm3 per year, predominantly in the gravel alluvial fans and gravel plains of these mountain areas. Table 2 summarizes the catchment flow for a number of wadis and whilst this is not negligible, compared to the rate of water used, the flows do contribute to recharge values. To increase aquifer recharge with surface water, 100 dams and barrier structures have been built to divert/retain runoff water (Ministry of Environment and Water, 2010).

---

[1] Sabkha is a saline flat/ depression area.

Figure 6. Hydrogeology map of Abu Dhabi Emirate



Source: Government of Abu Dhabi, 2013.

Table 2. Catchment flow (Mm3/yr)

Catchments	Surface water runoff (wadi flow)	Groundwater (through flow)
	Mm3/year	
Sumayni	0.2	**1.4**
Safwan	1.48	**2.6**
Musaydirah Kahal	1.4	**1.9**
Al Wadiyain	0.6	**4.7**
Hamad	1.9	**1.1**
Ajran	0.0	**1.0**
Sifah	0.0	**2.6**
Sharri	0.0	**2.4**
Al Fatah	2.1	**2.0**
Dank	0.0	**7.0**
Sawmahan	0.0	**2.6**
Al Hawl	0.0	**1.6**
Total	7.6	30.9

Source: Pitman et al., 2009.

2.1.2 Chemical status of groundwater resources

The chemical status of groundwater is an important consideration in Abu Dhabi as anywhere, as it controls the possibilities of usage. It is determined by many factors including recharge processes, the geology of the host rocks, and residence times and discharge processes. For example, the hyper-saline groundwater in excess of 200,000 mg/l found along the Abu Dhabi coastline is a result of slow groundwater movements allowing extensive dissolution of salts. Human contributions of new chemicals such as fertilizers/pesticides or brine and sewage disposal, or from abstraction practices resulting in upward groundwater movement from deeper formations also affect concentrations of particular chemical variables.

Salinity is arguably the most important chemical control on water use in Abu Dhabi and **Error! Reference source not found.** shows the spatial distribution of concentrations across the unconsolidated/superficial to medium depth aquifers. The least saline groundwater reserves are found in the recharge area near Al Ain and beneath the sand dunes north of the Liwa Crescent. In the latter, 40% of the total storage are fresh (<1500 mg/l) or low brackish (1500 - 6000 mg/l) waters. A few isolated bodies of fresh groundwater are known to exist in some locations where local rainfall has accumulated in thin lenses of fresh water floating on top of more saline water.

Moderately-brackish groundwater is found on the fringes of the fresh groundwater areas and around the Liwa mound. Two zones of moderately-brackish water extend from the fresh groundwater mound underlying the Liwa Crescent area. The more saline areas are in the coastal zone where saline intrusion following over-abstraction as well as natural processes leads to hyper concentrated conditions. Other saline areas in the south and south-east are naturally occurring saline areas characterized by sabkhas.

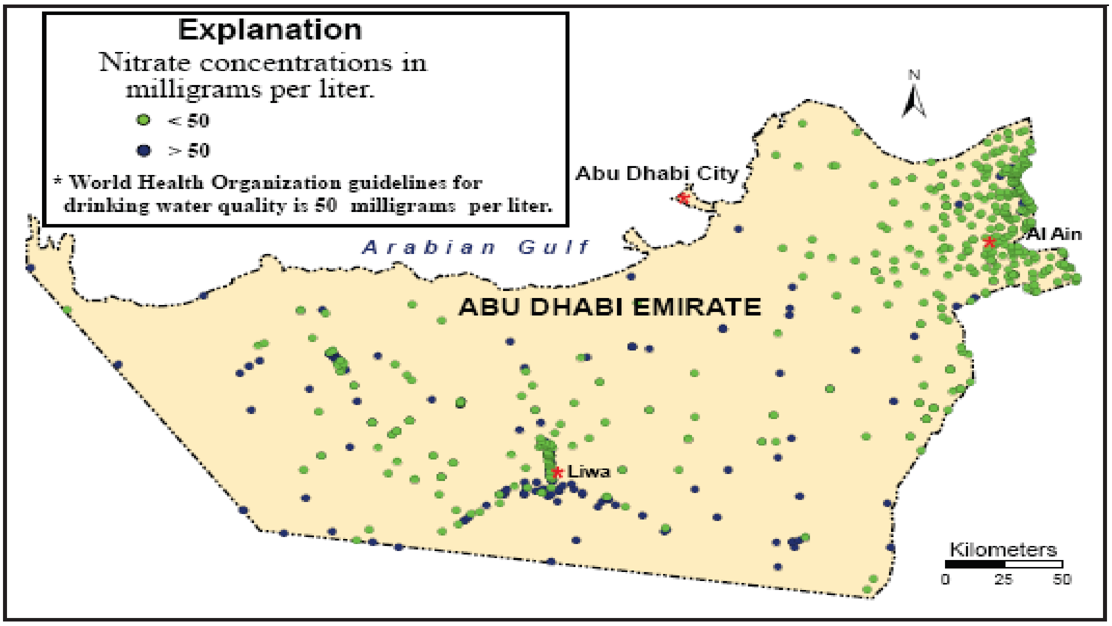
Various trace minerals also affect how groundwater may be used and in Abu Dhabi, Moreland et al. (2007) have indicated that nitrates and boron concentrations in fresh groundwater in the superficial aquifer exceed World Health Organization (WHO) Guidelines for drinking-water quality.

2.1.2.1 Nitrates

Excessive nitrate concentrations occur naturally in many wells in the Liwa Crescent (Wood et al., 2003). This is thought to result from a lack of vegetation in the arid climate of Abu Dhabi, where given that little or no nitrogen up-take occurs from the soil, nitrate concentrations continue to increase over time. The highest concentrations of nitrate occur in the saline water zones where evaporative concentration in sabkhas is a controlling factor.

These naturally occurring concentrations have been increased by anthropogenic activities. In Abu Dhabi, the farming areas in the east are located on sandy permeable soils which overlie an interbedded section of gravels, sands and clay-silts which support a shallow and normally unconfined aquifer with static water levels between 10-20 m; a pattern of over-application of fertilizer (in particular, urea) and continuous crop irrigation has led to nitrate transport into the shallow aquifer. Many of the wells in the Liwa Crescent area that contain high concentrations of nitrate are located near farming areas as shown clearly in Figure 7 (Alsharhan et al., 2001). In the Central Region at the Al Wathba Wetland, monitoring work by Environment Agency Abu Dhabi (EAD) has indicated groundwater nitrate values exceeding 200 mg/l as NO_3^- (Figure 7). Local observation and piezometric evidence strongly suggests that nitrate is entering the groundwater system from fertilizer application and urea at a nearby camel fodder farm.

Figure 7. Nitrate concentration map of Abu Dhabi



Source: Moreland et al., 2007.

2.1.2.2 Boron

Boron concentrations exceed the 0.5mg grams per litre (mg/l) levels of WHO Guidelines for drinking-water quality in most areas of the Emirate with levels reaching 2.4 mg/l in some places. Concentrations of boron in groundwater in the superficial aquifer increase with salinity levels and are controlled, in part, by evaporation. The source of boron in the superficial aquifer is derived from trace minerals from the ophiolitic rocks of the Al Hajar Mountains, and possibly from mixing of saline water that has leaked upward from underlying strata of marine origin.

2.1.2.3 Human inputs

Human activities also contribute to the chemical status of groundwater, and these are often concentrated in particular areas, increasing local pollution levels. High levels of nitro and phosphate species are found around concentrated livestock lots, especially in Al Ain, the Liwa Crescent and parts of the Western Region. Similarly, applications of chemicals used in agriculture such as fertilizers and pesticides seep into the groundwater and the enhanced levels in aquifers underlying cultivated areas have already been mentioned. Nitrogen levels in the Liwa Oasis have become particularly pronounced over the last 20 years in local groundwater systems.

In recent years the number of Brackish Water Reverse Osmosis (BWRO) plants has rapidly increased in the Emirate. The principal method of disposal of the reject brine is in surface impoundments of unlined ponds. Mohamed et al. (2005) found that disposal in this way lead to increased levels of salinity and heavy metals in the underlying aquifers.

2.1.3 Groundwater use over time

Historically, the entire Emirate's water requirements were met solely from groundwater obtained from shallow hand dug wells or through the traditional Falaj (plural aflaj) systems. There was a sustainability built into the technology used and the local governance of these common pool resources. At least 21 aflaj existed in the Al Ain area with Al Hili and Al Raki aflaj as the oldest dating back 3000 years to the Iron Age. The mother wells of the Dawoodi aflaj range in depth from 6.5 – 30m and Al Ain falaj which is the longest with a channel length of 15km. Today, 12 of the original 21 remain working and are under the management of the Aflaj section of the Parks and Gardens Department of Al Ain Municipalities and Agriculture. All Al Ain Aflaj are now dry, so a system of borehole support has been developed over the last 5-10 years. Boreholes, drilled to depths of up to 200m, pump water directly to the open surface and have been used to support the Al Ain oasis and Al Jimi falaj area.

The scale of usage has changed markedly since the time of the aflaj, and with the availability of motorized pumps and other enabling technologies, faster rates of abstraction and distribution have been possible. This, coupled with cheap energy and a rapid expansion of agricultural and forestry activities, has ensured that over the last 20-25 years this system has been placed under increasing stress from declining groundwater levels. Current estimates indicate that water use is more than 25 times total annual renewable water resources (Government of Abu Dhabi, 2013). Table 3 shows clearly the decrease of fresh groundwater reserves in the Emirate from an estimated 29,694 Mm^3 in the superficial aquifer during the pre-development stage to 26,269 Mm^3 in 2005.

Table 3. Pre-development and present day groundwater reserves estimate for Abu Dhabi Emirate

Salinity Zone Fresh (<1500 mg/l)	Pre-development Volume in Storage (Mm^3)	Present day 2005 Volume in Storage (Mm^3)	Change in groundwater storage %
Fresh – Northeastern Region	4,730	2,475	-47.7
Fresh – Western Region	24,964	23,794	-4.7
Fresh – Emirate	**29,694**	**26,269**	**-11.5**
Moderately Brackish – Northeastern Region	17,284	12,706	-26.5
Moderately Brackish – Western Region	77,039	76,304	-1.0
Moderately Brackish	**94,322**	**89,010**	**-5.6**
Brackish	137,578	132,311	-3.8
Saline	77,371	76,931	-0.6
Brine	80,193	79,915	-0.3
Brackish, Saline, & Brine	**295,142**	**289,157**	
Total Fresh and Brackish	**419,158**	**404,436**	

Source: updated by Pitman et al., 2009.

The greatest decrease of 47.7% occurred in the north-eastern region's freshwater reserves which declined from 4,730 to 2,475 Mm^3 due to over-abstraction. This has resulted in a decline in the average saturated thickness of the superficial aquifer from 22 m to 12 m. In the region between Al Ain and Al Saad, high pumping density and over-abstraction has depleted virtually the entire pre-development saturated thickness of fresh groundwater (Mooreland et al., 2007). This is clearly shown in Figure 5. Moderately-brackish groundwater in the Emirate overall declined by 5.6%, however, most of this decline occurred in the northeastern region where the decline was 26.5% of total regional reserves from 17,284 to 12,706 Mm^3. Most of the declines occurred between Al Ain and Al Khaznah and also near Al Wagan where dense concentrations of farms use large quantities of groundwater (Mooreland et al., 2007). Since these data were collected there have been updates to the total amount of freshwater resources available at the entire Emirate level but not for the different regions and across different salinity levels.

These values highlight the need for increased groundwater control, something already recognized by various Abu Dhabi government agencies. The Environment Agency Abu Dhabi (EAD) in particular is charged with developing, managing, conserving and protecting water resources and an extensive analysis of the various drivers and policies that have been used to manage groundwater reserves is given in Report 2.

Groundwater accounts today for a very small percent of domestic water supplies because of declining water quality and increased pumping costs as groundwater levels dropped. In the Liwa Crescent area domestic water supplies from groundwater grew rapidly between the late 1970s until 1996 when production was about 14 Mm^3/year. By 1997 it was zero (Hutchinson et al, 1995). Pumping was reduced because of the high levels of boron and nitrate in the groundwater both of which exceeded health guidelines. Al Ain groundwater was also the main source of domestic and agricultural water supply for the city and its environs, and usage grew from about 15 Mm^3/year in the late 1970s to peak at 70 Mm^3/year in 1998. However, abstraction for irrigation and domestic supplies caused groundwater levels to fall by 20-60 meters, and there were concerns that supplies would dry up. Municipal wells have been closed down and production is now far less than 10 Mm^3/year for municipal purposes. To improve the quality of pumped groundwater in Al Ain, 25 small-scale reverse osmosis plants provide about 0.6 Mm^3/year.

In recent years the extent of saline and brackish conditions has increased as a result of aquifer over-abstraction with either sea-water or older saltier groundwater infiltrating freshwater systems. A survey of 23,900 wells by the Al Ain Agricultural Department in 2000-2001 found that 88% of wells had a salinity of more them 2,000 parts per million (ppm of total dissolved solids) and 65% had salinity in excess of 4,000 ppm. A fifth had salinities greater than 8,000 ppm. This has increased even more in the interim with more zones of increasing salinity as shown in **Error! Reference source not found.**. Moderately brackish groundwater resources can still be used to irrigate a restricted range of crops and vegetation such as certain date palm species and various forage varieties that are salt tolerant. On some farms the waters are currently desalinated locally via small-scale reverse osmosis (RO) plants, particularly in the Western Region. This capacity has expanded over the last few years in many of the areas as a result of the increased salinity levels.

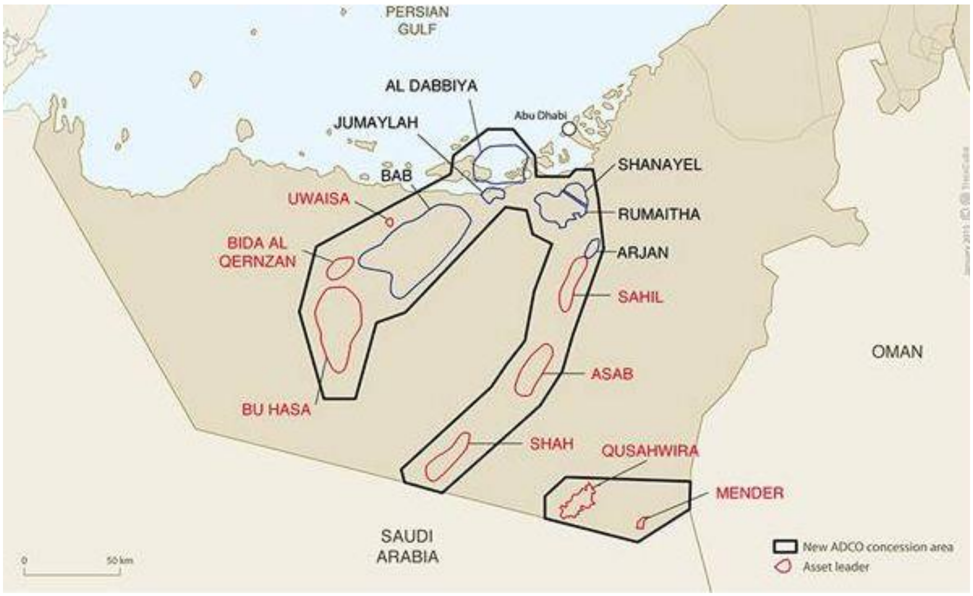
2.1.4 Produced water

A particular form of groundwater abstraction results from hydrocarbon production systems across the emirate (Figure 8). The Abu Dhabi National Oil Company's (ADNOC) 2013 freshwater consumption of ~35 Mm^3 is relatively minor considering that oil, gas and hydrocarbon downstream industries make up about 80% of the UAE federal government's funds although only 51.5% of Abu Dhabi's GDP (Statistics Centre - Abu Dhabi, 2015).

Until 2009 ADNOC abstracted a significant amount of groundwater from the fresh zone of the Liwa Aquifer for local oil and gas fields, but since then has reduced groundwater consumption significantly and deepened its abstraction wells to tap the brackish and saline zone (ADNOC 2009 and 2013). These water consumption statistics do not include produced water or information on the specific aquifer formations from which brackish and saline zones are tapped, however.

Statistics on production and process-water for ADNOC companies vary significantly from year to year and for 2011 and 2013 are not reported at all: in 2010 the group reported over 1BCM of production water while in 2012 reported ~350 Mm^3 (2010/2012 sustainability reports). Abu Dhabi Company for Onshore Petroleum Operations (ADCO) - the onshore oil and gas production company that has several major operations in or adjacent to the Liwa Crescent as shown in the map below - does not include statistics on production water and reports only groundwater and municipal water usage (ADCO sustainability reports 2012-2014). ADNOC reports that production water is currently re-injected into deep wells for disposal and in some cases to maintain well pressure (ADNOC, 2012). The volume of treated water re-used in ADNOC companies, about 10 Mm3 as of 2013 (ADNOC, 2013), indicates that production and process-water treatment and re-use could become a major source of non-potable irrigation water in the future.

Figure 8. The main oil production concession areas in Abu Dhabi emirate



Source: www.pennenergy.com/articles/pennenergy/2015/01/total-awarded-oil-exploration-concession-percentage-in-abu-dhabi.htm (Last accessed 27th June 2016).

Produced water quality varies significantly, and the range of technical challenges associated with treating water used in hydrocarbon extraction and refining processes is great. But new research on mechanical, biological and geo-remediation of hydrocarbon-associated water indicates that it could be a viable source of water in the UAE for irrigation purposes in the future.[2]

Consistent testing and effective regulatory oversight would be key to ensure the safety of using such water. Given the large volume of produced water, and the fact that it will likely rise with increased implementation of enhanced oil recovery techniques in Abu Dhabi's oil and gas fields, necessitates its inclusion in future water resource management plans. While treated production water is unlikely to be used for agricultural purposes in the near future, treated production water could more easily be used for forestry and some amenity plantings thus reducing pressure on groundwater resources overall by limiting its usage for those purposes.

Indeed, just this year the UAE government began to consider this option formally through the Ministry of Energy. The Ministry convened a working group including individuals from EAD in early 2016 to gather initial data needs and further develop the plan for long-term study of production water utilization. This baseline work is ongoing.

2.2 Non-conventional water resources

The naturally occurring groundwater resources have been increasingly supplemented in recent years by manufactured water – desalinated and recycled.

2.2.1 Desalinated Water

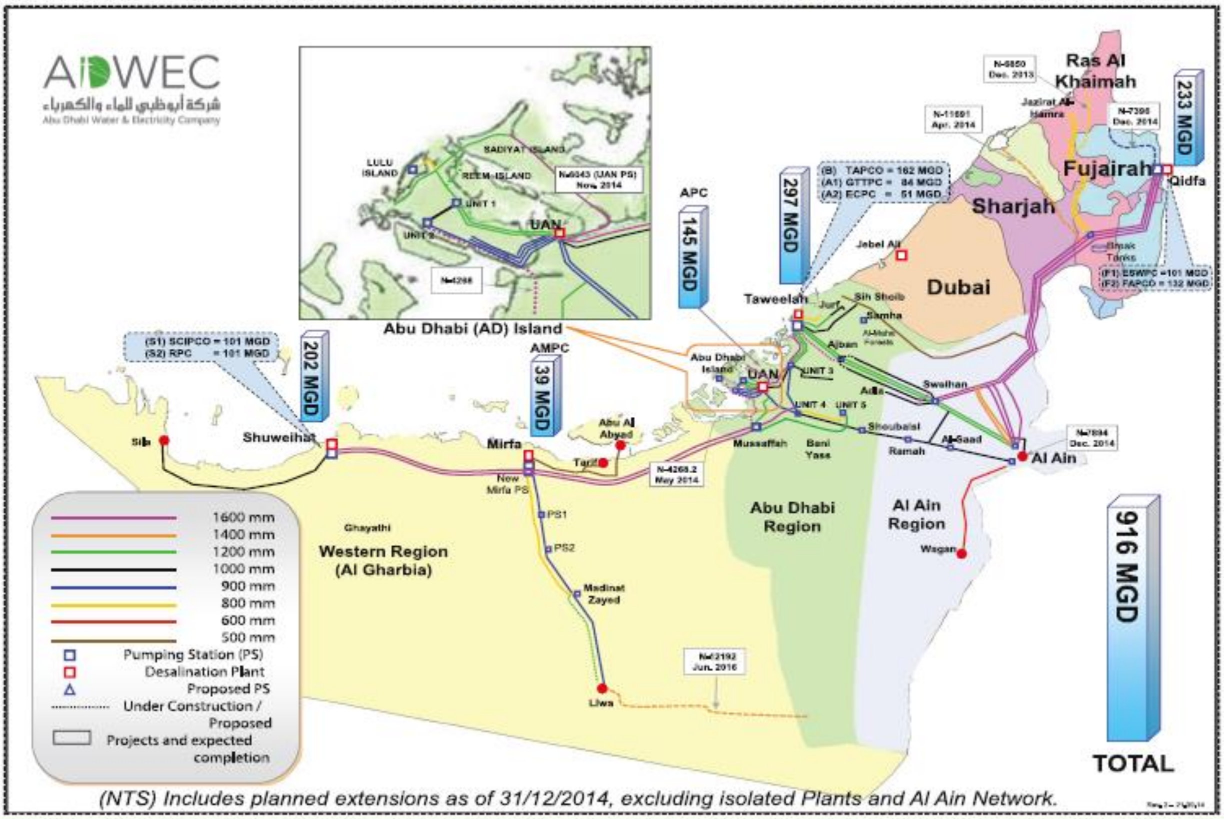
Desalinated seawater currently represents the primary source of potable water available in Abu Dhabi Emirate. Capacity to desalinate water to supplement groundwater supplies has increased

---

[2] Site-specific research within the UAE would be necessary to examine its viability given Abu Dhabi's particular soil characteristics, plantings, production water salinity, etc.

by over 330% between 1998 and 2012. Current production is primarily from eight desalination plants along the Arabian Gulf Coast, and another complex in Fujairah Emirate facing the Gulf of Oman to reduce production risks such as from oil spills, oceanic algal blooms known as red tide, and to take advantage of more energy-efficient desalination techniques such as RO which are more feasible using Gulf of Oman feedstock due to its reduced salinity compared to the Arabian Gulf water (Figure 9).

Figure 9. Abu Dhabi's desalinated water production and distribution network- 2014

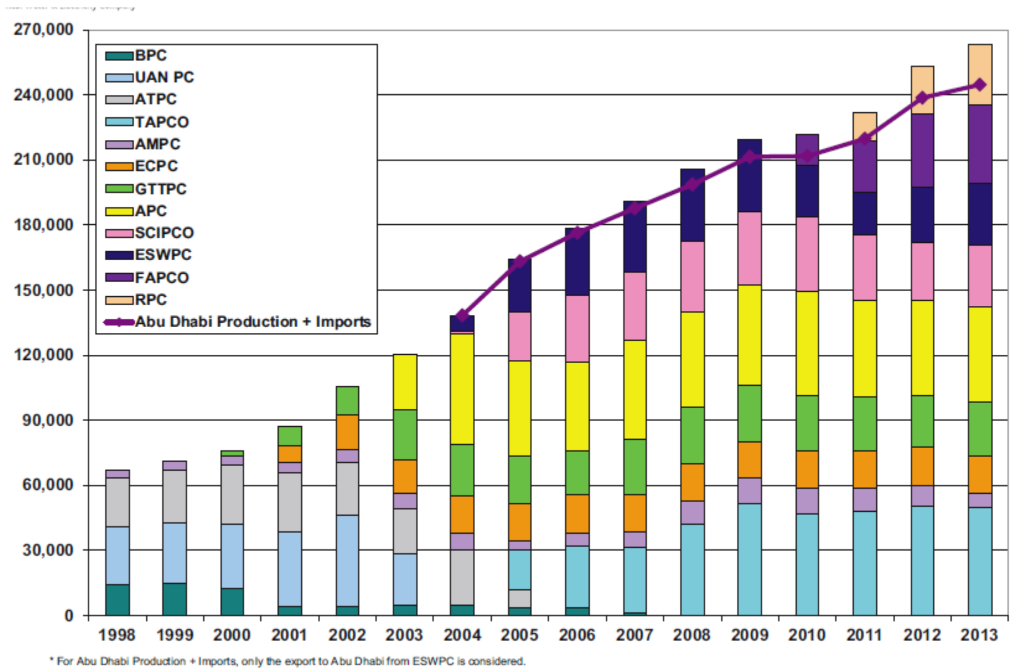


Source: ADWEC, 2013.

Annual water production in 2013 was 1,196 Mm^3 in total from the 9 plants (ADWEC, 2013) which have total capacity of around 1,500 Mm^3. The annual increase in production over the last few years is shown clearly in Figure 10. Demand has been from both within Abu Dhabi Emirate, as well as from other less economically developed emirates in the north of the country to which supplies are 'exported' (Figure 11). The northern emirates do not have the economic wealth of oil to support their development. A few small desalination plants using thermal and reverse osmosis serve some remote communities and oil production facilities and produce annually about 8 Mm3. There is almost no storage capacity in the desalination water transmission system, with only two days of water supply available if the desalination plants fail.

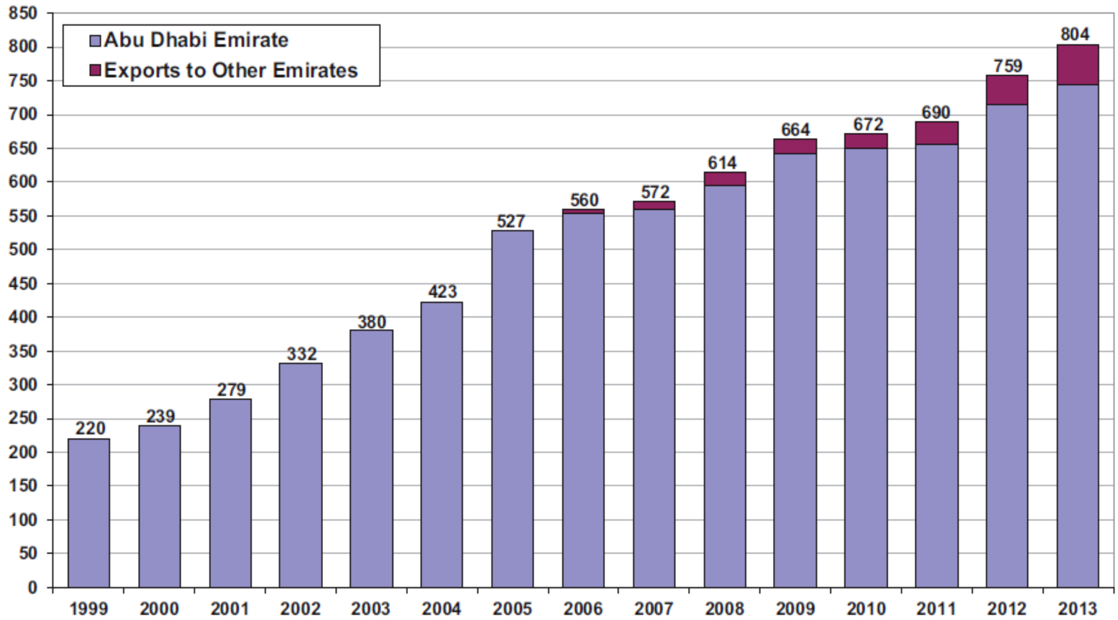
The production systems used, known as Independent Water and Power Plants (IWPP), are primarily tightly coupled co-generation systems with thermal-based multiple stage flash (MSF) or Multi-Effect distillation (MED) systems which produce water as a by-product of electricity generation. Seawater is raised to boiling point, the steam used to turn the turbines and then condensed to produce the desalinated water. Whilst in many other parts of the world Reverse Osmosis (RO) is the technology of choice for desalination, in the Gulf States and Abu Dhabi in particular, thermal desalination operations account for over 80% of the production. This is partly a result of the energy efficiencies gained in the linked co-generation, but also because of the proven robustness in the local extreme summer temperatures and humidity conditions as well as extremely high salinity of the seawater which challenge any technology. Increasing recurrences of red-tide algal blooms in the Gulf, which necessitate closure of RO filter based systems also lend weight to maintaining the thermal plants (McDonnell, 2014).

Figure 10. Water Annual Production by individual production company in Million Gallons



Source: ADWEC, 2013.

Figure 11. Peak water daily supply millions gallons



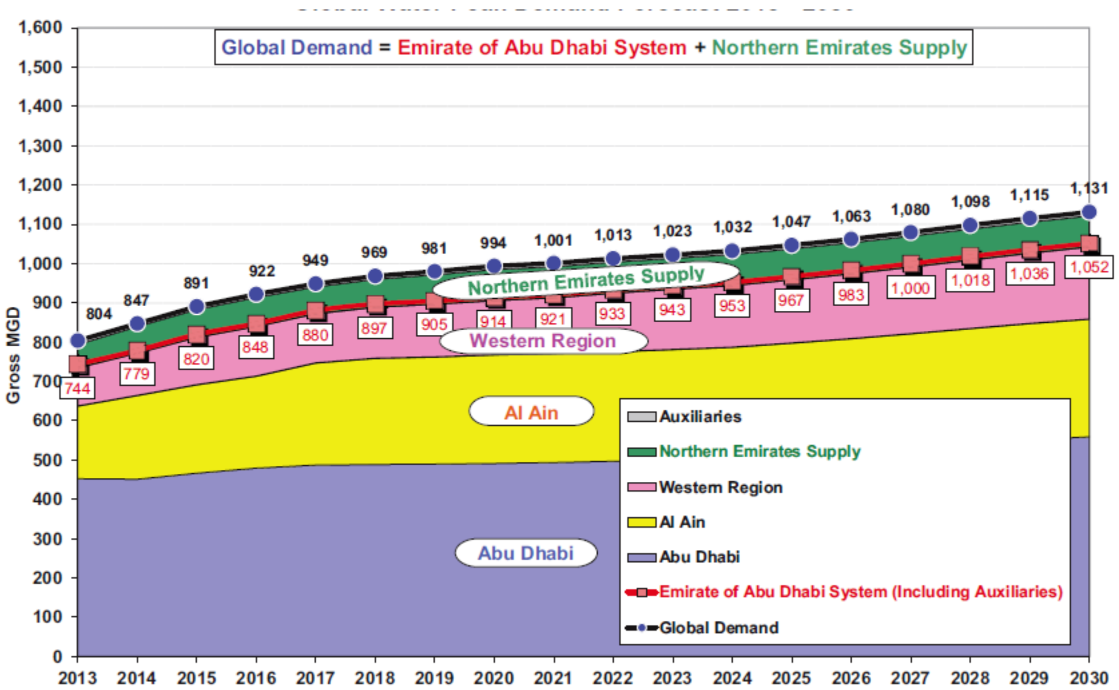
Source: ADWEC, 2013.

Co-generation brings a number of advantages but there are problems associated with the different seasonalities of peak demand for the two utilities. Electricity demand peaks in the summer for cooling and water demand peaks in the winter due to higher population and plant growing seasons. This has major implications for the management of the production systems. Co-generation power plants are designed to meet peak electricity demand in the summer resulting in excess water production. Some of this excess water is being pumped to an aquifer storage and recovery site in the Western Region as a security measure which is an expensive option with water.

The converse of the demand in-balance, the need for water in the winter when electricity is at its lowest demand, has led to the installation of RO capabilities in the various new hybrid plants. This filter based desalination, provides around 10% of dependable capacity.

The desalinated water is moved from the coastal plants through modern, well-designed and managed distribution systems. Some water is lost in the bulk water transmission system managed by TRANSCO and between the water supply companies and the consumers. According to ADDC total unaccounted-for-water in 2007 was 35% of the supply[3]. Physical leakage accounted for 16% and technical and administrative losses accounted for the balance. These latter losses include unregistered connections and illegal connections and are primarily a billing and financial accounting issue.

Figure 12. Predicted demand for desalinated water - million gallons



Source: ADWEC, 2013.

The major drawbacks of desalination plants are high energy demands and the hot/chemically enriched brine. Thermal processes to generate steam are energy intensive, while RO plants depend on electrical energy for pumping seawater at pressure through the filters. MSF and MED require heat at 70-130°C and use 25-200 kWh/m^3. RO needs about 4-6 kWh kWh/m3 for inland sea water (depending on its salt content), whilst for brackish water and reclamation of

[3] The source for this information is ADDC (2008), letter from Ahmad Saeid Al Mareikhi, General Manager.

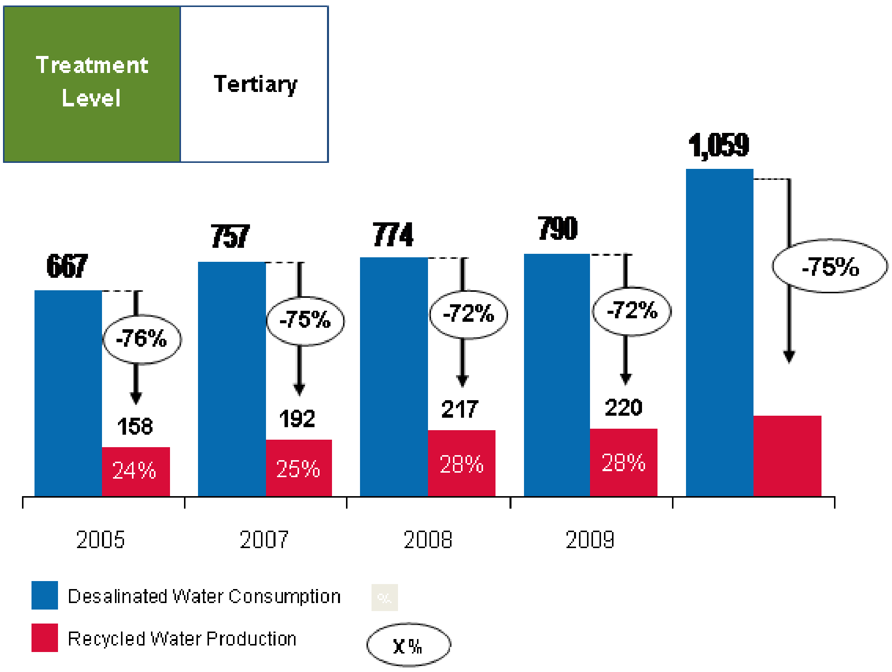
municipal wastewater RO requires about 1 kWh/m^3 (World Nuclear Association, 2008). The relative energy costs presently quoted for RO: MED: MSF: are 1: 1.4: 2 per unit mass of desalinated.

Currently most of the energy for co-generation plants in Abu Dhabi is derived from natural gas, predominantly through the Dolphin Gas Pipeline from Qatar. With restrictions to this market resulting from a moratorium placed on expanding future supplies by the Qataris, a clear decision to evaluate and develop nuclear energy was signaled with the publication of a policy white paper in April 2008. With nuclear power predicted to come online in the UAE from 2017 onwards a clear distinction will be in place in the future between water and electricity generation. New plants are likely to increasingly adopt hybrid technologies with RO, playing an increasing role in water generation. With peak demand predicted to continue to rise both within Abu Dhabi Emirate, and to the Northern Emirates (Figure 12), expansion of capacity is inevitable. The influence of changing economic conditions such as in oil prices might temper some of this demand.

2.2.2 Recycled water

Recycled water, which is waste desalinated water collected by the sewer system, has become increasingly valued as a water resource in recent years. With the population in Abu Dhabi Emirate rising rapidly by over a million over the last decade to nearly 2.5 million today, recycled water is an increasing and under-utilized resource. Given that, the opportunity to expand this source of water is hampered by the low rate of return into the sewage network of the desalinated water that is consumed. This is because much of the water is used outside of buildings for irrigation of domestic landscaping. Figure 13 highlights that around 75% of consumed desalinated water is lost to the recycled water system. Although such irrigation may lead to localized groundwater recharge, much of this water is evaporated away or otherwise infiltrates to the very shallow groundwater table which can lead to near-surface waterlogging.

Figure 13. Recycled water production relative to consumed desalinated water consumption between 2005 and 2012



Source: Government of Abu Dhabi, 2013.

The Abu Dhabi Sewerage Services Company (ADSSC) currently treats nearly 450,000m³ of wastewater a day. The treatment of domestic and municipal wastewater in centralized treatment works has been practiced in the Emirate since 1973 and today there are 32 treatment works operational, with waste collected through more than 6,000 km of sewers and 250 pumping stations.

The two major modern treatment plants serving the urban areas of Abu Dhabi and Al Ain, Mafraq, and Zakhar respectively, have been expanded in the last two years and with the increased capacity are capable of consistently producing potable water meeting WHO water quality standards. Together they treat some 95% of the wastewater collected by the sewer networks, including trade and some industrial aqueous effluents. This is an exceedingly efficient management system by international standards. However, this may be slightly overestimated as ADSSC state that the sewers also receive influent saline groundwater flows in some parts of the system.

Figure 14. Component parts for the STEP project in Abu Dhabi

Source: www.water-technology.net/projects/strategic-tunnel-enhancement-program-abu-dhabi/strategic-tunnel-enhancement-program-abu-dhabi4.html (Last accessed 27th June 2016).

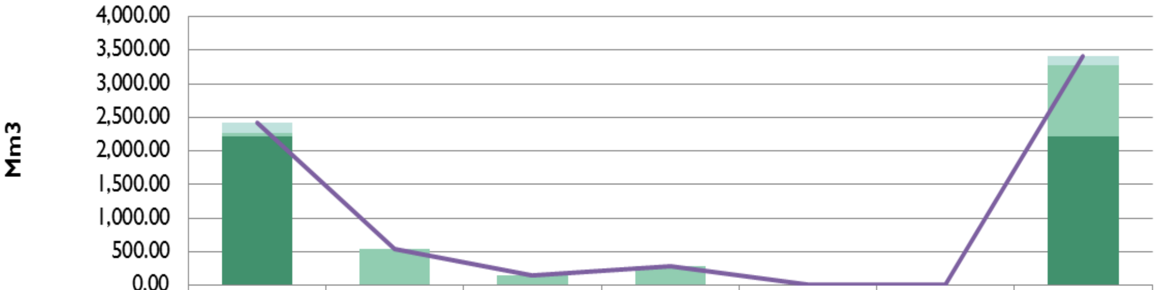
To accommodate increasing resource availability resulting from the rapidly rising population and economic expansion, further investment in the infrastructure has been required. A huge underground gravity-driven hydraulic wastewater network tunnel known as the Strategic Tunnel Enhancement Programme (STEP) is currently being constructed by ADSSC (Figure 14). Construction activities started in 2009 and are scheduled for completion in 2015, costing $1.9bn. The project is expected to supply 15 cusec of greywater for irrigation. It will be capable of treating 800,000m³ of wastewater when the project is realized. The tunnel will also help to address the issue of saline groundwater seepage into the sewerage network system which disrupts the efficiency of the treated wastewater plants and limits the reuse of the recycled water (Watertechnology.net, 2015).

In addition to the central treatments plants operated by ADSSC, a series of separate systems are also in place associated with individual mega-developments that have been constructed in the last five years. These new developments include large housing, office and commercial properties on the outskirts of Abu Dhabi Island that are built and managed by one company but owned by different organizations and individuals. They collect and treat the sewage water within the developments, using their own recycling systems with generated water being used for landscaping within the areas.

2.3 Evolution of water use by sector

Total water consumption in Abu Dhabi was estimated to be about 3,415 Mm^3 per year in 2012 (Figure 15). Agriculture and forestry continue to be the largest users and together they account for almost 70 % of total water use. With amenity water use being primarily for landscaping and roadside plantations, this means that almost 85% of all water use in Abu Dhabi is for vegetation. This is primarily from groundwater supplies although recycled water is being used increasingly for landscaping irrigation.

Figure 15. Total water demand in Abu Dhabi Emirate by Sector in Mm3/year (2012)



	Agriculture, Forests and Parks	Domestic	Commercial	Government	Industry	Other	TOTAL
Recycled	138.80	0.00	0.00	0.00	0.00	0.00	138.80
Desalinated	57.20	548.68	145.12	280.70	18.01	10.59	1,059.23
Groundwater	2,217.90	0.00	0.00	0.00	0.00	0.00	2,217.90
TOTAL	2,413.90	548.68	145.12	280.70	18.01	10.59	3,415.93

Source: SCAD, Abu Dhabi Statistical Yearbook, 2013; Government of Abu Dhabi, 2013.

2.3.1 Agriculture

With agriculture being by far the biggest consumer of water and groundwater in particular, the nature and extent of consumption is an important consideration in Abu Dhabi's water budget. Traditional communities cultivated oases systems with date palms layered with forage and vegetable crops. However, agriculture grew extensively from 1970 with the expansion of farms into the desert as wells and pumps were provided by the government. So by 2008 the total cultivated agricultural land under the ownership and management of Abu Dhabi citizens was 75,284 ha and today there are more than 80,000 permitted wells (Government of Abu Dhabi, 2013).[4] The growth of farms is shown in Figure 16. The total cultivated area in the Emirate grew from 69,000 ha to 419,000 ha at present, a remarkable achievement and driven by a vision of greening the desert and bring food security. In recent years this number has fallen by about 5% as farms become less viable with increasingly saline groundwater resources.

In 2014 there were 24,394 agricultural holdings in the Emirate of Abu Dhabi with a total area of 75,239 ha (SCAD, 2015a). The total sheep and goat population in the Emirate was 3 million heads, the largest proportion of which (64%) was in Al Ain area. The total camels herd was 377,728 heads, mostly in Al Ain area (55%). A breakdown of the livestock populations in 2014 by type shows that sheep and goats in the Emirate of Abu Dhabi represented around 88.0% of the

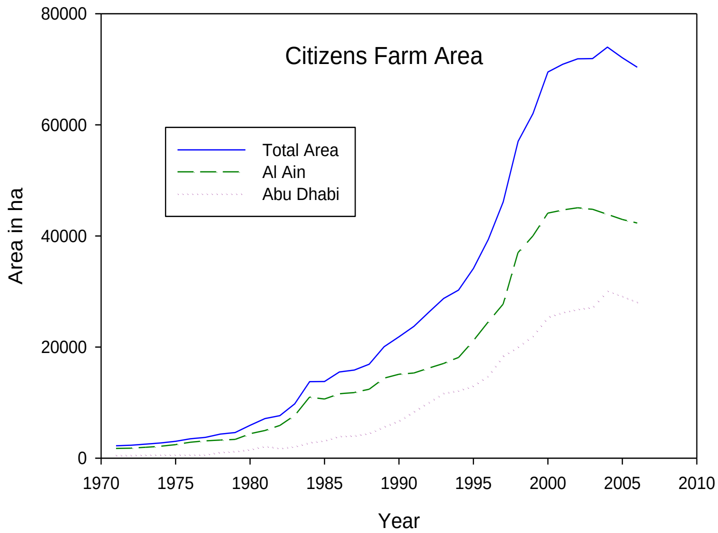
[4] Emiratis wishing to become involved in agriculture production were granted 2 to 3 ha lands for farming. Each farm usually has two drilled wells at opposite locations of the plot 100 to 200 m apart. Converting desert to farming communities effectively creates a closely spaced well field. Closely spaced wells create interference that significantly increases local drawdown of groundwater levels, increasing costs and causing upconing of deeper, poorer quality groundwater. Substantial subsidies for land levelling and irrigation development, wells and agricultural inputs encourage farming.

total size of the livestock raised in traditional holdings, followed by camels at 11.1 percent and cattle at 0.9 percent.

Farms were developed in dense clusters with typically two wells with limited distance between them. Such farm development has forced groundwater resources to become more stressed in terms of decreasing aquifer water levels and groundwater quality (Pitman et al., 2009). Farm subsidies have supported this expansion and have influenced the crops grown and the equipment used.

Given the aridity, all crop production is based on perennial irrigation. In 2013 fruit trees covered 49 percent of the total arable area (predominantly date palms) in Abu Dhabi Emirate, followed by field crops and vegetables (3 percent each) (SCAD, 2015a). The farms included around 10, 000 greenhouses with a total area of around 300 ha (SCAD, 2014). The agriculture sector provides a small contribution to Gross Domestic Product (GDP) and the employment. The economic contribution of farming, forestry and fishing was estimated as 0.6% of the national GDP (SCAD, 2015b).

Figure 16. Growth in farming since 1970 in ha

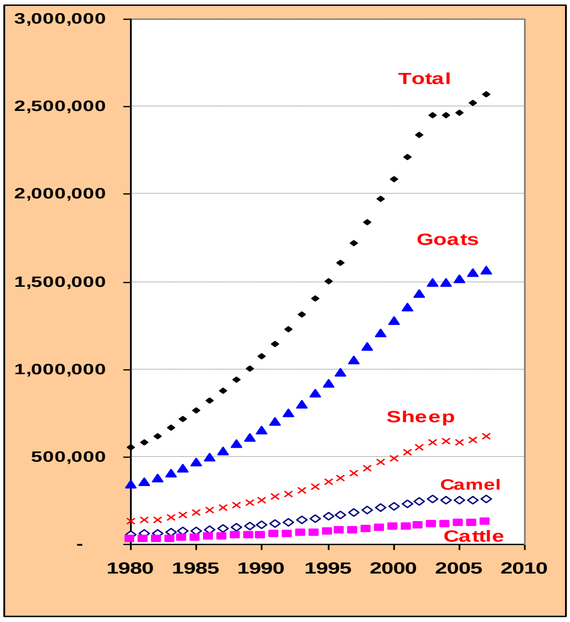


Source: Pitman et al., 2009.

The government provided most farms with drip irrigation systems and irrigation technology with direct subsidies. However, as most on-farm irrigation systems are operated by unskilled expatriate labor who bring with them highly inefficient traditional practices, there is over-watering or reversion to inefficient flood irrigation around the plants or trees. Ongoing studies by EAD with ICBA using sap flow meters in key crops such as date palms are indicating over-watering by at least 50% if not more, even accounting for a leaching requirement.

The increased production of forage has led to a substantial increase in livestock, particularly sheep and goats, whose numbers now exceed 1.5 million in Abu Dhabi (**Error! Not a valid bookmark self-reference.**). This has put a huge stress on rangelands and has a major impact on natural vegetation. There is also an increasing tendency to keep livestock in feedlots. Their high concentration results in large outputs of animal excreta that pollute the underlying aquifer and shallow groundwater.

Figure 17. Growth in livestock numbers Abu Dhabi Emirate



Source: Pitman et al., 2009.

Water demand from livestock was estimated to be about 20 Mm^3/year in 2007 (Pitman et al., 2009). Much of this demand is being met through wells in the brackish water areas and many of well owners have installed small reverse osmosis plants to provide potable water. A major emerging problem is that the brine concentrate produced by the RO plants is being dumped in adjacent desert areas where it percolates to the shallow water table, polluting both soils and groundwater.

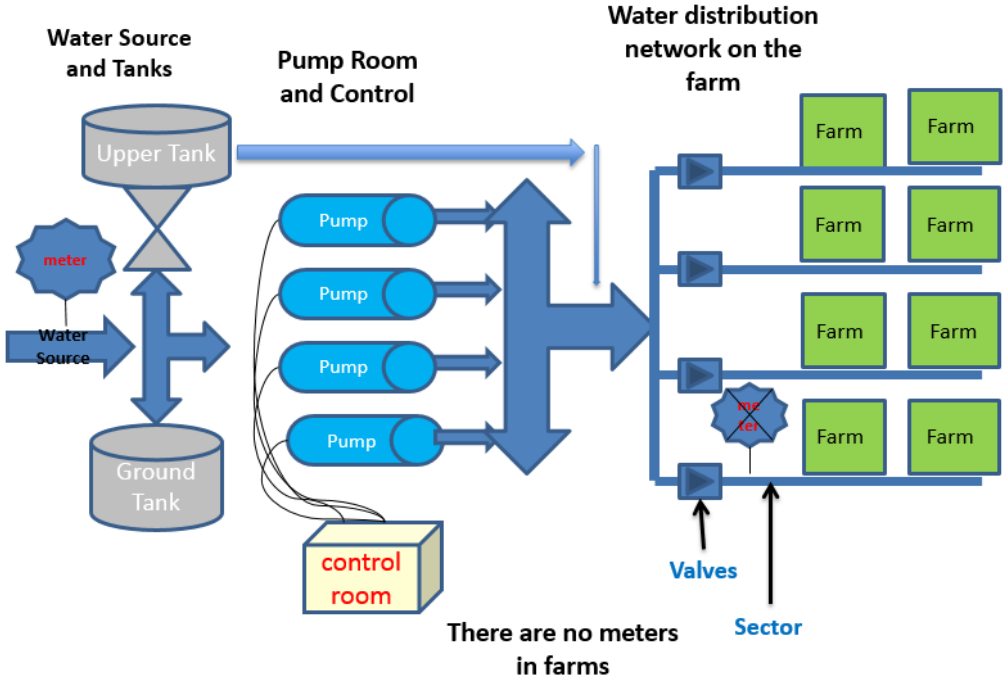
Figure 18. Brine water being deposited into an old well

Source: Author.

The primary source of water for agriculture is groundwater, but there are some farms that have been granted access to desalinated water from the major transmission systems. These tend to be in the Al Ain region. In addition, there have been as series of trial on farms using recycled water.

In Al-Ain about 4,000, Abu Dhabi about 2,900 farms and in the Western Region about 400 farms are provided irrigation water through pipe systems controlled by the Abu Dhabi Food Control Authority (ADFCA). These systems are significant in the agriculture sector in Abu Dhabi as they connect with approximately 1/3 of all farms in the Emirate. These collective irrigation systems consist of tanks, pump stations and distribution networks to farms and provide farms with water from desalination plants, ADFCA-controlled groundwater well-fields and in one area with treated wastewater (TWW) for 240 farms. According to the ADFCA these collective systems are used to provide irrigation water to farms where no other source is available, to enhance the quality of groundwater supplied, to control water supply for consumption optimization and to enhance crop production in terms of quality and quantity. The ADFCA provided Figure 19 below to illustrate how these systems work.

Figure 19. ADFCA-controlled irrigation networks



Source: ADFCA unpublished report.

In some areas these collective systems are the only irrigation water supply while in others they provide water for supplemental irrigation or are used to blend with farmers' own groundwater to decrease its salinity. In Abu Dhabi and the Western Region these collective systems are supplied through 90% desalinated water and 10% from well fields; consumption is approximately 1.55 million gallons per day from wells and 13.6 million gallons per day from desalination. In Al-Ain these systems are supplied 2/3 by ADFCA-controlled groundwater well-fields and 1/3 by desalination; water consumption per day is approximately 4 million gallons and 7.8 million gallons respectively.

In these systems, farms are allocated volumetric limits – although metering is rare - and schedules for irrigation water availability. For collective irrigation systems utilizing desalinated water, farmers must pay for the irrigation supply (Interviews A, 2016).

The ADFCA has recently concluded initial studies on farms' groundwater abstraction via multi-year observation of over 200 farms in Al-Ain, Abu Dhabi and the Western Region. Meters were installed on wells whose owners volunteered to participate in the project. The data will be used by the EAD and ADFCA to support policy initiatives and findings are not yet published formally. Therefore, the descriptions of the results provided here are kept general at the request of the provider. While extensive description of the project methodology was not made available, the data is broken down by farm cultivation types and the author was told that best efforts were made to ensure the direct comparability of regions by controlling for factors such as farm size, cultivation types, etc. Unfortunately, data provided for farms are not classified further by area. (Interviews A, 2016).

The data made available are shown in Tables 4 and 5 below and all values are shown as multiples of the water consumption volumes of farms in Abu Dhabi since in all categories Abu Dhabi farms utilized the least volume of water per unit classification. The data is presented in this manner at the request of the providing agency.

Table 4. Regional comparison of water consumption at farm level

Region	Avg. monthly consumption per farm (dates only)	Avg. monthly consumption per farm (dates AND vegetables OR mixed cultivation)	Avg. monthly consumption per farm (dates and fodder)
Abu Dhabi	1	1	1
Al-Ain	1.72	3.38	1.86
Western Region	6.63	6.05	3.02

Source: ADFCA, 2016b.

Table 5. Comparison of regional water consumption per irrigated dunum

Region	Avg. monthly consumption per dunum (dates only)	Avg. monthly consumption per dunum (dates AND vegetables OR mixed cultivation)	Avg. monthly consumption per dunum (dates and fodder)
Abu Dhabi	1	1	1
Al-Ain	1.44	1.29	2.87
Western Region	4.73	1.97	4.26

Source: ADFCA, 2016b.

The results of this project demonstrate very clearly that water management differs significantly between regions: farms in Abu Dhabi utilized the least amount of water per unit area for all farm types followed closely by Ali-Ain with farms in the Western Region using significantly more water per unit area. Not surprisingly, within the same region, farms which had ADFCA-controlled water supply had substantially lower water consumption overall compared to farms with private wells in this study, in some case less than 10% for similar cultivations for similar cultivated area within the same region as described by those familiar with the study findings (Interviews A, 2016).

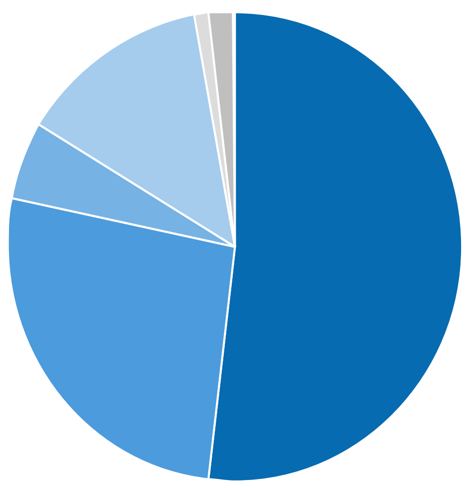
However, more detailed analysis requires information on cultivation intensity, presence of greenhouses, crop cycles per season, etc., which unfortunately was not possible with data provided. However, this initial comparison is valuable to highlight the different consumption patterns per region as a baseline to discuss on-farm water management challenges shown in the Liwa case study report (Fragaszy and McDonnell, 2016).

2.3.2 Domestic water use

Desalinated water supply, estimated at 1,060 Mm3 in 2012, is the main source of water for the domestic sector as shown in Figure 2 and 20.

Per capita residential water use has grown steadily over the last four decades in line with national policy that there be no restriction of water supplies to households. Rates of gross water consumption have been shown to be 565-920 litre per capita per day (lpcpd) depending on the source of information. Even the lower end of these values is high compared to many other nations, even within the GCC.[5]

Figure 20. Breakdown of desalinated water consumption in Abu Dhabi Emirate



Source: Government of Abu Dhabi, 2013.

There are large variations in gross residential water use among household types as shown by research from the Regulation and Supervision Bureau (RSB) (Table 6). The higher consumption in villas and shabiyats[6] is attributed to garden, car washing and other uses, and the significant difference between UAE nationals and expatriates is probably the result of the tariff structure but may also result from differences in social and cultural practices. The tariff structure has recently been revised from those of Table 7 to increased rates. It will be interesting to track the effects of this rate increase. It was resisted for many years by the government but the changes made have been welcome by the water industry as an important step in helping to manage

[5] Qatar, 555 lpcd; Kuwait, 385 lpcd; Dubai 363 lpcd; Lebanon 255 lpcd; Kingdom Saudi Arabia 235 lpcd; Egypt 190 lpcd (Government of Abu Dhabi, 2013).

[6] Shabiyats are Government built houses for locals, often from the rural areas.

water demand as various information campaigns and other policy instruments had not brought the impact needed.

Table 6. Residential daily water consumption by household type

Nationality	*Property Type*	*Gross Consumption (litres per capita)* Min	Max
Expatriates	Flats	170	**220**
	Villas	270	**730**
UAE Nationals	Flats	165	**-**
	Villas	400	**1,760**
	Shabiyats	610	**1,010**
Overall average		***525***	***600***

Source: RSB. 2008. *Water and electricity consumption by residential customers.* This is based on volumes and accounts from the Water Supply Companies and occupancy levels from the 2005 Census and the PB Power surveys (2005 and 2007).

Table 7. Previous and current water tariff structure

Consumer group	*Price per cubic meter (AED)*	*Consumer group*	*Price per cubic meter (AED)*
	before 2015		**2015**
UAE Nationals - domestic	0	UAE nationals flat	1.7/1.89
		UAE nationals villa	1.7/1.89
Non-UAE nationals - domestic	2.2	Non-UAE nationals -flat	5.95/9.9
		Non-UAE nationals -villa	5.95/9.9
Industry/commercial	2.2	Industry/commercial	4
Government and schools	2.2	Government and schools	9.9
Agriculture	2.2	Agriculture	2.2
Residents without meters	50	Residents without meters	90
1 US$ = 3.67 AED			*Different rates for up to 700/over 700 l/d*

Source: www.rsb.gov.ae, 2015.

2.3.3 Commercial/Industrial Water Use

The principal industries in Abu Dhabi other than hydrocarbon production and downstream activities are primarily service-based with tourism, finance and retail dominating economic activities (Figure 21). These commercial enterprises tend to consume desalinated water for most of their operations, although landscaping around buildings is with recycled water. Their consumption of around 11% of total water use and 14% of desalinated water reflects this.

The amounts and quality of water used in the industrial sector are difficult to analyse as there is very little data available publicly. The industrial sector is relatively small and its contribution to gross domestic product reflects this. Many of the major industries have developed their own water supply systems, particularly those such as the oil industry giant ADNOC that both produces and uses water in its operations. In recent years there have been moves to develop major industrial zones, so the needs in terms of both quantity and quality will have an increasing influence on water demand figures. The manufacture of airplane wings in Al Ain is one example. Whilst the water use by the industrial sector may grow, it is still small relative to agricultural and domestic usage.

Figure 21. A luxurious hotel in the Liwa Oasis on the edge of the Empty Quarter

Source: http://qasralsarab.anantara.com/activity.aspx (Last accessed 27th June 2016).

2.3.4 Forestry Water Use

Water used for forestry accounts for just over 11% of total consumption. This use grew rapidly under the 'desert greening[7]' policies that were introduced in the 1960s, with long-term average annual growth rates over the period 1990-2007 around 19,100 ha. Figure 22 highlights this growth. Today forested areas cover around 305,000 ha. The forestry sector is heavily dependent on groundwater, often brackish, competing with agriculture and other uses.

Trickle irrigation network, totals about 430,000 km in length[8] delivering around 1,900-2,500 m^3/ha per day when trees are spaced at 6 to 7 metre intervals. EAD uses an average value of 2,000 m^3/ha per day from investigations in the Western Region where 80 % of the Emirate's forests are located (Brook 2005). Within private estates forest water use is four times higher but these cover only a relatively small proportion of all forests.[9]

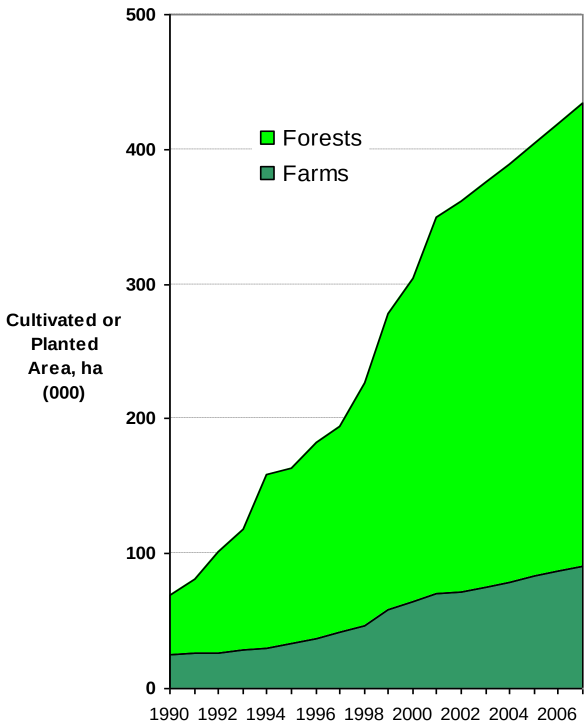
---

[7] Desert greening was a policy introduced by the late Sheikh Zayed bin Sultan Al Nahyan under which funds were allotted by the government for thousands of square kilometers under vast reclamation projects to increase the agriculture and forested areas. By the 2000s thousands of hectares had been brought under the plough and the green expanse in the country had grown extensively—470,000 hectares (1,616,370 acres) were being cultivated. The urban areas were also transformed into garden cities.

[8] At 7 m spacing a one ha block would require 14.2 rows of irrigation pipe. As 305,000 ha are under irrigation the total length is 14.2 x 305,000 = 433,100 km.

[9] Brook, M. 2004. "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.) This is equivalent to 822 mm/year.

Figure 22. Increases in forest and farm land since 1990s



Source: Pitman et al., 2009.

It is difficult to estimate the total water demand for afforested areas as not all seedlings planted reach maturity and meters are not used except in certain bulk supply well-fields. And unless the trees receive adequate irrigation and water quality they may stunt and die– most trees are fed with brackish water. Trickle irrigation with poor quality water also creates problems because removal of chemical deposition that clogs the drip orifice requires regular maintenance. Research by EAD indicated that "*the majority of trees receive under-irrigation [that] 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*" (Brook, 2005).

2.3.5 Amenity

Amenity[10] irrigation has been increasing in Abu Dhabi with the growth of urban development and highways/roads. Water features such as fountains, greenery and gardens are powerful symbols of development in this arid landscape and are found in even the most remote towns in Abu Dhabi Emirate. Tourist developments such as the area around Jebel Hafit in Al Ain (Figure 233) provide a green environment and an attraction. Away from the urban centres, trees/shrubs grown along highways and irrigated with groundwater are grown as wind breaks (in addition to any aesthetic qualities) to help manage the problems of sand being blown onto the road networks.

[10] Amenity includes parks, gardens and recreational areas.

Figure 23. New tourist development in Al Ain that provides a green landscape for amenity use

Source: https://media-cdn.tripadvisor.com/media/photo-s/00/11/96/86/mini-golf.jpg (Last accessed 27th June 2016).

This sector uses mainly marginal quality water (recycled water, brackish water, and even sea water in the coastal belts). Recycled water contributes about 31 % of the total water used for amenity proposes, with desalinated water and groundwater making up the rest. More extensive use of recycled water has been restricted by limits to the distribution network from the major treatment plants around the cityscapes. There are plans underway to ensure 100% of recycled water is used in the future. At the moment there is no charge to the municipalities for this water source. Going forward the Urban Planning Council's Master Plan (Abu Dhabi Urban Planning Council, 2007) included parks and amenities that were designed to offer considerable water savings through hard landscaping and plants better adapted to the arid climate. These have yet to be established in many parts of the Emirate.

3 Groundwater policies, governance, systems and outcomes in Abu Dhabi Emirate

3.1 Groundwater management and policy instruments

Managing groundwater is complex as it is notoriously difficult to measure and monitor both quality and quantity, not only because it is underground but also because the main abstraction points are scattered and dispersed across usually private land. Satellite images and other information technologies are little used as they are largely unable to detect details of the resource, so there is a reliance on observation wells for monitoring groundwater characteristics.

Today, in most countries in the Middle East North Africa (MENA) region, the responsibility to manage groundwater falls to that of a government agency with the state being ultimate legal owners of the resource. This has not always been the case with groundwater often being a common pool resource managed by communities with established rights and governance systems. As countries moved from tribal-based territories to modern bureaucratic states there has also been an assumption, in most cases erroneous, that groundwater is an individual private resource associated with land ownership, and it is often the legacy of this societal transition that is today challenging for water policy makers.

Today policies and management solutions usually aim to control both water quantity and quality with pollution being as much a threat as over-abstraction because of the contained nature of the resource within an aquifer system and the limited capacity for natural remediation. The principles of these policies are:

1. To manage the abstraction of water equitably to meet human/ecosystem needs both today and in the future at sustainable levels;
2. To limit the inputs of polluting materials that will damage the resource;
3. To maximize economic benefit whilst ensuring equity for local and national communities;
4. To develop policies and management strategies in a participatory manner to ensure all stakeholders are represented.

Given the special nature of groundwater, and that policy impacts are often long term and irreversible, very careful consideration and analysis is required in the policy development process. The usual range of policy instruments – information, economic and regulatory – is available and many different forms have been used over time to varying degrees of success. Ideally these would be combined in groundwater plans which were developed through cooperation, coordination, and combined across agencies and stakeholders. These plans would include supporting guidelines, aquifer availability and vulnerability data, an education strategy, legislative mechanisms, licensing tools and various economic incentives/tariffs. They could also be targeted and more site-specific rather than aiming for a one-size-fits-all across all the different aquifer systems within a country.

The policies used can be classified into two main categories as given in Table 1 and these will be used in the analysis of the different stages of groundwater development in Abu Dhabi Emirate. The institutional arrangements to develop and implement groundwater policy and management are vital with governance systems needed to bring together those institutions and stakeholders responsible for safeguarding the resource within the different user communities. As the MENA countries have developed economically, politically and socially over the last century, these structures have changed with the growing importance of government agencies in controlling groundwater and a shift away from community/tribal-based governance structures. These government agencies have developed legal frameworks and instruments as part of the enabling environment for groundwater management. They have also become the main organizations for implementing water policies and strategies with varying degrees of success, depending on the clarity of roles and the controls, powers and outreach capabilities invested in them.

Table 8. Groundwater policy instruments

Water policy measures	Examples of possible policy instruments
Groundwater quantity management	*Abstraction developments* - Collection and distribution of information on the state of the different aquifers and their use to stakeholders and development capacity - Regulate well developments including well locations and characteristics to manage water table levels - Regulate withdrawals by each user through monitoring with tariffs and other penalties for violation to manage water table levels - Regulate withdrawals through energy incentives and tariffs *Groundwater use* - Incentivize efficient water use through subsidies, tariffs or technology provision such as different crops, different irrigation methods - Replace policy instruments and drivers that incentivize unsustainable water abstraction practices - Incentive management strategies for different classes of water table levels that limit use to sustainable or acceptable levels in these areas such as zoning or restricting land use - Regulate land-based activities that might affect the quantity of groundwater used *Alternative water developments* - Develop provisions to increase groundwater levels such as ASR - Develop alternative water supply systems to groundwater - Support the development of alternative economic activities that use less water
Groundwater quality protection	*Abstraction developments* - Collection and distribution of information by the state about salinity and other chemical variables of the different aquifers and their use to stakeholders and development capacity - Regulate well developments including well locations and characteristics to manage salinity levels - Regulate withdrawals by each user through monitoring with tariffs and other penalties for violation to manage salinity levels *Groundwater use* - Incentivize use of saline waters through subsidies, tariffs or technology provision such as different crops, different irrigation methods - Replace policy instruments and drivers that incentivize unsustainable water abstraction practices in freshwater areas - Incentive management strategies for different salinity classes and water table levels that limit use to sustainable or acceptable levels in these areas such as zoning or restricting land use *Alternative water developments*

	- Regulate disposal of waste such as brine from desalination units through licensing and standards with tariffs and other penalties for violation - Provide alternative water and solid waste collection systems - Regulate land-based activities that might affect the quality of groundwater used - Develop alternative water supply systems to groundwater such as treated wastewater whilst managing water quality issues - Develop provisions to reduce groundwater salinity levels such as injection and dilution

In the following sections these ideas will form the basis of the analysis of the policy and governance systems in place during the various historical and political transitions in Abu Dhabi. Such analysis will consider the dynamics of groundwater use, the problems faced, the policy objectives, regulations, laws, strategies and public policies that were put in place, the policy instruments used, and the status of governance systems and the roles and influences of other actors (the users themselves, NGOs, tribes, etc.).

Water policies in the Abu Dhabi Emirate have followed various changing trajectories which have reflected many varying drivers as this once poor desert state has emerged into a global economic power. Through the various transitions in economic, social and political development, water has been an important determinant and facilitating resource. It has in addition continued to of great cultural and social significance as a symbol in this dry desert.

3.2 Customary and pre-independence water management

Before the discovery of oil and the emergence of the state of the United Arab Emirates, the Emirates were a tribal society and fundamentally nomadic but with some tribes partially settled. Careful water management based on access and use of particular wells was a fundamental prerequisite of survival and various rules and protocols supported this. Water rights were collectively owned by the various Sheikhdoms, of which Abu Dhabi was one, and by the different tribal groups, such as the large Bani Yas or Manasir tribes, or the nomadic Awamir or Afar people who frequented Abu Dhabi territory (Heard-Bey, 2005). Within this societal framework, rulers permitted tribesmen from their tribal confederation to fetch water from their wells because Islam demands respect of those in need (*Huquq al-sharb*, literally, 'right of drinking'), but more basically because the legitimacy of the sheikhs' leadership and the expansion of the settlements depended on the collective access to potable resources (Lambert, 2013).

There was no written code as to how or how much water should be fetched by a family, but great value and careful attention was paid to the wells and the resource. There was thus supply and demand-centred management. Tribal customs imposed harsh punishments to people who harmed a water resource, intentionally or by negligence. Water quality management was also in place where a person found intentionally polluting a well could be condemned to death. Within the community at that time, justice was the responsibility either of a tribal elder or alternatively the Hakim, i.e. the ruler, later called Emir (Heard-Bey, 2005). Beyond this judicial authority for crimes and disputes over natural resources, the ruler had no specific right over groundwater at that time; only over his family's or his tribe's property (Lambert, 2013).

The tribal leaders were ultimately responsible for providing water to their people. There were various Islamic values, which provided common beliefs and principles for water management. Water is a gift from Allah "*and we created from Water every living thing*" (Quran, chapter 21, verse 30). Humans are the stewards of water, as trustees bearing witness. Water management principles and practices needed to achieve and sustain water security were rooted in Islam values, such as: consultation and participation (*shura*), the seeking and sharing of knowledge (*ijtihad)*, not causing harm and equitable use (*fassad*), sharing of wealth (including water) with the poor (*zakat*), and the use of donated endowment funds (*waqf*), particularly for the poor. In Abu Dhabi water use and management was governed internally and for all important decisions the ruler had to perform *shura* through open meetings with all important community members, from the tribes and the merchant families. Any resident could bring their problems or disputes to the *majilis*,[11] where the leader would listen and help to resolve the issues. This constituted a fundamental Islamic and tribal institution from which extended to a considerable extent the leader's tribal legitimacy and personal reputation. The ruler was a *primus inter pares* and could rarely be a despot, for the simple reason that he could not afford the risks of an unstable tribal political environment (Lambert, 2013).

The rhythm of life for many during these times followed the seasons with oasis dwelling and nomadic farming in the winter, whilst during the summer heat the men and sometimes the families moved to the coast for maritime trading and pearl diving. In the inland areas the earliest inhabitants were sustained by periodic flash floods that provided shallow groundwater and permanent springs around the oases of Al Ain just east of the Omani Mountains and fossil groundwater in the location of Liwa in the south west. In the oasis settlements a more developed system of partial communal ownership developed, the aflaj, which can be traced back to Iron and Bronze Ages, although the majority of sites date back to the Islamic period (Given the relatively basic nature of the technology used - tunnels, shafts, channels and primitive materials to block/unblock gaps in the channels – the system was ultimately sustainable. The longevity of these indigenous systems was based on many factors including efficiency, transparency and equality in water distribution - by-words today in many definitions of good water governance - as well as an ability to adapt to environmental and social perturbations, and technological innovations. The dynamics and variability in water flow were reflected in the allocation and use patterns and technology use and governance systems developed around environmental constraints.

Figure 244). Many of the aflaj continued in use until pre-modern times and were regularly cleaned. The Iron Age aflaj have, however, long since fallen out of use and are now covered and blocked.

Three types of aflaj existed:

1. Aini (originate from springs and perennial in nature) water sources are invariably springs which develop due to impervious bedrock exposures;
2. Dawoodi (formed from sub-surface channels) are subterranean and are constructed channels which are accessed via vertical shafts;
3. Aili (surface water or base flow diversions).

For the dawoodi aflaj tunnels were on average 1-1.5 m high and 0.4-0.8 m wide (UNEP [United Nations Environment Program], 1983). Vertical shafts, connecting the surface to the tunnel, were dug at a distance of 20-30 metres to provide ventilation for the workers and the collection of excavated material (UNEP, 1983). A channel system was then developed to transport the water from the daylight point into the oasis and then distribute it amongst the water users.

[11] The majilis is an outside seating area in the territory of a particular leader, where all citizens are able to meet to discuss their affairs and problems. It is an open participatory governance system that continues to prevail in many Arab Gulf States and under different leadership arrangements.

Given the relatively basic nature of the technology used - tunnels, shafts, channels and primitive materials to block/unblock gaps in the channels – the system was ultimately sustainable. The longevity of these indigenous systems was based on many factors including efficiency, transparency and equality in water distribution - by-words today in many definitions of good water governance - as well as an ability to adapt to environmental and social perturbations, and technological innovations. The dynamics and variability in water flow were reflected in the allocation and use patterns and technology use and governance systems developed around environmental constraints.

Figure 24. Falaj in the Al Ain area

Source: https://sharetribe.s3.amazonaws.com/images/listing_images/images/72445/big/08-visit-abu-dhabi-home-page-2014.jpg?1419261470

This ancient technique involved local water quantity and quality management rules and community based governance systems. Originally, water rights were divided among users according to their share of capital or labour investment in the construction of the falaj. However, through time their allocation may change substantially as such rights can be bought, sold and inherited. While minor maintenance of the falaj came from the shareholders' free labour contribution, major maintenance was funded by the revenues from seasonal auctioning of a fixed proportion of the community's water rights. Often, such revenues could also be used to fund community institutions, such as mosques and schools (Wilkinson, 1977).

Water quantity controls were based on allocation of time units, not volume, defined according to the rights of each water user. This was measured using the sun and stars originally and using time rather than volume made calculations easier and allowed the risks of diminishing flows to be spread equally among all users (Wolf, 2000).

Water quality controls were also in place and were defined in terms of the activities that could be undertaken at certain parts of the channel system. Water for human consumption was withdrawn in an area close to where the water enters the oasis and then progressing along the channel a sequence of activities were allowed going from washing corpses, mosque ablutions, bathing, washing clothes and then irrigating crops. It ensured the cleanest waters were available for direct human ingestion whilst those containing increasing impurities were used in sectors for which water quality was not as vital.

The governance of the falaj system reflected a tight, complex social structure with rights and rules associated with water allocation and use with *shura* central to the governance system. Indeed, to the already considerable amount of time, capital and labour required to build the underground section (Beaumont et al., 1989), there was also significant upfront production and transaction costs for water allocation. Typically those involved in the development of a falaj formed an assembly which elected a manager with the task of allocating the water among the users and settling disputes (Beaumont et al., 1989). In bigger falaj the manager may be helped by accountants and measurers and, if a dispute cannot be resolved, a legal expert or the governor of the province can provide a judgment (Sutton, 1984).

The discovery of a fresh groundwater spring on a small coastal island in 1751 led to the establishment of Abu Dhabi and the eventual relocation of the tribal headquarters of the Bani Yas from the oases of Liwa to the present-day seat of government. As Abu Dhabi gradually evolved from settlements to coastal villages (late 19^{th} to early 20^{th} Century), the pattern of water resources management remained simple. It was, within each tribe, materially basic, communitarian and transparent, with nearly all water wells supplying potable water respectively belonging to a particular tribal group or extended family. This pattern can be characterized as ‘restricted communitarian’: i.e. neither belonging to an individual nor to a whole urban community, but to a specific community defined by kinship (Lambert, 2013). Town dwellers devised several schemes and techniques to capture and store the limited rainwater available but these were uncoordinated *ad hoc* family initiatives and the freshwater harvested did not last long. Except for these few limited initiatives, Codrai (1990: 100) noted that “*every drop needed had to be hauled manually from hand-dug wells*”.

3.3 Growth of the settlements, water crisis, and market initiatives

The founding of Abu Dhabi was the start of the many changes with gradual but irreversible transitions from tribes to the establishment of centralized political authority. The Bani Yas tribal confederation established a settlement on Abu Dhabi Island in the late 18th century, with archaeological traces suggesting they originated from Marib, in Yemen. The story of the city’s founding on the island of Abu Dhabi in the late 18th century resulted after the mythical discovery of freshwater by a group of hunters following a gazelle (*dhabi* in Arabic). A rare and precious resource at that time, a watchtower was rapidly built in order to protect the water source and over time a settlement became established based on trading (5a).

Over the 19th century, new fortifications and towers surrounded the water source, eventually constituting the Qasr al-Hosn, the fortified centre of political power of the emerging Abu Dhabi[12] (5b). The fort surrounding the source constituted a dominating defensive infrastructure over the island of Abu Dhabi (Lambert, 2013). Water continued to be essentially tribal in organization but with increasingly disparate power relations.

Figure 25. Abu Dhabi town with barasti houses in 1961 (a) and Qasr al Hosn fort (b)

a) b)

[12] This mythical history of Abu Dhabi is referred to in a variety of sources: governmental sources like Abu Dhabi’s Authority for Culture and Heritage, at www.adach.ae/en/portal/qasar.alhosnfort.aspx, with a specific perspective on the Qasr al-Hosn fort built around the island’s freshwater source.

Source: Al Fahim, 1995.

At the end of the 19th and early 20th century, the transformation of the coastal settlements into towns and the resulting over-exploitation of the wells led to increasingly brackish[13]and polluted waters. The tribal rules that had ensured safe and drinkable supplies for centuries began to break down under the growing population. As late as the 1950s, Lienhardt (2001: 114) noted that the brackish water of Abu Dhabi was "*in flavour* (...) *as bad as some of the worse Bedouin wells*". During 1907-1908 water was even traded over long-distances with Iraqi freshwater from the Shatt al-Arab River sold as far as Abu Dhabi for the few families that could afford it (Lienhardt, 2001: 114-115; Lambert, 2013). This continued as Abu Dhabi expanded and populations grew.[14]

During this period, whilst the traditional water quantity and quality management rules were still in place (Figure 266), the stress on groundwater resources from a growing and concentrated population ensured they were less effective. The ability to oversee the actions of more people in a less cohesive community, and the necessary increase in withdrawals to meet the growing demand needs led to the deterioration in groundwater quality. It suggested the policies and governance system were increasingly ineffective with an imbalance between resource availability and demand leading to deterioration in the water quality. Long-distance transport of water from Iraq, in other words supply augmentation from an alternative source, would not meet the long term needs of the population but was used by those who could afford this.

3.4 Colonization and oil - influences of the British/USA on economic development, political systems, and water management

At the same time as the coastal settlements were expanding, the British government slowly became increasingly involved in the internal affairs of Abu Dhabi as a result of securing its other Middle East and Asian interests (principally focused on trade). The new engineers and overseers brought different frameworks of thinking and technologies. This involvement deepened as strategic interests, now focused on oil, brought the need to protect British interests from other western nations, particularly the USA, as well as from internal political turmoil amongst the tribes. To encourage cooperation between rival tribes, the British political agents and oil companies made payments for oil concessions or other services only to the rulers (Lambert, 2013). The rulers were therefore in charge of redistributing the first oil revenues, thereby

[13] Lienhardt (2001) stressed in the mid-1950s the local water resources' brackishness in Abu Dhabi and concluded that both cities may not have been built on these locations because of the presence of these water resources, thereby contradicting the founding myth of Abu Dhabi.

[14] "In the 1950s, before any water distillation plant had been set up, sweet water to drink was being sold in the cafés in Abu Dhabi at an anna (roughly, then, a penny) a glass. This drinking water for the cafés and some of the houses was imported from the Persian Coast or from [the hinterland of] Qatar by launch in oil drums and retained some of the flavour of the containers, but it was still much preferable to the local water" (Lienhardt, 2001: 114-115).

creating a dependency that did not exist before, of the population towards them as well as incentives to attract and/or pacify remote tribes from the hinterland. This brought a concentration of power into the hands of a few that had not existed previously.

With these increased funds, rulers gradually departed from their status as heads of tribes and slowly to that of emirs surrounding themselves with a growing court and the beginning of a professional bureaucracy. Part of that bureaucracy was made up of British administrators and technical specialists who were increasingly relied upon (Lambert, 2013). British-trained local armies were set up and were remunerated by the rulers and composed of tribesmen under his orders. This changing situation was not always well received by the local population, who resented the preference granted to the limited tribal elite that they could not choose or influence anymore through the traditional consultative process. Heard-Bey (2001) described this British-induced evolution of the rulers/ruled relationship in the case of the Trucial States[15].

> "Since the early nineteenth century the status of an incumbent ruler had usually been much enhanced by the importance which the 'High Government' placed on a 'Trucial Ruler' to the exclusion of a tribal sheikh in the interior. But from the end of the second decade of the twentieth century, when the decline of the pearling industry spelled great economic hardship for the region, the population in these states, led by the merchants, strongly resented the fact that all the potentially lucrative arrangements and concessions, for which the British government or foreign companies made payments, were agreed exclusively with the rulers. This (…) encouraged alienation between the rulers and their people." (Heard-Bey 2001, p.119).

The British and the emir had in effect created a state, albeit pre-modern, which had gradually gained the monopoly of legitimate violence. With it, the British and the rulers could transform the pattern of property and usage rights as to the land, water and other natural resources. Most important to them was oil of course (Lambert, 2013).

Figure 26. Emirati women collecting water in Abu Dhabi

Source: www.gulfnews.com.

The new found wealth also offered untold opportunities for modernizing the infrastructure in the country to meet the needs of the local population. However, the emir in Abu Dhabi, Sheikh Shakhbut, was not in favor of investing in such projects having witnessed the wealth and decline

[15] Trucial States – were the group of sheikhdoms in the south eastern Arabian Gulf, which were signatories to treaties (hence 'trucial') with the British government. These treaties established an informal protectorate by Great Britain and the sheikhdoms, or emirates, were a British protectorate from 1820 until 2 December 1971, when the seven principal trucial sheikhdoms became the independent UAE.

of the pearl industry previously (Rabi, 2006: 37-44). This exacerbated the tension between the ruler and the local population, a part of whom had already fled the local poverty in the 1950s and early 1960s to find work in fast-developing Qatar, Kuwait or Saudi Arabia and had witnessed the new possibilities oil revenues could bring (Lambert, 2013). In 1966 a bloodless coup led to the emir's brother Zayed becoming the leader (the involvement of the British in this is still discussed amongst scholars).

Under the new emir Sheikh Zayed bin Sultan al Nahyan, a leader still greatly admired today and known as the father of the nation, many large infrastructure projects were launched, including a water pipeline to supply Abu Dhabi from the groundwater reserves of Al Ain, the first modern sewage works, and electrification of Abu Dhabi Island. Desalination capacity development followed and less than two decades later water was transferred from the coastal plants back to Al Ain in a reversal of the previous supply flows. The new desalinated water resource was then free for all in Abu Dhabi, with state oil revenues completely financing the new desalination industry. Sheikh Zayed took a deep interest in water resources and the possibilities offered by expanding the use of the resource (Figure 27).

Figure 27. HH Sheikh Zayed bin Sultan Al Nahyan water new date palms through pumped groundwater

Source: www.gulfnews.com.

During this period water policy was dominated by supply-side augmentation measures. Wells were now drilled by machinery and pumped by powerful diesel or electricity fueled motors. Groundwater was no longer controlled by tribal leaders or falaj rules and a rapid decrease in levels were found. These were all signs of the new found wealth and the excitement of the modern. Abu Dhabi was developing fast into a modern emirate. With these developments came a rising statism with a professional technical bureaucracy (largely British supported) with a new water department, and controls by the rulers that were not challenged as water was free and available like never before. The moves brought vertical instead of horizontal decision-making with a growing distance between water decision-makers and water users. During this period whilst some water continued to be owned as part of a restrictive collective in many areas these ties were reduced. With growing land distribution,[16] wells were drilled and individuals were now in effect the owners of this water. There were no controls on how many wells and their depth, or abstraction levels. There was little understanding of the possible consequences of the groundwater developments, with water seen as a great blessing from Allah. The derived

[16] The land of the uncultivated desert areas was owned by the state under the Constitution of 1971. It had been used by the tribes as part of a nomadic pattern of life but was not owned by them and little grew on these areas beyond sparse grasses. It was thus reallocated from the state to private ownership. The new owners assumed incorrectly they also owned the water beneath the land, which remained the property of the emirate (not the UAE country).

developments were viewed as symbols of the fast emergence and modernization of this emirate, which was all fueled by oil revenues.

3.5 The new nation state, the greening of the desert and supply-led policies (1971-2004)

The British Trucial States became the United Arab Emirates on December the 2nd 1971 with seven emirates and associated tribes brought together into a federal state. The capital city was Abu Dhabi and Sheikh Zayed as the ruler of this emirate, became the president of the country and the commander of the Union Defence Force. The modern state had been established.

The new constitution of the UAE demarcated the division of powers between the Federal and the Emirate levels of authority. Surprisingly water is not mentioned explicitly, but is covered in some of the provisions (Articles 23, 120, 121, 122) under the term "natural resources". These articles clearly state that these resources are the public property of each Emirate. The legal status of non-conventional water resources, like desalinated water and recycled water, is not explicitly defined in the Constitution (unlike electricity). They therefore become in effect the property of the relevant producers, and as such are for them to dispose of and allocate for further use. Under the Constitution, there is no clear indication as to responsibilities for water conservation/ demand management, although under Article 23 "Society" is '…responsible for the protection and proper exploitation of such natural resources and wealth for the benefit of the national economy'.

With independence, new ministries and emirate level agencies were established in the following years bringing a duality to water management. Strategic coordination and policy development for groundwater water and recycled water was the responsibility of the Ministry of Environment and Water (MOEW) and desalinated water that of the Ministry of Energy.[17] Operations and management of these water sources took place at the Emirate level with a variety of organizations involved ranging from municipalities to private companies. Thus, the constitutional emphasis on natural resources being the property of each emirate ensured that most organizations involved in water governance were found at this local level. In these new agencies the heads were local Arabs, but key British and Western consultants, advisors and technocrats remained active in developing and implementing water policies. Foreign models of water development were therefore still part of the framing of ideas and strategies.

The resulting institutional systems in the seven emirates developed relatively independently of each other and there is little commonality between them. With the wealth from oil revenues concentrated in Abu Dhabi Emirate, again resulting from the constitutional framework, the agencies here were able to establish a predominance facilitated by budgets and investments for the various sectors.

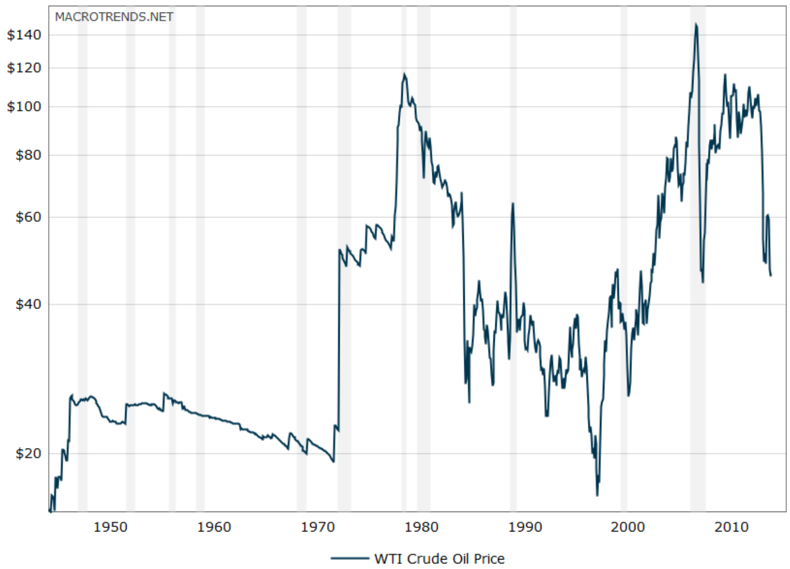
The various water sources were in effect nationalized. The Abu Dhabi Water and Electricity Department (ADWEC) was established to oversee desalinated and recycled water (and electricity) developments, whilst the Environment Agency Abu Dhabi (EAD) managed the newly nationalized underground resources of the whole emirate. The previous ownership of wells by families and tribal groups was transferred in theory to the new state but people still managed them as though they were still under their private ownership. The post-independence water administrations became vertical and monopolistic, and private actors had little role except through the later private-public partnerships of desalination plants.

The strength and legitimacy of the new state was often portrayed through new water developments in both the urban areas and in the desert hinterland. Starting under the British

[17] In a cabinet reshuffle in February 2016, water has become solely the responsibility of the Ministry of Energy

colonial period, but greatly accelerated following independence and rising wealth of the 1970s (8), a 20-fold increase in the price of oil between 1973 and 1981 enabled supply-side policies while in the hinterland, this was a period of grand water infrastructures and visible technical prowess reflecting the modernity, strength and legitimacy of the newly independent state. Supply-augmentation policies completely dominated water management strategies. Desalination capacity was greatly increased and it was provided free to all households during the 1970s. With the depressed oil prices of the 1980s and again in the mid-1990s, allied with steady demographic growth, a distinction was made in charges for water in Abu Dhabi between Nationals (the minority) and foreigners. The latter in both cities paid a small fee, flat and cross-subsidized, for their water consumption.

Figure 28. Changes in crude oil prices from 1950 to 2015



Source: www.macrotrends.net/1369/crude-oil-price-history-chart (Last accessed 27th June 2016).

The city of Abu Dhabi was landscaped with a large number of trees, parks and water fountains, to display the received *ni'mah* (the God-given 'bounty') that resulted from oil and gas revenues (see 9a and 9b). Various large water fountains reflecting local themes served as highly visible landmarks to highlight this post-independence discourse of God-given bounty (Lambert, 2013). Recycled water from the new sewerage networks and treated wastewater plants was used in some of the developments.

These new urban environments and services in tandem with jobs in the growing state apparatus were used to encourage some of the nomadic tribes to settle in the new United Arab Emirates, as opposed to crossing the new national borders into Saudi Arabia and other neighboring countries. Attracting and settling some Bedouin tribes in the urban areas helped secure their loyalty to the ruling family with their political conservatism helping to counter-balance more potentially pro-Cairo or pro-Baghdad Arab nationalists among their town-dwellers (Lambert, 2013).

The impact of policies of tribal settlement, stabilization and securing allegiance however, had the greatest impact in the desert hinterland on water use and management. During the late 1960s and greatly accelerated in the 1970s there was a vision from Abu Dhabi's rulers to 'green the desert'. Swathes of desert sands were flattened for agriculture in a bid to be food selfsufficient (Figure 3030). The new farmland created was given to various citizens. Nomadic tribesmen in particular benefitted from this and they along with urban dwelling citizens were given access to water through the drilling of wells for them by the government (not ownership), as well as land (which they owned), water pumps, seeds and other provisions to encourage them to settle in the UAE.

Figure 29. The changing urban landscape/waterscape of Abu Dhabi in 1966 (a) and late 1980s (b)

a)

b)

Source: a) www.uae-embassy.ae/Embassies/uk/Photo/4568 ; b) www.film.gov.ae/en/Images/Est%20Abu%20Dhbai%20Skyline%20001026_tcm24-15361.jpg

They applied through local government agencies in their districts which organized the transfers and practical support. The majilis was often the place of discussions for requesting the land and help. It was not some formal administrative process. The new land owners were guaranteed a price for the crops, even though they were often inedible for humans because of high pesticide content. A new form of small-holder agriculture emerged, that of the hobby farmer, where the main household income came from largely government jobs in the cities and towns.

Figure 30. Sheikh Zayed's vision to transform the desert into a green haven

Source: http://www.uae-embassy.ae/Embassies/uk/Photo/4568 (Last accessed 27th June 2016).

Very few land-owners were thus resident or were actively involved, with laborers from South Asia undertaking most of the work on the land. These laborers brought irrigation and farming techniques from wetter climates. Flood irrigation dominated, enabled by 24-hours pumping fuelled by subsided diesel and electricity, leading to large withdrawals of groundwater. There are marked changes in groundwater levels and associated increases in salinity in the freshwater areas of Al Ain and Liwa as a result of this rapid expansion in agricultural area and greatly increase pumping from the aquifers.

Further stress to the groundwater systems came with the planting of 100 million trees as part of the establishment of new forests with more than 330,000 hectares of the emirates covered with these new plantations (Figure 311). They have primarily been irrigated with brackish groundwater and more recently in some areas with recycled or desalinated water sources. Some of the trees were planted to help stabilize sand dunes to keep transport routes open.

Figure 31. Part of the green belt in Abu Dhabi Western Region

Source: http://colabradio.mit.edu/greening-the-desert-abu-dhabi-style/ (Last accessed 27th June 2016).

After independence Abu Dhabi emirate continued its supply-led policies with augmentation of ever stressed groundwater systems. Thus the United Arab Emirates at the end of the 20th century had markedly different water management and governance systems than existed even 50 ears previously due to the following major factors: Desalination capacity, modernizing State monopolies over water resources, centralized water administrations and their planned development, and, most importantly, the absence of any role for the private sector or tribal community enterprises in the field of potable water supply in complete contrast to the solely tribal and commercial nature of water initiatives in the first half of the 20th century.

Groundwater development and ownership became more concentrated into the hands of individual land owners with little control from the new state systems. It is important to understand that the emirate transitioned from a tribal to a national, centralized state in an area where no government like this had ever existed before. The emirate was very different to countries such as Egypt, Jordan and Lebanon that had a long history of centralized government in various forms. Whilst the new land owners settled and were learning to farm, often using irrigation for the first time[18], the untamed free-spirited nature of the tribesmen continued with little 'interference' from the new government. Water and other natural resources were legally

[18] Labourers from Egypt, Sudan and the surrounding areas were brought in to help on some farms.

nationalized under the new constitution but they continued to be managed and used by the individual land owners as they saw fit. There were no formal controls on the use of water at this time. The term 'hydraulic mission'[19] could be used in one sense as the government was supplying the capabilities to develop this expansion of water use, but it is important to recognize that resulting state controls were limited. Any political power obtained through this was in a loose and relatively unrestrained, unfocussed sense. Loyalty through the majilis and to the tribe was still important. The tribes in the past had freely crossed the borders between the UAE and Saudi Arabia without the notion of belonging to a country. This did not change immediately with the creation of the new state of the UAE.

The tightly-linked objectives of post-independence Abu Dhabi water administrations were the contentment of the people's demands for improvement of their living conditions, the modernization of the State and the country through both urban and rural hydraulic development, the State legitimization within and outside national borders and the fixing, nationalization and control of the tribes and their allegiances (Lambert, 2013). This required a revolution in the governance system as much as that in technology and engineering and was the emirate's own version of the hydraulic mission found in many countries during this period.

In summary, the water sector has shifted from an originally horizontal system of decision-making and decision-implementation for water initiatives - in which the ruler could only arbitrate between conflicting interests or launch his personally-financed private initiative - to a situation a mere few decades later in which the State is the sole driver of water supply systems, the administration of which is characterized by vertical, top-down decision making. Participatory governance, the consultative form of decision-making through the majilis, was replaced by government-led and associated statist models of development with strong influences from technocrat advisers from the West. Tribalism was still found in the meetings at the majilis and the stability and security were supported through the gifting of land.

3.6 The water sector governance and policy initiatives today- the realities of water scarcity and rising environmental consciousness

Following the death in 2004 of the Father of the Nation, HH Sheikh Zayed bin Sultan Al Nahyan his son HH Sheikh Khalifa bin Zayed Al Nahyan became President of the UAE and Ruler of Abu Dhabi, and put forward a new vision for the emirate. An overarching policy agenda for the emirate was developed from 2008 onwards, known as Vision 2030, with linked but specific agendas for areas such as the economy (Economic Vision 2030), urban development (Urban Structure Framework Plan 2030) and environment (Environment Vision 2030), which were generated by government departments and agencies responsible for those areas (Abu Dhabi Urban Planning Council, 2007).

Nine pillars were identified to form the architecture of the Emirate's social, political and economic future:

1. A large, empowered private sector;
2. A sustainable knowledge-based economy;
3. An optimal, transparent regulatory environment;
4. A continuation of strong and diverse international relationships;
5. The optimization of the Emirate's resources;

[19] Hydraulic mission is a term used to describe how through large water resources developments, the state (intentionally or unintentionally) was able to control space, water and people. It was an important part of everyday forms of state formation which was particularly pronounced in parts of the Middle East under many civilizations from ancient to the modern (Allan, 2002).

6. Premium education, healthcare and infrastructure assets;
7. Complete international and domestic security;
8. Maintaining Abu Dhabi's values, culture and heritage;
9. A significant and ongoing contribution to the federation of the UAE.

The government committed itself to direct public policy to strengthen and develop them with a focus on four key priority areas:

1. Economic development;.
2. Social and human resources development;
3. Infrastructure development and environmental sustainability;
4. Optimization of Government operations.

The increasing role of the private sector in traditionally state led apparatuses such as schools and hospitals was prevalent from 2005 onwards with the Private-Pubic-Partnership model (PPP) being particularly favored for water/energy supply system developments. This was following trends in many influential countries such as the UK as well as from organizations such as the World Bank, where this model was also being used. This period was one of fluctuating oil prices, the main source of revenue (The strength and legitimacy of the new state was often portrayed through new water developments in both the urban areas and in the desert hinterland. Starting under the British colonial period, but greatly accelerated following independence and rising wealth of the 1970s (8), a 20-fold increase in the price of oil between 1973 and 1981 enabled supply-side policies while in the hinterland, this was a period of grand water infrastructures and visible technical prowess reflecting the modernity, strength and legitimacy of the newly independent state. Supply-augmentation policies completely dominated water management strategies. Desalination capacity was greatly increased and it was provided free to all households during the 1970s. With the depressed oil prices of the 1980s and again in the mid-1990s, allied with steady demographic growth, a distinction was made in charges for water in Abu Dhabi between Nationals (the minority) and foreigners. The latter in both cities paid a small fee, flat and cross-subsidized, for their water consumption.

Figure 288), as well as rapid development of major urban areas, particularly Abu Dhabi city on its quests to diversify the economy away from hydrocarbons and to become a major commercial and financial center to rival neighboring Dubai. New roads, airports, airlines, hotels, office and mixed used developments as well as many thousands of new residential units were constructed. The population almost doubled in a decade rising from 1,374,100 in the mid 2005s, to 2,453,100 by 2014. By 2014 1.5 million people lived in Abu Dhabi city, 650,000 in Al Ain and 300,000 in Al Gharbia, the Western Region. The imbalance in gender - 1,747,833 male and 705,263 female – and nationality - 495,368 were Emirati and 1,957,728 expatriates - reflects the need for economic migrants, particularly in construction required to facilitate this rapid urban growth (Statistics Centre Abu Dhabi (SCAD), 2014).

Water increasingly became a focus of attention as the supply-side policies of the past were no longer judged to be sustainable, especially following the moratorium on new gas exports from Qatar from 2008, the relatively cheap and clean burning fuel driving the water and electricity generation sector. The Abu Dhabi Master Water Plan was produced in 2009 (Pitman et al., 2009) which reviewed for the first time in an integrated framework the state of the three main sources, water resource use, and the likely impacts of the developments proposed in the Urban Structure Framework Plan 2030 on the environment including carbon emissions. This will be reviewed in this section. First however, it is important to understand the water governance structures in place today in Abu Dhabi Emirate as these clarify the various agents involved with developing and implementing the policy agenda.

3.6.1 Water governance and government today

Whilst some changes to water governance came into effect in the late 1990s, major re-structuring of organizations took place in 2005. The governance structure today reflects a significant change in the role of the state with a move away from being major service providers and managers, into more regulatory role functions. This reflected moves to engage the private sector, one of the pillars of Vision 2030, as service delivery agents, particularly for desalinated water (and electricity generation).

Water governance continued to be shared between federal and emirate level organizations, with the latter being essentially the competent authority for implementation of national laws as well as local directives. Federal level ministries continued to have authority for strategic oversight and planning (Table 9). Today MOEW is the main authority whose strategic objectives include developing and implementing policies, plans and projects to protect the environment.

Table 9. Federal level agencies for water management

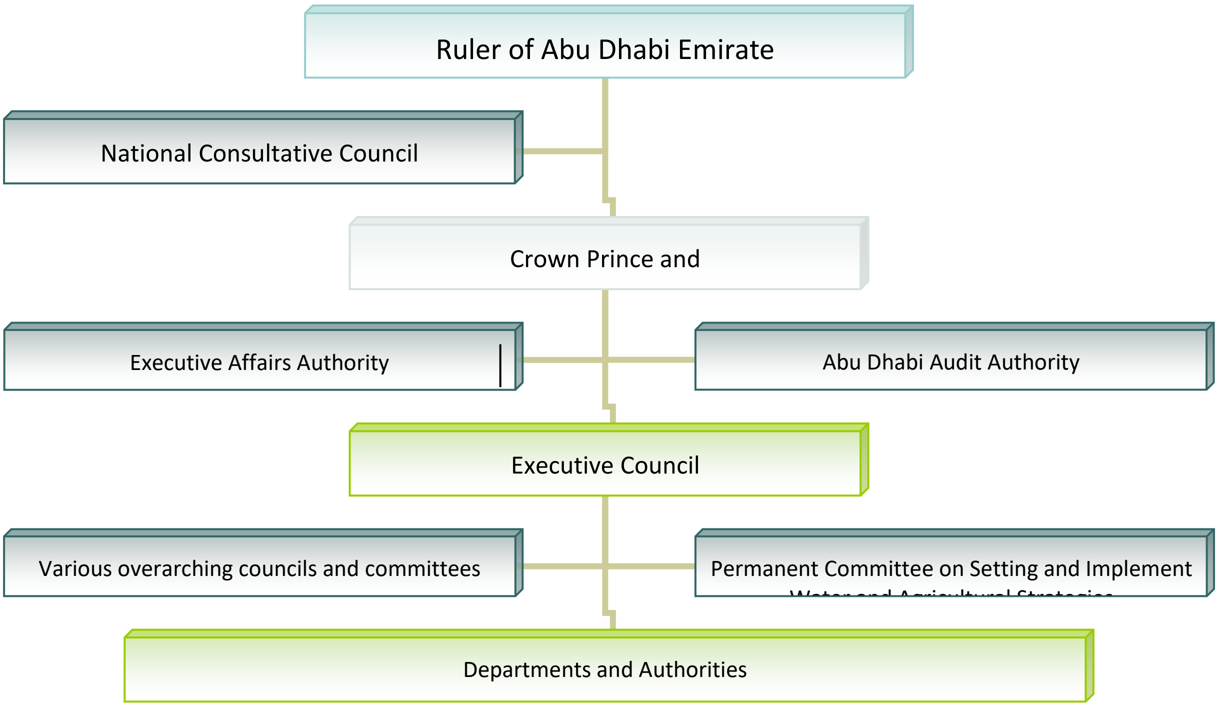
Organization	*Role*
UAE President's Office	Ruler's Private Office: Ultimate national policy decision-making authority; control over Presidential departments President's Private Departments (Water Resources Studies & Geology): Meteorology monitoring and limited groundwater research; conduct general studies, especially in the northern Emirates
Ministry of Environment & Water (MOEW)	Formed in 2006 to replace the Ministry of Agriculture and Fisheries; subsumed the powers of the Federal Environment Agency in 2009; wide remit to create and implement nationwide policies to develop and manage water resources, achieve food security and protect the environment Relevant undersecretary offices include the following: Water Resources & Natural Conservation Affairs Agriculture and Animal Affairs Environmental Affairs Regions

At the emirate level, various agencies and departments were given their mandate, roles and responsibilities, through the passing of different legislation in 2005 and 2006. They answer to the Executive Council through the agencies overseeing and regulating natural resources: Environment Agency Abu Dhabi (EAD) and non-conventional systems Abu Dhabi Water and Energy Authority and Regulation and Supervision Bureau (ADWEA and RSB respectively). The general governance framework for the water sector is one of different agencies responsible for certain parts of the resource system and this can lead to fragmentation and inter-departmental tensions (as shown in 2 and an overview given in Table 10).

One area in which this has begun to be addressed is in agricultural water use where a cross-organizational committee has been established within the Abu Dhabi government to support integrated thinking. The Permanent Committee for Setting and Implementing Water and Agricultural Strategies (PCWAS) in the Emirate of Abu Dhabi helps to ensure that the potential impacts of new policies and management decisions on the water resources may be examined in depth. Whilst these moves are important for the effectiveness of these cross-organizational committees, their effectiveness is difficult to assess to date.

The competent authority of natural water resources, **EAD,** and its position within the overall emirate governance system is shown in 2. It is directly answerable to the Executive Council and its authority and responsibilities are laid out in Abu Dhabi Law No. (4) 1996, subsequent amendments and Abu Dhabi Law No. (16) 2005. EAD's remit, as defined in these laws, covers many aspects of land and marine management and it is also responsible for regulating and reviewing activities that might impact the environment. Today this increasingly involves the licensing, compliance, and enforcement of established standards.

Figure 32. Simplified governance structure of Abu Dhabi Emirate



Department of Municipal Affairs

Department of Economic Development

Environment Agency Abu Dhabi (EAD)

Abu Dubai Water and Electricity Authority (ADWEA)

Regulation and Supervision Bureau (RSB)

Abu Dhabi Sewage Services Company (ADSSC)

Abu Dhabi Agriculture and Food Control Authority (ADFCA)

Abu Dhabi Farmers Service Centre (ADFSC)

Abu Dhabi Urban Planning Council (ADUPC)

Source: Adapted from Pitman et al., 2009.

EAD is the competent authority for managing the principal natural resource groundwater. These responsibilities are supported by Executive Decisions no 14 (session 8/2005) and No. 4 (Session 17/2005) which commissioned EAD to undertake an assessment of groundwater resources. However, one of the most important developments in water resources management was the passing in 2006 of Law No 6, which authorized EAD to regulate the licensing and drilling of water wells and to monitor usage.

Table 10. Main organizations and their roles/responsibilities in the Abu Dhabi water sector

Institution	Roles and responsibilities particularly for water
Executive Council	Emirate-wide policy decision-making authority
Executive Affairs Authority	Primarily responsible for providing Executive Council with advice on economic, political and energy affairs, but water resource management can fall under its strategic planning remit
Permanent Committee for Setting and Implementing Water and Agricultural Strategies in the Emirate of Abu Dhabi (PCWAS)	Membership includes representatives from the following institutions: EAD (groundwater & forestry); ADFCA (agriculture) ADSSC (treated wastewater); Dep. of Municipal Affairs & Western Region Municipality (amenities); ADWEA (desalinated water); Dep. of Economic Development (industrial water); Abu Dhabi Urban Planning Council (buildings and land-use planning); RSB (utilities)
Department of Municipal Affairs	Three regions- Al Ain, Abu Dhabi and Western Region Responsibility for urban centers, distribution of land to citizens, some forestry and amenity plantings.
Environment Agency Abu Dhabi (EAD)	Independent agency responsible for groundwater management policy development, initiating management strategies, commissioning needed research, monitoring groundwater strategy effectiveness
Abu Dhabi Food Control Authority (ADFCA)	Responsible for overall agricultural policy in Abu Dhabi and specific remit to achieve food security objectives including irrigation water use while advancing sustainable groundwater management
Abu Dhabi Farmers' Services Centre (ADFSC)	Agricultural extension services to Abu Dhabi farmers with specific focus on achieving sustainable groundwater utilization in the agriculture sector; marketing of agricultural produce
Abu Dhabi Water and Electricity Authority (ADWEA)	Umbrella organization of municipal power and water supply firms overseeing production, transmission and distribution (further details provided below).
Abu Dhabi Sewerage Services Company (ADSSC)	Remit to treat residential and commercial wastewater, legal obligation to work towards 100% utilization of treated wastewater
Regulation & Supervision Bureau (RSB)	Independent regulatory and oversight body for Abu Dhabi's water, wastewater and electricity sector
Abu Dhabi National Oil Company (ADNOC)	Responsible for managing the produced water from oil production and has worked with USGS and GIZ on major groundwater studies

The provision of water for agriculture is largely controlled by the **Abu Dhabi Food Control Authority (ADFCA)** which was established as per the decree No. (2) of the year 2005. Under Law No.9 of 2007 Establishing Department of Municipal Affairs Section 5, the mandate and powers previously held by the Department of Municipalities around agriculture were transferred to the

ADFCA which then become the competent authority for agriculture. Accordingly, ADFCA developed the agricultural policy and prepared the plans for achieving sustainable agricultural growth, while introducing regulations to mitigate the harmful effects of certain improper agricultural practices on the environment. The new agricultural policy was expected to take into consideration certain imperatives with better water management and use central to the concerns to be addressed:

- restructure the agricultural sector with a view to make it more sustainable;
- reduce harmful effects on the environment and the pressure on natural resources;
- ensure fair income for the farmers and increase their competitiveness in the market;
- focus on products that Abu Dhabi has a competitive edge on;
- improve the quality of agricultural products;
- strengthen national productivity for better food security.

These are difficult and challenging policy areas in an arid environment. The progress to date has been difficult because of many complexities involved with requesting farmers to limit their water use and the notion of controlling activities on land that is owned by farmers.

Its roles and responsibilities covered many aspects of agriculture and farming in the emirate including animal welfare, as well as food quality standards. In water management, it became possible from 2013 onwards for farm owners with agricultural service cards[20] to request the drilling of wells at the expense of the Abu Dhabi Food Control Authority according to the accredited conditions and requirements and given below (see discussion below and in Box. EAD continued to apply the same checks and balances as in all other well applications, with their approval and issuance of a license the well required before drilling could take place.

For this split in responsibilities to be successful there needed to be an alignment in policy objectives between the two organizations and this has not always been the case. The strategic policies from the main governing bodies are often poorly aligned with simultaneous drives for agricultural expansion and increased food security, yet at the same time requirements to manage more sustainably the groundwater resources. These are inherently conflictual strategic directions.. The resulting tensions between the respective agencies have been difficult to resolve although the three years of discussions at the PCWAS have helped greatly and there is increasing cooperation between the government departments today.

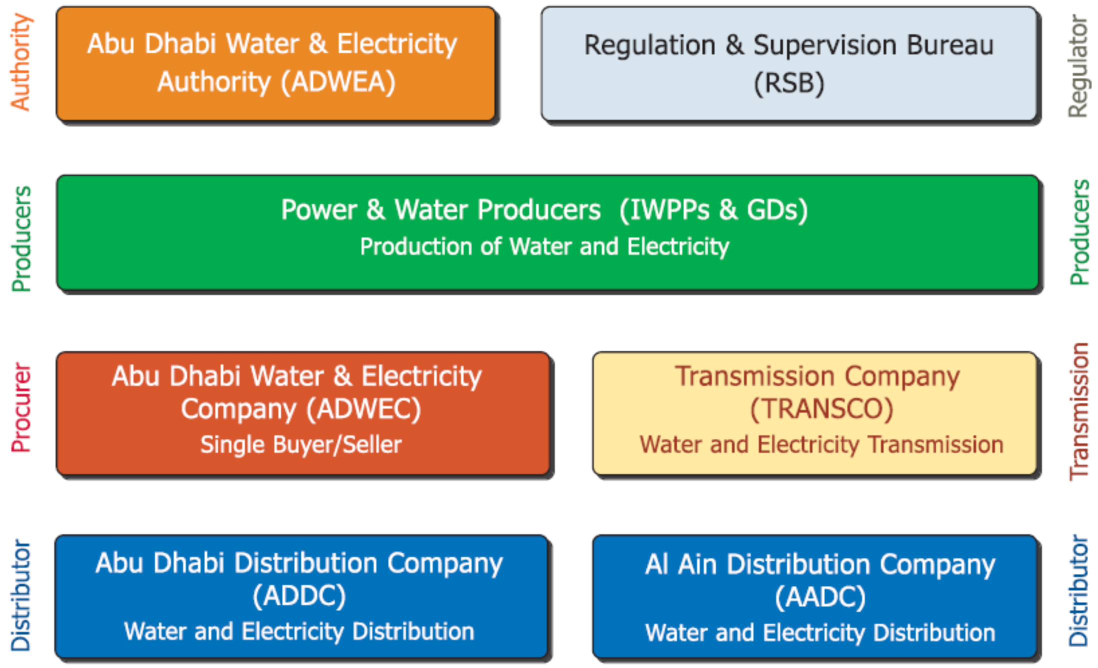
A further organization was established in 2009 to help bring greater water efficiency to the agricultural sector through greater technical support and advocacy. Under Law No.4 of 2009 the **Abu Dhabi Farmers' Services Centre (ADFSC)** was established with the responsibility of implementing Abu Dhabi’s agricultural policy by engaging farmers to adopt best agricultural practices. The centre began providing support to farms that signed up to its service agreement in the Western region to begin with and then their services extended to Abu Dhabi and Al Ain. It is involved with introduction of modern planning and production systems, training farmers in best practice including field demonstrations and model farms, assisting the introduction of farm management practices and in many ways the carrot is facilitating the marketing of local agriculture produce. Originally it was under the overall control of ADFCA but today it has become independent.

[20] To access the many services of ADFCA farmer apply for an Agricultural Services card. This enables farm and livestock owners to access ADFCA's agricultural services such as distribution of the hay among the animal breeders and financial aid among farm owners, animal resources breeders, and providing free or low price agricultural services for farmers.

The final authority that is involved in groundwater governance is ADNOC. It is the state-owned oil company of the UAE, which has the seventh-largest proven petroleum reserves in the world. As part of its upstream oil operations, ADNOC produces vast quantities of groundwater which is polluted by hydrocarbons. It injects some of this water back into the well systems to aid hydrocarbon recovery but manages the rest through its own operations on its sites. It is not subject to oversight by the EAD.

For non-conventional water the main government authorities are ADWEA and the RSB, both entities that report directly to the Executive Council. The current structure and authorities of the organizations involved in the production and distribution of drinking water were established under Law No (2) of 1998, and amended by Law No (19) of 2007. Various organizations under ADWEA's jurisdiction are responsible for different aspects of water provision as shown in 3.

Figure 33. The organizational structure of the desalinated water and electricity sector



Source: ADWEA, 2013.

These organizations have various ownership structures involving different combinations of the Abu Dhabi government and the private sector. All the activities and authority of these different organizations under ADWEA are defined and controlled by licenses issued by the RSB. Under Law Number 2 of 1998, the Abu Dhabi Water and Electricity Company (ADWEC) is the single buyer and seller of electricity and water and has the obligation under Article 30 to "*ensure that, at all times, all reasonable demands for water and electricity in the Emirate is satisfied*" ADWEC and its suppliers are a natural monopoly and its activities are regulated by the RSB. ADWEC supplies the fuel and purchases bulk supplies of water from the eight water and power producers under individual agreements. A single company, the Abu Dhabi Transmission and Dispatch Company (TRANSCO) is responsible for the transfer of bulk supplies to the distribution companies that pay for the service. On receipt, these companies (AADC and ADDC) retail supplies to their customers governed by tariffs and performance criteria regulated by RSB.

Desalinated water production developments have been based on a private-public participation (PPP) model that was embraced in many areas of the government from 2005 onwards. The model in the water sector involved the establishment of new Independent Water and Power Producer (IWPP) as a joint-stock company made up of a successful (foreign) bidder and a local holding company to be established by ADWEA. Forty % of share capital of the IWPP was owned by the successful bidder and the remaining 60 % owned by the local holding company. These moves transferred the need to raise the enormous capital involved in water-power plants from the government to the private sector. The project costs were funded through a combination of debt, equity and (if any) internally-generated net operating cash flows of the IWPP. The successful bidder was responsible for arranging the required financing and for negotiating financing agreements with the lenders. During the 1990s oil prices were very low and this model supported continued expansion of water supply without vastly-increased government financing. The project is often operated and maintained by an operating and maintenance (O&M) contractor, which may be a third party or a subsidiary of the shareholders of the IWPP.

At the time of the bidding, the bidder for the IWPP is required to specify the proposed O&M contractor, together with references and details about their experience. The O&M Contract between the IWPP and the O&M contractor requires the provision of all O&M services, including all maintenance, overhaul and special repair services by the O&M contractor based on a fixed fee plus escalation structure or on a cost plus fee pricing structure. The liabilities of the parties under the O&M Contract are determined based on the assessment of the actual power and water availability and actual fuel consumption achieved by the O&M contractor against the targets specified in the PWPA.

The other source of non-conventional water, recycled water, is managed by the Abu Dhabi Sewerage Service Company (ADSSC), a government owned organization established under Law No (17) of 2005. ADSSC reports directly to the Executive Council following its disengagement from Abu Dhabi Water & Electricity Authority (ADWEA) under a decree issued by the Abu Dhabi Government in 2009. It is responsible for managing the collection, treatment, disposal and recycling of sewerage water and its associated infrastructure. It also provides treated water and bio-solids to the Municipalities for horticulture purposes. Following this, Law no (18) of 2007 allowed other sewerage services companies licensed by the RSB, to connect to ADSSC assets to support an expansion of activities in this area. An example of this is the recent granting of licenses for wastewater treatment to Al Etihad Biwater Waste Water Company, Archirodon Construction (Overseas) Co. S.A., and Aldar Laing O'Rourke Construction L.L.C.

The moves in the water sector from community-based decision-making, management and operations to a professional system in which state agencies and private companies predominate are now well-established. The majilis still plays a role as a forum in which individual and community voices are heard and through this influence the final decision-making or implementation of policies and management strategies. The new governance systems, implemented through a series of laws, have led both to a concentration and diffusion of power in the control of the water systems. There are a series of agencies that are responsible for particular focus areas of the water resource system. The government agencies either directly or indirectly report to Abu Dhabi Executive Council which influences their scope and direction and has final approval of all new initiatives. The role of the Executive Council is "It assists the Ruler to carry out his duties and powers, through regular meetings to set the Emirate's general policy, set development plans and supervise its execution, authorize projects laws and decrees before submitting them to the Ruler, supervise work flow in departments, local entities, and coordinate among them, to achieve general well-being of the country".[21] Its 12 members are from the ruling family as well as chairs of major departments and agencies.

[21] www.ecouncil.ae/en/ADGovernment/Pages/ExecutiveCouncil.aspx (2015).

In the water sector, the development of specialist organizations which were technically competent led to fragmentation and separate power bases which has not always made for effective decision-making and water management. This has been increasingly acknowledged within the water sector in Abu Dhabi (Pitman et al., 2009) and the development of the PCWAS overseeing water and agriculture has brought new integration in planning that is not seen in other sectors. The result of the various complex negotiations and discussions of the member agencies has been the development of a more integrated management of agricultural water use with each adopting various roles and responsibilities for different aspects but which are much more coordinated. The new Abu Dhabi water master plan (Government of Abu Dhabi, 2014) is also an example of increasing collaboration across the agencies and government departments, with no outside consultancy service used this time.

In all these developments there has been a pronounced role in the new institutions and decision-making environments of Emirati citizens. The gradual replacement of ‘foreign’ employees by locals, who have been trained at US or European universities, is noticeable. This has followed the general policy in the country of Emiratisation in which there is a big push for locals to fill jobs wherever possible. This new group of Emirati technocrats is leading moves to manage water stress issues through both international ideas as well as an understanding of local conditions – political, environmental and social. They are widely travelled and attend the large water conferences around the world. They also interact extensively with the private sector and foreign governments to learn of both management and technical possibilities. The International Water Summit hosted each year in Abu Dhabi was developed as an alternative to the Stockholm and Singapore events, and is focused on technical possibilities in arid regions and those which link across the water-energy-food nexus.

3.6.2 The changing focus of water policy frameworks

In tandem with the changes in water governance, the main water organization responsible for groundwater, EAD, embraced the ideas of Integrated Water Resources Management (IWRM) as a framework for new policy and governance initiatives in response to ever more stressed and expensive (both financially and for the environment) water resource supply systems. This internationally adopted framework had been endorsed at various influential global water conferences such as in Bonn and Johannesburg during the late 1990s and early 2000s which delegates from Abu Dhabi attended and contributed to. It was actively promoted by organizations such as the Global Water Partnership and each country was tasked with developing river basin or discharge water management plans to be submitted to UN organizations.

As a result of the influences of IWRM thinking, as well as the local Urban Planning Framework Vision 2030 framework which set out the huge urban development plans for the city, the Abu Dhabi Master Water Plan was commissioned following a direct order from the Executive Council. It was published in 2009 which brought together for the first time data and insight from all three main sources of water and sectoral usage of them (Pitman et al., 2009). In addition to volumetric values for water use, carbon use and financial metrics were also given to show the costs of this. It highlighted the challenges ahead in meeting the requirements from rapidly expanding population and commercial sector as well as the many incentives that were driving current water use such as the subsidies on the growing of forage and vegetable crops. The Master Plan was adopted by the Executive Council and some of the recommendations were subsequently implemented such as the cutting of some agricultural subsidies and the establishment of a new ‘Permanent Committee for water and agriculture’. This Committee was headed by a senior member of the Executive Council and aimed to bring greater alignment between the water and agriculture sectors through discussions and agreements between the agencies responsible for them. The most successful example is probably that related to subsidies for cultivation of Rhodes grass, a particularly thirsty forage crop species; these subsidies were phased out and farmers are now paid (7,500AED approximately $2,000 per month) not to grow the crop on more than 10% of their land (see Fragaszy and McDonnell, 2016). This has led to a reduction of nearly 80% in the area of fodder cultivated.

There has since been a raft of new water and water-related policy reports launched since the Master Plan that gives more in-depth analysis and plans for related sub-sectors. For example further examination of the possible role of recycled water came with the publication of the 'Strategy for the Use of Recycled Water for the Emirate of Abu Dhabi in 2010 by EAD/ICBA. This gave an overview of the availability and quality of recycled water, existing and proposed regulations, limits to current use, and various policy and management options for increasing utilization.

For groundwater, EAD published in 2012, a report called 'Political, Economic and Social Assessment of Groundwater Management in Abu Dhabi' which aimed to identify opportunities to improve groundwater management policies and practices and to design an implementation strategy. It was developed from interviews with the leadership at ADFCA and ADFSC. It highlighted in its review of the state of water in agriculture, that whilst the shift in subsidies since 2000 from an emphasis on production to maintaining farms in good condition and to promoting commercial self-sufficiency, there had been little change to production methods which supported water efficiency. The problem of the sector being dominated by 'hobby' farming and little contribution to the national GDP or social impact was again emphasized.

The approaches to water savings did not just come from the agencies directly responsible for the resource. The 'Agriculture and Food Safety Policy' (2011) published by ADFCA embarked on an ambitious program of policy development and expanded responsibility for the entire food chain, from farm to fork, including the safety of foods imported into the Emirate. It consists of eleven general policies and fifteen agriculture policies. Within it is the Agriculture Water Use Policy (2011) which had the objective of maximizing efficiency and supporting sustainability through: i) overcoming barriers to efficient agricultural water use; (ii) water targets for use; (iii) water use impact assessment to addresses economic, social and environmental factors in reaching decisions on agriculture activities using water; (iv) collection of data for water impact assessments; and (v) liaison with other departments and agencies to achieve its objectives. The Agricultural Water Use Policy proposed both supply and demand side management measures, which coming from the agricultural sector was important. Whilst these are aimed saving water, all farms, small and large, still receive subsidized irrigation and other materials as Box 1 shows. The total values of these subsidies are not disclosed but it is known from interviews that without this financial support, agriculture would not be profitable.

These policy ambitions are still in place yet are proving difficult to negotiate and implement. The approaches required a multi-disciplinary and multi-agency approach and whilst there is a general acknowledgement of the importance and urgency of the measures and their implementation, progress has been slow if at all. The objectives are complex to implement with few funded practical means to do so. Cutbacks in government funding of the various government agencies from 2013 onwards has further exacerbated the challenges to implementing these.

Box 1. Application process for subsidized water pump from ADFCA

Through this scheme farmers can obtain a water pump at half price.

Process Description

- Submit the application along with the required documents at the Customer Service Centers.
- Pay the prescribed fees.
- Get and install the Water Pump.

Fees

Half price of the Water Pump.

Required Documents

Required Document	Special Consideration
Agricultural Services Card	Copy
Farm scheme	Copy
Half cost Water Pump application	Original
ID card	Copy

An important means of implementing the policy has been the growing coordination which resulted from more than a year of outreach efforts of EAD and ADFCA as well as the influence of the Permanent Committee. This led to a further policy brief being released by EAD and ADFCA at the end of 2012, "Advancing sustainable groundwater management in Abu Dhabi" providing more practical substance and examples of how these demand and supply management strategies would be addressed. Ideas put forward included replacing drip with subsurface irrigation, adopting new greenhouse technologies, rationalizing water for palm trees, and implementing aquifer storage and recovery to support the development of a strategic reserve. Whilst technology fixes were emphasized, managing water scarcity was being tackled through a number of approaches. The trial areas for subsurface irrigation are limited, involving a few farms, and there have been technology issues centered on the clogging of the valves. Greenhouses are much more widespread with up to 40% of vegetable-producing farms now including one or more of these systems on their plots.

At the same time as these specific areas of policy were being developed, the Abu Dhabi government (through EAD) published the important over-arching Environment Vision 2030, though it has not been formally approved by the Abu Dhabi government (2011). This framework gave an overview of the state of the environment in 2010 across many features and highlighted the stressed nature of groundwater resources, and that the Emirate has one of the highest water consumption rates per capita in the world. A series of priority areas were defined, with Priority Area 3 "Efficient management and conservation of water resources" with areas of focus further defined for groundwater and non-conventional water (see Table 4). Sector-specific priorities, outcomes and targets were also established to help target the objectives of the different priority areas and the ones pertaining to water are given in Appendix 1. Again demand-reducing policies were identified as priority solutions.

In the strategy, the 'business as usual' predicted trends for groundwater management were for a 40% reduction in water used in agriculture, but this is almost negated by a near five-fold increase in groundwater use in amenity landscape irrigation. The ambitious target set for groundwater highlights the desired reduction of 59% from 2010 values (see 11 and 4), with cuts in consumption across the three major user sectors to reduce Abu Dhabi's groundwater abstraction from a current rate of ~2.2km^3/year to ~2km^3 in 2030. The diagram also highlights that to return to sustainability of withdrawals equal to recharge an 88% reduction is required through policy and management changes.

Table 11. Priority Area 3 details from the Environment Vision 2030

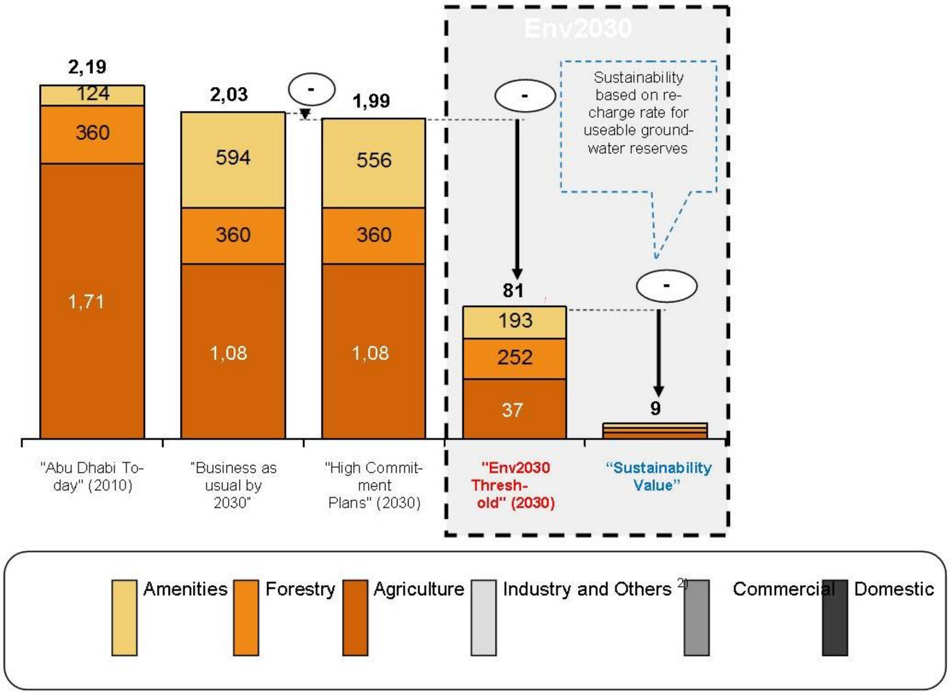
Priority area	Priority	Outcome	Measure	Baseline 2010	Target 2018	Target 2030
PA 3 - Secure and Sustainable Multi-source Water Usage Through Efficient Resource Management	Integrated and Efficient Use of Water Resources	Moderated average domestic water consumption	Domestic Water Consumption in L/capita/day	614	450	<340
		Maximised use of recycled water for amenity plantations	% of Total Water Consumed for Amenity Plantations	51%	100%	100%
	Sustainable Management of Groundwater Resources	Sustainable Groundwater Reserves	Effective Years Remaining in Usable Groundwater Reserves	<55	65	>74
		Increases in salinity in groundwater reserves within acceptable limits	Area (km2) of Aquifer where Water Quality is ≤ 1500 ppm TDS Concentration	NA	TBD	TBD

Source: EAD, 2011.

Meeting these targets has been difficult with progress slow. More than 640 inspections of wells took place in 2013 to ensure observance of licensing conditions. These inspections check for compliance with well licences, but are unable to ensure abstraction levels are adhered to as there are no meters present. They are too contentious with farmers and no metering takes place at present. The visits check whether any illegal wells have been dug on the property, that there has been no well deepening/widening. The visits also serve an important outreach function of EAD and signal that regulations are in place and should be adhered to. Greater outreach has also taken place through ADFSC and this too has led to a growing awareness of water demand management needs. The farmers interviewed in this study highlighted the efforts of both agencies.

A series of strategic policy announcements followed the publication and acceptance (but not yet implemented) of Environment 2030 such as the release in April 2013 of a high-level strategy and action plan, jointly produced by ADFCA and EAD titled "balancing the needs of agriculture with water availability". This directly addressed the requirements of Environment 2030 with a series of policy proposals which directly addressed ways of meeting the targets set.

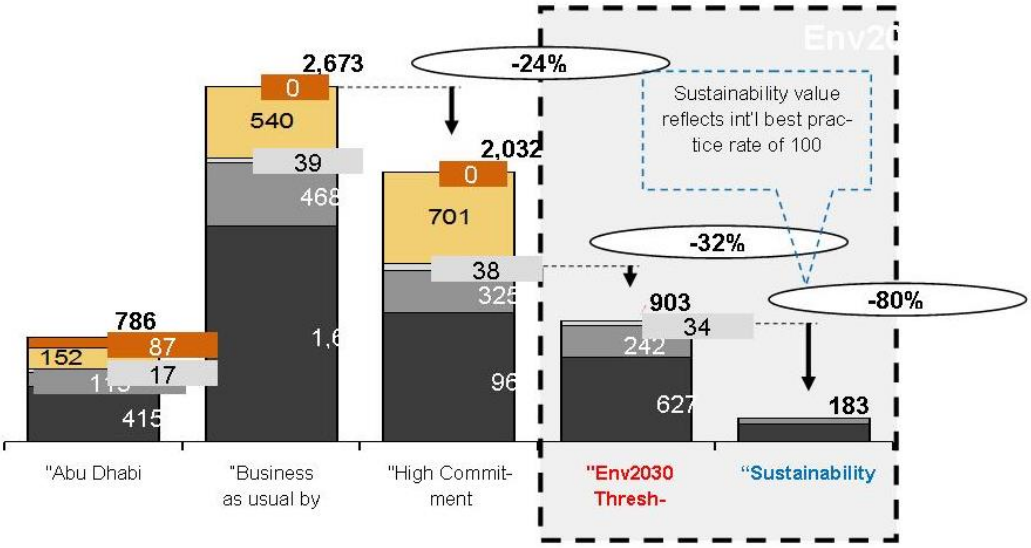
Figure 34. Groundwater consumption in Mm^3 per year in 2010, proposed reduction for Environment 2030, and the sustainability rate based on recharge



Source: Government of Abu Dhabi, 2013.

Similar targets were set under Environment 2030 for desalinated water consumption (shown graphically in 5). The snap shot of the state of water use in 2010, highlighted that domestic consumption was greatest but water was also being used in amenity irrigation, industry and agriculture. The plans under 'business as usual' would see a tripling in over consumption of desalinated water, met by further expansion of the generating system, although desalinated water use for agriculture would have been reduced and replaced by a greater consumption in industry, commercial and particularly domestic sectors. Under targets setup under Environment 2030 there would still be an increased in consumption but only be 120 Mm3, with desalinated water no longer being used in amenity and agriculture.

Figure 35. Desalinated water consumption in Mm^3 per year in 2010, proposed reductions under Environment 2030 and the sustainability rate based on demand best practices (key as above)



Source: Government of Abu Dhabi, 2013.

Subsequently the 'Water Resources Management Strategy for the Emirate of Abu Dhabi 2014-2018 was developed with the objectives and targets of Environment 2030 framing the policies and management plans. It outlined even more stringent ideas to bring water efficiency and was jointly developed by all the lead water agencies in the emirate. These built on the recommendations of the 2009 plan, many of which had failed to be implemented as a result of various factors such as lack of available budget, trained staff, or political will to tackle controversial issues especially following the Arab Spring tensions that began in 2011.

This Strategy summarizes the strategic principles for the water sector as follows:

An important development as part of the development of this strategy was a meeting held in Abu Dhabi in May 2013 in which it was agreed that a water allocation policy needs to be enacted and enforced by the government of Abu Dhabi. It requested that the policy be drafted, refined, discussed and approved by the Executive Council and embedded in the modus operandi of all the organizations concerned.

The strategy also highlighted various gaps and challenges in the water governance system in Abu Dhabi today and these are given in Appendix 2.

Table 12. Strategic principles for the water sector in the Emirate of Abu Dhabi

Strategic principles for the water sector in the Emirate of Abu Dhabi	
Water Security	The population shall have sustainable access to adequate quantities of and acceptable quality water for: Sustaining livelihoods, human well-being, and socio-economic development, Ensuring protection against water-borne pollution and water-related disasters, and preserving ecosystems in a climate of peace and political stability
Water access	Safe and sufficient water to satisfy basic human needs shall be accessible to all at an affordable cost to the users.
Water availability	At all times, all reasonable demand for water shall be satisfied.
Water quality	Water, effluents, and residuals shall be conserved, produced, treated or used to prevent pollution and disease, in full compliance with regulatory requirements where it is economic and efficient to do so.
Water allocation	Water allocation among users shall be fair and efficient. Consumers whether domestic, commercial, industrial, agricultural, and public, existing and future, shall use the best alternative water, whether groundwater, recycled or desalinated, taking into consideration economic, environmental, technical and cultural considerations.
Strategic water reserve	Sufficient water shall be stored to cover emergency needs. Improvements in transmission networks shall ensure flexibility of supply in times of emergency.
Well drilling	Wells shall only be drilled in areas where groundwater aquifers have adequate quantities of water of acceptable quality for the intended use and renewable.
Operational optimization	The operation of generation, transmissions and distribution systems shall be safe, efficient, and economical.
Water losses	Unaccounted for water (made up of physical losses from the distribution network leakage and unauthorised consumption) shall be minimised. Unaccounted for water is also referred to as non-revenue water.
Recycled water	As much as possible of the drinking and non-drinking water that is consumed indoors and outdoors shall be collected, treated and reused in the form of recycled water. Discharges of recycled water to the environment should be minimised.
Ecosystems integrity	Infrastructure and operations shall be managed to optimise resource efficiency and minimise pollution to the atmosphere, water or soil.
Water conservation	Users whether domestic, commercial, industrial, agricultural, and government, existing and future, shall conserve and use water as efficiently as possible. As much as possible, the government shall use demand side management policies to encourage water conservation and efficient use.
Water metering	All water supplied to the domestic, commercial, industrial, agriculture, amenities and forestry sectors, whether monitoring groundwater, recycled or desalinated water shall be metered and monitored.
Water data	Accurate and reliable data about water supply and consumption shall be available to inform decisions
Inter-sectoral policy	Urban, industrial, agricultural and forestry policies that have a major impact on water supply and demand, and hence on water scarcity, shall be aligned

alignment	with water policies to ensure that existing and future activities maximize economic and social welfare without compromising the integrity of vital ecosystems.
Inter-agency coordination	The various entities, committees and working groups shall ensure better coordination, complementarity and coherence of policies, programmes and messages affecting water resources management in the Emirate.
Integrated Water Resources Planning	Integrated planning of the three water resources shall be an essential element to guide water resources development plans and secure the availability of water under different scenarios.
Stakeholder engagement	Water planning and management shall be based on a participatory approach, involving policy makers, regulators, operators and users
Emiratisation	The recruitment and training of UAE nationals in the water sector shall be ensured.
Sustainable water funding	The water system shall become self-funded over time by the income generated by it. Government subsidies shall be gradually removed in the next 10-15 years so that water prices reflect water scarcity.

3.6.3 Groundwater policy implementation measures

There are thus a plethora of strategies and ideas for managing water efficiency with the focus today on meeting the Environment Vision 2030 "threshold values" which are designed to put Abu Dhabi on track to attain truly sustainable long-term groundwater management. This yawning gap between the status today and the intended conditions in 2030 indicates the severity of challenges facing policymakers and strategic planners in the formulation of groundwater sustainability plans vital for UAE to address long-term economic growth and quality of life objectives.

Various policy measures have been put forward and are in various stages of implementation to meet the policy aims. They will be reviewed under the headings given in Table 1.

3.6.3.1 <u>Water Quantity - Abstraction developments</u>

Data collection and inventorying

Executive Decisions No. 14 (session 8/2005) and No. 4 (Session 17/2005) - in 2005, Executive Decisions no. 14 and 4 commissioned EAD to undertake an assessment of groundwater resources. Today there are over 80,000 permitted wells in Abu Dhabi Emirate with annual new permits around 1750 (Environment Agency Abu Dhabi, 2012 2013). This well inventory started in 2006/7 was a crucial starting point for managing the groundwater system. Many different data variables were collected during this exercise including:

- Well depth, salinity of water
- Material used to construct the well, diameter,
- Crops types irrigated groundwater

There is no historical context to the data collected. This inventory data is today held in a GIS and in tabular form and is used by the regulatory department at EAD as the basis for decision-making for future well permitting/approvals. It has provided decision makers valuable information on the extent of groundwater withdrawals and using further data collection at the wells has permitted the drawing up of maps of zones of degrees of groundwater stress. This information formed the basis for subsequent legislation restricting future groundwater developments.

The monitoring network overseen by EAD was further enhanced in 2012 through a new partnership with the National Drilling Company – Abu Dhabi, through which 440 more groundwater wells were added to its monitoring network. This resulted, for the first time, in a comprehensive trans-national monitoring network (EAD, 2012). This again has been used in zoning and regulatory operations.

An update and expansion of this effort is currently being undertaken: the EAD in close collaboration with the ADFSC recently began a well census to locate, categorize and geotag all wells in the Emirate of Abu Dhabi. This is a multi-year undertaking which underpins other related programs. Currently only wells which were constructed after 2006 or have required deepening are identified in the EAD's database. Without an accurate and up-to-date database of wells in the Emirate, implementation of well-metering is not within the realm of possibility.

Also, owners of farms with old wells typically have very little to no interaction with the regulatory institutions. While legally EAD can access wells in order to implement its monitoring duties, in practice it requires the permission of the farm-owner. Farm-owners with old wells have fallen out of focus for agriculture management programs and EAD has typically worked through Municipalities and the ADFSC for farm-owner contacts. The well census, therefore, is also a point of entry to develop an up-to-date database of contacts for farm owners for the EAD and begin a relationship with them which is a critical first step in future outreach programs.

The well inventory links EAD's technical and engagement efforts and will serve as the launching pad of future behaviour change programs which will have the possibility of large-scale monitoring and evaluation. The inventory and associated future programs also focus on farm owners whereas many of EAD's past efforts have focused on farm workers. As reported, EAD has learned that while farm worker training programs are important, farm owners must be the agents of change in water management.

Regulation of groundwater

As stated earlier, groundwater in the emirate is the property of the emirate state and this was defined in the Constitution. Control over the use of this water is laid down in Law No. 6 of 2006 for Drilling of Wells and subsequent by-laws and amendments. Under this law EAD is authorized to regulate the licensing and drilling of water wells and to monitor usage. Each well has to be licensed and the right to pump water and the abstraction rate is defined in this license according to local conditions. Following the development of a well inventory across the whole emirate in 2006/7 each existing well was issued with a license. All new wells and changes to existing wells involves and application directly to EAD or through the ADFCA.

The actual process for applying for a new well or for changing an existing one involves landowners applying to either EAD (if they are funding it themselves) or ADFCA (when the government will cover the costs) for drilling for new wells, deepening, replacing and maintaining wells (see Box 2). This organization works with EAD on the possibilities, including determining well spacing and depths and if any existing wells need to be de-commissioned before the licence is issued. Drilling can only be undertaken by the private sector National Drilling Company which is under contract from ADFCA for this work. The law specifies that abstraction rates should be included in the licensing and there is provision for metering of new wells. This has not been adopted because of resistance by the landowners who view this as an intrusion and may lead to water charging. The water is free. Once the well is constructed a plate with its licence number and basic details is fixed to the structure.

Box 2. Application process for well drilling by ADFCA

Through this service, farm owners in Abu Dhabi can request for drilling wells at the expense of the Abu Dhabi Food Control Authority according to the accredited conditions and requirements.

(https://www.abudhabi.ae/portal/public/en/citizens/housing_and_property/farming_and_agriculture/service

Process Description

- Submit the application along with the required documents at the Customer Service Centers.
- Wait for a reply approving or denying.

Required Document	Special Consideration
Emirates ID	Copy
Drilling application form	Original
Agriculture Services Card	Original
Original Farm scheme	Copy

Both diesel and electricity pumps are used, with the former the most prominent. Both sources of energy were highly subsidized for Emirati citizens, although this is beginning to change. In the summer of 2015 all diesel subsidies were removed in the UAE, and in late 2015 electricity prices for Emiratis were raised a little, although the rate is still much less than paid by non-citizens.

The Law also gave EAD employees powers to access any land, farm or facility to conduct research or collect data on deep water resources. There are two inspection teams made up of 8 inspectors in the eastern area and 5 in the western part of the Emirate. They undertake daily visits to land owners to check wells and their plates to ensure they conform to the licences granted.

There has been in the past anecdotal evidence of agency staff being prevented from entering the land of irate farmers. Today because of the enhanced relationship between EAD, ADFCA and ADFSC and the farmers, accessing land to check on the observance of abstraction licenses is much easier and without personal risk. Around 640 inspection visits were made in 2013 (EAD, 2013) and this is increasing each year.

Enhanced Information/extension services: Establishing the ADFSC was aimed to achieve a 40 per cent presence of locally-produced fruits and vegetables in the markets of the Emirate by 2015 from the current share of about 15 per cent and reduce 40 percent water consumption by 2013. To implement the strategy, the FSC provides agricultural services and strengthen awareness, besides helping farmers market their produce. With this in mind, the FSC launched the Zera'atona ("our agriculture") campaign seeking to ensure economic diversification and agricultural sustainability through preserving vital natural resources by motivating farmers to adopt best agricultural practices, deemed essential to preserve their land, improve agricultural produce, protect the environment in general, preserve water in particular, and ensure better income for the farmers.

Prosecuting illegal well operations: EAD, ADFSC and ADFCA from 2013 began an 'integrated and holistic behavior change program involving both carrot and stick measures. It began with a public awareness raising campaign to ensure all key audience segments were aware of the serious issue surrounding ground water decline and quality. There was also a concerted effort to contain the illegal drilling of wells. EAD inspectors have found wells drilled by small private companies, often at night, that were not permitted. These are closed down when discovered and land owners prosecuted with an increasing frequency with 34 in 2012, and 87 in 2013 (EAD, 2013, 2014).

The second area of illegal well operations is the sale of tankers of groundwater by the farmers to industrial water users. This is particularly prevalent in the Western Region as industrial and commercial developments are taking place at a rapid pace here and water supplies from the ADWEA desalination points cannot keep up with demand. Tankers drivers are having to wait up to 12 hours to fill up to supply these developments. Farmers have set up pumping sites on their land and distribute water for a price to these developers. This is illegal as it goes against the use of water described in their well/abstraction licences. ADWEA are increasing the number of distribution points in the region now to help meet this demand but EAD continues to monitor and prosecute illegal groundwater tinkering.

Changing agricultural subsidies: Phasing out of subsidies for the cultivation of crops with high water consumption (Rhodes grass) has been an important policy measure and message in recent years. Under Regulation no. 7 of 2010 the phasing out of subsidies for the cultivation of crops with high water consumption particularly the forage crop Rhodes Grass was announced. This crop, highlighted in the 2009 Abu Dhabi Master Water Plan and shown to consume more that 59% of water irrigation in agriculture, was stopped being cultivated or greatly reduced on some 15,500 farms.

Alternative farm designs including salt tolerant crops: As an alternative to crops such as Rhodes Grass, the FSC, ADFCA and ICBA have set up model farms which show alternative farm management and cropping designs, including the inclusion of crops tolerant to salinity and drought. To compensate farmers' losses, a programme for improving farmers' income came into effect on April 1, 2012 providing they complied with the rules and regulations governing agriculture including the directives and advices of the FSC.

Modern irrigation systems for farms: ADFCA, through the FSC, is also working on rationalizing the use of water irrigation for palm trees, responsible for almost 34% of water consumption, the second highest water consumer after Rhodes grass. A total of 5443 out of 8,373 farms in the Western Region have been provided for free from ADFCA with modern irrigation networks which are expected to help reduce water irrigation withdrawals by 50%.

Replacing drip irrigation with subsurface irrigation: EAD and the Abu Dhabi Municipality are introducing subsurface irrigation as an alternative to traditional drip irrigation. This will help reduce large water losses resulting from high evaporation.

Adopting new technologies for greenhouse agriculture: ADFCA and EAD have partnered to set up the Abu Dhabi Protected Agriculture centre to promote the use of greenhouses and soilless agriculture, a technique that involves growing plants in hydroponic and soil alternatives. The process uses 90% less water for the same volume of crops produced.

Ongoing research into crop requirements: There has been a realization that over-watering is a huge problem in the emirate and before any measures can be introduced that link water allocation to crops to farms and forests, evidence is required on just how much each crop and tree species needs over a year. This applies to both agricultural and forestry activities, existing and future, should be as water efficient as possible. On-going research in which sap meters are fitted to various crop species and linked to ground sensors has been an important new initiative by EAD with the results expected in a year.

3.6.3.2 Alternative water developments

Using recycled water in agriculture: Recycled water is used well below its potential. Still today only 55% percent of treated wastewater water was reused for irrigation, with the remaining 45% was discharged to the Arabian Gulf due to the lack of proper infrastructure for transmission. ADFCA is currently implementing a project to irrigate 216 farms with treated waste water in Al Nahda and Al Wathba areas. The results will be used to inform future policies and incentive schemes.

Enhancing supplies to the strategic groundwater reserve through ASR: ADWEA and EAD started work on creating a protected strategic water reserve in Liwa for use for domestic supplies in an emergency situation, using Aquifer Storage and Recovery (ASR). Currently the emirate has just 2 days water stored for domestic use. In 2012, 17 billion litres of desalinated water, excess supplies from summer co-generation activities, were injected into the Liwa groundwater Aquifer, increasing the capacity to supply Abu Dhabi's emergency water needs to 90 days (including special measures to limit water consumption to all but the barest minimum needs). This part of the Liwa Aquifer is now protected by law, with in this area limited to 90% of the annual average recharge to ensure a balance between consumption and availability.

The success of these measures is hard to measure as they are relatively new and changing socio-economic conditions and growing salinity conditions are as much responsible for the decline in areas being farmed as much as government policies. There are no measures of groundwater consumption and observation wells across the emirate still show declines in level, although the rates vary between areas. The FSC is having an increasing impact and using this agency, with its system of consultants that visit farms regularly to offer advice as well as check on activities is proving vital. Farmers acknowledge that EAD agents also make visits to check on groundwater use, but these are less frequent and they are viewed as regulators not partners. The approach of sticks (regulations, removal of subsidies) and carrots (incentives, advice, evidence-based consultation) are important and with the development of a more community based thinking facilitated by the FSC, they are in many ways a return to previous views of water. However, the greatest challenge to the effectiveness of these measures is that most landowners are absent with decision-making taken by those with little vested interest in the sustainability of the emirate.

Water quality policy measures have been limited to date but there are increasing plans to include regulated controls to manage salinity levels in particular. There have been many calls for further controls on pesticide and fertilizer use. The FSC has been working with farmers to manage this through their extension work and control of supply systems in which subsidized products available through the service. Managing crops through the adoption of salinity tolerant species and reducing over watering are again through information and economic instruments rather than through regulation.

3.6.4 Proposed and in the early stages implementation policy measures

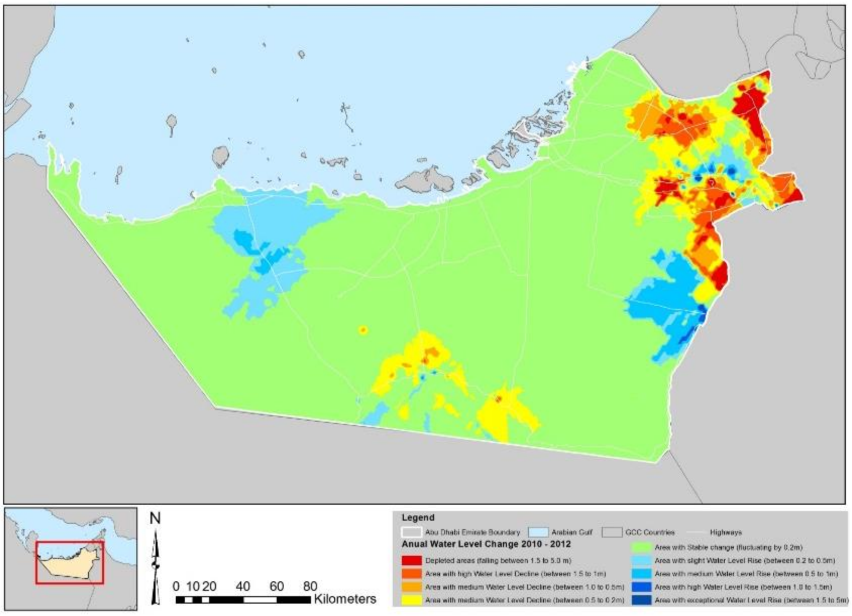
In addition to the policy measures reviewed in 2.5.3, a series of further ideas are in various states of review and implementation and give good insight on the pathways the government would like to follow. These were introduced in the various policy documents of 2012 and 2013 highlighted in Section 2.5.2:

Red zones

Red zones are areas where the quality of groundwater is deteriorating or areas that have a significant decline in groundwater levels (Figure 366). Drilling of new or replacement wells, and deepening of wells, should be prohibited in these areas where other alternatives is possible. These areas are still being discussed between the agencies because of farmer's discontent with the designations and the subsequent restraints on activities. There is a new study being undertaken in 2016 in which the red zones will be more systematically defined and once the new maps are agreed there will be moves to implement this policy. In the meantime some of the farms in these areas are running dry of water and more than a dozen requests have been made to bring treated wastewater to serve the needs. At the moment the cost of this would be prohibitive.

At present, EAD has authority to map changing groundwater levels and restrict access if groundwater is deteriorating. Deterioration was loosely defined and in the legal language and EAD has developed "red-zones" to outline areas of degradation. At present a groundwater red-zone is an area with 1.5m drawdown or greater per year. In theory, no new groundwater well can be installed and existing wells cannot be refurbished or deepened in these areas. As a result, much of Al-Ain and more recently parts of Liwa and Baynouna and Ghayathi have met these criteria. At present salinity is not present within the definition of groundwater deterioration but it is being considered for future inclusion since it is particularly pertinent in the Liwa area.

Figure 36. Map of changes in groundwater levels with red zones highlighting those areas under greatest stress



Source: Government of Abu Dhabi, 2013.

Location of new agricultural land

Any future allocation of land for agriculture should take account of the availability and quality of water, either recycled, desalinated or groundwater, and the suitability of the soils. Agriculture should be located in areas where there is a long term and sustainable source of water. No new agricultural land should be allocated in red zones, areas where the groundwater aquifer is being depleted rapidly or where the fresh and brackish element of the groundwater is almost exhausted.

Allocating different types of water

Fresh groundwater should be conserved to act as a source of fresh water in the event of large scale disruption to desalination plants. Therefore, where possible its used should be avoided for irrigation. Where the infrastructure exists or where it makes economic sense to develop the infrastructure recycled water should be used for irrigation. In some cases desalinated water should be used for agriculture irrigation but desalinated water should not be used to irrigate forests.

Prioritization of water allocation between agriculture and forestry

Where a choice has to be made between allocating water to agriculture or forestry then agriculture should take priority. For example, the current water requirements of the farms and the forests in the 'red zones' significantly exceeds the availability of groundwater which is causing the groundwater levels to decline at a significant rate. Access to recycled water is also limited and therefore an assessment should be made to determine the viability of forestry in the red zone areas.

Government well fields versus wells on farms

In areas where access to new groundwater is required and approved, the preference is to create government well fields to supply farms with the appropriate volumes of water, rather than providing wells on farms. Only where a government well field is not feasible should a new or replacement well be drilled on the farm. In these cases the wells should have permits with volumetric limits, and meters, which EAD will regulate.

Water metering

All water supplied to farms or forests, whether groundwater, recycled or desalinated water, should be metered and monitored. However, this has not been implemented because of the strong reaction to these provisions by the land owners.

Ultimately, the EAD aims to meter wells to monitor abstraction and have reliable data on which to execute regulatory actions and future groundwater management plans. Realizing this goal will be challenging for a range of reasons, the first of which is financial considerations: there are estimated to be over 100,000 wells in Abu Dhabi which would require meter installation. This would require a monumental effort, the equipment itself is expensive and also it must be able to withstand the very harsh conditions of the UAE desert. In addition, it's a highly contentious issue socio-politically because Emirati farm-owners believe that metering is the first step to charging for groundwater.

Political consensus is building on the need for metering but gaining buy-in from farmers will be difficult. Well-licensing and permitting, for which government officials expected backlash, was smooth. However, in 2006 after the beginning of well licensing, EAD began installing meters on wells but there were immediate complaints and the program was stopped. Since installation and maintenance of the meter will be dependent on farm owners, there must be significant buy-in from farm owners and also strong regulatory mechanisms to enforce their operation. Government officials interviewed during this survey believed that metering would be resisted, perhaps strongly, but several stated that as long as enforcement was even, it would be accepted in the end. They stated this is the case since awareness is building about the precariousness of groundwater supplies given the disastrous drawdown in the Al-Ain area and its impacts on agriculture. In any case, balancing subsidy incentives and enforceable punishments will be critical.

Unless a wide-scale command and control irrigation water supply system along the lines of the ADFCA well-fields in Al-Ain and Abu Dhabi is developed, well-metering is the lynchpin component of planned water demand management regulation efforts. Without accurate measurement of actual abstraction, regulatory efforts for agricultural water management will be impossible

Crop calculator

Longstanding research efforts by the ADFCA and EAD have been undertaken to determine crop water needs dependent on various conditions and in various seasons. This work is key in future efforts to determine volumetric needs based on cultivated area, type of cultivation and crop choices. The crop calculator project is a broad-based effort that will permit the creation of policy and regulatory tools in the future.

Ongoing studies in the UAE show that extant irrigation practices lead to significant over-watering of crops. For example, anecdotal evidence suggested that farmers typically apply ~150l of water per date palm per day in the summer and ~50l per palm in the winter, and the consumption statistics from farms participating in ADFCA's well-monitoring program suggest in some areas it may be much higher. Current research has shown those volumes to be in excess of plant requirements as determined through sap flow by at least two and a half times (Green et al, 2014). The EAD is currently utilizing this type of research for date palms, horticultural crops, etc., to create crop water calculators and associated irrigation support tools to help farmers irrigate only to crop water needs (Alhammadi, 2013; EAD, 2014; Interviews B, 2016).

Groundwater economic valuation

The EAD recently commissioned a groundwater valuation study in the Emirate suggesting that groundwater valorization may play a role in future policy developments for agricultural planning and water resources management in line with Abu Dhabi Environment Vision 2030. This is the first comprehensive study of its kind in the Emirate. The study took an integrated water resource and econometric dynamic optimization modelling approach to estimate groundwater values.

The valuation of agricultural water consumption utilized a standard FAO approach for estimating maximum achievable yields using crop-specific water requirements and net revenue achievable for given farm systems and land units. For forestry, carbon storage, habitat provision for wildlife and endangered species, support of cultural heritage and protection of roadway infrastructure values were estimated using social costs of carbon as well as willingness to pay and cost avoidance methods. For amenity use the value was simply equated to the total costs of desalinating and distributing water since it is a direct substitute in many instances. Finally, the strategic reserve value of groundwater was equated to the total costs of the Liwa aquifer storage and recovery project. The distribution of total net groundwater value across sectors by discount rate scenarios are shown below.

The study concludes that the strategic reserve value of water is the single largest component of overall groundwater value. With the 3% discount rate applied agriculture is the third-largest portion of total economic value whereas with the 5% and 8% rates it is second with amenity values following. Forestry values are the lowest in all scenarios. Agriculture is proportionally less valuable than forestry and amenity uses in the 3% discount rate scenario because values for forestry and amenity uses increase in line with projected population growth.

Table 13 Proportional groundwater value components

Scenario	Agriculture	Forestry	Amenity	Strategic Reserve
3% Discount Rate	21.0%	9.5%	29.8%	47.6%
5% Discount Rate	27.3%	4.0%	15.0%	64.4%
8% Discount Rate	21.0%	0.9%	4.7%	82.4%

Source: EAD,2016.

The marginal value of groundwater estimated in this study was calculated over a 50-year period and implicitly captures competing use values, consumption costs and the value of the strategic reserve for each groundwater supply area and then generalized for Abu Dhabi as a whole. In all discount rate scenarios, the marginal value of abstracting one cubic meter of groundwater in the first 15 years approaches the current cost of seawater desalination and is quite stable; in years 16-30 it is higher than the current cost of desalination for all scenarios – when using 5% and 8% discount rates more than double; in the years 31-50 the marginal values range from more than 2.5 to 13 times the current cost of desalination. This shows that generally the marginal value of abstracting each unit of groundwater increases at close to the discount rate with some variation dependent on the increasing consumption costs (higher electricity usage for pumping groundwater), varying levels of water quality and their impacts on utility, and maximum achievable value in each groundwater supply region.

The marginal value of groundwater represents the economic benefit of groundwater withdrawals and is the implicit price for groundwater. It would be the starting point to determine subsidy values for increasing efficiency, water pricing or abstraction fees. More generally, having information on the economic valuation of groundwater provides a baseline of information to understand the trade-offs in various policy decision-making scenarios. Given that water charges do not exist, these findings are beneficial at the general policy level to assess trade-offs and water management policy options.

New policy developments

A new water law linking the measures identified above is under consideration and recently passed through the General Secretary of the Executive Committee. Currently it is awaiting approval from the Ruler of Abu Dhabi. This law would provide EAD and ADFCA more expansive authority than under the current legal regime and it has three fundamental aims: 1. Regulate and control small-scale desalination since this has major impacts on the shallow aquifer; 2. Increase EAD powers to enforce bans of groundwater sales in the Western Region; 3. Set well abstraction limits for farms and individual wells based on cultivated area and crop calculator determined needs.

The specific instruments for implementing these policies was not discussed but general comments about the third point suggested that farms may have water abstraction permits based on crop calculator determinants plus a small buffer volume. If farms go past the allocation, subsidies may be removed in a tiered fashion and/or fines implemented. However, the full realization of this new law will take some time given that currently there are not accurate methods to monitor abstraction in the absence of meters and the difficulty inferring abstraction volumes from electricity consumption.

All these policy measures are however being only considered but mark a strong shift to greater regulation and so an increased role of the state. Given the prevailing environment of maintaining security and stability in the country, especially with the effects of the Arab Spring only too close, there are difficulties of introducing them in the rural areas where the Emirati population is much more dominant and cultural and heritage ties to the land are pronounced. The owning of land and the farming therein is a sign of prestige and moves to control this are met with resistance. Anecdotal evidence of water meters being disconnected and thrown down into wells on the few attempts made to enforce this measure are just one of a number of signs of non-compliance exhibited by the landowners. Some fear that the meter will eventually mean pricing for water. This continues to hold back the ability of government agencies to implement and enforce the various laws, regulations and policy instruments.

3.6.5 A new framework for the next decade

In recent moves, a new framework for water management has been introduced by the Secretary General for EAD, HE. Razan Al Mubarak. She introduced the concept of the 'water budget' at the International Water summit 2014, in Abu Dhabi:

> "Business as usual will not solve this looming crisis, we need to change the way we think about water, we need to plan around a defined volume of water which we carefully allocate within our economies. In other words we have a water budget. If we want to allocate more water to one sector of the economy we need to reduce consumption in another in the same way governments allocate funds across different sectors".

EAD have since added further details to this concept and states that whilst it is not EAD's mandate to set a 'water budget' for Abu Dhabi their intention is:

- To make the case that the current approach of continually striving to meet a growing demand is not sustainable
- To present an alternative approach i.e. using a water budget
- To present this water budget with numbers and options or scenarios
- To start a discussion and build support around the water budget concept

The agency has since commissioned research to quantify and clarify in detail the different components of the water budget including options, which takes a much accounting view of water situation. The aim is to bring the ideas of a water budget as central to Abu Dhabi's future water policy developments with a return to consensus building, but instead of it being tribal, it is based on the water community technocrats and decision-makers

3.6.6 Identified challenges to groundwater governance

The changes in water governance, particularly in the last decade have moved water management towards a more professional and business-like mentality. The Emiratis involved are highly capable, skilled and motivated policy and management professionals leading the discussions, strategic developments and planning who are aware of both the water scarcity situation but also the cultural nuances of introducing and implementing measures that many Emiratis would perceive as infringing on their natural rights.

The involvement of the ruling family in groundwater affairs is limited. The President's younger brother H.H. Sheikh Diab Bin Zayed Al Nahyan, was chairman of ADWEA and advocated and advanced the role of the private sector in desalination and electricity generation. He was part of the reformist group within the ruling family that was aware of the influence of the fluctuations of oil prices and the increasing cost of the welfare society on the emirate. Today the chairman of ADWEA is Sheikh Abdullah bin Mohammed bin Bati Al Hamed, not from the ruling family.

For the control of groundwater resources, the head of EAD has come from elite families connected to the ruling family. Today this is HE Razan Al Mubarak, with the previous incumbent H.E. Mansour Al Mazroui being invited to join the emirates Executive Council during his time as head of EAD. He was 'promoted' to head the Department of Municipalities. EAD today follows roles more focused on regulation and environmental protection than under the previous head, where large projects involving particular areas of conservation were prevalent. This re-positioning, reflecting both the needs of the emirate, and a new more-limited budget regime means that its ability influence through the ruling family and elite is important in introducing the required changes in groundwater governance and policies.

Groundwater policies themselves cannot be reviewed in isolation as there are many interlinked opportunities, challenges and issues between the three different resources. The controls and ability to control the three taps varies, as a result of the perceptions of the population towards the source and its value, the user sectors involved and the links to rights and ownership, particularly linked to land.

For desalinated water, the population generally understands the production is expensive and there is a need for the government costs to be offset through tariffs. There is however, a tacit 'social contract' between the Emirati population and the government that in return for managing the oil revenues, and for controlling foreign and domestic policy, elite will provide a welfare state in which their living expenses are heavily subsidized and employment opportunities are readily available. The case of the expatriates living in the emirate is more complex. The citizens often argue against the expatriates receiving subsidized water (and energy) as they do not contribute through tax to government revenues. However, there is also an acknowledgement that expatriate labor is a vital input to the economy. There is already a differential tariff rate, and in late December 2015 this was further increased for expatriates, although the subsidy rate is still around 50% by the government.

For recycled water, given that the main uses are for amenity and landscaping, governance is less controversial and more clearly define and managed. The regulatory system is clearly defined and monitored in terms of effluent inputs to the sewerage system, and standards for the treated wastewater. The three municipalities are the main recipients of the recycled resources and given that there is currently no charge for the water, they use this freely to maintain the lush urban landscapes that have come to define the Emirate. The limits to the distribution network ensures that around half of the resource is underused, although with current policy initiatives and performance indicators there is a major push to ensure 100% is utilized in the next few years. The ability to expand its use beyond the amenity sector is limited by public perception rather than regulatory or management restrictions. There have been attempts to offer free supplies to individual farmers who live close to the major treatment works, who are experiencing water stresses, especially increasing salinity. However, there has been little uptake of this free water resource as there are worries they will not be able to sell their crops and that the soil will become unusable. Ongoing trials at research centers such as ICBA, are highlighting the low coliform counts in vegetables and other crops, but still farmers are not open to using this alternative resource so far.

Groundwater is the most complex and challenging water resource for management. There are few people if any within the emirate who are not aware of the stresses on the resource. The media coverage, in both Arabic and English, regularly run articles quoting researchers and practitioners alike, highlighting the increasing stresses and limits to the resources available. The continued attempts by EAD and other agencies responsible for groundwater resource management, to introduce ever more inventive methods for controlling water abstractions and use, highlights the commitment of the government to this end. However, the implementation of the measures is proving particularly difficult.

Given the main sectoral user of groundwater is agriculture, it would be possible to argue that the possibilities for management and regulation are easier as it is largely controlled by government policy and associated subsidies. Farming in the UAE is not possible without these interventions. Up until the last 5 years the policies encouraging water conservation were at direct odds with those encouraging farmers to increase production to enhance food security. There were therefore mixed governments signals with the strength of the agricultural lobby both at the agency and citizen level, ensuring farming and associated irrigated water use continued unrestricted by the various policy initiatives being introduced.

Land ownership, the sole vestige of Emirati citizens, brings with it inherent expectations as to what can and cannot be controlled by the government. There is also the tied links to family honor and prestige. Given that the transfer of land to families has only taken place over the last few decades, the arguments of cultural heritage are weak but are still made by those wanting to maintain the status quo on unrestricted water use. Most of the farms are hobby farms with the land owners gaining most of their income from public or private sector jobs in the main urban centers. The vast majority of land owners and their families do not live on the farms, only the Asian laborers. However, with any new measures discussed even agreed between the agencies responsible, there is a push back by the land owners to the ruling elite through informal channels particularly through discussions at the majilis of members of the ruling family. The different majilis are held a number of times of week by different close members of the ruling family and these are well attended by male Emirati citizens. The policy instruments such as limiting abstractions and quotas are put on hold. The stability of the country, particularly amongst the local population, has therefore often been at the expense of much needed water reforms. The political unrest within the region in recent years has only exacerbated this.

The two measures that are having some traction are monitoring and zoning. With the latter, land owners in the red zone cannot extend their water use through new wells etc. Given the increasing salinity of the groundwater in these areas, and the need for deep drilling, changes in water use in these areas is as much as result of limits from the resource as to effectiveness in implementation of policy measures. With monitoring, the tighter working relationship established between the agencies responsible for agriculture and water, ensure that there is more effective monitoring and control over water use and new wells being drilled. EAD's approval is needed as part of the process overseen by ADFCA for well expansion. EAD is also visiting farms more regularly these days to take samples, as part of the contract with the Farmers Service Center. This linking across the agencies is bearing fruit and is likely to be the platform in the future for which policy reforms are developed and implemented.

In examining the UAE it is important to understand that the country is still only 44 years old. The state apparatus, so strong in many other MENA countries, has only really been developed in the last decade to a professional and technical level that it is effective and impactful through regulations, practices and policy measures. Ruling continues to be through consensus as it always has been. The so called social contract remains strong and is referred to in interviews with citizens, whereby the government is responsible for their well-being, whether through the provision of houses, jobs, education, health care, even weddings, in return for the ruling families managing the hydrocarbon wealth. Any changes to the well-being of the citizens, such as through the restriction of groundwater use on their farms, is met with displeasure and complaints through the informal system. The public airing of disquiet is not possible or acceptable culturally in the emirate.

4 Synthesis

The changes in Abu Dhabi's water policy and governance environment are as marked as those in the resource provision itself. The emirate has undergone remarkable developments with governance changing from community/tribal to individual to state. The societal and structural user base for all water resources is complex and reflects the remarkable economic developments of the last 60 years. The recent article on Abu Dhabi's hydrosocial cycle (McDonnell, 2014) highlighted the changes the water provision has brought not only in the activities and new landscapes supported, but also in altering society's relationship with and its subsequent use of water. Profligacy has replaced parsimonious use practices.

The largest changes to groundwater systems have resulted from agricultural policies in the last 40 years. The creation of a large group of Emirati landowners has transformed the agricultural production base from one of nomadic-pastoralism and limited oases cultivation to sedentary farming reliant on groundwater pumping and highly subsidized inputs and government marketing support. These landowners are not from a tradition of farming with many being given land as a form of patronage, although some are there from the policies of settling tribal families. Many of these farmers gain their main income from jobs in the urban centers, so farm labourers brought from outside the emirate are the majority of workers. The input to the national economy is limited and far outweighed by hydrocarbon and commercial revenues.

The changes this has brought are dramatic with moves from community based groundwater water systems to individual centered ownership. With growing populations, colonial influences and enormous repercussions from the discovery of oil, the old tribal systems with their rules and regulations have been pushed aside and replaced by an evolving statism that relied on patronage to establish itself. The creation of the nation-state in 1971 solidified this. It has evolved into a highly technocratic system but is still controlled by the powerful need to maintain the ruling status quo. Water throughout this evolution has been a symbol of bounty, wealth and modernity. The societal basis of its regulation has evolved from survival-based strategies, to relaxed laissez-faire facilitation of a vision of greenness, to a more focused and critical bureaucratic management effort as the true extent and limits of water resources and security have become acknowledged in the state apparatus. The path forward being followed today is one of integrated state management with policy measures supported by subsidies and tariffs as opposed to regulatory enforcement.

5 References

Abu Dhabi Urban Planning Council, 2007. *Plan Abu Dhabi 2030: Urban Structure Framework Plan,* Abu Dhabi, Abu Dhabi Urban Planning Council. (http://www.upc.gov.ae/?lang=en-US)

Abu Dhabi Water and Electricity Company (ADWEC) 2013. *Statistical Report 1998-2013*, http://www.adwec.ae/Statistical.html (accessed 12/8/2015).

ADCO, 2015. ADCO sustainability report 2012-2014. Abu Dhabi, ADCO.

ADFCA (2016a) Unpublished data: ADFCA-controlled irrigation stations in Abu Dhabi

ADFCA (2016b) Unpublished data: Water consumption in farms with well meters.

ADNOC, 2009. ADNOC Sustainability report. Abu Dhabi, ADNOC

ADNOC, 2012. ADNOC Sustainability report. Abu Dhabi, ADNOC

ADNOC, 2013. ADNOC Sustainability report. Abu Dhabi, ADNOC

Al Amari, K.A., 1997. Assessment of Environmental Impact of Re-Injecting Oil-Field Water in the Miocene Clastic Sediments on the Shallow Aquifer at Bu Hasa Oil Field, United Arab Emirates: Unpublished M. Sc. Thesis, UAE University, Al Ain, United Arab Emirates.

Allan, J.A. 2002. The Middle East water question: Hydropolitics and the global economy. London and New York: I.B. Tauris

Alsharhan, A.S., Rizk, Z.S., Nairn, A.E.M., Bakhit, D.W., and Alhajari, S.A., 2001. *Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas*. Amsterdam, Elsevier.

Beaumont, P., Bonine, M. and McLachlan, K. (Eds). 1989. *Qanat, Kariz and Khattara*. Wisbech, Middle East and North African Studies Press.

Brook, M. 2005. *Water Resources of Abu Dhabi Emirate*, Abu Dhabi, EAD.

Codrai R. 1990. *The Seven Sheikhdoms: Life in the Trucial States Before the Federation of the United Arab Emirates*. London, Stacey International.

Environment Agency - Abu Dhabi and International Center for Biosaline Agriculture, 2010. *A strategy for the Use of Recycled Water in the Emirate of Abu Dhab*i, Unpublished report Abu Dhabi, EAD.

Environment Agency - Abu Dhabi, 2011. *Abu Dhabi Environment Vision 2030*. Abu Dhabi, EAD.

Environment Agency - Abu Dhabi, 2012. *Political, Economic and Social Assessment of Groundwater Management in Abu Dhabi.* Abu Dhabi, EAD.

Environment Agency – Abu Dhabi, 2016 (2016) Unpublished report: Economic Valuation of Groundwater in the Abu Dhabi Emirate.

Fahim, M. 1995. *From Rags to Riches: Story of Abu Dhabi*. London, The London Centre of Arab Studies.

Fragaszy, S., and R. McDonnell. 2016 *Oasis at a crossroads: agriculture and groundwater in Liwa, United Arab Emirates*, Project Report, USAID 'Groundwater governance in the Arab World', Cairo, Dubai.

Government of Abu Dhabi, 2013. *Water Resources Management Strategy for the Emirate of Abu Dhabi: A high level strategy and Action Plan for Efficient Management and Conservation of Water Resources*, Abu Dhabi, Government of Abu Dhabi.

Government of Abu Dhabi, 2013. *Water Resources Management Strategy for the Emirate of Abu Dhabi: A high level strategy and Action Plan for Efficient Management and Conservation of Water Resources*. Abu Dhabi, Government of Abu Dhabi.

Hamdan, A.A., and Anan, H.S., 1989, The Paleocene tectono-sedimentary events, of Jabal Malaqet, east of Al-Ain, west northern Oman mountains. Ain Shams University Earth Science Services Report, pp. 209-214.

Hassan, A.A., and Al-Aidarous, A., 1985, Regional aquifer geology - onshore Abu Dhabi. ADCO project report 1584-50. Abu Dhabi, ADCO

Heard-Bey, F. 2001. *The United Arab Emirates: transition in a federal state.* Occasional paper, University of London, Centre of Near and Middle Eastern Studies.

Heard-Bey, F. 2005. *From Trucial States to United Arab Emirate.* Abu Dhabi, Motivate Publishing Ltd.

Hutchinson, C.B., K.D. Al Aidrous and Budebes, O.A., 1996. *History of water resources development in Abu Dhabi Emirate*. Abu Dhabi, USGS/NDC

Interviews A, 2016. Interviews with ADFCA officials in Abu Dhabi conducted in May 2016.

Interviews B, 2016. Interviews with EAD officials in Abu Dhabi conducted in May 2016.

Jorgensen, D.G & Al Tikriti, W.Y, 2002. A hydrologic and archeological study of climate change in Al Ain, United Arab Emirates. *Global and Planetary Change*, 35, 37-49.

Khalifa, M.A., 1997. Hydrogeology of the geothermal fractured-rock well field at Jabal Hafit, Abu Dhabi Emirate: *Proceedings of the Third Gulf Water Conference*, Muscat, Sultanate of Oman, pp. 125-140.

Lambert, L. 2013. *Water Governance in the Gulf Cooperative Council Countries: A comparative analysis.* Unpublished DPhil thesis, University of Oxford

Lienhard, 2001. *Sheikhdoms of the Eastern Arabia*. New York, Palgrave.

McDonnell, R. A. (2014). Circulations and transformations of energy and water in Abu Dhabi's hydrosocial cycle. *Geoforum*, 57. 225-233.

Ministry of Environment and Water, 2010. *United Arab Emirates Water Conservation Strategy.* Dubai, Ministry of Environment and Water.

Mohamed, A.M.O., Maraqa, M. and Al Handhaly, J. 2005. Impact of land disposal of reject brine from desalination plants on soil and groundwater. *Desalination*, 182,11-433

Moreland, J.A., Clark, D.W and Imes, J.L. 2007. *Groundwater – Abu Dhabi's hidden treasure*. Abu Dhabi, National Drilling Company. Abu Dhabi, USGS/NDC

Pitman, K., McDonnell, R., Dawood, M. (Eds) 2009. *Abu Dhabi Master Water Resource Plan*. Abu Dhabi, EAD.

Pitman, K., McDonnell, R., Dawood, M. (Eds) 2009. *Abu Dhabi Master Water Resource Plan*, Environment Agency Abu Dhabi, Abu Dhabi, UAE.

Pitman, K., McDonnell, R., Mellor, C., Al Mulla, M.A., Ebraheem, A. (Eds) 2010. *United Arab Emirates Water Conservation Strategy*, Dubai, Ministry of Environment and Water.

Rabi, U., 2006. Oil politics and tribal rulers in Eastern Arabia: The reign of Shakhbut (1928-1966). *British Journal of Middle Eastern Studies*, 33, 37-50

Rizk, Z.S., and Alsharhan, A.S., 2003, Water resources in the United Arab Emirates, In Alsharhan, A.S. and Wood, W. W. (Eds.), *Water Management Perspectives: Evaluation, Management and Policy,* pp. 245-264. Amsterdam, Elsevier Science.

Rizk, Z.S., and El-Etr, H.A., 1997. Hydrogeology and Hydrogeochemistry of some springs in the United Arab Emirates. *The Arabian Journal for Science and Engineering*, King Fahd University for Petroleum and Minerals, Dhahran, Saudi Arabia, 22, 95-111.

SCAD, 2014. *Agricultural land uses 2013 Statistical Report*. Abu Dhabi, SCAD

SCAD, 2015a. *Abu Dhabi Statistical Yearbook 2015.* Abu Dhabi, SCAD

SCAD, 2015b. *Annual National Accounts Gross Domestic Product, 2010-2014*. Abu Dhabi, SCAD

Schlager, E. 2007. Community management of groundwater. In Giordano, M. and Villholt, K. G. (Eds), *The agricultural groundwater revolution: opportunities and threats to development*. Wallingford, UK and Cambridge, MA, CABI.

Statistics Center Abu Dhabi, (2015) *Abu Dhabi Statistical Yearbook 2015*. (Accessed through http://www.scad.ae/. September 2nd, 2015)

Statistics Center Abu Dhabi, 2014. http://www.scad.ae (accessed Aug 8th 2014)

Sutton, S. 1984. The falaj- A traditional co-operative system of water management. *Waterlines*, 2 (3), 8-12.

Symonds, R. B., Robledo A. R. and Al Shateri, H. A. 2005 Use of environmental tracers to identify and date recent recharge to the surficial aquifer of northeastern Abu Dhabi Emirate, United Arab Emirates. *WSTA Seventh Gulf Water Conference – Water in the GCC – Towards and Integrated Management* . *Vol 1,* 19–23 2005 November, State of Kuwait, 471-486

UNEP (United Nations Environment Programme). 1983. *Rain and storm water harvesting in rural areas*. Dublin, Tycooly International Publishing Ltd.

USGS/NDC 1996. *Groundwater resources of Abu Dhabi Emirate*. Abu Dhabi, National Drilling Company.

Whittle, G.L. and Alsharhan, A.S. 1994. Dolomitization and chertification of the Early Eocene Rus Formation in Abu Dhabi, United Arab Emirates. Sedimentary Geology, 92, 272-285.

Wilkinson, J. C. 1977. *Water and tribal settlement in south-east Arabia: study of the aflaj of Oman*. Oxford, Clarendon Press.

Wolf, A. T. 2000. Indigenous approaches to water conflict negotiations and implications for international water. *International Negotiations*, 5, 357-373.

Wood, W. W., and Imes J. L. 2003. Dating of Holocene ground-water recharge in the Rub al Khali of Abu Dhabi - Constraints on global climate-change models. In: A.S. Alsharhan & W.W. Wood (editors). *Water Resources Perspectives: Evaluation, Management and Policy*. The Netherlands, Elsevier Science.

Wood, W. W., and Imes, J. L., 1995. How wet is wet? Constraints on late Quaternary climate in southern Arabian Peninsula. *Journal of Hydrology* 164: 263- 268

Wood, W. W., Rizk, Z.S. and Alsharhan, A.S., 2003. Timing of Recharge, and the Origin, Evolution and Distribution of Solutes in a Hyperarid Aquifer System. In: A.S. Alsharhan & W.W. Wood (editors). *Water Resources Perspectives: Evaluation, Management and Policy*. The Netherlands, Elsevier Science p. 295-312.

Woodward, D.G., and Menges, C.M., 1991, Application of uphole data from petroleum seismic surveys to ground water investigations, Abu Dhabi, United Arab Emirates. *Geoexploration*, 27,193-212.

World Bank, 2014. *World Development Indicators*, http://data.worldbank.org/country/united-arab-emirates

6 Appendix 1

Sector performance indicators in delivering on Environment 2030 Vision of the Abu Dhabi Government that relate to water.

Sector specific policy targets		
Sector	**Policy imperative**	**Target**
Agriculture, Livestock and Fisheries	Optimise groundwater use for agriculture	Annual groundwater abstractions for agriculture not to exceed 750Mm^3 and 18% improvement in water efficiency
Agriculture, Livestock and Fisheries	Minimise groundwater pollution and salinisation attributed to agriculture	100% measured application of fertilisers and pesticides
Public Realm Amenities and Forestry	Develop low water requirement amenities and forestry sectors	60% reduction in the average water intensity of all amenities relative to 2010
Environment Sector	Explore innovative solutions for groundwater use and conservation	100% of freshwater bodies protected as strategic reserves
Environmental outcome targets		
To extend the lifespan of Abu Dhabi's usable[*1] groundwater		from 50 to 75 years
To limit the increase in salinity of groundwater reserves		To be determined
[*1] usable groundwater is defined as the fresh and brackish water which has salinity below 10,000 ppm total suspended solids. Currently 21% of the groundwater is fresh or brackish; the rest is saline and not usable.		

7 Appendix 2. Gaps and Challenges In Governance as defined in Government of Abu Dhabi 2013

GAPS AND CHALLENGES IN GOVERNANCE AFFECTING THE PERFORMANCE OF THE WATER SECTOR					
#	Governance tasks (*)	Clear definition of roles and responsibilities	Performance	Ga ps	Already being addressed? How?
1	Provide policy direction	☒		The PCWAS has limited powers to ensure coherent policies across all the water sources and uses.	PCWAS proposed the creation of a Water Council in October 2012. To be approved by GSEC
2	Develop integrated sector strategy and action plans	☒		No agreed all-stakeholders shared strategy	GSEC will request all sectors to jointly develop sectoral plans starting in 2014
3	Set sector targets	☒		Lacks integration across Agencies. Several entities set their own targets but they may differ. Baseline data is not reliable and this makes difficult reaching agreement on common targets	This strategy is a starting point.
4	Monitor and evaluate strategies and action plans	☒		No agreed system to monitor and evaluate the performance of existing or future strategies.	GSEC will propose a mechanisms to monitor and evaluate sectoral plans starting 2014
5	Establish coordination mechanisms	☒		No overall coordination to ensure the best allocation of the three types of waters amongst users. No overall coordination from Production to Use, e.g. structural misalignment of government departments between ADSSC, DMA (ADM) and UPC, TPD affect recycled water management	Non-Drinking water business proposed to PCWAS, still to be approved. Creation of numerous Committees. Policy agreement between ADSSC and DMA (ADM)
6	Set and enforce policies and regulations	☑		Tankering regulations may be required. RSB regulates recycled water up to the point of transfer after which there is a regulatory gap that needs to be addressed	Water Supply and Water Quality Regulations in force. Recycled Water and Biosolids Regulations promote quality and Reuse. Trade Effluent Control Regulations protect Recycled Water quality.

7	Provide technical guidance and standards	☑			High level technical guidance available for both water and wastewater quality and supply/disposal. Irrigation and Landscape Standards and Specifications update under progress
8	Provide incentives	☒		Lack of a suite of incentives to encourage water conservation behaviour	Tariff proposals have been developed along with impacts.
9	License and permit activities			Need more rigorous implementation of licence conditions. Implement incentives and performance measurement. Utilise performance reporting in the public domain.	
10	Inspect, monitor performance and enforce compliance with policies and regulations	☑		In some areas network metering is not complete	
11	Collect, analyse and publish data	☒		Lacks integration across Agencies No regional water balance and budget. Data published by many sources sometimes data is not consistent amongst different sources or from year to year No integrated water sector report.	Annual Report and Annual Technical Reports produced by RSB and EAD. RSB currently collecting and analysing data with a view to publishing water balance information (water, wastewater, recycled water) The Pearl Operational Rating System (PORS) will collect empirical data from Pearl Rated projects.
12	Conduct research and innovation	☒		Lacks a focused approach across Agencies Consumption rates for water between premise types and consumer types needs to be better understood. Joined up research would be useful – many agencies looking at similar issues No clear mandate to research new technologies Links with academia and Masdar	Waterwise Office at RSB conducting study to better understand the domestic consumption patterns for potable water.

13	Raise awareness and behaviour change	☒		Multi-agency responses lack consistency Lack of a structured media campaign to promote water conservation	Waterwise Office at RSB tasked with raising awareness and influencing behavioural change with regard to domestic water consumption. ADFCA jointly with ADFSC tasked with raising awareness and influencing behavioural change with regard to irrigation water use in farms.
14	Develop human capital	☑		Lacks a focused approach across Agencies	Individual approach rather than inter-Agency e.g. training etc.
15	Develop partnerships	☑		Lack of formalised partnerships	Relationships healthy but solution creation is lacking across Agencies
16	Deliver infrastructure projects	☑		Lack of distribution infrastructure to end user to ensure full use of recycled water. Currently around 45% of the recycled water in the Abu Dhabi area is being dumped to sea. End-user Demand realisation	Five Year Planning Statements drive infrastructure projects. Need linking to better data. Investment in Transmission. ADSSC has already invested over 1 billion AED in expanding the transmission network in the mainland and Yas Island. It is designing and implementing a significant extension to its recycled water network. Will allow far greater volumes of recycled water to be delivered to consumers. In addition, DMA (ADM) is currently preparing the Irrigation Master Plan with the main aim of Irrigation infrastructure development and improvement to meet DMA (ADM)'s landscape irrigation water requirements up to the year 2030, in line with the UPC Abu Dhabi Plan 2030, Abu Dhabi City Landscape Master Plan, Estidama Guidelines, EAD's Environmental Strategy 2030, and integrating with ADSSC TSE-Master Plan
17	Provide finance for initiatives	☑		Finance is not regarded as a barrier to advancement. Approval processes for projects should be readily.	

INTERNATIONAL WATER MANAGEMENT INSTITUTE (IWMI)

The International Water Management Institute (IWMI) is a non-profit, scientific research organization focusing on the sustainable use of water and land resources in developing countries. It is headquartered in Colombo, Sri Lanka, with regional offices across Asia and Africa. IWMI works in partnership with governments, civil society and the private sector to develop scalable agricultural water management solutions that have a real impact on poverty reduction, food security and ecosystem health. IWMI is a member of the CGIAR System Organization, a global research partnership for a food-secure future, and leads the CGIAR Research Program on Water, Land and Ecosystems (WLE).
www.iwmi.org

127, Sunil Mawatha, Pelawatte, Battaramulla, Colombo, Sri Lanka
Mailing Address: P.O. Box 2075, Colombo, Sri Lanka
Tel: +94-11 2880000 Fax: +94-11 2786854 E-mail: iwmi@cgiar.org Web: www.iwmi.org

International Water Management Institute