GROUNDWATER USE AND POLICIES IN OMAN

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Groundwater governance in the Arab World

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1 Introduction

Oman presents a fascinating case study for any investigation into groundwater governance in the Middle East North Africa (MENA) region. Its arid conditions and mountainous landscape bring many challenges for water resource management especially with regards to food production. The landscape is dominated by the Hajar Mountains which run from the United Arab Emirates border through to the Arabian Sea. In the west and south-west is the Rub Al Khali desert wherein lies the border with Saudi Arabia. The coastal zone is the flattest area and the location of most economic activity, particularly farming

The country's governance is centred on an absolute monarch and His Majesty Sultan bin Said al Said has been the hereditary leader of the country since 1970. He is the longest-serving ruler in the Middle East. In terms of the economy, Oman is different to its hydrocarbon neighbours as its modest oil reserves are ranked as only 25th globally. There has been a concerted effort to use the wealth generated from hydrocarbons to support development in the country and by 2010 the UNDP ranked Oman as the most improved nation in the world in terms of development during the preceding 40 years. It has a GDP of around $82,254 billion with GDP per capita at $25, 014.244 (2014) with sector contributions from agriculture (1%), industry, (34.6%) and services (64.4%) (International Monetary Fund, 2014; Central Intelligence Agency, 2015).

Oman's population passed the 4 million mark in April 2014, with Omanis making up 56% of the total and the annual demographic growth rate of citizens at 2.79% (National Centre for Statistics & Information-NCSI, 2015). More than 75% of the population live in urban areas. By 2040 the Omani population is expected to rise to 3.6 - 4 million with a further 1.1 - 1.35 million expatriates if current policies to reduce the proportion of expatriates are fully implemented (NCSI, 2015; Hendawy, 2010).

Groundwater is the principal water resource in the country and its management is critical to the country's current development as well as those of future generations. The systematic over-abstraction of groundwater resources has resulted in aquifer depletion, collapse of traditional irrigation systems and groundwater salinisation in the coastal zones. Oman is now increasingly reliant on non-conventional water sources such as desalination and treated waste water (TWW) to fill the gap between supply and demand.

This report takes stock and outlines the issues challenges of groundwater governance in the country. 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. It has a rich tradition of community based groundwater governance that still functions today. The major transition in water resources provision taking place in Oman today is in response to a series of demographic, socio-economic and environmental drivers which have led to an increasingly water stressed situation.

This report is divided into two main parts. The first part reviews the main groundwater systems and their use today. This gives insight on changes of the state of the resource and the developments in both supply and demand systems across the different parts of the country, particularly focusing on the Al Batinah and Salalah (Dhofar) regions (Figure 1). In the second part, from Section 5 onwards, the groundwater governance systems and policies in place to manage the water budget are reviewed. Water resource governance in Oman reflects the developments in the country from a traditional communal customary based society to an established state headed by Sultan Qaboos bin Said al Said, in which organizations such as the

Ministry of Rural Municipalities and Water Resources (MRMWR) have responsibilities for protecting the groundwater reserves.

Figure 1. Map of governorates and main settlements in Oman

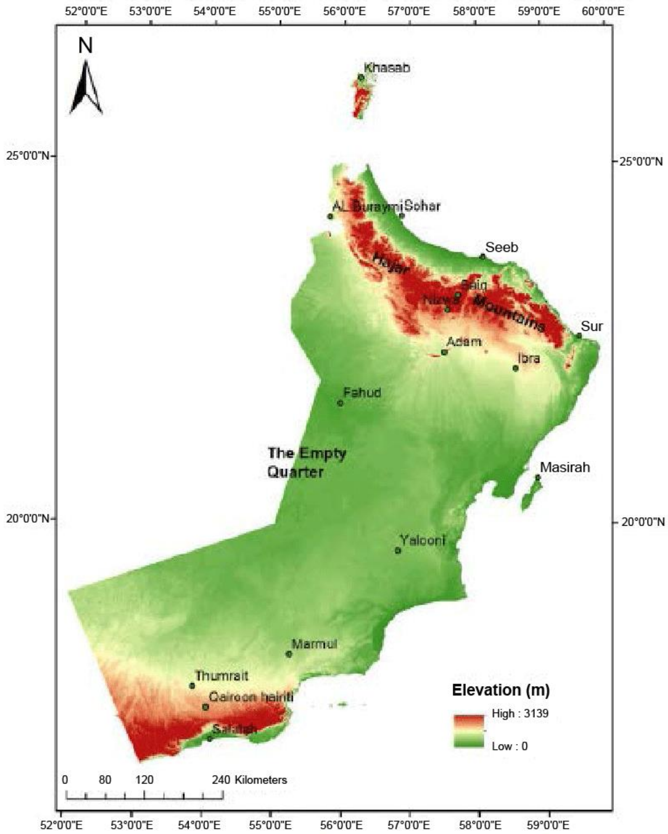
Source: www.mapsofworld.com.

2 Natural water resources

The natural aridity, coupled with coastal and orographic influences, ensure that the natural water resources of Oman are a mix of surface and groundwater systems. The land surface area of 309,500 km^2 broadly consists of deserts (~83%), mountains (~14%) and coastal plains (~3%). The country can be divided topographically into four major areas reflecting the influences of geography on economic activities, habitation and water systems: the Batinah coastal plains in the North, the most populous area and most important agricultural region; the Salalah coastal plains in the south; the interior mountainous areas consisting of the Hajar mountains that run from the Straits of Hormuz in Musandam to Ras Al-Hadd in Sharqiya Province as well as the Dhofar mountains; and finally the great internal desert regions that make up part of the Empty Quarter (FAO Aquastat, 2008) (Figure 2). The highest point is Jebel Shams in the Hajar Mountains reaching 3,000 metres. The dominance of mountainous and desert areas in the

Oman landscape means that areas for agricultural are limited. The main concentrations of economic activities are in the coastal areas of the Batinah and Salah.

Figure 2. Major elevation features of Oman

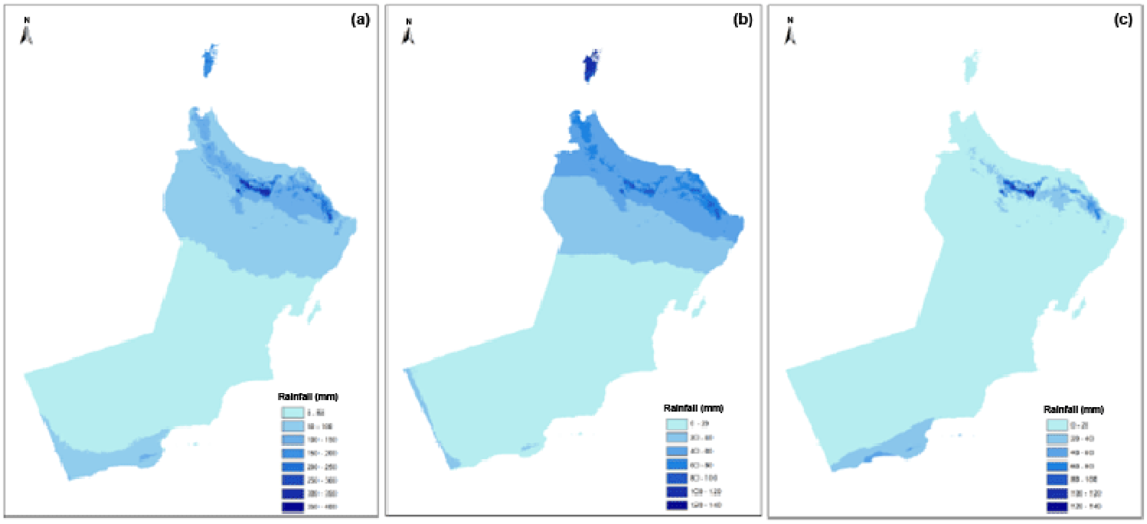


Source: Charabi, 2013.

2.1 Climate and background information

The overall climate of the country is hot and arid with an annual precipitation less than 100mm. However, the range of precipitation is significant with some interior areas averaging under 20 mm/year and some mountainous, coastal areas receiving up to 400mm/year (Kwarteng et al., 2009). Rare cyclonic events such as the landfall of Cyclone Gonu in 2009, and Cyclone Keila in 2011 can produce significantly more rain in a single day than average precipitation for several years. These extreme events brought extensive destruction to coastal areas. One rain gauge station in the Dhofar mountains near Salalah registered 400mm rain in one day with over 700 mm registered between 29 October and 4 November 2011 (DGMAN, 2012). Figure 3 illustrates the concentration of precipitation in the northern and southern mountainous regions of the country.

Figure 3. Rainfall patterns in Oman for the period 1961-1990 a) annual average b) winter average c) summer average



Source: Charabi, 2013.

Oman’s modern hydrometric monitoring network was primarily established between 1980 and 2000 and now consists of over 300 rain gauges, 130 wadi flow gauges, 31 dam gauges, 2,100 monitoring wells, 500 aflaj gauges and ~1,300 salinity gauges (Al-Sarmi, 2014). In volume units, the average annual amount of rain falling on Oman is estimated to be about 19,250 million cubic meters (MCM). Of this total, some 80% evaporates leaving approximately 3,850MCM as effective rainfall, of which 25% is runoff to the sea, and the remaining 75% is direct infiltration to groundwater (Ministry of Rural Municipalities, Environment and Water Resources – MRMEWR, 2005).

In northern Oman, the rainy season occurs between December and April and accounts for 58 to 83% of the annual rainfall, most of which is focused in February and March. The northern coastal regions are typically very humid and significant groundwater recharge occurs primarily through wadi bed infiltration both inland and closer to the sea in the Batinah Plains (ICBA, 2012).

The Salalah area is influenced by the Indian monsoon and receives strong summer rains in June to September that bring precipitation in the range of 100-300mm/year, but typically towards the lower end of that range (Kwarteng et al., 2009). In the monsoon affected coastal strip this brings a quite different landscape and agricultural production system than the rest of the country (Figure 4 illustrates). On average, southern Oman has less rainfall and less abstractable groundwater recharge than the north of Oman; groundwater flow-paths to the sea via coastal aquifers are quite short and the groundwater flow-path north and west to the desert leads to the Umm Al-Sammim depression where groundwater evaporates leading to increased groundwater salinity (ICBA, 2012).

Figure 4. The natural landscape in the Salalah coastal zone is strongly influenced by the monsoonal system

Source: http://www.world66.com/asia/middleeast/oman/salalah/lib/gallery.

2.2 Surface water

Given the orographic rainfall and highly dissected topography, there are significant surface water sources originating in wadis across Oman (ICBA, 2012). However, most of these surface water resources emanate from flash floods and are not perennial water-courses. The largest wadis, Dayqah and Quriyat, do have perennial flow that average over 60 MCM/yr, and Wadi Halfayn has a catchment area of over 4,000 km^2. Surface runoff is highly variable temporally and spatially; discharge largely occurs as a result of flash-flooding and is thus infrequent and typically lasts only for a few hours to a few days after a storm. Wadi beds mainly consist of coarse alluvium and fissured rock so flash floods provide good opportunities for groundwater recharge (ICBA, 2012). The annual average total wadi outflow volume across Oman is estimated to be between 915 MCM (ACSAD/AFESD/KFAED, 1986) and 1,050 MCM (FAO Aquastat, 2015). Table 1 shows by region the major wadis and average annual surface runoff.

Table 1. Main wadis and surface runoff

Region	Main wadis	Surface runoff (MCM/year)
Musandam		23.40
Al-Batinah – east and center	Alansab, Rasyl, Smael, Taw, Ma'awel, Beni Kharouss, Fara'Beni Ghafer, Hager, Mabbara	180.02
Al Batinah – north	Helw, Qarr, Hatta, Feid, Rajemi/Zaben Fazz, Beni Omar, Souk, Al-Gazy, Yanbo, Gelati/A'hen, Saken, Sarami, Hawasna, Shafan	168.10
Oman interior	Al-Ula, Sifam, Al-Ghoul, Bahla, Tenouf, Nazwi, Moayden, Yahle, Helfen	143.20
Eastern region	Andam, Qanet, Upper Sound, Upper Ethli, Fath, Mangrid, Aghda, Al-Zaher, Ebra, Tima, Selim, Al-Qabil and Beni Khaled	95.90
Az'zahera (north interior basins)		121.70
Quryat and Sur		90.10
Salalah and southern wadis	Dorbat, Arzat, Sandah, Dikan	67.90
Dhofar and northern wadis	Eidyem, Andour, Hallouf, Gurrah	27.30
Total		917.80

Source: ACSAD/AFESD/KFAED, 1986 as given in Nouh, 2006.

To try to capture some of the fast flowing surface runoff, three types of dams have been built in Oman since 1985. The most commonly used are the 89 surface retention dams, with 45 purpose-built recharge dams and 14 flood protection dams built in more recent times (Al-Shibli, 2014). In 2015 a further seven dual-purpose flood protection and surface retention dams have been tendered (Sundar, 2015).

Wadi Dayqah Dam, shown in Figure 5 below, is the largest storage dam in the Sultanate and is situated in Wilayat Qurayat in the Muscat Governorate. This wadi has perennial water flow which reached a maximum recorded outflow of 260 MCM in 1997, though average annual flow is about 60 MCM (MRMEWR, 2005). Dam construction started in 2006 and was completed in 2010 and the reservoir's total storage capacity is 100 MCM. The pipeline transmission system from the reservoir, Oman's first large-scale surface water supply project for municipal purposes, is designed to provide the Qurayat region with ~15 MCM/year for irrigation and municipal purposes and Muscat a further 20 MCM/year for municipal supplies.

Figure 5. Wadi Dhayqah Dam

Source: Times of Oman July 6th 2014 Times of Oman.

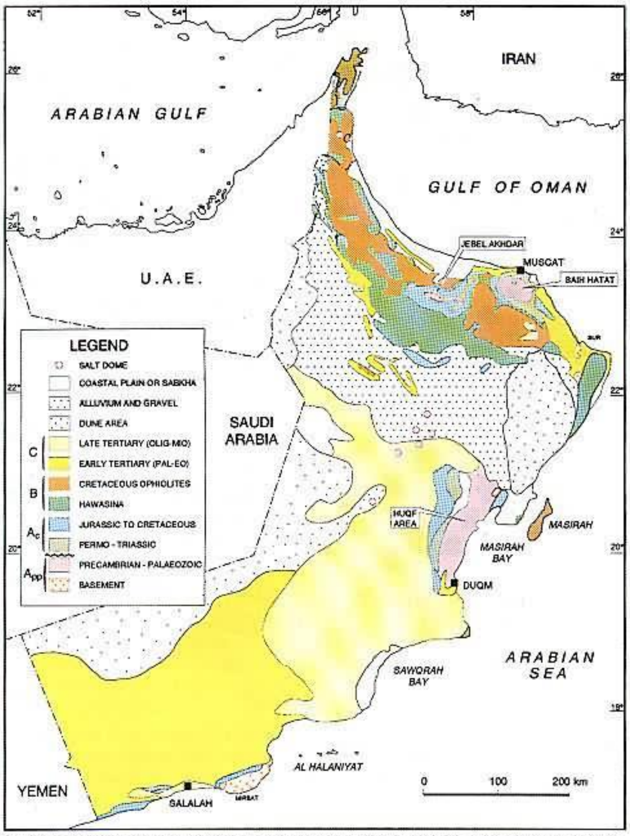
2.3 Groundwater overview

Groundwater is the main water resource utilised in Oman for domestic, industrial and agricultural purposes. Wells and wellfields contribute around 20% of the supplies for domestic/commercial/industrial sector managed by the Public Authority for Electricity and Water (PAEW) - 60MCM in 2014 (PAEW, 2014). Most of this is from major wellfields connected to the main systems, but other groundwater supplies are typically through single wells or small wellfields serving isolated systems mainly in rural areas. There are 744 wells supplying water to the distribution system with the greatest numbers in the Adh Dhahirah and Ad Dakhliyah regions (PAEW, 2014). Values for groundwater abstraction for use in agriculture is limited.

While there is significant groundwater recharge on an annual basis in the coastal plains and mountains in Oman's northern and southern regions, abstracted groundwater resources include fossil water originating from past, wetter climatic conditions. Fresh, in other words non-saline, groundwater is mostly available in the northern and southern mountains and coastal plains of Oman. Most of the groundwater in desert areas is brackish to saline. There are several hundred springs in Oman, most of them are located in the mountainous areas and are connected to *falaj* (plural, *aflaj*) systems (see Box 1). Coastal aquifers are under severe stress and saline intrusion is a major problem in both the Batinah and Salalah coastal plain. Estimates of total groundwater demand in Oman vary widely from the Ministry of Environment & Climate Affairs (2013) reporting figures of over 2,700MCM/year to the more frequently cited figures of 1,600-2,200MCM/year (FAO, 2009; MAF/FAO, 2012; Al-Shibli, 2014).

Oman's geology and hydrogeology is complex and a wide variety of aquifer systems exist, many of which are only locally relevant (Figure 6). The main aquifer systems include the alluvial aquifers running from the mountains to the coasts following wadi courses, sand dune aquifer systems in the interior, and the underlying regional aquifers of the Fars Complex and the Umm al-Radhuma systems. The most significant alluvial aquifers are in the Batinah Plains which lie between the Hajar Mountains and the sea in the northwest of Oman.

Figure 6. Major geological structures of Oman



Simplified geological map of Oman showing the three major geological provinces, the Oman mountains in the north (including the Musandam Peninsula), the Huqf area west of Masira Island and the Dhofar mountains.

Source: http://www.oocities.org/suonnoch/Oman/geology_of_oman.htm.

Three main types of natural recharge to the shallow aquifers in Oman can be distinguished:

- Throughflow from precipitation entering the groundwater system in the mountains that flows down-gradient within the saturated zone to coastal plain aquifers;
- Direct recharge from rainfall over the plains;
- Indirect recharge from wadi stream beds.

In addition to natural recharge, both induced and artificial recharge play an increasingly important role in groundwater management. These are achieved through recharge dams and well–injection using treated wastewater. The latter currently only occurs in a managed way in Salalah where it is undertaken to mitigate seawater intrusion into coastal aquifers. Its usage in the Batinah plains is undergoing extensive study.

The improved efficiency of infiltration when recharge dams are used varies highly depending on initial soil conditions, soil type, wadi bed structure, etc. However, assessments in Dhofar have shown recharge efficiency of up to 75% of water entering the recharge dam, and work in northern Oman has suggested that recharge dams can double groundwater recharge compared to the natural baseline (Shammas, 2007; Haimerl, undated). The impact of enhanced recharge using dams has not been studied comprehensively within Oman, but it is estimated to increase recharge by between ~30MCM/year and 50MCM/year (FAO, 2009).

Box 1. Aflaj types in Oman

There are three types of aflaj systems in Oman: Ainy, Dauadi and Ghauli, of which Ainy and Dauadi utilise groundwater.

Ainy (from the Arabic word for spring) aflaj are less common because they are channels built to direct the flow natural springs, some of which are naturally hot, highly mineralised springs.

Dauadi aflaj intercept the groundwater table and constitute about 45% of active aflaj systems in Oman. They are usually perennial in nature and can provide high discharges reaching up to 2000 l/s as is the case for aflaj Dares in the Al-Dakhiliyah Province. Dauadi aflaj consist of underground tunnels often of tens of km in length with depth reaching tens of metres at the source of water as shown

Ghayli aflaj consist of channels that direct surface water from a wadi after periods of continuous rainfall. Naturally, the discharge depends entirely on rainfall and so typically increases quickly after rainfall events and decreases rapidly after they cease. They vary in length from 500 to 2,000 metres and are mainly located in northern Oman. Ghayli aflaj constitute about half of all aflaj in Oman

Source: www.unep.or.jp/ietc/publications/techpublications/techpub-8f/C/Oman1.asp.

The lion's share of groundwater abstraction, approximately 58%, occurs through the ~130,000 active irrigation and livestock watering wells that were identified and registered during the National Well Inventory Project that took place in the early 1990s (Al-Obaidani, 2014). These are utilised primarily by the agricultural smallholders that dominate the Omani agricultural sector and irrigate the approximately 67,000 hectares of land that was cultivated as of 2010 (ICBA, 2012). Approximately 8% of modern groundwater abstraction occurs through large well-fields that have been developed to supply the domestic, municipal and industrial demands that make up about 8% of total groundwater abstraction (Al-Obaidani, 2014). The remaining proportion of groundwater abstraction, about 34 percent, is through the 3,110 *aflaj* that are in active use (Al-Obaidani, 2014). These are privately owned systems used extensively in Oman, some of which have been operational for over 2,000 years (FAO, 2009).

Two large scale inventory projects were carried out in the 1990s to establish a complete database for all existing wells and aflaj. The National Well Inventory Project, embarked on 1992, was initiated with a registration process (167,000 wells) and followed by field inspection that provided a comprehensive data set on water levels, water quality, pump types, water use and irrigated areas. The total number of active wells inventoried was 127,000 (ICBA, 2012). The National Aflaj Inventory Project, commenced in 1997, recorded a total of 4,112 aflaj of which 3,108 were found operational. Service areas of individual aflaj vary significantly but most are less than 2 ha; the largest single system extends over 1,227 ha. The total area serviced by aflaj in Oman was found to be 26,500 ha of which 66% was under crop at the time of the field survey (ICBA, 2012).

2.3.1 Major aquifers systems and their status

The primary aquifers in terms of agricultural and municipal utilisation are the shallow coastal aquifers which receive modern recharge from throughflow generated in the mountains, small amounts of direct recharge from intense precipitation events, and indirect recharge through wadi bed infiltration (ICBA, 2012). This section examines the major aquifer systems to highlight their nature and state. In addition to these easily-accessible, highly-productive alluvial aquifers, two recently-developed, deeper and more complex aquifers are introduced briefly, the Umm al-

Radhuma and Sharqiya Aquifers. The need for agricultural expansion beyond traditionally cultivated coastal plains and wadi valleys will drive the increased utilisation of these primarily fossil-water aquifers in Dhofar and Sharqiya states in the near future. Table 2 (Al-Khamisi, 2011) shows a selection of major aquifer systems and their estimated storage in Oman.

Table 2 Major aquifer systems in Oman

Aquifer Name	Location	Storage (10^6 m^3)
Nejd	Dhofar	5,000
Al Masarrat	Ad Dhahirah	19,500
Ash Sharqiyah Sands	Ash Sharqiyah	12,000
Wadi Al Ma‟awil	South Al Batinah	100
West Al Wusta	Dhofar	1,000
Wadi Rawnab	Al Wusta	100

Source: Al-Khamisi, 2011.

2.3.2 Aquifer systems of the Batinah Plains

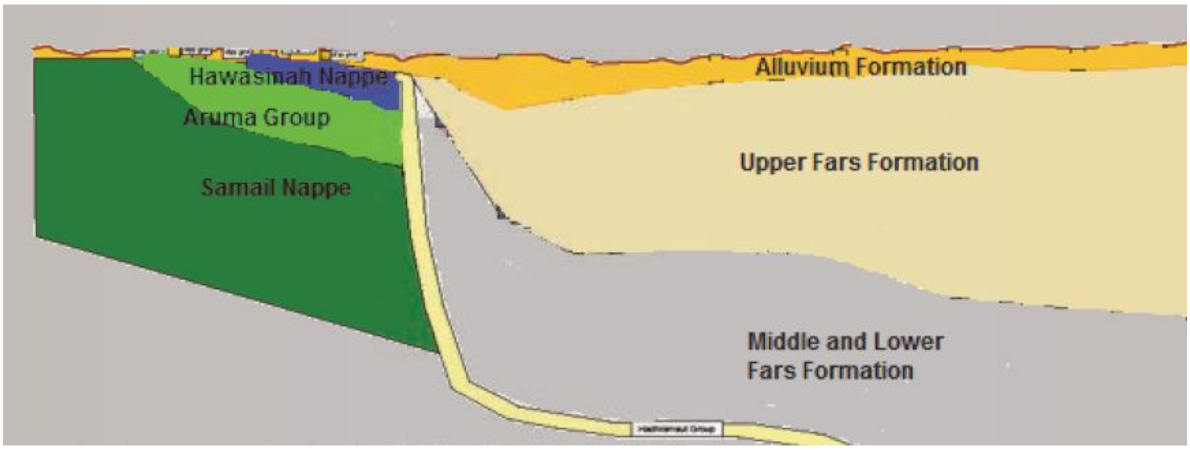
The alluvial formations of the Batinah Plains are divided into two groups: the Northern Batinah coastal plain in which groundwater occurs in both the alluvium and the underlying Upper Fars formation - from which less than 1% of current abstraction originates - and the Southern Batinah coastal plain in which groundwater occurs in the alluvium aquifer. This shallow alluvial aquifer consists of clay from weathered limestone interbedded with loose Ophiolite gravels. Gravels are coarser near the mountains and finer near the coast, and they are unconsolidated near the surface and consolidated towards the base of the aquifer. The representative cross-section in Figure 7 illustrates the alluvial aquifer and the underlying formations in the region from the Gulf of Oman to the Hajar Mountains (ICBA, 2012).

Depth to groundwater in the alluvial aquifer is typically quite shallow – one well record shows that it was 0.3m in the early 19980s – although in some areas it is over 50m below ground surface. The current groundwater table elevation ranges from 230m above level to 24m below sea level in Sohar where depth to groundwater is 33.3m. The thickness of the Quaternary-aged alluvium ranges between 8m and over 300m (ICBA, 2012).

Recharge to the alluvial system overall is estimated to average 396MCM/year with major inter-annual variation depending on precipitation patterns; in the 1982-2010 period, annual groundwater inflow from the mountains within the saturated zone, by far the largest source of recharge, has ranged from 132MCM to 516MCM. Other relevant hydrological characteristics of the Northern Batinah alluvial aquifer include the following (ICBA, 2012):

- Hydraulic conductivity ranges from 0.3m/day to 449m/day. The lowest hydraulic conductivity is associated with cemented, clayey sands, while the highest values were associated with uncemented sands and gravels.
- Storage coefficient values range from $1x10^{-5}$ to $1x10^{-2}$. The highest values were found within the unconfined, uncemented sands and gravels.
- The transmissivity ranged from 0.9m^2/day to 16900 m^2/day.
- Aquifer yield ranged from 1 l/sec to 515 l/sec.

Figure 7. Representative cross-section illustrates the alluvial aquifer and the underlying formation in the region from the Gulf of Oman to the Hajar Mountains



Source: Geo-resources Consultancy, 2006.

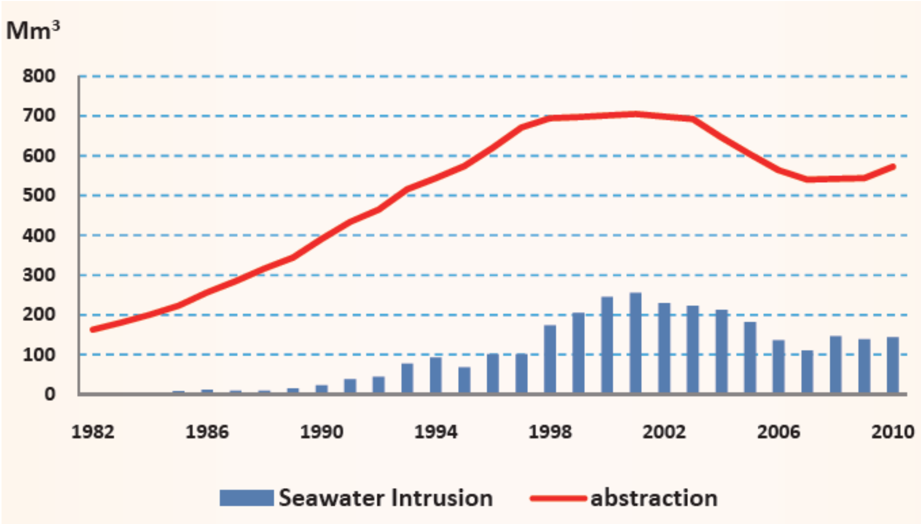
Groundwater abstraction from the Batinah alluvial aquifer exceeded natural recharge on a continual basis beginning in the late 1980s and since the early 1990s has led to significant seawater intrusion in areas of heavy abstraction. Groundwater salinity rises were first reported extensively during the 1982-1984 drought period when direct recharge was reduced precipitously, and 1984 estimated inflow to the shallow aquifer was about 44% of its 28-year running average. Figure 8 shows estimated groundwater abstraction and seawater intrusion for the 1980-2010 period (ICBA, 2012).

Seawater intrusion has led to incredibly rapid groundwater salinity rises, well abandonment, soil salinization and a sharp reduction in land that is cultivable using groundwater. The governorates of the Batinah Plains lost over 12,000 feddans (5,040 ha) of cultivated area due to groundwater salinisation between 1997 and 2010 (ICBA, 2012). Figure 9 shows this through the distribution of abandoned wells which follows groundwater salinisation patterns closely. While the level of over-abstraction has declined somewhat from its mid-2000s peak, it will occur for the foreseeable future. Agriculture expansion has reduced but still the production is heavily reliant on irrigation and over-abstraction, with few if any restraints, and will continue as result of government policies and associated subsidies driving this. This is discussed in greater detail in the second part of this report.

Well hydrographs for those located in the coastal strip generally showed a declining trend in most of the catchments, some catchments showed a rising trend (Figure 10). The increase water levels were likely to result in areas where there was a move away from agriculture on the land, so groundwater was not abstracted as much, or the well was in an area supported by recharge dams (ICBA, 2012).

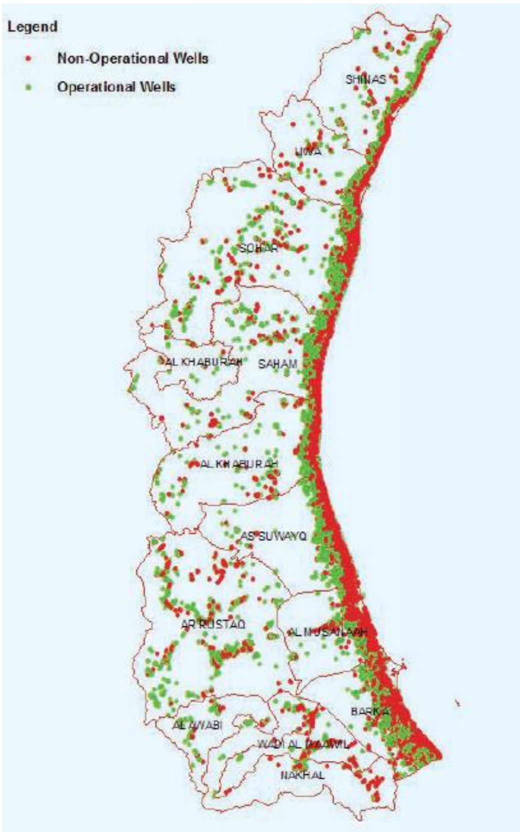
The results of water salinity mapping showed that there is an increase of saltwater encroachment over time in most of the catchments in the areas close to the coastline. These figures show that groundwater salinity levels were lower at the beginning of the groundwater development phase (in the 1980s). Since that time, agricultural activities that used groundwater wells for irrigation have increased in Al Batinah region. This uncontrolled pumping has exploited the aquifer in many places, causing decline in water levels to alarming levels. It has also caused seawater intrusion in places where the water table was below sea level, as can be seen in the trends of increasing salinity near the coastline (Figure 11).

Figure 8. Sea water intrusion and changing abstraction levels in the Al Batinah region from 1982-2010 (ICBA, 2012)



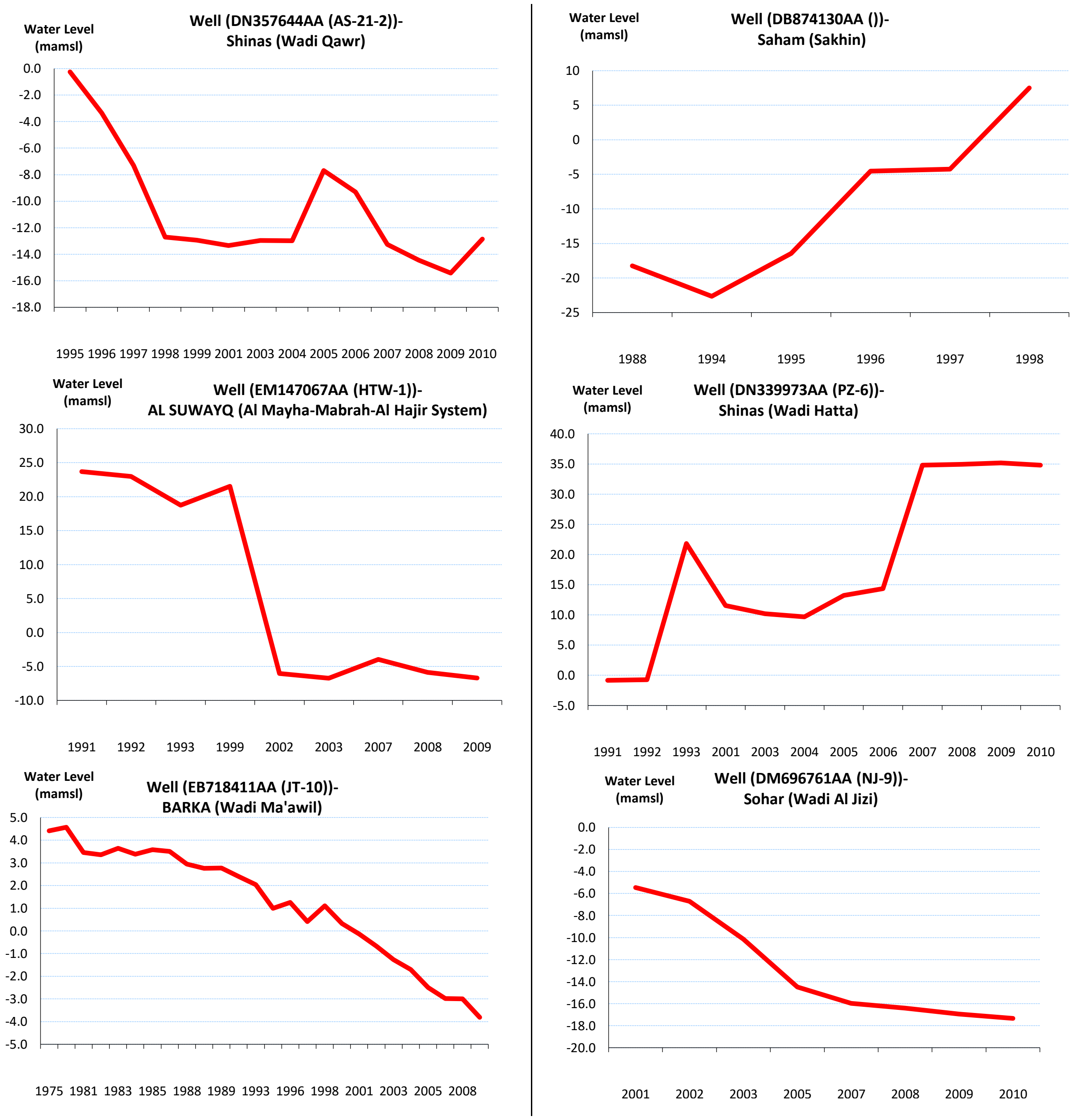
Source ICBA, 2012.

Figure 9. Wells along the Al Batinah Region highlighting the distribution of abandoned wells



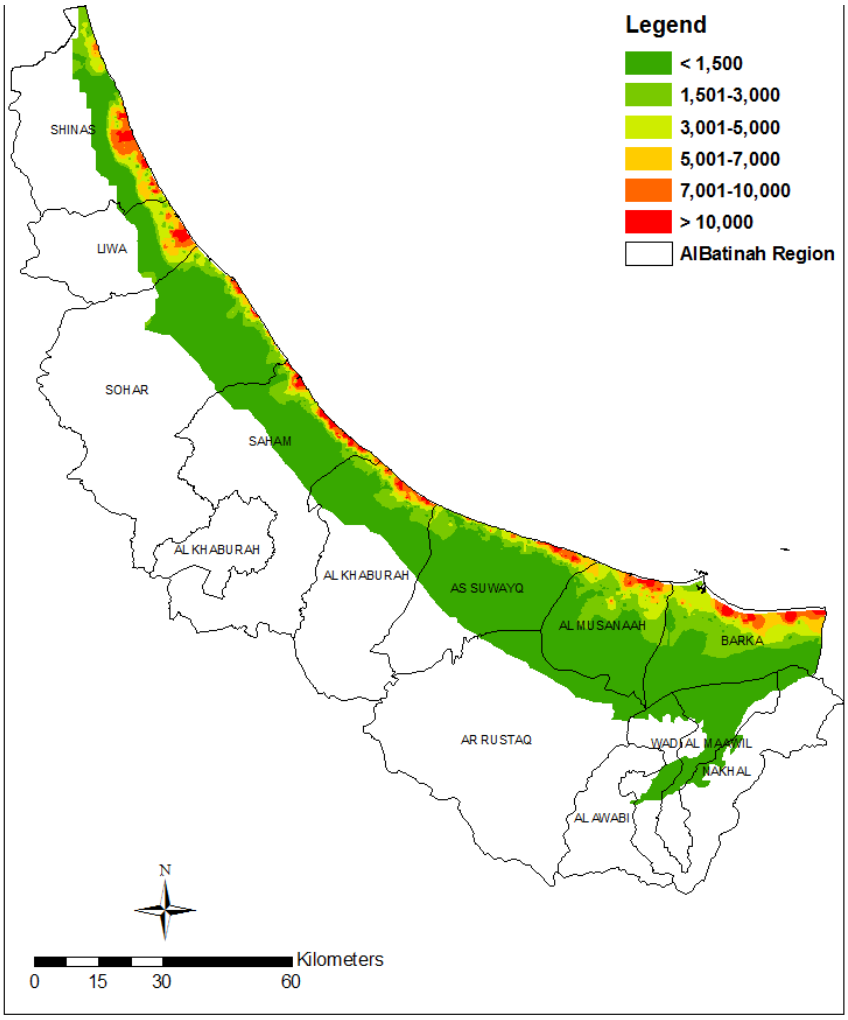
Source: ICBA, 2012.

Figure 10. Changing well levels at a number of different locations in the Batinah Plains



Source: ICBA, 2012.

Figure 11. Observed groundwater salinity in 2010

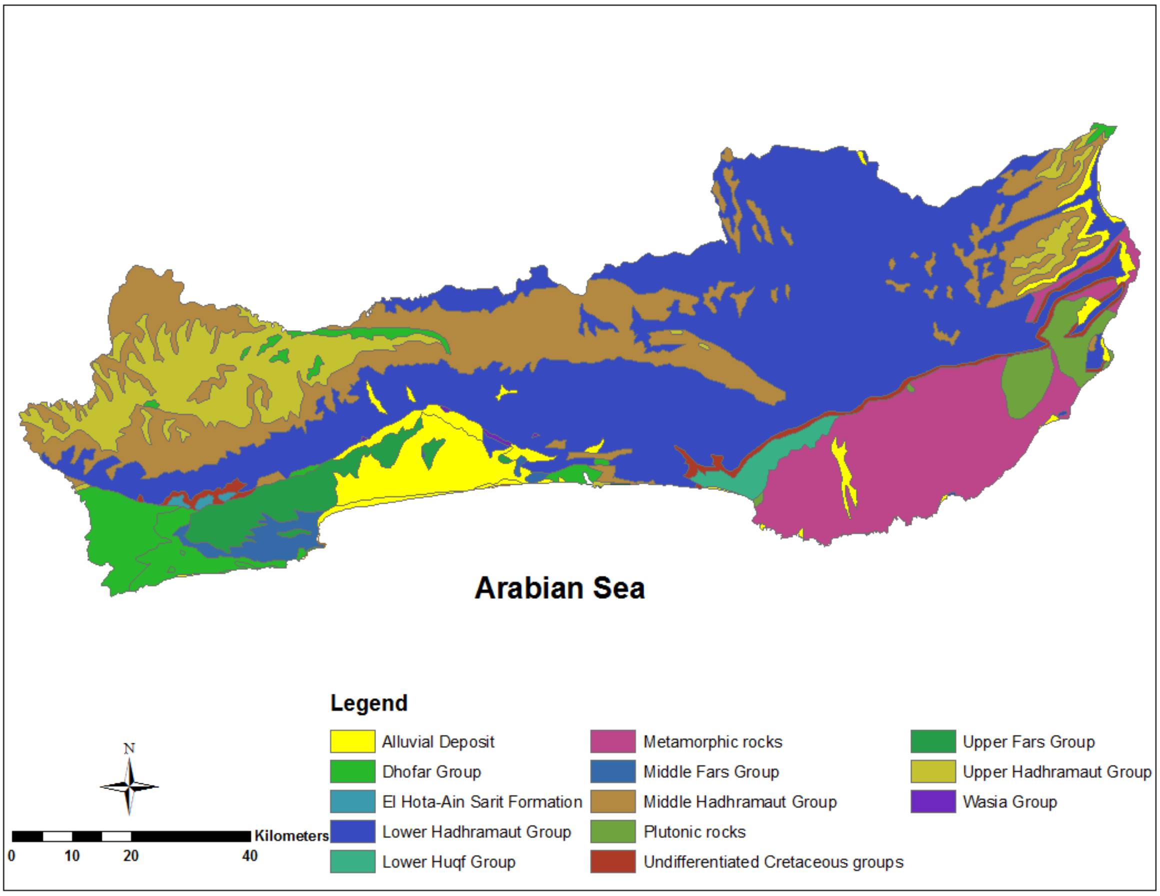


Source: ICBA, 2012.

2.3.3 Salalah coastal aquifer systems

The primary aquifer in the Salalah Plain area is the Adawnib alluvial aquifer of the Fars group which is recharged primarily by inflow from the mountains as well as limited direct recharge from precipitation events as well as indirect recharge from wadi beds augmented by the presence of two wadi recharge dams (Figure 12) (Muller, 2012; Bawain, undated). The majority of the recharge is a result of throughflow from mountain runoff during the annual summer monsoon rains, and rare cyclonic events contribute substantially to direct recharge as well.

Figure 12. Geology map for Salalah coastal plain



Source: ICBA, 2012 compiled from Oman geological map.

The plain aquifer is generally brackish, except where freshwater occurs in the central plain (< 1500 mg/l) and along the piedmont (ICBA, 2012; Bawain, undated). The main characteristics of this aquifer include the following:

- Saturated thickness typically 60-70m with a maximum of about 120m;
- Very high transmissivity ranging from 1000 to 200,000 m^2 / day;
- High permeability associated with karstic features;
- Hydraulic conductivity ranging between three orders of magnitude, from 10s to 1000s m//day.

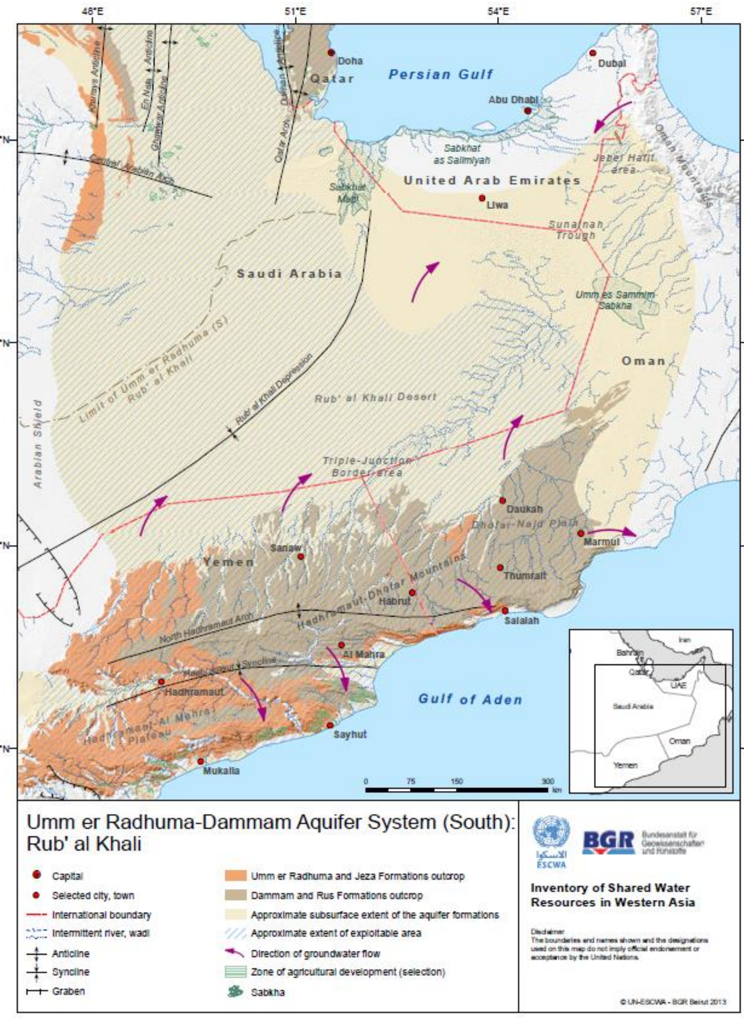
Natural annual recharge is estimated to be approximately 60MCM/year, and in addition approximately 7.3MCM/year of treated wastewater are injected annually to prevent seawater intrusion (ICBA, 2012). Groundwater table levels are quite flat in the plains area, ranging from 10 above mean sea level near the mountain front to sea level near the coast. Given the unusually high transmissivity, groundwater level trends showed very little rising and declining trends as depletion in freshwater storage is rapidly replaced by adjacent brackish or seawater inflow. Given the experiences of salinisation in the Batinah Plains and Salalah's especially high vulnerability to seawater intrusion, a wastewater treatment and re-injection project was established in 2003 (ICBA, 2012).

The project has been highly successful in reducing saline intrusion in the central plains area – the largest and most important agriculturally – partially due to the aquifer characteristics in that region which permit rapid dispersion of the injected water (Shamas, 2008). In the eastern and western edges of the aquifer it has been slightly less successful, though even there it has slowed the advance of saline intrusion. In combination with programs to shift the cultivation of Rhodes Grass from the Coastal Plain to the interior of Dhofar in the Nejd as well as the planned completion of a desalination plant and expansion of the wastewater treatment plant to increase its effluent output capacity, the program can be considered a case study of effective integrated water resource planning (Helmi et al., 2010; Shamas, 2008).

2.3.4 Nejd aquifers

Aside from the coastal plains aquifer, the major aquifer in Dhofar is the Umm al-Radhuma aquifer system, otherwise known as the Dammam or Nejd aquifer. It is a vital, hydraulically linked regional aquifer system that extends throughout the Arabian Peninsula and constitutes a significant proportion of Saudi Arabia's water supply as well as Al-Ain's irrigation water supply in the United Arab Emirates. In northern Oman, the aquifer is the main water supply source for interior gravel plains regions east and south of Al-Ain (See Figure 13).

Figure 13. Hydrogeological map of Nejd aquifers



Source: UN-ESCWA & BGR, 2013.

Although the majority of groundwater in the Umm al-Radhuma system was recharged during more humid paleoclimates, in Dhofar all portions of the aquifer receive modern recharge as evidenced by isotope tracer studies and hydraulic modeling studies (Al-Mashaikhi, 2011; Muller, 2012). This modern recharge is estimated to be an average of 4.3mm/year according to modeling estimates, though virtually all of it is thought to occur during the infrequent cyclone events which can lead to quick infiltration and travel along fracture lines (Al-Mashaikhi, 2011; Muller, 2012). The aquifer consists of four major formations in Dhofar, of which three are water-producing, and they exhibit the following characteristics (Clark, et al., 1987; Bawain, undated; Al-Mashaikhi, 2011; Muller, 2012; ICBA, 2012):

1. Dammam and Rus Formation - mostly unconfined aquifer made up of marl and gypsum with saturated thickness between 200 and 400 m, salinity ranges from 800 to 2500 µS/cm in most of Dhofar, increasing northwards along groundwater flow paths and storage coefficient of 3.2 x 10-6;
2. Upper Umm Al-Radhuma – confined aquifer with thickness ranging from 100 to 200 m and storage coefficient of 1 x 10-6;
3. Middle Umm Al-Radhuma - high-yielding aquifer with saturated thickness ranging from 100 to 150m and salinity typically 500 to 2000 µS/cm, again increasing northwards and westwards away from the recharge zone, with a storage coefficient of 1.5 x 10-4;
4. Lower Umm Al-Radhuma - poorly explored and likely non-productive aquifer with saturated thickness ranging from 100 to 200m.

Agricultural expansion is occurring quickly in Dhofar province as some of the aquifers are increasingly tapped for large, modern farms using center-pivot and drip irrigation systems. In addition, increased utilisation of enhanced oil recovery operations, typically with steam injection, have put further demands on these recently exploited aquifers. While the Umm al-Radhuma Aquifer has yet to be exploited intensively, the fact that it receives minimal modern recharge and primarily consists of fossil water increases the need for careful planning and management of its utilisation (ICBA, 2012).

2.3.5 Sharqiyah Basin aquifers

In the Sharqiyah Basin in eastern Oman, the groundwater is primarily exploited from two aquifer systems: the Aeolianite upper aquifer and the underlying alluvial aquifer known as the Sharqiyah Sands. The Aeolianite Aquifer is not as well understood as the Sharqiyah Sands, from which the majority of abstraction is derived. The Aeolianite Aquifer has been mapped over about 1,500km2 and it extends southwards significantly beyond this region though it likely holds brackish and saline water beyond this area. There is very limited natural recharge of ~10MCM/year and discharge occurs to the sabkhas to the southeast of the mountains (Al-Sulaimani, Z., undated). The aquifer can be considered fossil water with a saturated thickness typically over 100m.

The alluvial aquifer, the Sands Aquifer, is the main water-bearing formation in the basin. Its thickness is over 600m in some areas, though the upper gravel layer, which never exceeds 160m, is the most productive. The aquifer primarily receives recharge through bedrock seepage and groundwater throughflow from wadi beds estimated at upwards of 65MCM/year.

The Sharqiyah Sands project begun in the mid-1990s and saw the development of major wellfields tapping both the aeolianite and alluvial aquifers to supply interior towns as well as Sur, the capital of Sharqiyah. 50 new wells (production and monitoring) in two desert fields were sunk, 700 kilometres of pipeline laid, 4 reservoirs and 3 pumping and treatment stations developed and 35 tanker-filling stations, tanks and generators built (Islamic Development Bank, 2014).

Though the *aflaj* systems of Sharqiyah are under severe strain, this does not reflect a general deterioration of the major aquifer system as parallel developments in the Batinah Plains do. Rather, it reflects the failure of groundwater management in the specific upland regions. Given the Sharqiyah aquifers' extent, storage capacity and active recharge, its increased utilisation in the lowlands that has already begun to occur will likely accelerate.

2.4 Produced water

One major category of groundwater utilisation that is not counted in official government statistics on water resources in Oman is production water associated with hydrocarbon extraction. There are several reasons for this oversight within Oman and the GCC states more generally (Al-Lawati, 2015; Daza, 2014; USAID, 2010):

- Production water comes from deep aquifers that in Oman are not currently used for water supply due to the cost of pumping and frequently water quality issues;
- Production water is a by-product of the oil industry which in the GCC typically has its own water and electric utility services that are under separate regulatory regimes than those of the national grids to which they are usually not connected;
- Production water is frequently re-injected into the petroleum-bearing aquifer in order to maintain output pressure and volumes, at times without treatment depending on the baseline water quality of the aquifer;
- Production water treatment is viewed as a cost of doing business – a liability rather than a resource;
- Production water is typically managed by sub-contractors of national oil companies who focus on complying with environmental disposal requirements and permitting regimes.

These attitudes and institutional barriers to usage of production water other than for re-injection for reservoir support are slowly changing in the GCC, especially in Oman because of its proportionally greater production water output than the other states. Omani oilfields are more challenging and less productive than those of the southern Gulf and production water is close to global averages: nearly 1 barrel[1] of oil to 9 barrels of production water. In contrast, Kuwait's ratio is 5 barrels of oil to 1 of water and Saudi Arabia's is ~2.5 barrels of oil to 1 barrel of water (Al-Lawati, 2015). The ratio of produced water to oil is increasing steadily in Oman due to the use of enhanced oil recovery techniques, many of which rely on steam and increased volumes of water re-injection (Daza, 2014).

Recent estimates from Al-Lawati (2015) show the Omani oil sector produces ~800,000-860,000m^3 of water per day, at the low end approximately 300MCM/year. This volume is approximately 20-40% of current total water usage in the nation. As such, the water resource potential of treated production water cannot be ignored in Oman's future water supply balance and groundwater planning.

The cost of disposing of production water is very high and rising since water treatment and deep well disposal are energy-intensive endeavours as the case study of the Nimr oilfield in Oman shows. The Nimr oilfield, one of Oman's largest, has a daily water output of ~250,000 m^3. While the utilisation of production water will necessarily be limited due to the myriad water quality, human health and environmental issues it poses, in other parts of the world however, it is currently used for restricted irrigation purposes such as in the water-scarce Central Valley of

[1] 1m^3 = 6.2898 barrels.

California. Installation of production water has not been a priority of GCC water-planners and managers in the past.

3 Non-conventional water resources: desalination and treated wastewater

The rising demand for water against a background of declining groundwater levels and deteriorating quality has ensured that new sources of water have been sought over the last few decades. As in other Arab Gulf countries, desalinated water and treated wastewater have begun to play an important role in plugging the deficit between demand and supplies.

3.1 Desalinated water

Oman's national drinking water policy is to eliminate groundwater from potable supplies in order to reduce pressure and reliance on groundwater resources (ICBA, 2012). Desalination capacity has more than doubled in the last decade and major new plants are still under construction. Oman's first desalination plant began operation in 1976, and the Public Authority for Electricity and Water (PAEW) currently purchases desalinated water from seven major plants operating in Oman that have a total capacity of ~240 MCM/year. Smaller desalination plants produce around 10 MCM of which nearly half utilised brackish water while the rest had seawater as their source (PAEW, 2014). In 2014 nearly 225 MCM of desalinated seawater was produced accounting for ~10% of Oman's total freshwater supply (PAEW, 2014).

The Ghubrah, Barka and Sohar desalination plants serve the Main Interconnected System (MIS) which supplies the most populous areas of northern Oman in the Batinah Plains, including Muscat. The Sur desalination plant serves customers in Al-Sharqiyah region, a separate and extensive water transmission system. The Salalah plant serves Dhofar province's needs through a separate water transmission system and was constructed in order to reduce pressure on groundwater resources in Salalah see Figure 1). Table 3 shows the main power and water plants as well as their production capacities. In order to meet projected water demand increases in Oman due to population growth and industrialization, two further major water projects are underway in Qurrayat and Suwaiq, both located in the Batinah Plains to the south and north of Muscat, respectively. The two plants together are expected to increase desalination capacity by nearly 50% in line with national policy to eliminate reliance on groundwater for drinking water supplies (Al-Shibli, 2014).

In contrast to other GCC countries, the majority of desalination capacity, about 65%, is reverse osmosis, and the remainder through multi-stage flash distillation units coupled to gas-fired power plants. In addition to these major plants for municipal and industrial supplies, other municipal, industrial and even agricultural organizations have added to this capacity in both coastal and interior regions through small-scale seawater and saline groundwater desalination plants.

Table 3. Major desalination plants in Oman

	Capacity (m^3/day)	2014 Production MCM	2014 Load factor %
Ghubrah Including temporary plant	163,880	56.93	95%
Barka (1)	91,200	31.24	94%
Barka (1) extension	45,455	8.89	54%
Barka (2)	120,000	42.24	96%
Sohar	150,000	48.82	89%
Sur	80,000	25.80	88%
Salalah	68,190	n/a	n/a

Source: PAEW, 2014 ; Bryniak, 2015.

These major desalination plants are built, owned and operated by private consortiums with unique terms in comparison to other GCC states to encourage active foreign and local involvement in the Omani water and electricity sector. One hundred percent foreign-ownership of independent water (IWP) and independent power and water (IPWP) projects is legal typically for an initial 3-year period from company formation. After that time, 35% of shares must be listed on the Muscat Stock Exchange. These terms are highly beneficial to foreign investors who are able to capitalise on early exits post-project completion and beneficial to Omani economic development since the IPOs add significant value to the Muscat Stock Exchange and permit substantial ownership of water-production assets (Bryniak, 2015).

The PAEW purchases the water produced by these plants through the Oman Power and Water Procurement (OPWP) Company and then manages the supply, storage and distribution to the Omani population. Desalination capacity is expected to increase significantly in the coming decade. The water tariffs paid by the customers is highly subsidized by the government, with exact figures not given but estimated to be in excess of 75% of the cost.

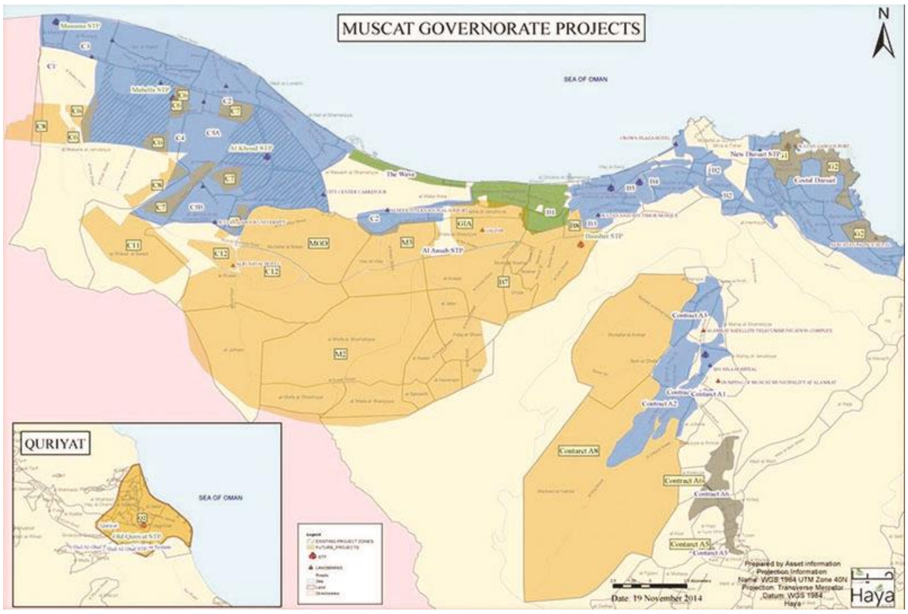
3.2 Treated wastewater

Treated wastewater utilisation presents a major opportunity to expand water supply in Oman and to reduce pressure on groundwater resources, especially in the densely populated and intensively irrigated Batinah Plains. National policy since 2000 has supported the importance of a massive expansion of sewer networks and wastewater treatment plants as well as increased wastewater re-use. At present approximately 50MCM/year of treated effluent are produced in Oman, about 33MCM of which is in the greater Muscat area.

In 2002 Haya Water was formed as a government-owned sewerage utility to serve the greater Muscat area, the Salalah Sanitary Drainage Services Company was established to serve Salalah, recently the Sohar Development Office was tasked with serving the Sohar region while the MRMRW was tasked with expanding wastewater treatment and re-use in the rest of Oman. Significant fiscal outlays for the sewerage sector were included in the 6th-8th five-year development plans that were enacted between 2001-2015, and over OMR1 billion (~$2.94 billion) was allocated for the 2016-2020 period (Al-Asmi, 2014).

Haya's target is to connect 80% of households to the sewer network in Muscat Governorate by 2017, and the utility has also recently concluded agreements with the government of Oman to construct wastewater projects outside of Muscat itself (Al-Asmi, 2014). As of early 2014, 12 treatment plants served Muscat and treated approximately 90,000 m3/day, ~33MCM/year (Al-Muslehi, 2014). Table 4 (Al-Muslehi, 2014) identifies sewage treatment plants currently under planning and construction in the greater Muscat area served by Haya (see Figure 14). Outside of Muscat, 52 major treatment plants treat about 64,000 m^3/day and produce ~45,000 m^3/day of effluent, about half of which is in Salalah and used for groundwater recharge (Al-Asmi, 2014).

Figure 14. Current and future developments of Muscat's wastewater system



Source: [http://omanobserver.om/haya-water-set-to-boost-capex-for-muscat-water-reuse-project/.](http://omanobserver.om/haya-water-set-to-boost-capex-for-muscat-water-reuse-project/)

Table 4. Major Treated wastewater plants in Oman

STP Name	Phase	Design Capacity (m^3/day)	Total Capacity (m^3/day)	Expected Completion Date
Al-Seeb	1	60,000	130,000	2014
	2	20,000		2017
	3	50,000		2019
New Al-Ansab	1	57,300	140,000	2010
	2	30,000		2017
	3	52,700		2019
Al-Misfah	1	35,000	35,000	2017
New Darsait	1	37,000	50,000	2015
	2	13,000		-
Al-Bustan, Sidab & Muscat	1	10,000	25,000	2019
	2	15,000		-
Muttrah	Different Packages	20,000	20,000	2021
New Al-Amerat	1	18,000	27,000	2016
	2	9,000		2022
Al-Hajir	1	10,000	10,000	2022
New Quriyat	1	15,000	15,000	2022
Hail Al-Ghaff	1	200	600	2012
	2	400		2013

Source: http://www.water-technology.net/projects/muscat/.

Using treated wastewater for productive purposes in Oman faces a variety of challenges, the foremost of which is infrastructural. At present, about 30% of treated wastewater in Muscat is discharged to lagoons or the sea for lack of demand and seasonal imbalances in supply and demand. This figure is not expected to decrease to less than 20% - and may even increase to nearly 50% - before the end of 2020 depending on utilization patterns and whether a pipeline connection to a major irrigation district in Barka is used. This treated effluent surplus, which could reach 73,410m^3/day by 2020, could be beneficially used for agricultural irrigation and also injection into shallow aquifers to prevent seawater intrusion relieving pressure on aquifers (Al-Muslehi, 2014).

The challenges to using treated wastewater in agriculture are primarily infrastructural include:

- Currently there are no large-diameter pipelines to transport treated wastewater to major agricultural areas, though a pipeline from Muscat to irrigation districts in Barka is under construction (Al-Khamisi, 2014);
- The cost of treated wastewater far exceeds that of groundwater abstraction since farmers do not pay water fees for abstraction from their own wells and electricity is subsidised significantly within Oman (ICBA, 2012);
- Acceptance studies indicate that farmers are somewhat reluctant to utilise treated wastewater prior to significant outreach and extension activities (World Bank, 2011)

4 Water consumption in Oman

Groundwater constitutes the vast majority of total water supply within Oman, and agricultural water demands shape water consumption patterns. While groundwater still contributes significantly to municipal supplies – particularly outside of the urban areas of the Batinah and Salalah Plains and Sur – drinking, municipal and industrial water supplies are increasingly being met by desalination and in the near future by treated wastewater. These sectoral distinctions are explored briefly in this section, though the main emphasis lies on agricultural usage because it is the largest user of groundwater.

Ranges of water consumption figures by sector provided by officials from the MRMWR (Al-Abri, 2012; Al-Shibli, 2014) show that approximately 78-83% of water supply goes to agriculture with a further 1% for livestock, 12% for household consumption, 6% for commercial, industrial and government usage, and 3% for the environment. The makeup of this supply also ranges with estimates of the proportion of groundwater in the total supply varying between from 78% (Al-Abri, 2012) to 83% (Al-Shibli, 2014) with desalination (up to 12%), surface water (up to 6%) and treated wastewater (up to 3%) filling in the balance. Statistics from 2005 reported by the FAO (2009) show agricultural water usage as a higher proportion of the total, over 90%, and groundwater meeting up to 94% of total supplies.

This slight decrease in groundwater's overall role in Oman's water supply mix can be ascribed to several factors:

1. The major increase in desalination;
2. The increase in surface water storage and utilisation enabled by the recent completion of several storage dams, especially the Wadi Dayqah dam;
3. The increasing utilisation of treated wastewater for municipal irrigation;
4. The decrease in agricultural irrigation in the Batinah Plains due to farm abandonment and urbanisation explored below predominant driver of groundwater abstraction in Oman (ICBA, 2012).

4.1 Agriculture in Oman

The land resources in Oman suitable for agriculture are very limited. Of Oman's area, only 7 percent or 22,000 square kilometers (km2), has soils that could be used for agriculture (MAF)/FAO, 2012). A further 14,300 km2 are marginally suitable because of moderate to severe limitations that, in aggregate, will reduce productivity or benefits and require increased inputs so that their utilization may be only marginally economic (MAF/FAO, 2012). Currently 680 km^2, are under cultivation and about 65 percent of the cultivated area is located in coastal areas. The most intensely farmed areas in the Sultanate are located in the 320 km long Batinah coast northwest of Muscat and these accounts for two-fifths of total area under agriculture.

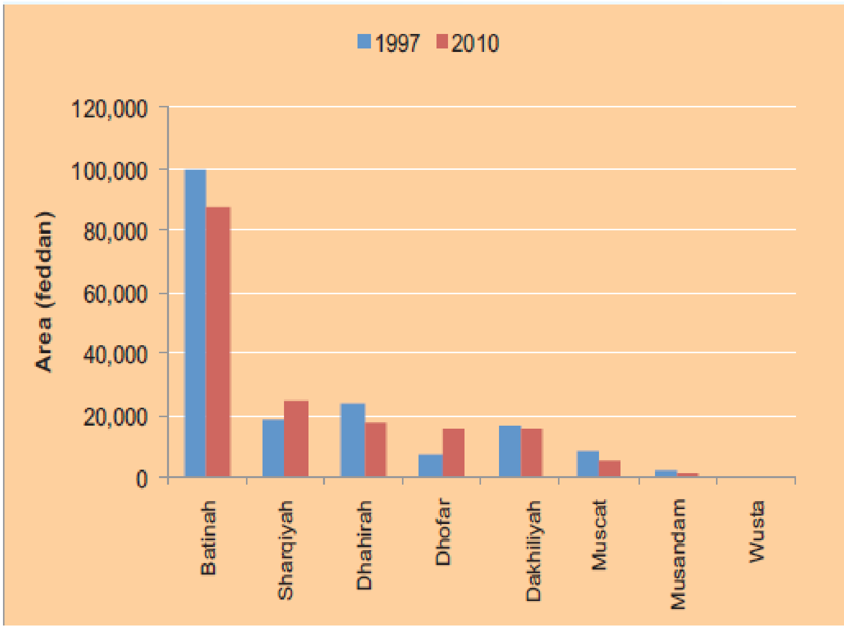
4.1.1 Crop production

In 2013 a total of 138,000 feddans (57,960 ha) was devoted to crops and a further ~200,000 (84,000 ha) to mixed livestock, crop and poultry rearing, representing a significant decline from the national peak of 175,000 feddans (73,500 ha) cultivated in 1997 (NCSI, 2014). Oman's crop mix is diverse, with date palms and other fruit trees constituting the majority of cultivated area (about 45%) with forage crops, primarily Rhodes grass and alfalfa, making up ~30% of farmed land. Vegetables make up nearly 17% and the remainder is field crops largely grown for the local market.

Of the currently farmed land, just over half is in the Batinah Plains, and that region provides about 60% of Oman's total agricultural production (MAF, 2012; ICBA, 2012). This is gradually changing though as this area urbanizes and increasing groundwater and soil salinity contribute to farm abandonment. Increased production is taking place in Dhofar and Sharqiya provinces as a result of national investment plans, increased access to deeper groundwater resources, some of which is fossil water, as well as the regions' comparative advantage in higher value crops than northern Oman (FAO/MAF, 2012).

Generally, between 1990 and 1997 agricultural production increased substantially (by 76 percent) reaching 1,232,400 tonnes. This was followed by a general decrease in agricultural productivity in subsequent years, as it fell from an average of 1,232,528 tons over 1997-2000 to an average of 1,174,278 tons over 2006-2010* (Figure 15). While this represents an overall decrease of 58,250 tonnes (i.e. 4.7 percent) at the Sultanate level, Al Batinah had the greatest decline of 45,659 tonnes, followed by Dhahira (25,802 tonnes), Muscat (16,952 tonnes) and Wusta (820 tonnes) among the regions (ICBA, 2012) resulting from agricultural land abandonment and salinity issues.

Figure 15. Oman's cropped areas comparison



Source: ICBA, 2012.

Farms are primarily irrigated by groundwater wells. However, a very large number of small farms receive water from *aflaj*. Over 80% of *aflaj* serve farms less than 1 feddan (0.42 ha) in size, and farms reporting using dug and bore wells have average sizes of 5 and 17 feddans (2.1 and 7.14 ha), respectively (MAF, 2014). Over half, 55% of all farms surveyed for whom respondents knew their main water source utilized *aflaj* and springs. However, they represented a small portion of total farmed area, less than 15% (MAF, 2014).

In terms of crop water demand, values generated for the Al Batinah region and the coastal region highlight falling levels between 1997 and 2010 (Figure 16). The dominance of fruit crops, primarily date palms is clearly shown.

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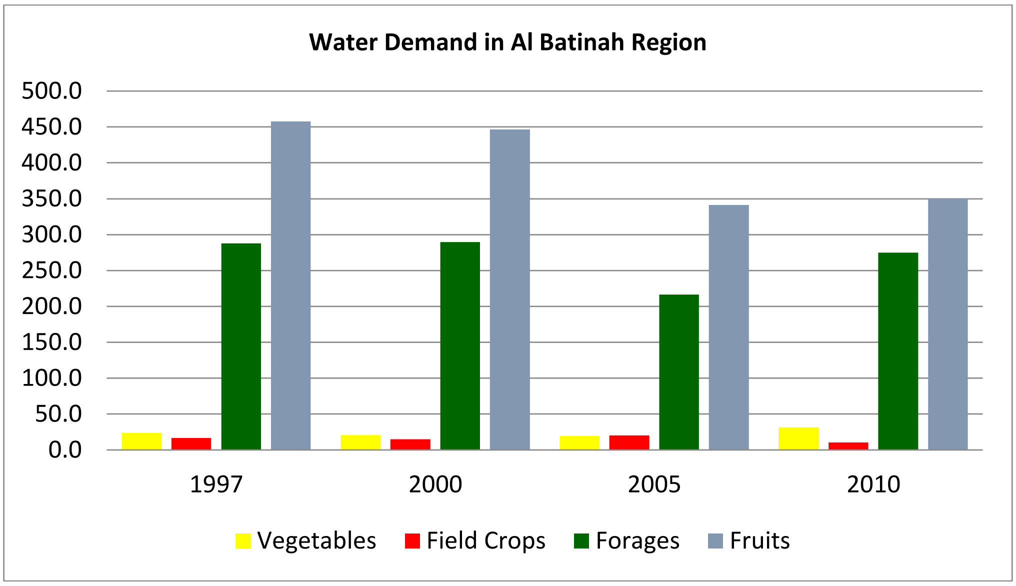
* Buraimi was excluded from analysis as data were not available for the years before 2009.

Figure 16. Agricultural water demand for different cropping groups in a) Al Batinah region and Al Batinah coastal area (MCM)



Source: ICBA, 2012.

Oman's agricultural water-use efficiency has great room for improvement. Traditional surface-flooding is still the dominant method of irrigation; only 15% of all date palms and other fruit trees are watered with modern irrigation systems such as sprinkler or drip mechanisms and the value for forage crops is only 55% (ICBA, 2012). In an area of high evapotranspiration rates, there are good opportunities through irrigation technologies, to reduce the losses. Regional disparities are clear as Dhofar governate, which has witnessed major expansion of cultivated area in the last decade, has one of the highest proportions of farms with modern irrigation systems (MAF, 2014). Groundwater over-abstraction for agriculture is also highly regionalized with the most severe over-drafts in the Batinah Plains.

4.1.2 Livestock production

Oman is the leading livestock producer in the Gulf region. Goats are the most numerous livestock species, followed by sheep, cattle and camel (Figure 17). The livestock numbers in the Sultanate, especially of goats, has increased considerably in the last two decades. The total number of animals in 2009 stood at 2.4 million, which represents a 63 percent increase since 1996. An important consequence of this for water usage is that more forage and fodder production is needed for feeding the livestock. As non-saline soils or fresh waters are mainly used for more economic and cash crops, there is a limitation for the development of forage crops in the Sultanate (ICBA, 2012).

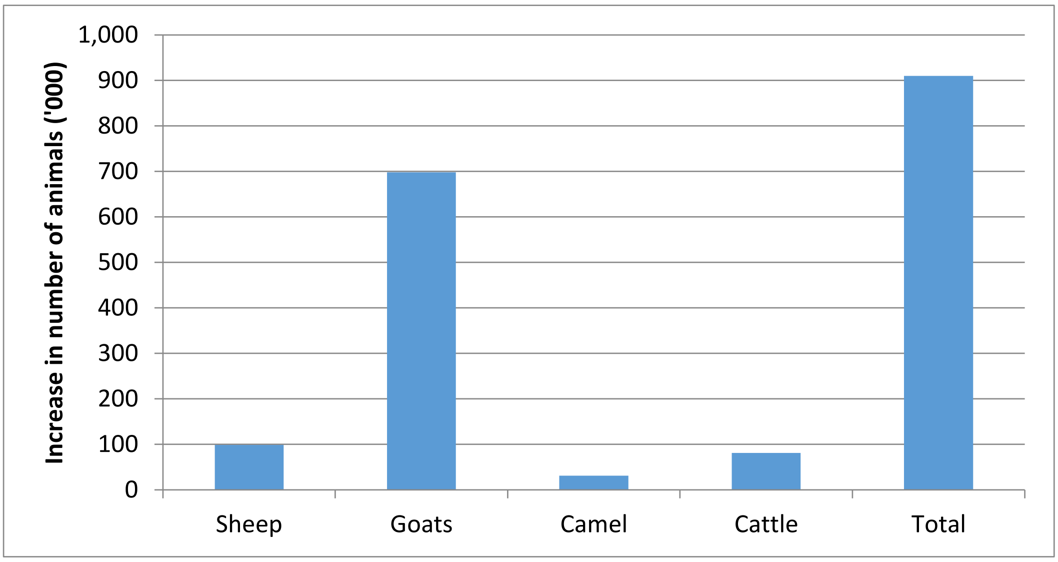


Figure 17 Changes in livestock numbers in Al Batinah region

Source: Agricultural census data 1992/93; 2004/5; ICBA, 2012.

4.2 Domestic water use

With ever increasing urbanization and population growth, the domestic sector is using ever more water. The daily average usage of water in the country exceeds 180 litres per day. The ongoing long-term national investments in water supply and sanitation have paid significant dividends in terms of health outcomes in Oman, with increases in access to water supply and sanitation highly correlated with reductions in infant mortality. In 2010, 89 percent of the population was using an improved drinking water source (78 percent of the rural and 93 percent of the urban population) (UN Water, 2012).

In some areas new mega developments are introducing a more water thirsty way of living with swimming pools and more extensive landscaping. The Wave is one such development on the outskirts of Muscat (Figure 18). With greater urban expansion and population growth planned the imbalances between the water resources consumption rate and water availability is likely to require greater investments in desalination. Water demand is expected to further increase during the next 20 years as a result of increasing population from 2.85 to 330 Mm3/yr according to predictions given in the National Water Resources Master Plan for the period 2001-2020 (MREMWR, 2000).

Figure 18. The Wave mega development offering high quality housing, amenities and tourist resorts

Source: The Times of Oman, 2nd May 2015.

4.3 Industrial water use

Industrial water use has a long history in Oman with copper being extracted in Sohar more than 5000 years ago. These mining operations continue today with copper, gold and silver being the main products. These industries require water for washing, cleaning and concentrating the products.

Today the hydrocarbon industry dominates industrial sector contribution to GDP, and while is a net producer of water as highlighted in Section 2, the water is largely of poor quality. In the petroleum refining industries water is used in many of the processes involved in extracting the various products. It is needed for steam generation, to replace evaporation and blow-down from cooling towers, and for washing the gases and liquids in the process streams. Today there is increasing effort to re-use waters to increase efficiency.

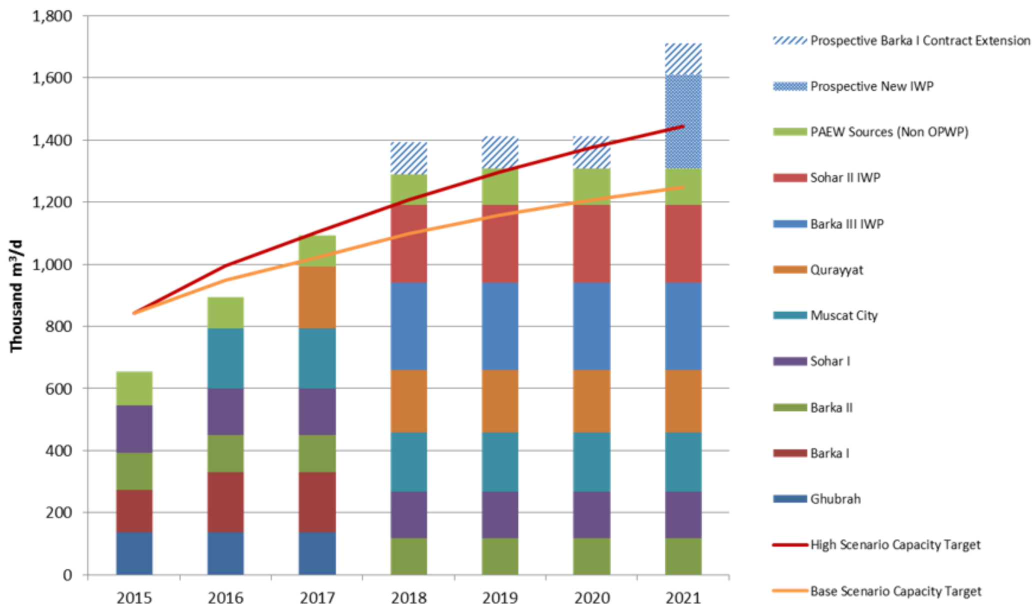
In total the industrial (and commercial) sectors combined account for approximately 5 % of water consumption. With plans to reduce the economic dependence on hydrocarbon industries by expanding the service sector, especially tourism, there are likely to be changes in total relative consumption, especially in areas such as around Muscat, Sur and Salalah.

4.4 Estimates of future sectoral water use

Nationwide projections of agricultural water demand do not envision overall increases given that agricultural land is contracting and slowly and modernized irrigation techniques and protected agriculture are becoming more prevalent (ICBA, 2012). As usual, this generality masks regional differentiation – continued agricultural expansion in Dhofar and Sharqiya will necessarily lead to increased groundwater demand while farm abandonment and urbanization will reduce demands in the most vulnerable areas of the Batinah Plains. Future municipal, industrial and drinking water supplies will increasingly be met through unconventional water resources and newly developed surface water resources.

Northern Oman's Main Interconnected System is likely to be fully served by desalination and surface water as soon as 2017 according to data taken from the as yet to be released Water Master Plan shown in Figure 19 below (Al-Kiyumi, 2015).

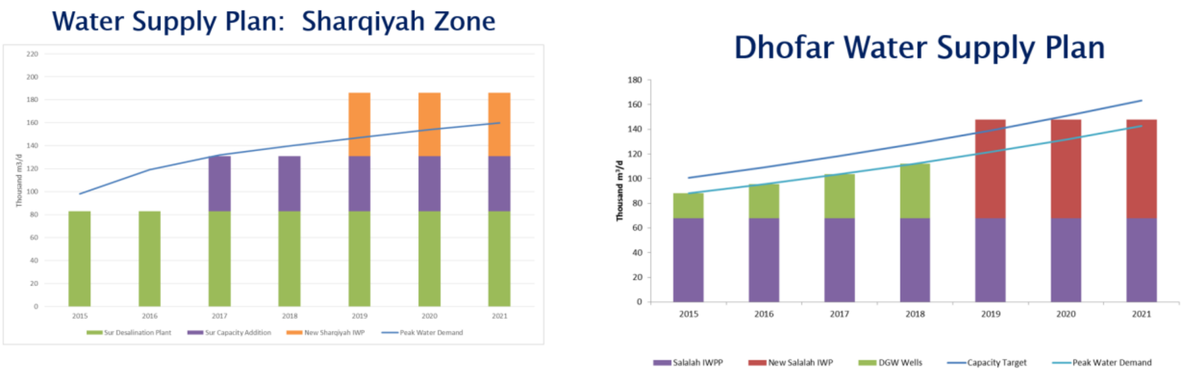
Figure 19. The planned expansion in water supply provision to meet growing demands through desalination capacity development



Source: Al-Kiyumi, 2015.

Similarly, Dhofar and Sharqiya's networks are expected to meet their regional demands through desalination by 2019, with the balance currently met by groundwater abstraction. Interior and otherwise remote regions will continue to rely on groundwater resources for the foreseeable future (Al-Kiyumi, 2015) (Figure 20).

Figure 20 Planned expansion of water supplies to a) the Sharqiyah and b) Dhofar areas



Source: al-Kiyumi, 2015.

Economic drives to diversify Oman's economy from its reliance on hydrocarbons have led to the expansion of industrial, logistics, manufacturing and mining activities in and near major cities, reflected in the significant increase in water demand in Muscat, the purpose-built port city of Sohar and Salalah. The scale of increased demand is evident from Figure 21 above which shows demand on the MIS doubling in a period of just six years. Much of this increase in demand is due to network expansion but increased water demand per capita as a result of economic activities and lifestyle are significant drivers as well.

4.5 Summary

In summary, these major trends illustrate Oman's ongoing groundwater management challenges, especially those encountered in the most densely populated and cropped areas in the north of the country. Agricultural and economic development in other sectors has been underpinned by groundwater exploitation. This has led to enormous impacts on the resource systems, which has influenced possibilities in the future. The declining water levels and increased salination are a direct result of over pumping and given that the effects have been known for more than 20 years now is worrying that there have been few initiatives that have brought the desired results of reducing consumption. The wells data that show declining levels of consumption are in areas where salinity levels are now so great that the water cannot be used for irrigation, or where the land has been abandoned.

The move to non-conventional water resources systems is inevitable as the deterioration of groundwater in terms of both quality and quantity shows little sign of halting. This is an expensive option and reflects a supply-side focus in new initiatives. There is a need to expand the use of treated waste water as currently much of this is being wasted and essentially dumped in the sea. For this to happen there needs to be an expansion the distribution networks to the agricultural areas, as well as to information, economic and regulatory policy instruments to support this. Farmers and consumers both need to be convinced that there are no adverse health and environment impacts of using this water resource with clear and open regulatory instruments supporting this. Economic instruments are needed to encourage the use of this water as currently groundwater is free. Perhaps most required is information that highlights the safety in using the treated waste water in Oman, supported by both local research and inputs from success stories such as from Jordan, Tunisia and California.

Demand management should also be a major part of these strategies and so far success in this area has been limited to negligible. Domestic and industrial consumption have increased dramatically in recent years due to socio-economic changes and industrialization, but at present there are no incentives to demand-management there, either. In the next sections these initiatives and supporting legal and regulatory frameworks will be reviewed in more detail.

5 Oman's political history – the context to water governance and policy development

Following the preceding overview of the sources and consumption of water in Oman, the attention will now turn to the governance and policies for managing these resources. It will give important insight on the priorities of subsequent administrations and the interplay between development, politics and the role of water.

Oman has existed as a distinct nation for several thousand years, making it quite different to the other more transient and younger states of the Arab Gulf. Ancient settlements in Oman, initially associated with nomads, date back to c.6000 B.C. For much of the last 2500 years, various powerful civilizations exerted control over the country, particularly in the coastal areas. From the 6 century BC, the Persians dominated with the land known as Magan (Chatty and Peterson, 2001). Around two millennia ago southern Oman was a major producer of the much sought after frankincense and Sumhuram was founded as port near modern day Salalah, and the ruins still visible today testify to the wealth of that period. It was closely linked to ancient Sheba.

In the 6th century A.D. the people of the region converted to Islam, and the country was successively controlled by the various invaders including the Umayyads, Abbasids, Karmathians, Buyids, and Seljuk Turks. Further invasions brought the coast of Oman under controlled of the Portuguese from 1508 to 1659, when the Ottoman Empire took possession. The Ottoman Turks were driven out in 1741 by Ahmad ibn Said of Yemen, who founded the present royal line.

The modern state – the Sultanate of Oman – is a creation of the last two hundred years and has general since remained as an independent Arab and Ibadi/Sunni Muslim entity (Chatty and Peterson, 2001). The traditional territorial concept of Oman came later in this period following the independence of the north-western part of Oman as the UAE, and the annexation (in 1829) and retaking (in 1879) of the Dhofar region into the modern country territory (Peterson, 2004a). This region still retains a separate cultural identity more linked to Yemen than the rest of Oman and their trading links follow different courses with East Africa and the Hadramat Region of Yemen being their closest (Peterson, 2004a). Dhofaris are entirely Sunni, whereas in the north, near half are Ibadi muslims. The population in Dhofar are largely drawn from the Al Khathir tribe but there are also large elements of Khuddam, descendants of former slaves and others of African descent (Peterson, 2004b)

Omani culture did not have a caste system but operated in a hierarchy based on family connections, relative wealth and religious education (Chatty and Peterson, 2001). At the top of the pyramid was the sultan and his immediate family, the Al-Saids. This was followed by a larger tribal group, the Al-Bu Said. Tribal systems were important for the native Omanis with each having their own well or aflaj system with their own rules, and codes of practice and governance. This basic social stratification is largely still in place today and influences many aspects of water governance and management.

5.1 Customary and pre-independence water management – aflaj systems and oasis management as common pool resource management

The landscape and associated tribal groups within Oman have essentially been defined by the dominant topography characteristics. Low lying coastal areas have been the main areas of settled agriculture, whilst in the inland mountains and gravel plains transhumance dominated. For example the Al-Qara group living in Jabal Dhufar are commonly called jabbalis or mountain people and they established bases at small settlements with mud-and-stone roundhouses but roamed through their individual[2] tribal territories with their herds of goats and small-hardy mountain cattle (Peterson, 2004b). Similarly the Al-Mahra were nomadic camel herders, living in the northern desert of Dhufar. In these traditional systems, leadership was paternalistic rather than authoritarian with the Sheikh responsible for his tribe, mimicking his role within his own family (Peterson, 2012). The consensual relationship between the ruler and the ruled was facilitated by the compactness of society at that time. Leadership was exercised directly by the ruler, often be decisions reached in open court after ascertaining the opinions of his advisers, family members and other notables of the local society. Dissent was not possible, and any opposition generally meant expulsion from the community (Peterson, 2012).

During this period, shared property rights or land use rights were held by custom and generally tribal in origin (Chatty and Peterson, 2001). Thus much of the interior and arid lands used by the nomadic pastoralists were recognized and uncontested by local inhabitants and other tribes. For water management similar rules were in place with tribes having their own wells with the associated rules and governance structures. Taking water from other tribes' wells was not acceptable and broke these unwritten rules. The majlis, the communal gathering of the male tribe members, was the governance forum where disputes were initially discussed. The ultimate decision-maker however, was the head of the tribe and any disputes that were not resolved consensually were taken for his consideration and dispensation.

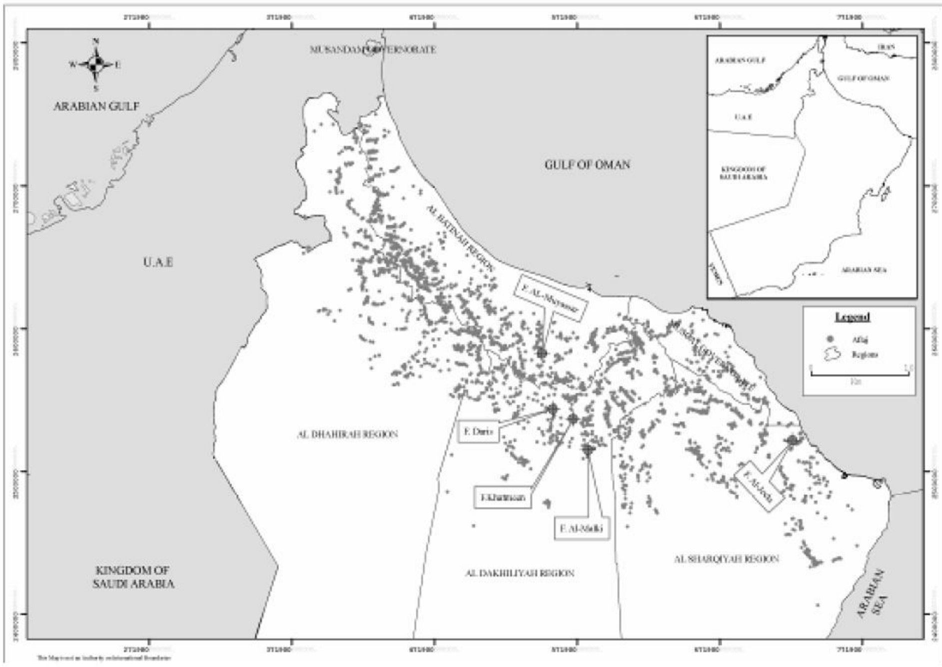
5.1.1 Settled agriculture and aflaj systems

Pre-modern settled agriculture in Oman predominantly relied on the aflaj irrigation and water management systems that are still in use throughout the Middle East, North Africa and Central Asia. Oman has the second-highest number of active aflaj systems following Iran, some of which have likely been in active use for over two millennia (Beaumont et al., 1989). Though their proportional contribution to Omani agricultural and economic output has declined significantly in the last few decades, they are still relevant to both and continue to serve incredibly influential social and cultural roles. In Oman, three types of aflaj exist – those based on permanent springs, ephemeral wadi flows and interception of the groundwater table. Basic information on their physical structures and hydrological components is provided in Al-Rawas & Hago's (2000) examination of their construction.

It should be noted that while aflaj no longer provide domestic water on a large scale, prior to the modern era they were the primary source of domestic water supplies in Oman with the exception of the immediate coastal plain where dug wells were utilised. Open access to aflaj systems for domestic consumption for both people and livestock is enshrined in customary law systems with only certain restrictions to ensure water quality. The discussion here, though, focuses on aflaj's irrigation water provision functions. The distribution of aflaj in northern Oman is shown in Figure 21, and it highlights their placement along the mountain foothills, whereas farming in the lower Batinah plains was typically much closer to the coast where groundwater tables were closer to the land surface and therefore could be accessed by hand or animal-drawn dug wells (Al-Sulamaini et al., 2007).

[2] The Al Qara people are organized into around 12 tribes occupying narrow contiguous strips of territories (Peterson, 2004b).

Figure 21. Distribution of aflaj in northern Oman



Source, Al-Sulamaini, 2007.

Extensive study of aflaj systems in Oman by Europeans dates to the dawn of the modern oil era. In the modern era researchers from a wide range of disciplines have examined them closely to assess their role in the historical and political development of Oman, as highly effective indigenous institutions to manage common pool resources, as vehicles for sustainable and equitable development and more recently for methods to protect, rehabilitate and improve the irrigation efficiency of aflaj systems in the face of the myriad challenges they face today (Wilkinson, 1977).

The building, upkeep and utilisation of aflaj have highly developed management systems that shape the communities' dependent on the common pool resource they exploit. Their management was the defining feature of historical Oman's agricultural political economy and this section examines the mechanisms underpinning their success as effective water management institutions.

5.1.2 Water rights in aflaj systems

Though the last major period of aflaj construction in Oman was around the mid-1600s period of Omani empire-building following the permanent expulsion of the Portuguese from Muscat and the subsequent consolidation of Omani commercial dominance in Zanzibar and coastal East Africa, it is important to examine the rules associated with their building to understand their evolution. When a new falaj was constructed, permanent water entitlements representing a limited proportion of falaj flow-time were divided among its builders according to their capital and/or labour investment (Al-Marshudi, 2007). Thus there are no notions of seniority in water rights within aflaj systems since each system's entitlements were allocated simultaneously with the inception of the falaj itself.

These permanent entitlements are assets that are distinct from any land ownership or tenure rights and can be bought, sold and inherited. The separation of land and water rights is a critical feature of alaj systems since the falaj itself is a communally-owned corporate entity – a falaj estate – which owns a portion of the flow-time. Falaj flow time is allocated in time rather than volumetric units easing the division of water resources and ensuring shareholders share the risk of diminishing flow proportionally (Al-Marshudi, 2007).

Water allocation follows a fortnightly cycle (*dawra)*. Each day within the cycle is split into a day (6AM-6PM) and night period (*badda)* comprised of 24 units of 30 minutes each (*athar)* that can be subdivided further into fifteen and seven minute units. The timing of an entitlement holder's water delivery is usually not fixed but spread over the cycle providing flexibility in the management system. This is a valuable feature since frequently farmers have land plots scattered throughout the falaj system, and also it helps share the burden of night-time irrigations. Within each cycle, a set proportion of falaj-flow is allocated for entitlement holders. The remaining flow-time is owned by the falaj estate and is sold at auction (Al-Ghafri, 2008). The water auction is typically held seasonally, and, unlike entitlement rights, auctioned water shares are usually fixed in timing of delivery. Thus, auctioned water share prices fluctuate significantly according to overall water supply and demand within the falaj system (Zekri et al., 2012).

The major cash crop from aflaj systems was dates. However, in most aflaj communities integrated agriculture is practiced with farmers cultivating date palms, other fruit trees, and fodder crops on the same land parcel which also supports poultry and livestock. In many cases, each community cultivates a mix of date palm varieties reflecting local conditions. As expected in such a system, the option to purchase water shares serves as an opportunity and risk management strategy for farmers who must optimize their production systems based on flows which can be variable (Zekri & Marshudi, 2008).

5.1.3 Aflaj management and aflaj estates

Aflaj entitlement holders form an association with overall management authority for the system. The association elects a *wakeel* (Arabic for manager or agent) who has no strict term limits but can be removed by the assembly if they deem it necessary. The manager is responsible for administering and monitoring water allocations, overseeing repairs to the falaj system and management of the falaj estate and settling disputes. In the case of large aflaj systems the manager has oversight responsibilities for accountants and legal experts as well (Beaumont et al., 1989).

The manager has overall responsibility for the falaj and traditionally was overseen by both the association and the village leader, the *sheikh,* who might be involved in both ceremonial roles and when necessary to legitimize major actions such as the sale of part of the falaj estate. The manager receives a set portion of revenue, typically about 10%, from the water share auction as well as the sale of dates from the falaj estate. Thus the hiring of the manager results in significant ongoing transaction costs for water allocation in aflaj systems (Zekri et al., 2012).

The rest of the auction proceeds go to a variety of uses. While minor maintenance of the falaj comes from the shareholders' required free labour contribution, major maintenance of both above and below-ground portions of the falaj is funded by the revenues from the water share auction and in case of extraordinary need is paid by entitlement holders in direct proportion to their time entitlement rights. Revenue from the share auction and sale of falaj estate products is also used to pay the labourers who farm the falaj estate and for its upkeep. Beyond these needs, revenues from the falaj estate are typically used to help fund community institutions such as mosques and schools (Wilkinson, 1977).

The existence of the falaj estate helps to solve the free-rider problem of common pool resources by ensuring a continuous revenue stream to provide cost recovery. The auctioned shares are essentially public water rights guaranteed through a market mechanism in that they support the provision of the entire water resource. Auctioned shares – public water rights - typically constitute between 2-30% of the total depending on the difficulty and cost of system maintenance. The remaining share is divided among the permanent entitlements. *Daudi* falaj systems have the highest proportion of public water rights reflecting their higher maintenance and operation costs (Zekri & Marshudi, 2008).

5.1.4 Aflaj in the modern era

In modern Oman, aflaj management associations are legally recognized authorities for water management within the predefined aflaj zone. Since 1987 they have been protected by national regulatory regimes which restrict private well-digging in aflaj areas and prohibit private well-digging within 3.5km of aflaj mother-wells. However, the lack of enforcement for these provisions as well as the sheer number of private wells and volume of their abstraction – which are under the purview of the central government - has led to severe groundwater table drawdown. This, in turn, has led to the drying of over 50% of *daudi* aflaj in Oman (Zekri & Mashrudi, 2008). Given their cultural, social and economic importance in terms of agriculture and increasingly for tourism, aflaj protection and rehabilitation has become a prominent concern of the central government. However, nothing short of wholly balancing the groundwater supply and demand equation in each aflaj region will be able to stop the drying of aflaj in Oman.

The economic costs of drying aflaj are significant and varied. One in-depth analysis of the annualized loss of a dry aflaj system - which doesn't include cultural, social and tourism values - shows that direct crop losses make up only 15% of a household's total loss. The majority comes from impacts on human and animal consumption as well as the price differential in providing drinking water via tanker, desalination or local well-fields and piped networks (Zekri et al., 2012).

Not all problems facing aflaj are external, of course. For example, one of the major problems they face currently is the fact that they are sub-divided into very small holdings typically smaller than 1 feddan. These small farm sizes limit a single farmer's income stream and collectively limit the ability of aflaj farmers to take advantage of modern agricultural inputs, techniques and methods. Another issue is that the vast majority of aflaj irrigation is through field-flooding that is highly inefficient, and the physical and institutional structure of aflaj systems makes it difficult to implement modern irrigation systems.

Aflaj systems and the institutional management mechanisms they employ have survived under various ruling political and legal regimes for thousands of years. They have proven durable and effective in managing scarce common pool water resources in highly arid and marginal environments. Their continuity highlights the importance and benefits of effective management of common pool resources and serves as a counter-point to the private water-rights regime that has developed in modern Oman under the influence of Western, particularly British, legal systems that have shaped Oman's legal and resource governance regimes in the modern era.

5.2 Colonialization and its influences on economic development, political systems and water management (15th to mid-20th century)

The waves of colonization of Oman brought many changes to the country which challenged and supported moves away from traditional practices. The Portuguese conquests of Muscat and other coastal towns in the 15th and 16th centuries brought a strong impact through modernization influences with military and technological principles and organizations being introduced. Building on the traditional systems, effects from the Ottoman as well as European empires contributed significantly to the developing political and resource governance systems. Furthermore, unlike the other GCC states, the Sultanate of Oman and Zanzibar were highly involved in Indian Ocean trade systems and therefore connected to British commercial interests in East Africa and South Asia from the 1600s onwards. In many ways, Oman followed a similar trajectory to colonial India in that from the late 1700s onwards the Sultan's authority in political and economic affairs slowly devolved to local elites in various parts of the Omani empire who were under the influence and later control of officials from the British East India Company (Onley, 2005).

The development of British rule in Oman as a protectorate overseen from British India meant that it was never an outright colony, and followed a course of development typical of British informal empire-building. During this period local issues such as financial ruin and loss of indigenous support undermined the Omani rulers' outright political control, leading to them relying on British aid in propping up their regimes economically and militarily. The East India Company and other British commercial entities often signed financial agreements with political rulers as individuals as well as heads of state. Later, when either the ruler or the state slipped into default or was challenged politically, the British installed agents to prop up their regimes and control their expenditure and revenue streams to ensure the debt was paid satisfactorily.

This led to the Sultans of Oman losing control over external affairs and general government spending but they increased and consolidated their power significantly over internal affairs compared to traditional tribal systems due to the rulers' support from the British (Bhacker, 1992). After the world wars of the 20th century, and following Indian independence and the Suez crisis, Britain came under increasing pressure both from with the UK and globally, to step back from its direct influence in the Arabian Peninsula. However, Oman's location importance in an era of growing air power and the potential oil deposits ensured British interests remained and its officials were involved in the country long after independence.

The consequence of the British military protection was the concentration of economic power within the central government and the hands of the ruler to an unprecedented extent. This is exhibited clearly in the structure of many of the original oil concession agreements between British companies and southern Gulf rulers. These agreements were predicated on the notion that since oil exploration, at least initially, occurred in areas that were not private property, land tenure reverted to state control and subterranean resources, including oil and groundwater, therefore belonged to the state, which was represented in these agreements by its ruler (Sorkhabi, 2008; Lambert, 2014).

This signalled a move away from informal but established tribal ownership of land and water that was extensively regulated under existing customary and codified Islamic law, to an increasing state appropriation (Lambert, 2014; Heard-Bey, 1997; Zubari, 2009). Any land and associated water distribution that took place by the ruler was linked to securing political strength and for rewarding loyalty amongst members of the ruling family or their close allies.

5.3 The discovery of oil and its impetus to development

Although oil exploration started in Oman in the 1920s and reserves were finally struck in Dhofar in the early 1940s, it was not until 1964 that large fields were discovered in northern Oman, with exports beginning in 1967. These discovered and recoverable oil and gas reserve base pale in comparison with that of the other GCC states with the exception of Bahrain - Oman's proved reserves are less than 5% of the UAE's, for instance. Therefore, their impacts whilst important were not as transformative as those in Saudi Arabia and Kuwait in particular.

The Sultans derived up-front payments and/or set proportions of oil revenues as individuals aside from the state's cut, which to an ever-increasing extent they controlled (Peterson, 2013). Using these revenues rulers consolidated power among a very small and tightly-knit elite patronage network. However, development of infrastructure and social services was slow, in comparison to the other Gulf States, thus the distribution of benefits was limited.

During this period, Sheikh Sultan held steadfast to his policy of isolation. Oman was not part Organization of Petroleum Exporting Countries (OPEC) or Organization of Arab Petroleum Exporting Countries (OAPEC), or the United Nations or Arab League, and the ruler's sole concession to membership of an international body was to the World Health Organization. He was content to accept British military and financial assistance whilst striving to hold Whitehall's demands for liberalization and development at bay (Peterson, 2004c). The British colonial "developmentalist" ideology structured its relations with the ruler and as a condition of British subsidies in the 1950s and 1960s, forced the development of agricultural farms (Peterson, 2004c). This meant irrigation schemes, beyond the aflaj were introduced using wells and pumps during this period. The state thus informally assumed overall control of groundwater resources that were not previously accessed from private or communal property such as aflaj management associations.

These developments became more limited, particularly from 1965 onwards, when the focus of attention and finances was on internal conflict within the country. The interior of Oman had been relatively autonomous of the coast and when Sheikh Sultan occupied the area in 1955 with the help of British forces, a complex and sustained civil war began partly supported by finances and arms from Saudi Arabia (Peterson, 2011). This was a period of more general Arab nationalism with concerted moves away from colonialist influences. The situation in the south of the country was even more difficult and serious. Opposition here to the exceedingly paternalistic rule of Sheikh Sultan lead to the Dhofar Wars which started as small skirmish in 1962 between disgruntled tribesman who attacked irrigation systems and American oil-company vehicles (Peterson, 2004c). It escalated into a Dhofari nationalist movement in the late 1960's with the support of South Yemen, and then from China and the Soviet Union. The war was financially draining and Sheik Sultan was forced to spend increasing amounts on expanding his armed forces, with some British assistance. He retreated permanently to Salalah in 1958. He was removed from as ruler, with the help of the British, by his son Sheik Sultan Qaboos.

5.4 Sultan Qaboos and the modernizing of Oman (1970-2000)

Sultan Qaboos' tenure from July 1970, commonly known as the Omani Renaissance, was a period of stability and prosperity in stark contrast to the violence and upheaval of the 1950s and 1960s. It was also a period of rapid economic and social development and the concomitant consolidation of sole power and authority into the hands of Sultan Qaboos through his role as benefactor and distributor of state expenditure. The personal authority of the sultan remained unquestioned. The sultan was the only son of his father and had no children so the situation was very different from other Gulf state ruling families where there were numerous family and close relatives vying for position.

One of the first actions taken in 1971 was to appoint an Interim Council composed largely of returning expatriates to oversee the transition (Peterson, 2004c). Various capable Omanis came back from exile and took up positions in the new government, exercising an influence not found previously in the country. The first ministries were established and with the appointment of new ministers and under-secretaries various tensions arose amongst this elite from the mix of different backgrounds, experiences and expectations. One result was the assumption of the role of prime minister by Sultan Qaboos following internal wrangling and disagreements on the appointment.

In the coming years senior members of the ruling family began to take over positions, and other ministries and portfolios were apportioned to important tribes and various regions (Peterson, 2004c). The system of 'wasta' persisted where a citizen with a complaint could by-pass local authorities and go directly to a minister or other high official who was from the same tribe or family.

Gradual governance developments let to the sultan seeking greater involvement of the public in government processes. Political participation has increased hand in hand with the growth of an educated and sophisticated middle class within Oman that is not directly reliant on support from the ruler. It is within this group that discussions on transparency were most forthcoming. In 1981 the State Consultative Council was formed which was formed to provide advice to the government when requested. This was replaced by the Majlis al Shura (Consultative Council) whose members were elected, with the suffrage eventually becoming universal. In 1997 the Majlis al-Dawlah was created (State council) which was made up of nominated members, and partly created to balance the elected Majlis al Shura. The Basic Law[3] of the State of Oman, the nation's legal constitutional framework was promulgated in 1996.

These new bodies and the constitution gave some legitimacy to the state system, but the greatest supporting factor to the increased stability was the social and economic developments that took place. They were one side of the implicit social contract between the state and the people in that in return for the providing for the population's well-being, the people give their loyalty and obedience (Peterson, 2011).

In the 1970s the emphasis on development and the creation of a comprehensive and relatively efficient government were crucial elements in establishing the legitimacy of the new ruler (Peterson, 2013). The British 'developmentalist' ideology continued to shape the post-independence regime's economic planning, proscribing rapid economic growth through aggressive exploitation of all available resources (Adams, 1992; Woertz, 2013). For the first time a rational process of assessing the needs of the country/people and actively addressing them led to the first five-year development plan began in 1976, with emphasis on infrastructure expansion.

The country was overwhelmingly rural and poor with the large majority of the population reliant on subsistence agriculture. The obstacles facing Sultan Qaboos and his adviser in 1970 were huge. There were few Omanis with any education with most of the educated living outside of the country. The existing government was minimal and ill-suited to development. The country lacked nearly all infrastructure including roads, schools, electricity outside the capital area, and there were not even government offices away from Muscat (Peterson, 2004c). The country was still in a state of civil war, which did not finish until December 1975 with capitulation to the new Sultan.

Funds for this new government were limited relative to the enormous needs, and were derived principally from oil. The cessation of the Dhofar War and rising oil prices facilitated a period of relatively rapid development. The Sultan instigated along with government modernization, socio-economic development and re-creation of a national identity which had been fractured through the loss of East African territories and numerous rebellions in the 19th and 20th centuries. This relatively small resource base and large native population in comparison with

[3] The White Book. The Basic Law of the Sultanate of Oman Adopted by: Royal Decree No. 101/96, issued on 6 Nov 1996 by Qaboos Bin Said, Sultan of Oman.

other GCC states increases the immediacy of economic diversification and national development needs

Oman's development initiatives were primarily guided by the cycle of Five-Year Plans that were promulgated from 1970 onwards. Overall these focused extensively on infrastructure and human capital development. GDP per capita has increased from approximately OMR 160[4] in 1970 to OMR 5,800 in 2009 and education, health and social indicators have improved nearly as quickly. The jump in GDP aligns closely with periods of rapidly escalating oil prices in the 1970s and then again from 2000 onwards **(**Ernst & Young, 2011)**.** Continuous efforts to diversify the economy from dependence on direct hydrocarbon exports have only been partially successful. Non-oil GDP is slightly over 50% of the total, though hydrocarbon revenues contribute over 80% of the government budget. Like other GCC states, fuel, electricity, water and food subsidies remain significant – they total over 10% of government expenditure - and contribute significantly to high municipal water demands and pumping of groundwater in excess of renewable recharge (Zekri, 2008). In 2015 and 2016, with falling oil prices, these subsidies are increasingly under review with some on fuel, electricity and water for certain sectors cut.

Government involvement in water management through the early 1980s focused on developing the machinery of the state to address water issues overall as well as creating piped networks and increasing groundwater supplies to Muscat and Salalah. In the interior and rural areas, the increased provision of water by digging municipal well-fields was an important government objective primarily in connection with major national health programs that were initiated in the 1970s. Agricultural water management remained primarily in the hands of aflaj associations which continued to be the primary source of irrigation water through the late 1980s or early 1990s before they began to eclipsed by private well development and national scale oversight (Al-Yousef, 1997; FAO, 2009).

With the increasing demand for water, legislation was prepared to safeguard the water rights established by customs and traditions. Under the first law aimed at protecting groundwater resources in the Sultanate from depletion and pollution, Royal Decree No. (82/1988) Considering the Water Reservoir and National Wealth, it said "Declares the groundwater reservoirs a public wealth to be exploited subject to water use regulations to be prepared by the Ministries of Environment and Water Resources and MAF, in a manner that will not affect the available water resources".

This was followed by Ministerial Decision No. 2/1990[5] that decreed that all existing wells needed to be registered and that permits were required to modify existing wells or dig new ones. Under Article 5 the Ministry of Water was given the mandate to specify the permissible quantity discharged and establish the need to install flow meters on each well. Other Articles included details on the registration of drilling well contractors, their duties and penalties for non-compliance to various stipulations.

In this decree, the control of wells is instated through "Each new or substitute well, constructed after the end of July 1990 should have a legal permit and should be inventoried and registered, otherwise it should be considered illegal". Water rights were strictly attributed to a specific use such as agriculture, industry, or service. Water sales were also strictly controlled. Unlike other countries in the region, water trading amongst farmers was not permitted. A farmer for example could not sell water to his neighbours for agricultural purposes but he can sell water for drinking purposes (ICBA, 2012).

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[4] The Omani Rial has fixed to the US Dollar since 1973. From 1973-1986 the rate was OMR 1 = $USD 2.895 and from 1986 has been OMR 1 = $USD 2.6008.

5 Ministerial Decree No. (2/1990) Regulations for the Registration of Existing Wells and New Well Permits Article.

Groundwater abstraction was also subject to monitoring, with a mandated need to install meters and that the MWR could impel farmers to install a meter or the MWR can install one and charge the farmer for the cost. There were also penalties for interfering with the meter. However, this law was not yet effectively applied and there no meters installed on wells.

One of the biggest problems facing implementation of the law was that there were few records of the wells in the country. Therefore, under Royal Decree No. 374/1992 a national computerised well and *aflaj* inventory was established to assess the quantity and quality of groundwater and its use. Two major initiatives resulted with the National Well Inventory Project that began in 1992 leading to the registration of over 167,000 wells and field inspections of the sites to gather data on water levels, water quality, pump types, water use and irrigated areas. This was followed by the National *Aflaj* Inventory Project which began in 1997 under which 4,112 *aflaj* were recorded; 3,108 were found to be operational. At the time it was found that the total areas serviced by *aflaj* in Oman was 26,500 ha, of which 66% was under crop at the time of the field survey (ICBA, 2012).

These regulatory initiatives were further strengthened through Ministerial Decree No. 13/1995 which included articles to cover further development in well registrations, permitting procedures. Water property rights were further embodied in the Basic Law of 1996, which is in effect the Constitution, where Article 11 states that:

> *All natural resources are the property of the State, which safeguards them and ensures that they are properly utilized while taking into account the requirements of State security and the interests of the national economy. No concession may be granted, nor may any of the country's public resources be exploited, except in accordance with the Law and for a limited period of time, and in such a manner as to preserve national interests.*
>
> *Public property is inviolable. The State shall protect it, and citizens and all other persons shall preserve it.*

These various developments highlight the increasing role of the state in the 1990's. Through government bodies, greater control over the water resources is assumed. Various measures enshrine into law that groundwater is now the property of the state, as opposed to the community or landowner, and that access to this resource is subject to controls.

At odds with these increasing protective controls on groundwater were the developments in the agriculture. The government involvement in agriculture in the 1970s was minimal and largely consisted of commissioning research studies and laying the infrastructure baseline, especially rural electrification, necessary to facilitate private sector agricultural development. However, the need to feed a rapidly expanding population and diversification initiatives aimed at increasing Oman's non-oil revenues provided the impetus for the range of direct subsidies and programs that ultimately facilitated and incentivized private-sector expansion of agriculture in the 1980s and 1990s (Owtram, 1999; Allen and Rigsbee, 2000).

As part of this drive to encourage agricultural expansion, the government capitalized the Oman Bank for Agricultural and Fisheries in 1981 to provide subsidized medium and long-term loans primarily to small-scale farmers with the majority under OMR 10, 000 ($26,000). Through the 1990s the Bank emphasized infrastructure and equipment purchases including groundwater pumps and other groundwater well-related services and the MAF through other mechanisms set up direct subsidies for diesel and later electric groundwater pump purchases that became widespread since the 1970s.

At the same time the government set up the Public Authority for Marketing Agricultural Products (PAMAP) in 1985 which became a major buyer and value-added contributor to agricultural market chains in the country. This highlighted the move from food production to feed the family farming unit, to selling it into the market space. This supported expansion in crop and livestock production fuelled by subsidies and ever increasing groundwater-based irrigation. The PAMAP was criticized as an agricultural price support system that encouraged the spread of cultivation regardless of resource limitations and the quality of outputs (Allen and Rigsbee, 2000).

6 Water policies and groundwater governance in Oman today

Today the government continues to be headed by Sultan Qaboos who as head of state holds final authority on all policy matters. He appoints the members of the Council of Ministers and National Development Council which assist in policy planning and execution. The Majlis Oman, through its two branches of the appointed State Council and elected Shura Council, continues to play advisory roles and provides comments and feedback on potential legislation which is passed to it by the Council of Ministers governing. Local government is through the five regions and four governates with the regions further subdivided into 61 districts (wilayat) where responsibilities are largely in the areas of health and education.

Oman's water sector is governed in a top-down manner with the highly important exception of aflaj systems which continue to be run communally by aflaj management associations. Various aspects of groundwater, land, environment and agricultural management fall under the remit of four separate ministries with MRMWR continuing to be the most directly involved in groundwater management. MAF and the Ministry of Environment and Climate (MEC) have direct roles in water and land management while the Ministry of National Economy is involved in economic planning and infrastructure development and also provides approval for agricultural subsidy and loan programs. Though there are clearly defined roles and responsibilities for each of the ministries, there are regulatory overlaps and gaps, especially in the management and disposal of wastewater and the protection and conservation of the natural water environment.

Natural water sources, desalinated water and treated wastewater are regulated and managed under different ministries with distinct legal and regulatory regimes. In recent years the private sector has had an increasingly prominent role in the provision and management of unconventional water resources - desalinated and treated wastewater - under the broad regulatory authority of the PAEW. Private sector involvement in the water sector so far has been limited to municipal water supply and treatment and has been encouraged to provide foreign direct investment in the sector.

6.1 Natural water resource governance

Groundwater represents the strategic water reserve. At the national level, responsibility for groundwater and surface water assessment, management and conservation falls to the MRMWR. Its water-specific functions come under the auspices of the Under-Secretary for Water Resources and associated general directorates. Aside from playing a central coordinating role in the management of water resources, the MRMWR's task is the management and assessment of water resources through the maintenance of aflaj, digging wells, building dams, monitoring water status, implementing projects for the utilization of unconventional water resources, and improving awareness of the importance of protecting water resources from depletion and deterioration.

Within the water sector the MRMWR completes the following duties:

- Formulate water policies, plans and programs, implement them and assess their effectiveness;
- Collect statistics and provide laboratory services to monitor water quality for health and resource status purposes;
- Manage water resources and ensure it is in balance with renewable resources;
- Encourage and ensure the wise and efficient utilisation of water resources;
- Spread awareness of the importance of wise water usage and water conservation;

Outside of Muscat, Salalah and Sohar develop the wastewater treatment network and in all areas provide related services to wastewater treatment and particularly to monitor its usage and disposal to combat groundwater pollution

With its duty to control and rationalize groundwater usage and abstraction, the MRMWR has gradually increased its role in regulating abstraction and well-drilling activities (See Annex 2, 3, 4). The initial groundwater protection laws of the 1990's were further strengthened with the passing of. Royal Decree No. 29/2000[6] on issuance of the Law of Protecting the Water Resources along with regulations concerning a) wells and *aflaj*[7] and b) the use of desalination units in wells[8]. Under Royal Decree No. 29/2000 Articles (2), (3) and (5) reiterate the importance of water and empowers the MRMEWR to take actions to protect aquifers:

> *Article 2: Water in the Sultanate of Oman is considered a national wealth, the use of which is subject to controls set by the Ministry to regulate its optimum exploitation for the benefit of the overall development plans of the state.*
>
> *Such controls should include delineation of protection zones and determination of the activities prohibited in such zones without obtaining a permit, as well as the regulations governing digging and maintenance of wells and use of their water, as well as construction and maintenance of aflaj, in addition to water monitoring regulations and procedures set to detect water pollution.*
>
> *Article 3: The Ministry shall take the necessary actions and measures to prevent water deterioration in terms of quality and quantity in all areas of the Sultanate and shall take remedial actions if such deterioration occurs.*
>
> *Article 5: Activities that adversely affect aquifers shall be prohibited, regardless of who owns the land in which the aquifer lies.*

Across the various laws and regulations, the following measures, overseen by the MRMWR, characterize groundwater water control and use:

- There are no authorized tariffs for groundwater;
- Permits are required to drill new wells, drilling of new wells, the deepening of existing wells, increasing a well's diameter, repairing or maintaining an existing well even if diameter or depth are not increased, substituting an existing well for a new on, changing the permitted use of a well, installing a new pump, transporting and selling water,

6 Royal Decree No. (29/2000) Water Wealth Protection Law.

7. Ministerial Decision No. (264/2000) issuing the regulations on walls and *afla*j.

8 . Ministerial Decision No. (243/1997) Issuing regulations for organizing the use of water desalination units in wells amended by Ministerial Decision No. 263/2000 Amending the Regulations on the use of Desalination Units on Wells.

replacing a pump installed with one of higher capacity license requirements (See Annex 2);

- Only the owners of the land can apply for a permit (See Annex 3);
- Aflaj managers must provide approval for wells to be drilled within 3.5km of a falaj motherwell (See Annex 4);
- Areas are classified as *deficit or open* with each requiring different arrangements;
- Water cannot be transported to irrigate newly cultivated areas away from the well;
- Only licensed contractors can carry out well drilling;
- Licences are subject to various terms and conditions;
- Well registration can be cancelled if the well is dug without obtaining a permit or if the well depth has not reached groundwater.

The resulting permits approval matrix is given in Annex 1 illustrating the various categories of protection zones. The various procedures for obtaining permits to establish project using water wells, for undertaking maintenance work, and for excavating wells are given in Annexes 1 and 2 respectively. From these various laws and regulations the MRMWR technically has the mandate to specify allowable well abstraction and discharge. In practice it has been impossible to enforce and measure even if all wells had flow meters, and in reality, only small pilot projects of wells with flow meters have been created so far. Any controls on groundwater use have largely come about indirectly through changing agricultural practices, or movements out of farming rather than actual groundwater legal or regulatory changes.

The legislation and regulations in place are fit for purpose but the implementation has led to negligible control of groundwater abstractions. Landowners are not willing to be subject to these controls by the state, feeling that the water under their land is theirs to use as they see fit. There are few enforcing officers and with limits to government funding from recent oil price declines means this situation is unlikely to change. There is also little desire to antagonize the elite, some of the biggest landowners and water users, given their influence on political stability. Added to which is the MAF whose mandate under the recent Five Year Plans has still been to expand food production for the country. It is the MAF's role to interact with the farmers to enforce the water regulations in irrigation and this has largely been avoided by it officials with communication on water issues woefully inadequate to gain the farmer's buy-in.

A recent pilot project undertaken by Sultan Qaboos University was for 40 farms in the Batinah Plains over one aquifer. This aquifer serves 8000 farms. Online electronic meters were installed and the abstraction of each farmer was measured. The resulting data highlighted large differences in water usage ranging from 20,000 m^3/ha/year through to 60,000 m^3/ha/year. The farms were largely small holders with a mixture of date palms, vegetables and forage. Some of the differences in water usage observed could be explained in terms of irrigation technology used with drip/sprinkler based farms using less than flood-based systems. There were however differences within the technology types highlighting how individual farms operated quite varying water use practices.

The FAO is currently developing a new agricultural strategy for Oman which is in draft form. The need to manage groundwater resources more effectively through metering etc. is being emphasized as vital if farming is to have a future. This is an important development as this is being developed for the MAF.

6.2 Non-conventional water governance

Non-conventional water resources including desalinated water and treated wastewater have become increasingly important in Oman's overall water balance equation in the last fifteen years. The policy of providing domestic, municipal and industrial water users with desalinated water has been implemented quickly in Oman, particularly since the private sector has been involved through the development of independent water and independent power and water projects (IWPs/IPWPs). The legal framework for these activities is relatively recent, dating from 2004 onwards, and institutional restructuring has transferred many duties from the former ministry of Housing, Electricity and Water to the PAEW which was established in 2007 in order to:

- Plan for the production and supply of potable water;
- Operate and maintain water treatment and supply infrastructure;
- Issue regulations for the production and supply of drinking water;
- Ensure potable water demands of population growth and development are met.

Simultaneously, an independent regulator was established, the Authority for Electricity Regulation which oversees the governance, technical and economic regulation of the power and desalinated water sector. Oman Power and Water Procurement Company (OPWPC) is the state-owned single buyer and seller of commercially-produced desalinated water. It buys water from IWPs/IPWPs and sells it to various government authorities under bulk supply tariffs approved by the Authority for Electricity Regulation. Subsidies are provided by the Ministry of Finance to water suppliers to cover the gap between utilities' costs and incoming revenues (United Securities, 2011).

With both desalinated water and wastewater treatment, the private sector has played an important role in the development and operation of infrastructure. The role of the state is more strategic and regulatory to ensure that institutional, political and economic structures are in place to facilitate private sector investment and long-term commitments. Private enterprises bring experience as well as technical and business knowledge to Omani water sector, but their involvement should be understood within the government's overall strategic framework for national development (Bryniak, 2015; ICBA, 2012a).

6.3 Agricultural governance and policies

Given the demands of the agriculture sector on water resources it is also useful to consider its governance too. The coordinating governing body for developing agriculture, crop and livestock production is MAF. The many duties of the MAF listed below highlight the constraints it operates in to develop agriculture while conserving the fertility and capacity of the land as well as groundwater resources. The ministry is responsible for water use in agriculture including irrigation management and protecting and enhancing traditional aflaj systems. The MAF undertakes the following major responsibilities:

Prepare, execute, and follow-up agriculture and animal wealth development plans in a way that ensures the sustainability of resources and its revenue for the citizen and the country, in coordination with the other government entities.

- Preserve and protect plant and animal wealth from insects and diseases;
- Develop agricultural water resources ensuring its best use and sustainability;
- Protect agricultural lands, plains and other related resources;
- Organize investment and marketing in agricultural and animal related areas;
- Prepare and publish statistical agricultural information and build databases at the Ministry.

Ministerial Decree No. 41/2010 issuing the Implementing Regulations on the Agricultural System sets out to control agricultural land through establishing a need for owners to register to. All who acquire farmland have to register this in the Centre of Agricultural Development. Once this takes place and a card is issued, this registration process enables people to access various agricultural services including extension activities. The Decree also put forward a systematic set of rules for the use of agricultural land and its potential use in other areas. It states that agricultural land must be used for farming unless:

a. There is no source of water and no permission is allowed for drilling of wells and;
b. The level of water salinity is more than 20 000 ppm.

It quite clearly states that agricultural land cannot be used for building unless permission is granted and this involves a defined set of procedures. Any changes in farmland to any other purposes are not allowed where they are irrigated by the falaj. The regulations also state that waste water is not allowed to be used for irrigation. In further provisions, a number of other measures put into place by this decree to support financially and technically the adoption of modern irrigation systems on farms. New systems should also be installed if previous ones were more than 15 years old and this would be financially supported by the MAF.

These measures should contribute to enhance groundwater management and to some extent have been effective. However, the biggest challenge across groundwater governance is the poor inter-sectoral coordination of water use and conservation policy development. Each ministry pursues its own agenda, as defined in the Five Year Plans, and these are often contradictory. A single coordinating body is needed to integrate policy objectives across the organizations, each of which has distinct ultimate goals and agendas and to develop a common groundwater management strategy could be of great benefit in Oman.

6.4 Water policies in modernizing Oman (2000 to present)

The water policies of the last decades reflect a more nuanced, if rather disparate approach to development with an acknowledgement that development of resources at all costs is not possible. The rising salinity levels have resulted in more than 30% of agricultural land being lost to future production. Given that this lost land is in the flattest areas close to urban areas, this has had an impact on the ability of Oman to manage a basic level of food security. Groundwater is still predominantly used in agriculture, with ever an increasing network of desalinated water being piped to even the most remote villages, replacing the use of this resource of domestic consumption and commercial activities. Policies and instruments have therefore focused on managing the groundwater use in agriculture, with less emphasis on expansion of farming.

6.4.1 Strategic policy areas

The starting point to modern water policy in Oman is the 1991 National Water Master Plan and 1990 Agricultural Development Plan which highlighted various priority areas related to groundwater management and provided the basic structure of subsequent water conservation strategies (Zekri, 2008; ICBA, 2012; UNEP, 2001):

- Improve irrigation efficiency by expanding the usage of modern irrigation systems;
- Substitute date palm trees for vegetable crops;
- Create appropriate tariff structures for irrigation and non-agricultural water purposes;
- Use treated wastewater for municipal and agricultural irrigation;
- Support research programs and extension services to improve farm performance;
- Focus fodder production on low water and highly saline tolerant varieties.

These were further developed under the strategic economic growth and policy objectives of Vision 2020 and related documents which proposed a mix of supply- and demand-side solutions to address groundwater problems. The supply-side objectives were (FAO, 2008):

- Continue exploration for water resources;
- Continue construction of recharge dams and other hydrological structures;
- Expedite the extension of potable water distribution networks;
- Maximize agricultural productivity within the natural limitations of climate and water resources availability and sustainability;
- Realign agricultural subsidies towards larger and technologically advanced projects.

Demand-side measures included the mechanisms described above as well as the following measures and new controls:

- Rationalize the allocation and size of new agricultural lands;
- Promote seasonal crops (more water efficient) and limit perennial cultivation;
- Determine appropriate quotas according to water situation in different areas;
- Continue to subsidies the maintenance of *aflaj* systems, while transferring the onus for implementation to the recipient communities;
- Expand well-field protection zones and monitoring networks;
- Expand monitoring networks.

In addition to the more general areas of water management, one of the most pressing issues was tackled in the Oman Salinity Strategy (ICBA, 2012). They highlighted that without addressing measures to reduce and eventually eliminate groundwater overdraft salinization would continue. Many recommendations were put forward including:

- Improving coordination between ministries;
- Improving agricultural extension services and capacity development, and developing model farms;
- Investment in upgrading on-farm irrigation efficiency;
- Support changes in production systems, including the use of alternative crops that are more tolerant of saline conditions;
- Identifying the causes of on-farm yield gaps and development of policies and management approaches to enhance agricultural productivity.

To date they have not been implemented.

6.4.2 Implementing the policies

These various measures have been put into practice through various policy instruments. Section 10 already detailed various regulatory instruments introduced to put into effect increasing control on groundwater abstraction and use.

Economic instruments are often major drivers in groundwater consumer practices through the cost of water and in encouraging its use. In Oman only urban water users pay for groundwater when it is distributed through tanks and a distribution network. Industry and farmers, the main users of groundwater, do not pay any charges. However, the sector does pay for the electricity for pumping; to which most farmers now have access. The average cost of pumping from a 21m deep well is US$0.05/$m^3$. The cost of drilling a well is estimated at US$125/m for public wells. Although private organisations are not allowed to dig new wells, the reality is they do and the price ranges from US$50-70/m (ICBA, 2012).

Aflaj water is private property and farmers own a time share of water within a predefined water cycle. The water is freely conveyed from the source to the farms by gravity. When farmers do not own water shares or when they own insufficient water they usually lease part of the common water shares. The lease prices observed in the aflaj vary considerably. On average the water price varies from US$0.02-0.142/CM. This is a sophisticated water market with prices fluctuating according to supply and demand and supplies are subject to auction (ICBA, 2012)

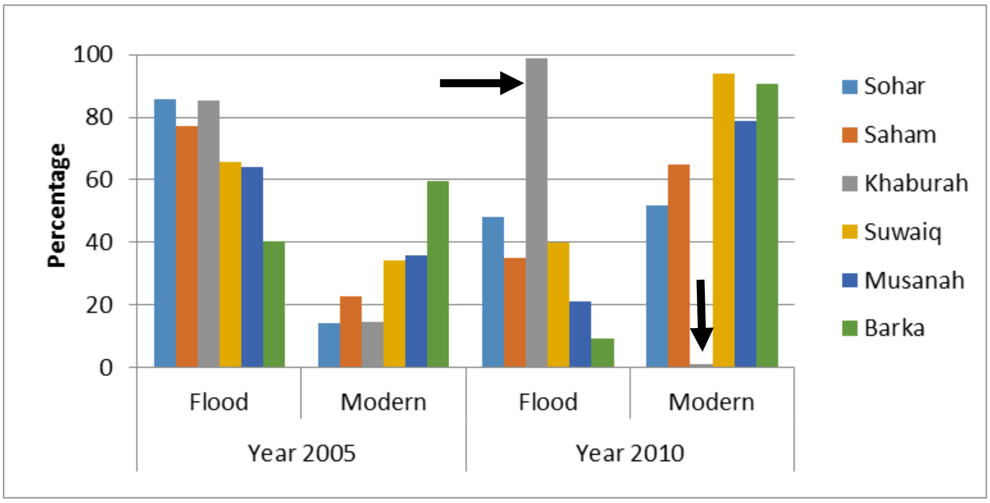
With both groundwater abstraction wells and through the aflaj system, the cost of water is small especially in comparison to alternative sources of water such as desalination and treated wastewater. There is little economic incentive therefore to move away from pumping groundwater resources especially for use in agriculture.

For the domestic and commercial sectors economic investments have been to provide alternative resources to groundwater. Since the 6th Five-year plan the water sector has been an increasingly prominent recipient of state funds as desalination, wastewater treatment and the expansion of piped network capacity have been increasingly important government priorities to address population growth and groundwater deterioration. The results of the various investments and development were detailed in Section 3 and have led to a large reduction in groundwater use for the domestic and commercial sectors. These supply-augmentation strategies are predicated on highly consolidated, state-centric political structures and the guiding developmentalist ideology that frames economic planning. They have opened up water governance in Oman to include new regulators and private sector producers which bring new framing of water resource systems.

Subsidies that encourage a particular water use or that off-set water abstraction costs have been an important part of policy implementation in Oman. They have been used to support developments in various economic and geographic areas in response to policy directions. Subsidies from the 1980s onwards were available for well drilling and for the provision of pumps. In the 1990's an irrigation subsidy program was introduced by the government to help support water conservation initiatives, with RO 5 million allocated for the Al Batinah coastal area and RO 7 million for the rest of the country (FAO, 2008). This was not a blanket subsidy and eligibility criteria included farm size, low water salinity and only one farm per owner, with the subsequent subsidy ranging from 75% for small farms (5-10 feddans) to 30% for larger one (50-100 feddans). Since 2000, farmers introducing modern irrigation technologies have received 100% subsidies as long as they have gained prior approval from both the MAF, and a well licence for the water source from the MRMWR (ICBA, 2012). In recent years, and especially in 2016 with low oil prices drastically impacting state spending, these subsidies have been cut and are now zero. This has led to a dramatic fall-off in farmers migrating to this form of irrigation. Their argument has been that they are waiting for the 75% subsidy to return before they invest in such schemes.

The relative effectiveness of these subsidies has been marked. From 2005 onwards, the area irrigated by flooding was reduced in the Batinah Plain, especially in Saham and Sohar. In Suwaiq, and Barka, more than 90 percent of the area is now being irrigated with modern irrigation system. In Suwaiq, around 50 percent is irrigated with drip irrigation only, whereas in Barka, bubbler and sprinkler irrigation methods contribute 32 and 39 percent, respectively (See Figure 22). A further area of government subsidies in recent years has been to support major programmes in the introduction of greenhouse technology to both improve productivity levels and manage water use. The government has offered varying percentage cost offsets for building these structures to increase water use efficiency especially in vegetable production.

Figure 22. Comparison of flood and modern (drip, sprinkler and bubbler) irrigation systems in Oman



Source ICBA 2012, 2005 Agricultural Census.

Indirect subsidies have also had a marked impact on groundwater abstraction with those for diesel and electricity particularly important (Zekri et al., 2013). In the Batinah Plains farmers using less than 7.000kWh receive a direct 50% subsidy and those using over 7,000 a 33% direct subsidy. These figures also don't include the opportunity cost of Omani natural gas being utilized in electricity generation – it is provided to power companies at below-market rate– and so the total economic cost of electricity subsidies is actually much higher (IRENA, 2014). Electricity subsidies were estimated to cost the state nearly $700 million in 2012 (United Securities, 2011).

6.5 Summary

Groundwater governance and policies are in put into place to protect the natural resources for the common good of current and future populations, protect the environment, yet at the same time use them to support social and economic development. In a country as arid as Oman, in which much of the groundwater resource is non-renewable, the need to protect these resources is vital. Developments in water infrastructure from the drilling of wells, through to sophisticated desalination and treated wastewater plants have been driven by supply-side based water policies, and required a developing legal and regulatory framework. In place are laws and regulation that meet international standards. The division of roles and responsibilities to various regulatory bodies reflects similar structures in other Gulf state countries, particularly the UAE. The role of the private sector in delivering water services has meant that in some areas, the government's responsibilities are as a regulator and developer of strategic directions, rather than a service provider.

In terms of groundwater, whilst the government is responsible for the development of well fields to provide the domestic and other sectors, it is principally a plethora of individual farmers who are the principal users of this resource. Groundwater demand-management in this sector's use as agricultural cultivation and groundwater abstractions have grown so rapidly since 1970. A major challenge lies in persuading the hundreds of thousands of farmers, the vast majority of them smallholders, of the urgent need to improve irrigation efficiency. The lion's share of farmers still cultivate very small holdings with traditional methods, and that is a major barrier to improving irrigation efficiency. Widespread perceptions that groundwater is a privately-owned resource to be utilized as the owner sees fit and resistance to using flow meters, which are frequently cited as the first step on the way to water charging, are major limiting factors to monitoring, assessing and reducing groundwater abstractions. These wells are vital lifelines in the country's rural and interior regions and their owners are wary of government attempts at groundwater management for fear it could turn into appropriation of control over water resources.

This brings complications in terms of implementing law and regulations as there is a need for enforcement officials to check individuals' compliance in addition to the issuing of permits and licences. Not only does this require a large work force of compliance officers, but also the support of the farmers for the required checks to take place. With the power of land owners to oppose the implementation of regulations through *wasta* and in particular the tribal community structures being considerable, it is little wonder that there has been little success in implementing the laws and regulations.

Enforcement is further complicated by roles and responsibilities for groundwater management and irrigation use falling between two ministries. The MRMWR is responsible for access and abstraction and has the legal and regulatory authority to oversee well drilling and groundwater extraction, monitoring and enforcing well usage. MAF is responsible for water use in agriculture including irrigation management. There is little appetite in MAF to confront farmers as part of the implementation of MRMWR rules and regulations. This complicates water demand-management in agriculture and is indicative of the institutional challenges to water demand-management overall.

The policies for both water and agriculture have been focussed on developing supplies and servicing the demands for food security. Agriculture remains the biggest user of water today. Agricultural production increased rapidly in the first 10 years as a result of the policies and incentives of Vision 2020, but poor water management led to growing problems of water and soil salinization (ICBA, 2012). The cost of land falling out of production was very high in terms of the potential cost of rehabilitation as well as lost incomes (Zekri et al., 2013). Equally high costs are associated with loss of useable water resources which have not been costed but has important repercussions for future generations as this is the country's strategic reserves. With fluctuations in oil prices and moves around the world to a post-oil era, reliance on hydrocarbon revenues to pay for future desalinated water supplies is precarious. The recent rapid fall in oil price gives some insight in likely future scenarios. Oman's economy has been hit hard in 2015/16 so the ability to tackle the groundwater issues through economic measures has significantly decreased. The alternative now is an active engagement with farmers to highlight that groundwater management is essential if future farming is going to be possible.

7 Conclusions

Oman has changed rapidly over the last 40 years resulting in greatly enhanced social and economic conditions for its populous. The country has under gone rapid development and the population are enjoying a lifestyle unimaginable forty years ago. The investments in health, education and infrastructure under Sultan Qaboos, and fuelled by hydrocarbon revenues have transformed the country. The government has also developed into a nation state with concomitant governance, legal and regulatory frameworks introduced to manage, guide and protect the country, its people and environments. The stability offered by the government along with oil revenues has brought rapid changes to this once isolated and low income country.

The rapid expansion in agriculture, population, and lifestyle enhancement has brought increasing stress on water resources. The consumption rates have rapidly increased even though the natural resources are limited by the arid conditions of the country. The government has responded through the active support of using desalination and treated waste water systems. This has expanded the resource base, especially for the domestic sector, enormously with further expansion planned.

The cost of the unrestrained expanded use of groundwater has been increasing salinity of aquifers and falling water table levels. The case of the Batinah Plain is stark with more than 30% of the land now no longer in agricultural production as a result. The government responded with new laws, regulations and adjustments to agricultural subsidies but these have led to little change. The land owners are not willing for meters to be added to their wells and for their water use to be curbed. There is a general consensus amongst the farmers that the groundwater is theirs to do as they want. The need to appease these powerful water users trumps that of preserving the resource base. In the meantime, the water levels continue to decline and the salinity levels increase. It is only in areas of abandoned wells or those that are salinized beyond normal use that there is a reduction in groundwater depletion.

The ability to enforce the water laws is further reduced by the division in responsibilities between the MRMWR and MAF. This plays out in a number of areas especially in policies and subsidies to support food production being in direct conflict with those in place to help conserve the groundwater systems. The farmer facing is through MAF yet the directives are from the MRMWR. Until there is a more joined up approach to water and food security this will continue to be a challenge and this should involve a range of information, economic and regulatory policy instruments. This needs to be backed by a concerted approach across all of government departments as stressed water resources have wide ranging economic, security and social impacts. The tensions resulting from the conflicts within the Middle East North Africa as well as more locally at home in Oman from the lack of a succession plan for the leader, ensure that firm enforcement of water regulations across the will of powerful landlords is a major challenge. The need to maintain stability in the country is bought at the cost of groundwater reserves.

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Annex 1. Guidelines for well permitting policy (Source: Ministerial Decision No. 264/2000 issuing the regulations on wells and *aflaj*)

		Falaj protection zones/3.5			**Deficit areas**			**Open areas**		
No.	Permit purpose	New well	Substitute well	Well deepening	New well	Substitute well	Well deepening	New well	Substitute well	Well deepening
1.	To increase the area of the agricultural land or to cultivate a barren land	No	No	No	No	No	No	Yes	Yes	Yes
2.	To maintain existing farms (fruit trees and date palm)	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
3.	To maintain existing farms (other crops)	No	No (except construction failure cases)	No	No	No (except construction failure cases)	No			
4.	To support a falaj within its own protection zone	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5.	To support a falaj within the protection zone of another falaj	Yes (after consent of the other falaj's agent)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6.	Public water supplies (MEW) for mosques, schools & hospitals	To apply Article 15 of these Regs.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7.	Private water supplies for domestic purposes and animal consumption within towns and villages where other water sources are available	No.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

8.	Private water supplies for domestic purposes and animal consumption (outside towns and villages and several kilometers away from the nearest water source	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9.	Manufacturing (other than fodder production)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10.	Tree planting & landscaping	No	Yes (for tree planting only)	Yes (for tree planting only)	No	Yes (for tree planting only)	Yes (for tree planting only)	Yes	Yes	Yes
11.	Industrial estates	To be dealt with by the DG Water Resources Management								
12.	Individual industries	No	No	No	No	Yes	No	Yes	Yes	Yes
13.	Exploration and monitoring	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14.	Sale of water	No	No	No (unless no other water source is available for consumers)	No	No	No (unless no other water source is available for consumers)	Yes	Yes	Yes

Annex 2. Guidelines for obtaining permits to establish commercial and industrial projects relating to water wells

1) Type of Activity: Establishment of commercial and industrial projects or activities (water projects, sale of water, poultry farms, agricultural farms, car wash, etc.) on wells.

2) Authority concerned: Water Resources Affairs Section at the municipality where the project is located in the regions + General Diwan of the Ministry in Muscat Governorate + General Directorate of Environment and Water Resources where the project is located.in Dhofar Governorate

3) General Conditions:

Water pumped from the well should not exceed the amount specified by the ministry.

The well should be inventoried and registered.

Water metre to be installed on the well according to the ministry's specifications.

Designated staff of the ministry should be granted unrestricted access to inspect the project or to read metres.

Water should not be exploited for purposes other than those permitted.

Water must be suitable for purposes permitted.

On no condition should water be sold outside the approved site without prior consent of the ministry.

The project owner should ensure full adherence to the environmental regulations aimed at preventing surface and groundwater pollution.

The project owner should submit approvals obtain from other relevant authorities.

The ministry shall have the right to take an appropriate decision, in the event of violation of any of the aforementioned conditions as stated in chapter eight of the Regulations on Wells and Aflaj issued by Ministerial Decision No. (264/2000).

4) Technical Procedures:

The project/activity location should be outside water supply well fields and should not impact adversely on them.

The project/activity location should be outside the verges of mother aflaj and springs.

The project/activity should not be located in water deficit areas.

The establishment of the project /activity should not have an adverse impact on the quality of water in wells, aflaj or springs.

As for bottled water projects, it is not permissible for them to use the government water networks or tanker water.

5) Preliminary Procedures:

The applicant should submit an application to establish commercial and industrial projects to the competent authorities stated in the following list (each as per the project location).

An assessment of the application followed by a technical report on the location should be submitted to the concerned Director General in the General Diwan of the ministry.

The applicant shall be informed in writing whether his application was accepted or not and the reasons for rejection shall be in accordance with those stated in Appendix No. (1) of the Regulations on Wells and Aflaj issued in Ministerial Decision No. (264/2000).

6) Required Documents:

- Approvals issued by government authorities concerned with the establishment of the project/activity.
- Copy of the feasibility study or detailed statement of the quantity of water which will be extracted by the project per month/annum.
- Copy of the well inventory, and certificate of registration if the application is made for an existing well.
- Evidence of ownership of the site (deeds, maps etc.).

7) Applications for obtaining water permit shall be received from 8 a.m. to 12.30 noon during working hours.

8) In the event of further enquiries or complaints, please refer to the section or department that issued the permit.

Annex 3. Guidelines for Obtaining Water Wells Permits

1) Type of Activity: Carrying out maintenance works on wells.

2) Authority in charge: Water Resources Affairs Section at the municipality where the project is located in the regions + General Diwan of the Ministry in Muscat Governorate + General Directorate of Environment and Water Resources where the project is located in Dhofar Governorate

3) General Conditions:

Applications for wells permits shall be made on the prescribed form, accompanied by documents establishing proof of ownership of the location of the well in the case of new wells, and an inventory and registration certificate in the case of existing wells.

If the application is for the establishment of a new or additional well in a protection zone, the applicant shall be notified by registered mail of the rejection of his application without need for investigation of the location. In locations other than that, the concerned authority should investigate the location in the presence of the applicant and thereafter prepare a report indicating the outcome of the investigation.

If the applicant did not show up on the date fixed for investigation, his application shall be pending, and if he failed once more to attend without a reasonable excuse, his application shall be discarded.

The applicant shall be informed by registered mail in the event of rejection stating the reasons as per Appendix No. (1) of the Regulations on Wells and Aflaj.

The permit shall be issued in the prescribed form and shall be handed over to the applicant, with a copy to the contractor as well if any.

4) Preliminary Procedures:

A completed application form for well permit duly endorsed by the applicant's Sheikh or Wali should be submitted to the Ministry.

A date should be fixed for the designated staff of the Municipality to visit the site.

5) Technical Procedures:

Pumping tests should be carried out on existing well/s in the site to determine the quantity of available water.

The water situation of the site should be evaluated through calculation of available quantity of water in the wells and aflaj against the required water demand.

In the event of approval of the application, a financial insurance shall be paid which will be refunded at the expiration of the permit provided the applicant and contractor adhered strictly to the conditions of the permit.

An applicant issued a permit to dig a new or alternative well shall submit to the authority concerned an application to inventory or register the well as per the prescribed form in addition to attaching a work completion certificate.

After investigating the site and establishing that the applicant and the contractor adhered satisfactorily to all conditions, the authority concerned shall issue a well inventory and registration certificate on the prescribed form, and in this case, shall refund the insurance to the applicant.

If the investigation establishes non-adherence by the applicant and contractor to the conditions stated in the permit, the procedures to be followed to correct the situation within thirty days from the date of his notification. shall be clearly stated on the relevant form.

If the person issued a permit did not carry out any work during the period of the permit's validity, the insurance shall be refunded after the original permit is returned.

The permit shall include the following details:

- Name, address and status of the applicant.
- Type of work and uses for the permit
- Location and depth of the well.
- Type of well (open or borehole).
- Well diameter and other dimensions.
- Drainage pipe diameter.
- Pump size.
- Daily production capacity.

6) Requested Documents:

- Evidence of the ownership of the site (deeds, krooki, etc.)
- Copy of the well inventory, and registration certificate for an existing well.
- Copy of valid Identity Card or Passport.

7) Applications for obtaining water permit shall be received from 8 a.m. –12.30 p.m. during working hours.

8) In the event of any enquiries or complaints, please refer to the section or department that issued the permit.

Annex 4. Guidelines for Obtaining Permit to Excavate Water wells

1) Type of Activity: Affiliating with the ministry as water wells excavation contractor.

2) Concerned Authority: Water Resources Affairs Section at the municipality where the project is located in the regions + General Diwan of the Ministry in Muscat Governorate + General Directorate of Environment and Water Resources where the project is located in Dhofar Governorate.

3) General Conditions:

The application should establish the region's need to increase the number of contractors practicing water wells excavation activity.

Contractors must adhere to the ministry's regulations and laws.

Provision of workers depends on the scope of work and adherence to the ministry's regulations.

The prescribed form must be duly filled and submitted for the renewal of the affiliation certificate.

The adherence of the contractor to the ministry's regulations shall be evaluated and execution of the project during the validity of the previous affiliation period shall be a main condition for the renewal of the affiliation in addition to ensuring ownership of the excavation equipment used in implementing the project.

4) Preliminary Procedures:

Submit a completed application form for water well excavation that specifies the excavation method (mechanical, manual, traditional).

If workers are needed for the digging of water wells (mechanical, manual) the following conditions should be met:

The contractor shall be provided with sufficient workers at the beginning of the registration exercise as follows:

- Manual (3 workers to dig water wells).
- Mechanical (3 water wells excavation workers + drilling rig operator).
- Traditional (Omani workers).

The regulations allow the employment of additional manpower on the following conditions:

Fill out the prescribed form, specifying what is required (additional workers, replacement of departing or runaway workers, transfer of sponsorship, and change of profession).

The contractor's need for workers shall be evaluated according to the strength of the request, considering matters such as the number of excavation equipment in his possession, work already accomplished, and adherence to the ministry's regulations during the period of affiliation.

If the application is approved, the contractor shall be officially notified by the concerned municipality officials after which the application is further referred to the other concerned authorities for finalizing the procedures for issuing a permit

5) Technical Procedures:

The region's need for additional new contractors shall be evaluated by competent officials in the regions, and if the application is approved the applicant (commercial establishment) shall be given a 'To Whom May Concern'.

Certificate indicating the ministry has no objection to the water well excavation activity being included in the commercial register. Computer print out showing that the activity has been included in the register should be submitted to the relevant authorities within a period not exceeding three months from the time of receiving the approval.

Apart from submitting a completed application and a valid ID or Passport, contractors for traditional water wells shall be exempted from all procedures and the above mentioned attachments.

According to the procedures in force, the applicant shall be granted water wells excavation contractor registration certificate enabling him to practice his activity in the specified field (mechanical, manual, traditional) for two years, which is renewable subject to the regulations in force.

6) Requested Documents:

- Valid copy of commercial registration.
- Valid copy of a certificate of affiliation with Oman Chamber of Commerce and Industry.
- Signature specimen.
- Mechanical equipment ownership deed.
- Photo of the mechanical equipment (drilling rig) or manual (air pressure)

7) Applications for obtaining water permit shall be received during working hours from 8 a.m. – 12.30 p.m.

8) In the event of any enquiries or complaints, please refer to the section or department that issued the permit.

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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).
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