The Water Demand Management in the Kingdom of Bahrain

Mohammed Saleh Al.Ansari

Abstract- ***Many factors affect the availability and sustainability of the water supply in Bahrain: climate change, water quality, pollution, and the production capacity of new technologies and non-conventional methods. With growing demand due to climate change, booming industrial complexes and population growth, groundwater abstraction is no longer a sustainable water resource on its own and other methods must be put to increasing use. In Bahrain, non-conventional methods such as desalination and treated sewage effluents (TSE) are increasingly used to meet the water demand for agricultural, municipal and industrial purposes. Pollution, seawater intrusion and other issues continue to thwart non-conventional water resource methodologies and services, creating a bottleneck for the water demand. Water conservation methods for managing the water demand seem promising in all sectors and at all levels, including transmission and household level use.***

Keywords: Water Resources, Virtual Water, Desalination

I. Water Situation

Whether water conservation is optional or obligatory on the part of the government and the people who utilize this delicate and finite resource is not an easy question to answer. Both the supply management and demand management side of the water situation come into play when it comes to water conservation. Water resources factors on the supply side of water management include: limited groundwater, little rainfall and arid conditions. All of these conditions lead to little renewable water. Demand also plays a large role in the water situation. Determinant factors on the demand side of water management include: high population growth rate, improvement of living standard, and industrial development. The decrease of limited renewable water paired with increasing water demand causes the need for groundwater mining in order to provide the supply needed in order to meet the demand.

Both demand and supply management are effected by environmental and economic factors. Environmental and economic factors affecting the chains of supply and demand include drawdown of the groundwater levels, increase in the salinity of groundwater, the continuing dryness of natural springs, deterioration of local agriculture, problems with the domestic water supply and infrastructure, problems with local industry.

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Environmental and economic factors can be dealt with on the supply side of water management in a variety of ways, including, but not limited to the development of non-conventional water resources, such as: desalination of the water supply, reuse of treated wastewater, and reuse of drainage water. Environmental and economic factors can be dealt with on the demand side of water management with the institution of such measures as: tariffs on water supply, water conservation, leak detection in the water supply chain and infrastructure, and the control of water pressure throughout each geographical area.

However, taking measures to control water demand and also initiating the development of non-conventional water resources can lead to a multitude of challenges for those who are in need of a flowing water supply, such as individual, agricultural, and industrial users, as well as those in charge of managing the water supply. Among these challenges are environmental challenges, economic challenges, social challenges, institutional challenges, and even legal challenges.

A. Water Resources

When considering the necessity for water conservation it is important to consider the available water resources and options for creating or accessing additional water supplies in order to facilitate demand management. In general, water resources in the geographic region are limited. In 2011, the total amount of water resources in Bahrain amounted to only 471.9 Mm^3. This amount of water supply is unable to meet the current water demand. At present, the 471.9 Mm^3 of water resources are divided nearly equally between traditional and non-conventional water resources. The current distribution shows that 54.6 per cent of Bahrain's water resources are coming from groundwater, while only .01 per cent is coming from drainage. The remaining 45.3 per cent of water resources, however, are derived from non-conventional methods: desalination at 35.6 per cent and treated sewage effluent (TSE) at 9.7 per cent.

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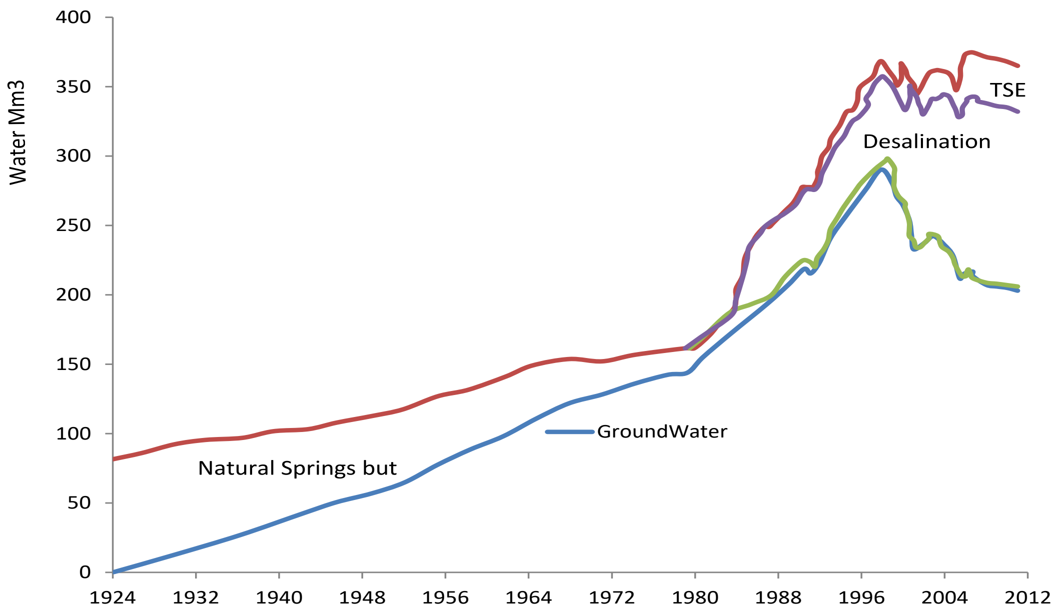

Figure (1) Historical Water Resources in the Kingdom of Bahrain

The current water supply number, however, is expected to increase by 2025 to at least 617 Mm^3. This increase will largely be due to increases and expansions in non-conventional water resources, such as an increase in the capacity of treated sewage effluent (TSE) and desalination, which means that non-conventional sources are likely to make up the bulk of the water supply by 2025 and could overtake the 50 per cent margin much sooner. Construction is currently slated for a new Al-Dour RO desalination plant that will contribute substantially to the increase in the availability of water resources.

B. Groundwater

Groundwater is currently the most used, most relied upon and most demanded water resource in Bahrain. It is pulled from four different levels of the ground including the upward flow, the lateral flow, the aquitard and the aquifers beneath the surface. The Aruma layer, or Aruma shales, are at the bottom of the upward flow, which travels from the Aruma through the Umm Er Radhuma layer and the Rus layer of the ground to reach the surface, where the water is collected through multiple methods including abstraction. Groundwater abstraction is most commonly utilized as a method of collection in the Khober and Alat levels of the ground, once the upward flow has forced the water towards the surface. Natural recharges occur in these levels of the ground, but water resources managers may also see seawater intrusion in these levels, especially in the aquitard levels between normal ground surface levels, such as the Neogene level, the Orange Marl, and the Sharks Tooth Shale levels. The most common locations for groundwater abstraction are through the A level, known as Alat, the B level, known as Khober, and the C level, known as Rus Umm Eradhuma.

C. Groundwater Abstraction

Abstraction of groundwater is necessary in order to maintain adequate levels of water supply for the current demand for water resources. Water resources from groundwater are often taken from upward flow, aquitards and aquifers. Water demand caused an increase in groundwater abstraction from the Dammam aquifer from 63.2 Mm^3 in 1952 to around 254 Mm^3 in 1998. However, as use of other non-conventional water collection and supply methods were introduced, abstraction from this aquifer gradually decreased to 182.5 Mm^3 in 2004. The most current estimates were 147.6 Mm^3 in 2007. Groundwater abstracted from the Dammam aquifer is used for multiple different purposes, although drinking water is its main purpose. Around 66.8 per cent of the water abstracted from the aquifer is used for drinking water, followed by industrial purposes at 17.1 per cent and agriculture at 16.1 per cent. Abstraction rates from Rus Umm Eradhuma, on the other hand, have seen a significant increase in recent years. In the year 2011 alone, the abstraction rate skyrocketed from 2 Mm^3 to 55.7 Mm^3. The groundwater abstracted from the Rus Umm Eradhuma is used for different purposes, although its uses continue to change and grow with the times. More than 69.5 per cent of the water abstracted from Rus Umm Eradhuma is used for agricultural purposes, while only 27.4 per cent is reserved for drinking water and 3.1 per cent is used for industrial purposes.

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D. Potentiometric Levels

Measuring potentiometric levels helps to determine the abstraction rate from different groundwater sources. While the potentiometric method measures a hypothetical surface it helps engineers to determine the level that groundwater would rise to if it were not trapped beneath the ground in aquifers. In Bahrain, potentiometric levels show the decline and increase of these hypothetical water levels from the trapped aquifers over time. Between 1924 and 2007, potentiometric levels showed a drawdown ranging from 3.24 metres to 5.24 metres from Alat. The range at Khober from the same time period was from 7.08 metres to 8.08 metres. At Rus Umm Eradhuma, the drawdown remained relatively stable at 6.3 metres. Increases in water demand and the introduction of new, non-conventional methods for enhancing the water supply help to account for these changes in water drawdown levels.

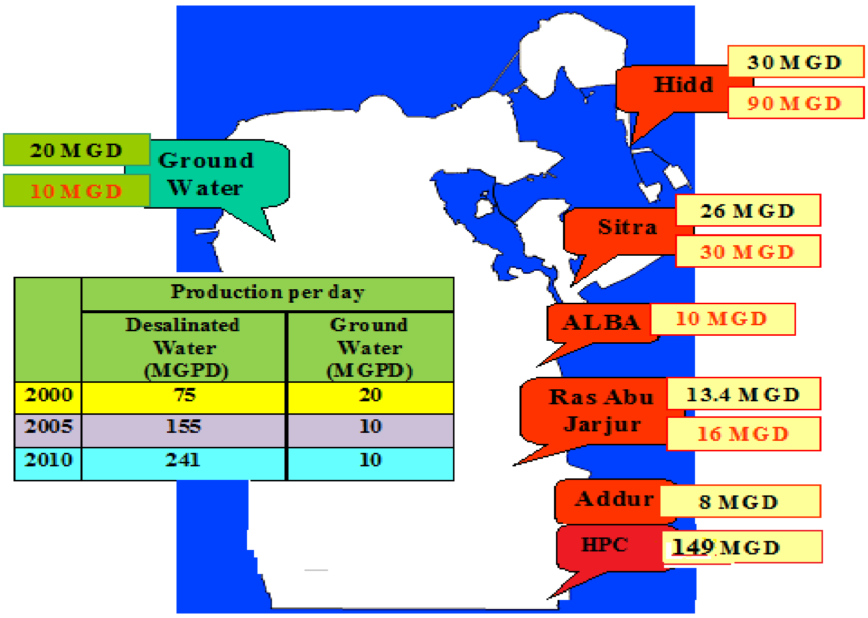
E. Groundwater Quality & Groundwater Mining

Along with the levels of groundwater available for drawdown and abstraction, the quality of groundwater resources is also on the decline. The severity of the decline in water quality varies from location to location of abstraction sites. These variances are most often depending on the source of pollution into the aquifers as well as the natural recharge of the aquifers. Locations suffering from intrusion into the aquifers by seawater caused the most severe and negative impact. In these cases the salinity of the groundwater increased to 6000 ppm intrusion and in some cases to as much as 15000 ppm.

In addition to those locations experiencing severe increase in salinity, other locations also experience higher levels of salinity. Locations directly up flow from the Rus aquifer to Khober experience increase in salinity up to 4000 ppm. Pollution causing groundwater salinity was also increased in western abstraction areas where drainage from agriculture and brackish water from sabkha infiltrated the water resources. North-western groundwater salinity also experienced an increase in recent years up to 2500 ppm. Despite the increases in salinity in many abstraction areas, groundwater mining in Rus Umm Eradhuma has remained steady and has continued to climb at slow rates over the past three decades. The only departure from this rate of growth in groundwater abstraction was during a severe dip in 2005, followed by a large increase between 2005 and 2010. Groundwater mining in the Dammam aquifer, on the other hand rose at a high rate from1950 through the 1990s and in more recent decades has seen a significant increase. In 1995, groundwater mining was at an all-time high, and since then has seen significant decreases.

II. Desalination

Desalination, though a non-conventional water resource supply management method, is a staple in Bahrain and is growing in both popularity and necessity. Currently, there are five desalination plants located in Bahrain that serve to treat and cleanse water for drinking and other purposes.



Figure(2) Maps of the Kingdom of Bahrain and allocated desalination plants

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However, these plants have a limited total capacity for desalination at 266.4 Mm^3. Together, the plants are nearly at full desalination capacity, making it difficult to grow this resource unless capacity is increased or additional plants are built. Actual production of desalinated water in Bahrain began in 1980 with 3.3 Mm^3. Production increased to 132.3 Mm^3 in 2009 and to 172.3 Mm^3 in 2008. Most recently, in 2011, production levels hit their near maximum at 245 Mm^3.

Table 1: Desalination plants, capacity and Technology, 2008

Plant	Commissioning date	Capacity		Feeding sources	Technology
		MGD	Mm^3/yr		
Sitra	1975	25	.415	Seawater	MSF
Ras Abu Jarjour	1984	16.5	.274	Rus – Umm Er Radhuma	RO
Alba	2003	7	11.6	Seawater	MSF
Aldour	1990	10	.166	Seawater	RO
HPC	2007	90	149.3	Seawater	MSF - MED

Currently desalination levels are spread unequally amongst the five plants. The desalination plant at Hidd produces 149.3 Mm^3 per year, followed by the Sitra plant at 41.5 Mm^3, the Ras Abu Jarjour plant at 27.4 Mm^3, the Al-Dour plant at 16.6 Mm^3, and finally, the Alba plant at 11.6 Mm^3. While most of the plants have provided a steady amount of production each year since the mid-1980s, the Hidd plant saw high increases in production from 1998 forward.

A. Drinking Water Quality

The quality of drinking water in Bahrain is dependent on the number of total dissolved solids (TDS) in the drinking water at the time of testing. These dissolved solids are comprised mostly of salt, which, in Bahrain, are apparent in drinking water due to the increase in pollution from the intrusion of seawater into the groundwater supply. Total dissolved solids (TDS) present in the water supply have changed over the past decade, reaching a high in 2005 and coming back down to more acceptable levels since 2007. In 2000, total dissolved solids (TDS) testing reported 1196 ppm in the drinking water in Bahrain. The following year, in 2001, the levels were at what would be the lowest rate for the next seven years at 1190 ppm. The rates over the following years continued to rise: 1340 ppm in 2002, 1392 ppm in 2003, 1391 ppm in 2004, and 1565 ppm in 2005. Rates dropped to 1425 ppm in 2006 and back to 1209 ppm in 2006. Global climate change (GCC) and local Bahrain standards for total dissolved solids (TDS) levels are currently at 1000, leaving the most recent rates well above the standard.

B. Desalination Cost

In order to manage water supply in Bahrain, the continued development and addition of more non-conventional methods, such as desalination are needed. However, these water sources are becoming more expensive to maintain. The cost for desalination in Bahrain has increased around .079 BD/m^3 (1$= 0.378 BD) in recent years. In 2004, the average cost for desalination was 0.210 BD/m^3. But most recent estimates place this cost at 0.289 BD/m^3. Cost increases have been most significant since 2006, when production increased overall and also increased exponentially at the desalination plants in Alba and Hidd. The costs of desalination have continued to rise over time due to increases in the costs of chemicals used in the treatment process as well as the cost of fuel.

III. Treated Wastewater

In addition to desalination, the reuse of treated wastewater as an acceptable non-conventional water source has been gaining ground in Bahrain for several years. In 1988, capacity in Bahrain for treated sewage effluents (TSE) rested at 1.5 Mm^3. By 2006, the number had risen to 14.6 Mm^3 and it more than doubled to 33 Mm^3 in 2006 while reaches close to 41 Mm^3 by 2011. Currently, Bahrain's capacity for the product of reusable wastewater is at 36.1 Mm^3. These numbers show a dramatic increase from the slow and steady rise that occurred from 1988 until 2005, when production capacity numbers began to skyrocket. Current projections indicate that treatment capacity in Bahrain for treated sewage effluents (TSE) will likely increase to around 148.2 Mm^3 by the year 2015. Not all treated wastewater can be used for agricultural, industrial or drinking water purposes. Some of this water is affected by multiple factors that leave it with a lower quality than necessary for these uses. The quality of some treated sewage effluents (TSE) declines due to excessive loads from hydraulics and organic materials which cause deterioration, reduce effluent quality and cause restrictions for the use of this water for public health, development and other use plans. From 2006 to 2007 multiple quality factors were tested in treated wastewater including temperature, pH, electrical conductivity, turbidity, total suspended solids (TSS), volatile suspended solids (VSS), chemical oxygen demand, biological oxygen demand, ammonia, nitrite, nitrate, total phosphorous, parasites, and e-coli. Many of these factors tested were found to be outside the Bahraini Standards for Irrigation, though six in particular showed significant levels above the acceptable range.

Electrical conductivity, with an acceptable range of 4000 µS/cm, was measured at an average of 5895 µS/cm and a maximum of 7780 µS/cm. Turbidity, with an acceptable level at 0.5 NTU, was measured at an average level of 1.6 NTU and a maximum 18 NTUs. Total suspended solids are afforded 5.0 mg/l, but were measured at an average of 10 mg/l and a maximum of 26 mg/l. Nitrite was measured at a maximum of 6.7 mg/l, above the acceptable 5.0 mg/l and Nitrate was measured at .99 mg/l, above its acceptable level of 0.5 mg/l. Additionally, parasites were measured at an average of 6.1/1000 ml and a maximum of 200/1000 ml, while the acceptable level is a low 0.1/1000 ml, and e-coli was measured above its acceptable level of 20/100 ml with a maximum reading of 2005/100 ml. Increasing the quality of treated wastewater is of high concern for water supply management specialists. Currently, the plans for upgrading the Tubli WPCC in order to not only increase capacity for treated sewage effluents (TSE) but also to allow for improved quality and to allow for the construction of two additional waste water treatment facilities: one in Muhraqq and one in the Southern governorate.

A. Virtual Water

Water supply management also requires a fair look at the virtual water module for Bahrain. In 2001, the virtual water imported was reported at 714.6 Mm^3. This number increased by more than 5.1 per cent by 2006 to a new yearly total of 915.7 Mm^3.

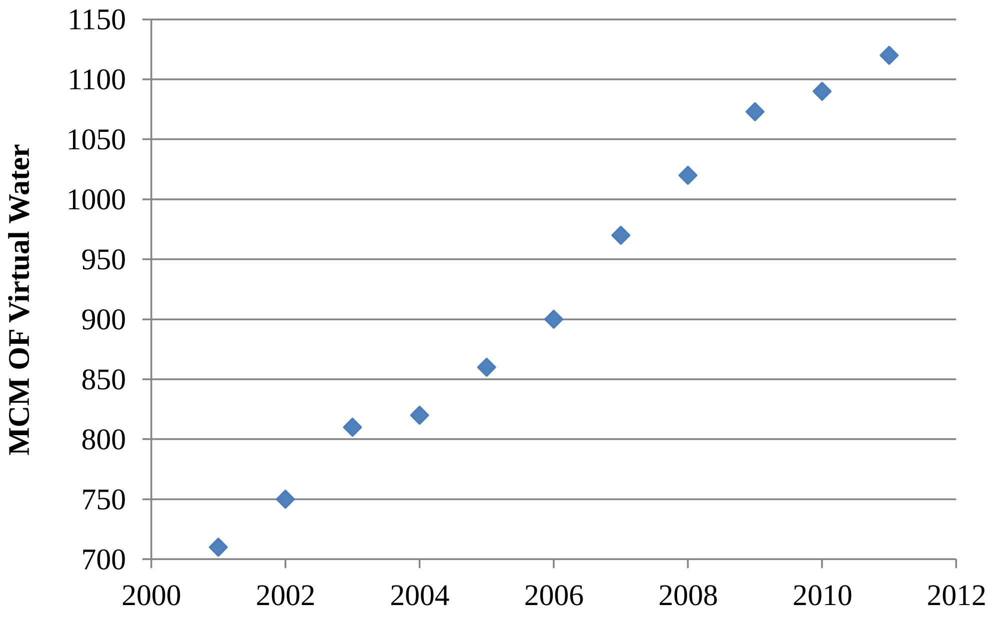

Figure (2) Virtual Water Imported to the Kingdom of Bahrain

Recent estimates report that the amount of virtual water imported in the year 2007 was around 1058 Mm^3 with the needs and numbers rising every year as the population and water demand both continue to grow.

B. Actual Per Capita Water Share

Although there are many numbers reported for water usage, water supply and water demand in Bahrain, including those for virtual water, it is important to also pay close attention to actual per capita water shares so that changes and plans can be made for the future in order to ensure the survival of the water supply management system currently in place and any water demand modules that may have to be implemented in the future. Currently the numbers show as follows per capita:

- Renewable groundwater accounts for 108 Mm^3
- Unsustainable groundwater abstraction accounts for 88 Mm^3
- Desalination accounts for 127 Mm^3
- Treated wastewater accounts for 35 Mm^3
- Virtual water accounts for 1018 Mm^3

Together, these per capita shares of the water supply account for 1340 Mm^3 per capita each year.

IV. Water Demand

As population and development continue to rise, so too will demand for additional water resources. According to recent data, the water demand in Bahrain has increased nearly three times from what it was in 1952, when the demand was at 116.68 Mm^3 per year. In 2011, the water demand was calculated at more than 354.6 Mm^3.

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These increases are caused by three main events in Bahrain: the growth rate of the population, living standards improvements, and the development of industry and commerce through out the Kingdom. At present, municipal uses account for 47.4 per cent of the water demand in Bahrain, followed by agriculture at 44.5 per cent and industrial and other commercial uses at 8.1 per cent.

A. Agricultural Sector

Although Bahraini agriculture has a long history, this industry has suffered in recent years due to a significant lack of quality water resources and availability of sustainable water resources. Other factors that have affected agriculture include the quality and condition of the soil, lack of investment into agriculture by industry and other commercial giants, poor drainage from agricultural properties, quickening of urbanization in areas previously reserved for agriculture, and poor labour base from which to draw skilled workers.

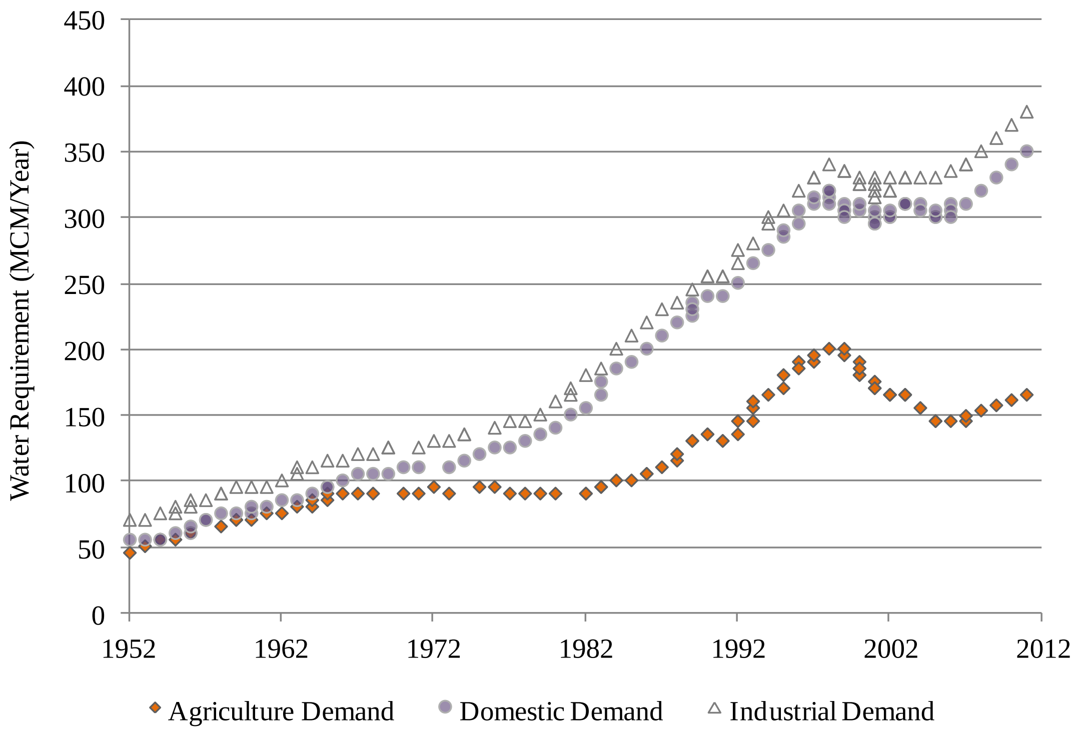

Figure (2) Water demand

Water demand for agriculture increased to 200.5 Mm^3 between 1952 and 1998, but then decreased gradually over time as the agricultural sector deteriorated. In 2007, this demand had dropped to 148.8 Mm^3, which included groundwater, treated sewage effluent (TSE), desalination and drainage water. In 1956, there were more than 6460 ha in cultivated lands in Bahrain. From 1956 to 2006 that number decreased to 4454 ha in cultivated lands. Overall, the per capita land used for agricultural purposes in Bahrain decreased during the period of fifty years from 0.036 ha to 0.006 ha despite the growth in population that occurred over the same period.

In previous decades, high food self-sufficiency was the norm, but to the decrease in cultivated lands and only small increases in recent years in sustainable agricultural production, self-sufficiencies have dropped to 14 per cent for fruits and vegetables and for overall food self-sufficiency to only 10 per cent. By 2006, the gross domestic product (GDP) in agricultural production for Bahrain was down to only 0.5 per cent of the Kingdom's total GDP and the trade deficit had risen to 144.75 BD. Currently, the main crops in Bahrain include palm trees (2150 ha), vegetables (660 ha), green fodders and fruits (440 ha). Around 72 per cent of cultivated vegetables utilize traditional irrigation, while the remainder are serviced by modern techniques.

B. Municipal Sector

While agricultural requirements for water resources and demand have declined, demand has increased in the municipal sector. The 5.1 Mm^3requirement of 1952 had risen to more than 158.7 Mm^3 by 2011. In 2007, municipal water needs were met: 39.8 per cent (30.4 per cent in 2011) by European Water Association (EWA) plants, 36.8 per cent (55.4 per cent in 2011) by privately owned plants and 23.4 per cent (14.2 per cent in 2011) by groundwater abstraction.

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In 1980, the per capita water consumption rate was 335 lcd, but increased to more than 575 lcd by the year 1990. Water conservation efforts in the face of increasing populations throughout the Kingdom helped to reduce per capita water consumption to 418 lcd in 2011. However, this number is still considered an alarmingly high rate for Bahrain.

C. Industrial Sector

Like the municipal sector, industrial sector water demand has increased significantly since the 1980s. In 1979, water demand for the industrial sector was at 15 Mm^3 and the number increased to 27.2 Mm^3 by 2007. The majority (92.4 per cent) of industrial water demands is covered by ground water, with the remaining 7.6 per cent covered by desalination. Despite this enormous coverage for industrial purposes, the industrial sector is prohibited from using groundwater abstraction in the Dammam aquifer for their purposes by Bahraini law, no. 12.1982. Despite this restriction, water saving technologies have not been widely introduced into the sector.

D. Municipal Water Use Efficiency

Utilizing municipal water resources efficiently is critical to ensuring an on going and sustainable water supply for this purpose. There are three levels of efficiency: plant efficiency, transmission and distribution efficiency, and household efficiency. Plant efficiency requires water and electricity production directorates for the five plants that produce desalinated water for municipal purposes. Water resources directorates must also be put into place for groundwater abstraction at the Dammam aquifer, the other major supplier for municipal water demand.

Table 2: Water Balance for the year 2007

Water Resources	Available Water	Water uses					Deficit
		Agricultural	Municipality.	Industrial	Total	Operational uses	
Conventional Resources:	124.8	111.6	66.4	14.1	203.3	11.2	
Dammam Aquifer	112.3	102.6	40.4	4.6	147.6	0.0	-35.3
Rus-Umm Er Radhuma	12.5	9.0	26.0	9.5	55.7	11.2	-43.2
Non-conventional Resources	168.6	37.2	118.3	13.1	168.6	0.0	0.0
Desalinated Water	132.3	0.9	118.3	13.1	132.3	0.0	0.0
Treated wastewater	36.1	36.1	0.0	0.0	36.1	0.0	0.0
Drainage water	0.2	0.2	0.0	0.0	0.2	0.0	0.0
Total	293.4	148.8	158.7	27.2	371.9	11.2	-78.5

At the transmission and distribution level, where water is typically unaccounted for, there must first be transmission directorates that help determine whether water will be placed in ground tanks or elevated tanks. There must also be a method to determine whether leaks are present in the system. From there, directorates for distribution to industrial uses, commercial uses, agricultural uses, fire fighting and operational uses must all be put into place to ensure proper delivery of the appropriate amounts of the water supply. The difference between the metered water supplied at this level and the unaccounted-for water (UFW) must be reconciled in order to save the associated costs and conserve the limited water supply. In more recent years, the associated costs and the UFW have had more crossover, though the costs have increased. According to recent data, UFW was as high as 47.4 per cent of the water supply in 2006. This puts the water losses at 24.8 per cent and uses as high as 75.2 per cent. At the household consumption level, there should be water and electricity conservation directorates to help individual water users conserve their water supply for domestic use. Personal use is determined at the rate of water actually used versus the reasonable use per capita per day. Worldwide, the average daily use is 180 lcd, whereas Bahraini tradition and high living standards put suggested use throughout the Kingdom at 220 lcd. Actual use in 1993 was at 487.3 lcd, a number that decreased to 344.9 lcd by 2006, making the water efficiency level 63.8 per cent. Efficiency at this level is equivalent to the Unaccounted for Water (UFW) and equal to the ratio between produced water and water metered at household level. Based on the Bahrain 15 years Master Plan and Customer Service Directorate data (CSD), the Gross UFW ranged from 30.7% in the year 1993 to 33.8% in the year 2006 with an average of 28.7%. The highest Gross UFW was 33.8% (2006) while the lowest was 21.1% (1999). The average annual cost corresponding to these losses was 5.7 MBD with a maximum of 11.1 MBD in the year 2006. It is expected to reach 24 MBD in year 2015.

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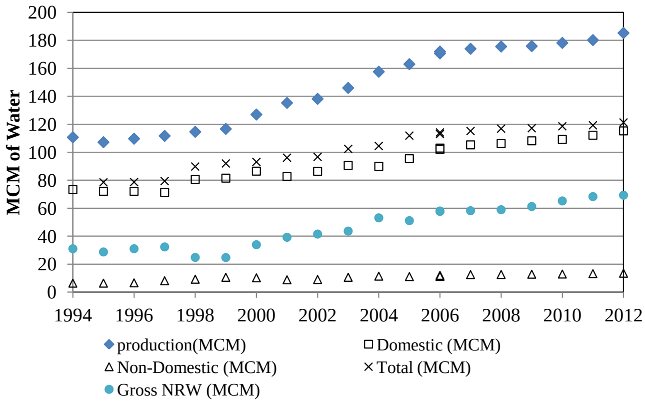
Table 3: Gross NRW 1993 - 2006

Year	Production (Mm^3)	Leakage (%)
2000	127	18.30
2001	135.3	18.44
2002	138.2	18.74
2003	146	20.08
2004	157.6	19.5
2005	163	19.0
2006	170.7	18.4
2006	172	19
2007	174	19.5
2008	175.6	20.1
2009	175.9	20.3
2010	178.2	20.5
2011	180.2	20.9
2012	185.3	21.9



Overall efficiency for municipal use is at a low 45.2 per cent. However, this means that there is the possibility of water conservation methods having a positive impact. Improving efficiency is a difficult task requiring large investments and awareness at all levels. Some important points for water users include:

- Bahraini water production costs more than in other countries
- The environment is affected by water production
- Bahraini water consumption is significantly higher than other countries
- Reducing water consumption will enhance, not detract from, wellbeing
- Government subsidies for water are at 75 per cent; a reduction is subsidies could help with the maintenance and improvement of services and water quality.

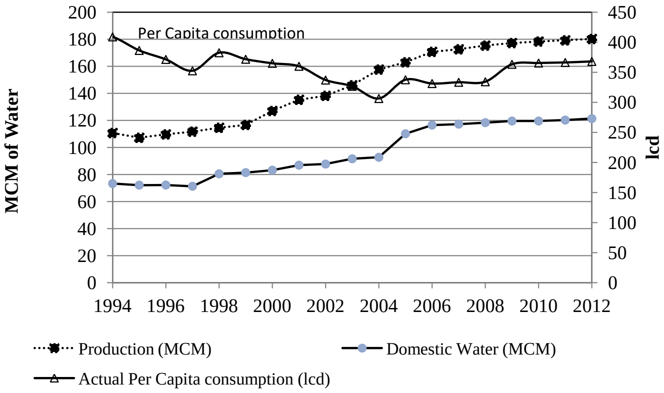


Table 4: water use efficiency and population+

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Year	Population (Capita)	NRW CSD (%)	Ratio of Domestic water (%)	Water use Efficiency (%)
2000	625032	26.7	89.4	54.8
2001	661325	29.0	90.4	55.6
2002	712589	30.0	90.6	59.3
2003	768429	29.9	89.5	61.2
2004	828794	33.7	88.7	65.3
2005	893747	31.3	89.6	65.0
2006	963348	33.8	90.1	69.1
2007	1123562	34.2	91.2	70.2
2008	1134865	35.2	92.3	71.2
2009	1236589	36.3	93.4	72.5
2010	1325692	37.4	94.5	76.3
2011	1423568	38.5	96.2	77.2
2012	1425638	39.2	97.3	74.5

E. Agricultural Water Use Efficiency

Agricultural water use efficiency is the ratio determined between the amount of water supplied and the amount that is used to benefit agriculture. In 2006, the total agricultural land was 4454 ha, only 3712 ha of which was actually being cultivated. At the time, water supply was calculated at 153 Mm^3 or 41223 m^3/ha.

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In 1992, evapotranspiration was estimated in reports at 30 m^3/ha/d or 10950 m^3/ha. Water requirements at the time were estimated at 26790 m^3/ha. Recent deterioration of the quality of both water and soil used for agricultural purposes, compounded by climate changes in Bahrain, have caused the water requirement for a dwindling agricultural cultivation area to increase to 31015 m^3/ha.

Based on recent data, while the classic water efficiency for agriculture was measured at 26.5 per cent, the effective efficiency was actually 75 per cent, a promising figure. Despite this reality the application of modern irrigation techniques could continue to improve efficiency of water use for agricultural purposes and reduce waste. One of these methods is soilless cultivation, which can improve water use efficiency, productivity, plant nutrition, and control of the growing and root environments, and also reduce required labour as well as dependency on quality soil. Disadvantages of this application, however, include increased costs of implementation and maintenance, necessity for technically skilled labourers, and the need for technically skilled researchers and extension services to provide on going support, all of which may be costly.

F. Per Capita Water Share

Although Bahrain Kingdom has been able to meet the high water demand from its population over time, this has occurred at a high cost. Drinking water is provided at an average cost of 0.31 BD/m^3. While agriculture has seen a decreasing need for water, both the municipal and industrial sectors have seen a marked increase in their demand for these same resources. From 1998-2007, the decreases paired with the increases across sectors should a relatively minor increase in the water demand of roughly 0.8 per cent.

Currently, Bahrain's annual per capita share of renewable water resources is estimated at 108 m^3. This translates over time to water shortages, a higher water poverty index, and increasing scarcity of water resources. However, current indexes showing the impact and its proximity to current times don't provide enough information and context can only be provided by pairing this data with the Human Development Index in order to extrapolate meaning.

G. Food Security

In 2008, Maplecroft developed the Food Security Index, which evaluates the risk of food insecurity—or food shortages—in 162 countries. Index evaluations are based on 18 insecurity indicators including availability, stability, food supply access, nutritional outcomes of insecurity, and more. Those countries with a low per capita water share and/or a low HDI are often indicated as having a high food insecurity index, though they are not the only countries indicated for issues and potential issues. Although Bahrain Kingdom has faced problems with quality water and soil resources, it is currently listed as one of those countries with high food security. But this was not done without some work. In 2011, the Bahraini government imported agricultural commodities for a cost of 270 MBD. The cost of the virtual water supply in this instance was 0.26 BD/m^3. This dependency on virtual water puts the Kingdom at great risk and is not a sustainable way to ensure lasting food security for the Bahraini people.

H. Public Awareness and Positive Incentives

Public awareness of the water supply and demand situation in the Bahrain Kingdom is necessary for water conservation of limited resources. Currently water use efficiency remains at very low levels, despite multiple efforts to increase efficiency and the availability of additional water resources. According to recent data, 82.5 per cent of water customers in Bahrain Kingdom are aware that the Kingdom faces quality and quantity problems with the water supply, but this still does not reduce consumption enough for conservation needs. Data reports that despite this awareness 45.5 per cent of Bahraini and 64.9 per cent of non-Bahraini water users never implement devices or techniques for water conservation. Clearly awareness is not enough and additional action must be taken.

In an effort to reduce water waste and increase efficiency, EWA started a program that provides a prize of 100 BD to encourage water use customers to reduce consumption by 5 per cent. Current proposals also aim at requiring those customers unwilling to engage in cost saving and water efficiency measures to install devices that will help them reduce their use without a conscious effort. Additional proposals for the EWA suggest subsidization of water conservation devices to ensure continued availability and access for all customers in all markets.

I. Water Tariff

In order to conserve water, a water demand management technique for water tariffs could be implemented in order to control consumption. If the average family of six requires a per capita consumption of 220 lcd, monthly consumption is 39.6 CM, which is much lower than the actual block of use reported. The first block of needs, reported at 53 per cent of the monthly water usage in the Kingdom, does not actually represent the needs of families and creates a problem for water supply and consumption, not to mention conservation efforts. The current water tariff projections show the third block without signals for water shortages, abilities to cover production costs, cross subsidies or opportunity costs, which should be factored in to a successful water tariff.

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Currently all blocks are subsidized, with high-income water customers receiving more subsidies than low-income water users. Non-Bahraini customers are most likely in the first block of customers, who use 53 per cent of the water demand supply each month and Bahraini customers are typically among those accounting for the middle 11 per cent and end 35 per cent usage of water resources each month. By reducing use in the first block of users from 39.6 m^3 to 25 m^3, and raising the prices for those water users in the second and third usage blocks, water production and management services can take in income to cover a high percentage of their original production costs, thus substantially lowering the cost to meet the water demand in the Bahraini Kingdom.

J. Unaccounted for Water

Unaccounted for water (UFW) is high in Bahrain today, and it represents large losses in water and in the economy for the entire kingdom. While encouragements can be made to individual water users at the domestic and home level to reduce water consumption, this method for conservation is useless when high amounts of UFW still exist and remain unmetered. A clear plan is needed in place for Bahrain that reduces the amount of UFW across the Kingdom by 13% or more. The plan must include plans for investments and implementation that clearly define who does what, when they are going to do it, how they are going to do, who is going to finance it, and how accountability and success will be measured. The plan must provide measures for monitoring and evaluation to assess the progress of implementation procedures and maintenance, and corrective actions that should be taken when delays and other issues are discovered.

V. How Demand Management Fits In

At present, the Bahraini Kingdom meets all water demands through a costly water supply method that involves both traditional and non-conventional water supplies. Comprehensive water resources planning can help create a balance between the water supply measures in place and water demand. The demand for water in Bahrain is ever growing and the supply has not significantly increased. Multiple aid agencies across the globe, such as the World Bank, the Overseas Development Administration (ODA) of the United Kingdom, and the Danish International Development Agency (Danida) are increasingly in support of integrated water resources management approaches that include decision support systems, and a system that balances water supply and demand to ensure sustainability of the water resources in world countries. This requires collaboration between engineers, development planners, water resources managers, environmentalists and multiple other engaged and interested parties who can determine what is best for the environment, the economy and the population as a whole.

Worldwide, agriculture tends to require the greatest amount of the water resources in most countries. In Bahrain, this has not been as true but agriculture still demands a significant portion of the water supply, and a water supply that has quality water at that, since poor water supplies cannot sustain agriculture. Water planning and agriculture should be looked at side by side in all land use planning projects and development projects to ensure that adequate water resources are available to sustain such projects. Many new approaches accept that new water resource management policies and programs require significant input from the government, including strategies from the government level to support change, policy and management support and changes, policy reform, and institutional changes at both the industrial and municipal levels.

Many countries with limited renewable water resources exist now in the Middle East, North Africa, Central Asia, and SubSaharan Africa, where water may be limited to 1000m^3 per person (22 countries) or 2000m^3 per person (18 countries). In these countries, the population is growing quickly and may already or may soon outgrow the water supply. The world population is currently over 7 billion and is estimated to reach more than 8 billion people by 2025 (up from 5.3 billion in 1990), making the need for water resources for human consumption, especially drinking water, increasingly important. Additional human use needs will increase dramatically in urban areas where excessive water is required for use in domestic settings, industry, and sanitation. This will also be of issue in currently developing countries, which may need even more water to get started.

The increasing demand for water will likely increase the cost of accessing water for most people, since the demand for increased water supplies will force governments to access and import water from other locations. The cost of virtual water pulled in from far outside major cities can double or triple the cost of water production and supply. Increased need for water based on population growth is not only limited to human use, but also includes more water for increased irrigation and improvements to agriculture to ensure an adequate food supply. The use of rivers, basins and aquifers for groundwater access may become more complicated since multiple regions and countries share many of these resources. Accessing and abstracting water resources in one area will invariably alter the water supply and access in another area, creating the demand for an integrated plan that provides for cooperation between neighbouring countries and constituencies. Currently, there are more than 2,000 agreements and 300 water treaties in the world, but disputes continue.

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The creation of multi-purpose agencies to oversee these types of projects can often be useful not only in resolving disputes but also in creating solutions that solve the problems which lead to disputes and create water supply issues. Countries facing these types of issues can learn from the past experiences of the United States, Canada, India, Pakistan, Zimbabwe and other countries. Since current projections show that the world's dependency on irrigation for agriculture is now at around 60 per cent it is increasingly important for all countries to promote conservation efforts, consider changes to the efficiency of water transmission and distribution, and integrate multiple facets of engineering and planning into the current and future water plans.

VI. Conclusion

The Bahrain Kingdom is one of the most successful countries in the world at meeting the demand for adequate water supplies for its population for drinking water, municipal, domestic, agricultural and industrial uses. This success has been brought about by the use of not only traditional methods—such as groundwater abstraction from aquifers, ground layers and aquitards—but also from non-conventional water supply methods—such as desalination, treated sewage effluents (TSE), and even the use of virtual water. However, meeting the demands for a quality water supply in the kingdom has led to high costs for the production, transmission and distribution of water, without a way for production plants and water service providers to recoup these costs, such as a water tariff. A water demand management process has not yet balanced the current method of water supply management.

Increasing demands for quality water are based on climate change, population growth, and growth in the municipal and industrial sectors. Although agriculture has seen marked decreases, the rate of decrease in this area of water demand does not and cannot keep up with the increases in water demand in other areas to keep the overall water demand for the Kingdom level. Increased population over time will result in increased needs for agriculture, sanitation, housing, medical, and other needs for a booming population. This makes it critical for water supply management to be met with water demand management so that conservation of limited quality water resources can be made possible for the future of Bahrain. Increases in the capacity of desalination and other non-conventional water resources are only the beginning. An integrated water resources management plan is necessary to ensure the sustainability of any water supply management plan that is put into action since current capacity-increasing measures may not be able to keep up with the growth of population and demand in future decades.

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