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Qatar water challenges

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Qatar water challenges

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ABSTRACT

Qatar has experienced rapid economic growth due to the discovery and production of fuel oil and natural gas (NG). The natural renewable water resources (rainfall and groundwater [GW]) are depleted; and are estimated as 71-m³/per year per capita in 2005. This is far below the water poverty line of 1,000-m³/yca. The GW withdrawal is excessive (compared to replenishment) and is used mainly for irrigation. A very small amount of GW is treated to become potable water and is distributed to consumers. The municipal potable water mainly contains (99%) desalted seawater (DW) and 1% GW. The consumption of DW and electric power (EP) is continuously rising due to the increase in both population and the standard of living. The population have been more than doubled from 2000 to 2010. The DW is produced in power plants generating both EP and DW, and is called Cogeneration Power Desalting Plants (CPDP). These CPDPs are using either: simple gas turbines (GT) cycle or GT combined with steam turbine (ST) to form a GT combined cycle (GTCC). A thermally driven multi-stage flash (MSF) desalting system is mainly used to desalt seawater. Large MSF units are operated in the CPDP to get their thermal energy (as steam) needs either from: (i) heat recovery steam generators coupled with GT or (ii) steam extracted or discharged from the ST of the GTCC. The CPDPs consume large amounts of fossil fuel (FF), mainly NG. The burning FF pollutes the environment by emitting the carbon dioxide (CO₂), carbon monoxides, and nitrogen oxides (NO_x). The CO₂ and NO_x are greenhouse gases causing global warming. Raising the efficiencies of EP and DW production can reduce their negative impact on the environment. The sustainability of water in Qatar is questionable: the extracted GW is several times its replenishment rate. The municipal water supply depends almost on desalting seawater by MSF, which is energy intensive and costly process. Deploying a more energy-efficient desalting system such as Seawater Reverse Osmosis system can save a lot of NG, the nation's main source of income. The use of treated wastewater (TWW) is limited to some agriculture and landscaping. The ratio of TWW to municipal water supply is low, about 25%. It is also essential to promote conservation measures for both water and power. This paper reviews the water profile in Qatar and recommends solutions to solve the growing water scarcity in Qatar.

Keywords: Desalination; Wastewater treatment; Cogeneration power desalting plants; Multi-stage flash desalination; Seawater reverse osmosis desalting system

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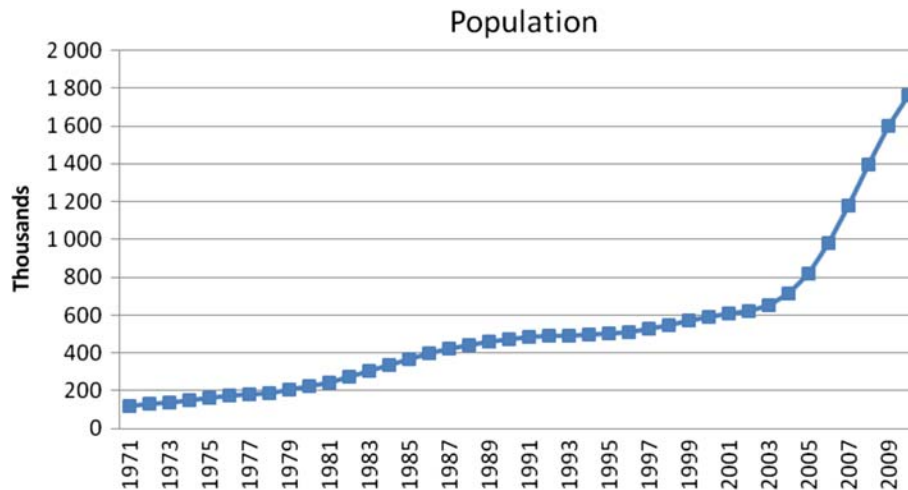


Fig. 1. Qatar population growth rate against years [1].

1. Introduction

Qatar is currently experiencing great expansion in economic activity and a significant increase in population. The population increased from about 0.744 to 1.7 millions (M) during the years 2000–2010, or 2.28 times increase (see Fig. 1). The Qatar Environment and Energy Research Institute, established in 2011, is interested in setting the energy, water, and carbon footprints of different sectors in Qatar. This paper is the first step to review the water profile of Qatar.

2. Qatar water main sources

Qatar is an arid country of harsh and fragile environment, high summer temperature ($>40^{\circ}\text{C}$), low rainfall (annual average 82 mm) with high evaporation rate (annual average of 2,200 mm), and low nutrient availability in the soil. Natural renewable water resources such as the rainfall and groundwater (GW) are scarce. Continued population and economic growth raise concerns about water security. Water security means reliable access to safe water at an affordable price for every person to lead a healthy, dignified, and productive life. The annual per capita (yca) natural water resource was estimated as $71\text{-m}^3/\text{yca}$ in 2005 [3], far below the water poverty line of $1,000\text{-m}^3/\text{yca}$.

In 2005, the annual water withdrawal was 440 million cubic meters (Mm^3), with a share of 59% for agriculture, 2% for industrial, and 39% for municipality. This annual withdrawal includes renewable freshwater resources as well as potential overabstraction of renewable GW or fossil GW and eventual use of desalted seawater (DW) or treated wastewater (TWW). In the same year (2005), the agriculture water consisted of 220Mm^3

of GW and 25Mm^3 TWW, while the municipal water consisted 149.2Mm^3 DW, and 1.2Mm^3 GW. The renewable share (58Mm^3) of total freshwater withdrawal (221Mm^3) is about 26%. These data prove that water use is unsustainable, withdrawal exceeds recharge rates, and the GW is overexploited. In 2009, the DW provided almost 99% of Qatar's municipal water demand and some commercial uses [4].

2.1. Water rainfall

Average annual rainfall are low, variable, unpredictable, and highly erratic in time and space. The average annual rainfall during the last 20 years was almost $92\text{mm}/\text{y}$, Fig. 2, while the rate of evaporation is high. Rainfall is not considered to be reliable for meeting the irrigation and agriculture needs owing to its low intensity and variability. Yet, it serves as the main source of irrigation water in the form of recharge to GW [3].

2.2. Groundwater

There are two main basins of GW: the Northern GW (NGW) and Southern GW (SGW) Basins; and three secondary basins called Abu Samra, Doha, and the Aruma deep GW Basins in the southwest of the country (Fig. 3).

The NGW Basin is the most important GW source. The GW found in this basin is found to be of acceptable quality suitable for agriculture. Its salinity varies from 500 to $3,000\text{mg}/\text{l}$ and increases toward the sea reaching $10,000\text{mg}/\text{l}$ near the coasts due to seawater intrusion. It covers about 19% of the total land area and at 10–40 m water depth below ground.

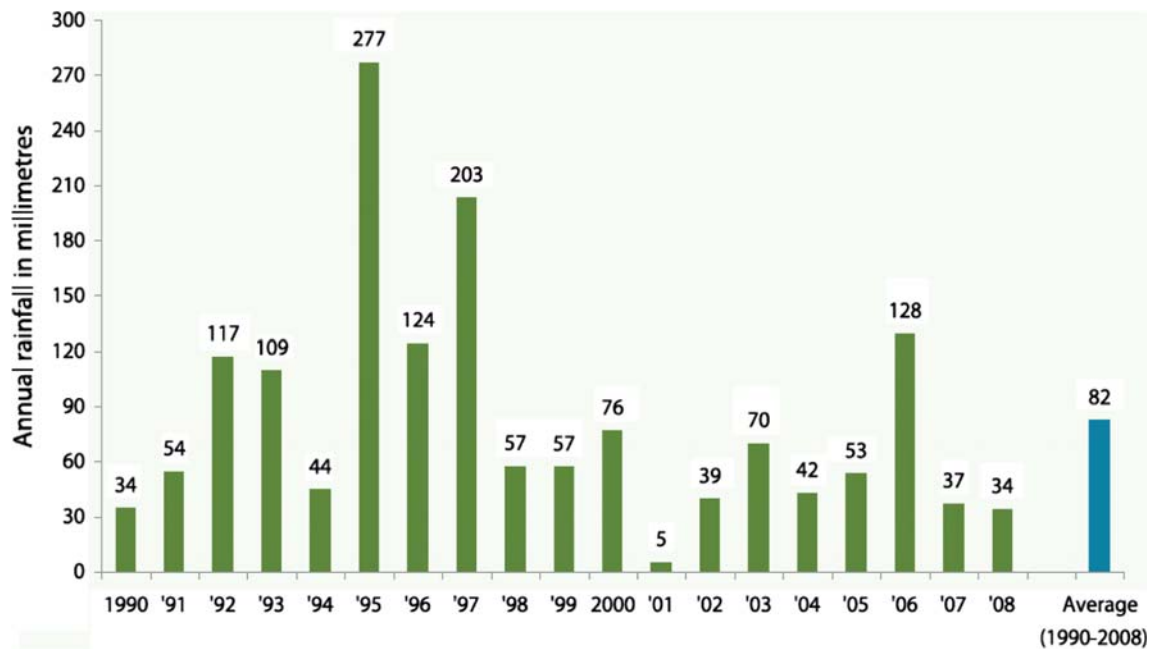


Fig. 2. Annual rainfall in Qatar through the years showing an average of annual 82 mm [2].



Source: Redrawn from Amer and Abdel-Wahab, 2003, derived from FAO Studies Project, 1981

Fig. 3. GW Basins in Qatar [2].

The SGW Basin extends to about half of the land area. Its replenishment rate is much less than that of the NGW Basin. Within the basin, the water levels are mostly at least 30 m below the surface. It is a poor aquifer lacking continuity with adjacent aquifers. Water salinity is relatively high and not suitable for agriculture (3,000–6,000 ppm) [2].

The SGW Basin draws on the Alat artesian aquifer that is located in Abu Samra. The Abu Samra aquifer recharge source is placed in Saudi Arabia. The aquifer extent is limited with an average thickness of 15 m. The total depth of wells ranges from 22 to 80 m below the ground surface. Its salinity ranges, in general, from 4,000 to 6,000 mg/l.

The Aruma aquifer in southwest Qatar is composed of approximately 130 meters of granular limestone belonging to the Aruma Formation. The drilling data of exploratory and production wells indicate that a relatively good quality water (with a salinity level of about 4,000 mg/l) at deep depths of 450–650 m is found in southwest Qatar.

The average annual GW recharge from rainfall is estimated internally at 55.9 Mm³/y. In addition, there is an inflow of GW from Saudi Arabia estimated at 2.2 Mm³/y, making the average total renewable GW resources 58.1 Mm³/y for the period 1972–2005.

Extraction of GW from both the NGW and SGW was about 220.2 Mm³ in 2004–2005 as shown in Fig. 4. This resulted in water abstraction rate several times the natural GW recharge rate. Continued overexploitation

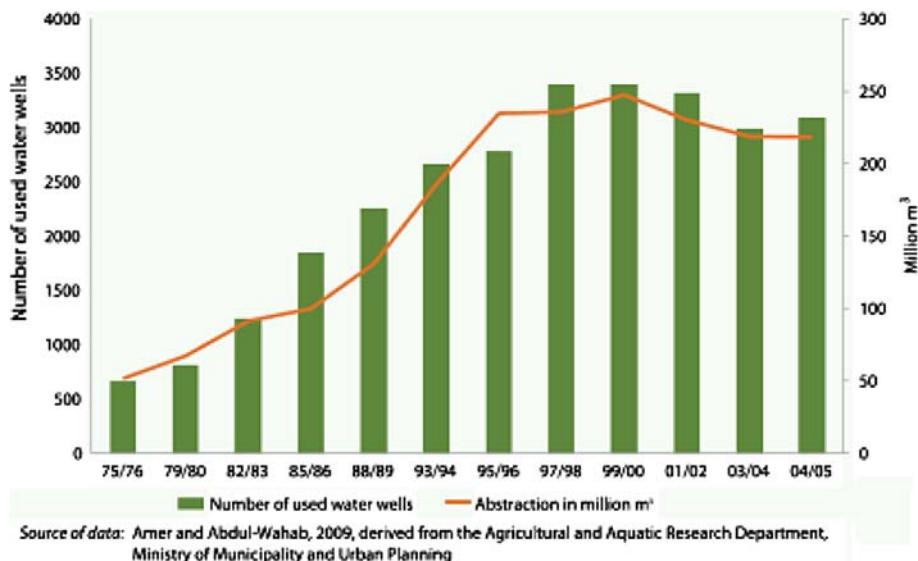


Fig. 4. Number of wells and water abstraction in Qatar [2].

of the fossil GW reserves threatens to endanger the remaining reserves from saltwater intrusion, while overuse of GW for agriculture has resulted in soil salinization and desertification.

2.3. Treated wastewater

Qatar's population has access to pure drinking water, while the sewage network covers about 68% of all over Qatar's buildings and 95% of Doha's buildings. About one-third of municipal wastewater (WW) is treated and recycled. The remaining WW is lost as water leakage or from buildings which have not been connected to the sewer system in the suburb. In 2004, the number of Qatar residents connected to sewer was 54,766, while 19,794 residents were not connected, (i.e. 26.5% not connected). Most of the supplied municipal water is of potable quality. However, this potable water is wasted away and misused in services not needing this high-quality water such as in garden irrigation, for washing cars, for flushing toilets, and similar such activities. The flow rate of treated effluents from the two main TWW plants in Doha had reached between 140,000 and 150,000 m³/d in 2005. The two main sewage treatment plants used tertiary treatment and accounted for 96% of the TWW influent, while a number of smaller plants serving smaller communities accounted for the remaining percentage of the TWW influent. The well-known TWW plants in Doha and their capacities in (m³/d) are given as follows: Doha West known as Saliyyah (135,000), Doha South known as Nuaija (112,000), Doha North known as Lusil (60,000), Doha Industrial area (12,000), Al Khor

(4,860), and Al Thakhira known as Dakheri (30,000). Consequently, the capacity of all the wastewater treatment (WWT) plants stands at 354,000 m³/d. Another WWT plant with 28,700 m³/d capacity started to be built in 2009 at the new airport site for its landscape irrigation. Consequently, the capacity of the total WWT plants is expected to increase to 129.4 Mm³/y.

The recycled TWW is used for the irrigation of few crops and landscaping is carried out as shown in Fig. 5. The reclaimed TWW for re-use has become common practice worldwide and it is a water source that should be fully utilized specially in arid areas such as Qatar. The treatment cost for re-use with potable quality is lesser than the cost of desalting high salinity brackish or seawater. It is an available water

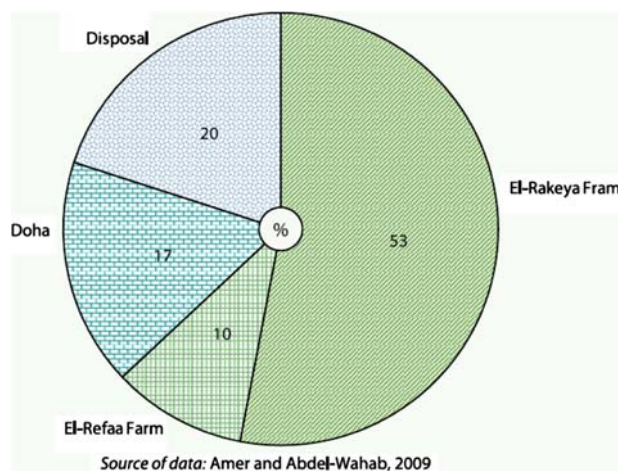


Fig. 5. Use of TWW in 2005 [2].

source that exists right at the doorstep of urban communities. It increases with the increase of inhabitant numbers, per capita consumption, and standard of living. Extending the WW treatment of tertiary level of limited usage for irrigation to quaternary level (of potable water quality) using hyperfiltration (reverse osmosis) has opened the door to using the TWW as part of municipal water. This will improve the water security by not becoming completely dependent on the DW. DW production is vulnerable to oil spills, operation interruption, and so on.

2.4. DW and municipal water

The first desalination plant in Qatar was commissioned in 1953 and had 680 m³/d capacity. More such desalination plants were added on later, while some were taken out of service. The largest desalination facility is located in Ras Abu Fontas (RAF), in the southern part of Doha, and meets most of the civil sector's demands. Other desalination plants are mainly used to supply water to the industrial sector in Dukhan, Ras Laffan, Mesaieed, Umm Bab, the remote outskirts of Abu Samra, and the Al Shamal Military Camp. Large capacity desalting plants are combined with power plants (PP), forming what is called Cogeneration Power Desalting plants (CPDPs). Table 1 shows the main CPDP in Qatar with their electric power (EP) capacities in MW, and DW capacities in million imperial gallons per day (MIGD) and/or in cubic meters per day (m³/d).

The DW plants' capacity reached 1.49 Mm³/d in 2011 when the new desalting plants in Ras Abu Girtas and RAF entered into operations. There is heavy reliance on DW, and its production is on the rise. The DW production by the predominantly used multi-stage

flash (MSF) units is an energy-intensive and costly process, which negatively affects the environment. Recently (in 2012), Qatar had entered into a contract with a firm to build a 5,760 m³/d multiple-effect distillation thermo-compression desalination plant for \$8.3 M or \$1.54 M/1,000 m³/d [5]. Efforts are needed to use more efficient desalting systems to minimize the carbon emission due to the combustion of fossil fuel (natural gas [NG]) that is used for desalting, and the threat it poses to sensitive marine environments.

The annual DW production in million cubic meters per year was increased from 178 in 2004 to: 226 in 2006, 251 in 2007, 312 in 2008, 340 in 2009, and 373 in 2010, a significant annual increase of 14%. The annual fuel energy consumed by the desalting units in Qatar is estimated in the next section along with its effect on the environment (Fig. 6).

2.4.1. MSF desalination energy consumption

The most DW in Qatar is produced by the predominantly used MSF desalting system that is combined with PP. The MSF units are supplied with steam from the heat recovery steam generators (HRSGs) using the hot gases that are exhausted from the gas turbines (GT) to produce this steam. Also, the steam can be extracted (or discharged) from the steam turbines (STs) of GT combined cycle (GTCC) to the MSF units. The HRSG in GTCC utilizes the exhaust gases from GT to produce steam, which is supplied to STs producing additional EP without fuel supply. The GTCC is the most used type power cycle nowadays due to its high efficiency ($\cong 50\%$). In GTCC, shown in Fig. 8, each GT is combined with one HRSG. The steam generated from three HRSG (also three GT) is

Table 1
Main power and desalting plants and their capacities [2]

Desalination plant	PP capacity, MW	Total capacity, m ³ /d	Total capacity, MIGD	Starting date
Ras Abu About				
RAF A	497	318,226	70	1980
RAF B	609	150,000	33	1995
RAF B1	377	240,000	53	2002
RAF B2	567	136,000	30	
Ras Laffan A	756	181,843	40	2003
Ras Laffan B	1,025	272,760	60	2006
Mesaieed	2,007			2009
Ras Girtas	2,730	286,400	63	2010
Satellites	184			1983
Total	8,752	1,450,229	349	

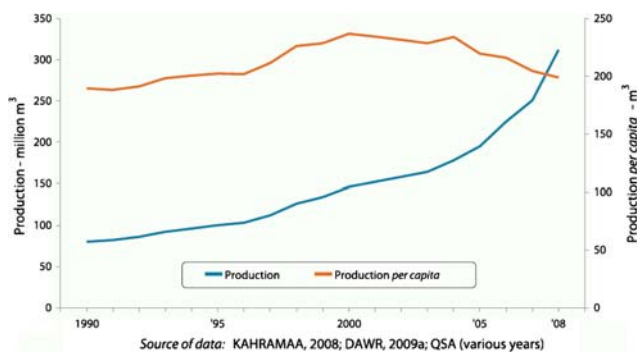


Fig. 6. Qatar DW increase from 1990 to 2008 [2].

supplied to one ST. The GTCC cycle is used in several PP in Qatar such as: RAF A, RAF B, RAF B2, Ras Laffan-A, Ras Laffan B, Ras Laffan C, Ras Girtas Power, and Mesaieed PP.

When the MSF units are combined with the GTCC, two types of STs can be used. The first type is Extracted-Condensing Steam Turbine where part of the expanding steam is extracted to the MSF units, while the other part continues its expansion to a condenser. The other type is the Back Pressure Steam Turbine where the entire expanding steam is exhausted to the MSF units at the pressure required by these units as shown in Figs. 7a and 7b. Typical energy consumed by the MSF system is: pumping energy of 4 kWh/m^3 (14.4 kJ/kg work or electrical energy), and 270 kJ/kg of thermal energy obtained by condensing the supplied steam to the MSF brine heaters. This steam is usually supplied at 2–3 bar pressure and a saturation temperature of 120°C .

The real value of the 270 kJ/kg thermal energy supplied as steam to the MSF units lies in its ability to

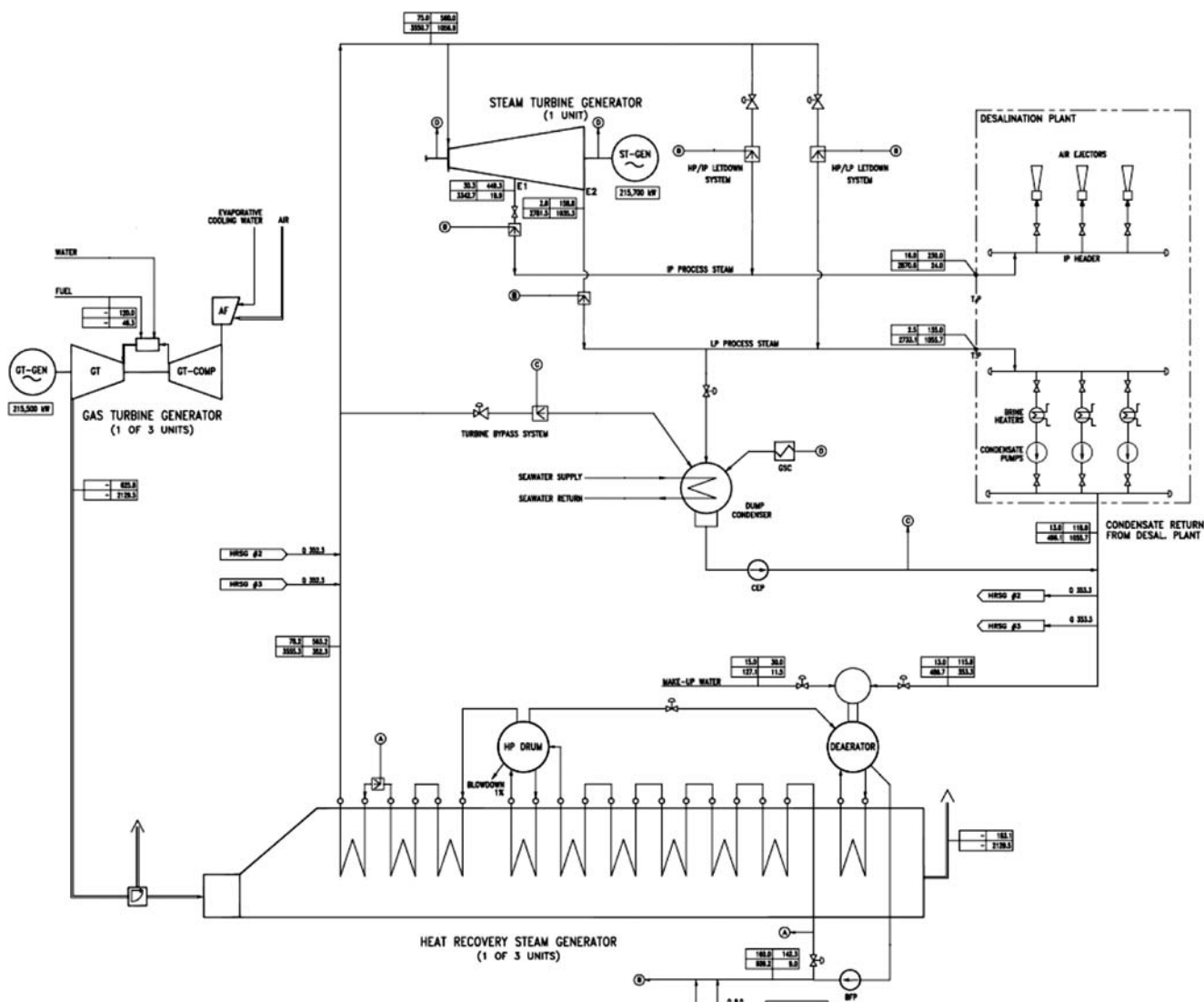


Fig. 7a. CPDP using GTCC of 3GT, 3HRSG, 1 steam turbine, and 3MSF units [6].

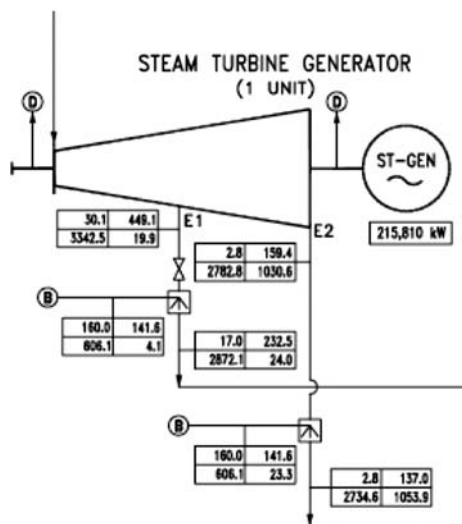


Fig. 7b. Steam cycle conditions in the CPDP [6].

produce work (or EP). If this steam were expanded in a low pressure (LP) turbine to the condenser, it would produce more power. So, supplying steam to the MSF is considered as work (or EP) loss, which can be calculated and it would be equivalent to the thermal energy supplied to the MSF unit.

The case considered here is for a real plant, see Fig. 8, having three MSF desalting units of 15 MIGD capacity each (or 2,638 kg/s total capacity). The steam leaves the turbine at the rate of 1,050.6 ton/h (291.83 kg/s), 2.8 bar pressure, 159.4°C temperature, and 2,782.8 kJ/kg enthalpy. If this steam were expanded in the LP turbine to a condenser pressure at 8 kPa, its enthalpy would be 2,330 kJ/kg and the work output would be:

The work loss due to the steam supplied to the three MSF units = $291.83 (2,782.8 - 2,330) = 132,142$ kW.

Another small amount of steam is extracted from the ST, but at a higher pressure to operate the steam ejectors of the three MSF plants at 19.9 ton/h (5.53 kg/s) flow rate, 30.1 bar pressure, 448.1°C temperature, and 3,342.5 kJ/kg enthalpy. If this steam were expanded in a turbine to the condensing pressure of 8 kPa, its enthalpy would be 2,330 kJ/kg and the its work output would be:

The work loss due to the steam supplied to three MSF ejectors = $5.53 (3,342.5 - 2,330) = 5,599$ kW.

So the total work loss by the steam supplied to the 45 MIGD (2,368 kg/s) is 137,741 kW, or 58.2 kJ/kg (16.16 kWh/m³). Since the pumping energy of the MSF is in the range of 4-kWh/m³, the total equivalent

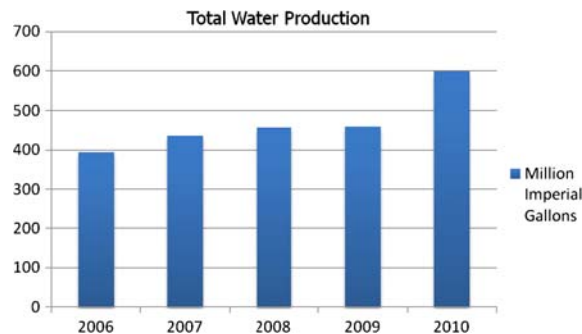


Fig. 8. Water storage capacity development from 2006 to 2010 [4].

mechanical energy (counting for pumping and thermal energy) to produce one m³ of desalted water is about 20 kWh/m³.

The fuel energy consumed by the CPDP to produce 20 kWh/m³ equivalent energy required for DW production can be calculated by assuming the PP efficiency of 45% as $20 \times 3,600 / (0.45) = 160,000$ kJ/m³ or 160 MJ/m³. This goes to prove the clear benefit of combining the MSF units with the PPs. If the steam required to the MSF units were taken directly from a fuel operated steam boiler, then the fuel energy that is required for the brine heater would at least be equal to $270 / 0.9 = 300$ MJ/m³, where 270 is the thermal energy required in MJ/m³ and 0.9 is the best small boiler efficiency. Thus, the use of CPDP saves at least 50% of the fuel energy when the MSF is directly driven by a fuel operated boiler.

2.4.2. Consumed fuel due to desalting seawater and its CO₂ emission

Desalination energy consumption and CO₂ emission. In 2010, the Qatar production of EP was 28,144 GWh and of DW was 373 Mm³ (1.022 Mm³/d). The calculation pertaining to the consumed fuel energy and its resultant CO₂ emission to generate the EP and DW are calculated here. The equivalent consumed EP per m³ of DW by the MSF desalting system was given before, it was about 20-kWh/m³. So, the consumed equivalent EP to desalt 1.022 Mm³/d is given as:

Consumed EP for DW per day = $1.022 \text{ Mm}^3 / \text{d} \times 20 \text{ kWh/m}^3 = 20.44 \text{ GWh/d}$.

Consumed EP for DW per year = 7,460.6 GWh in 2010.

This calculation gives the total equivalent EP output of both electricity and DW as 35,605 GWh, (28,144 for EP + 7,461 for DW), with a DW share of 21%. By

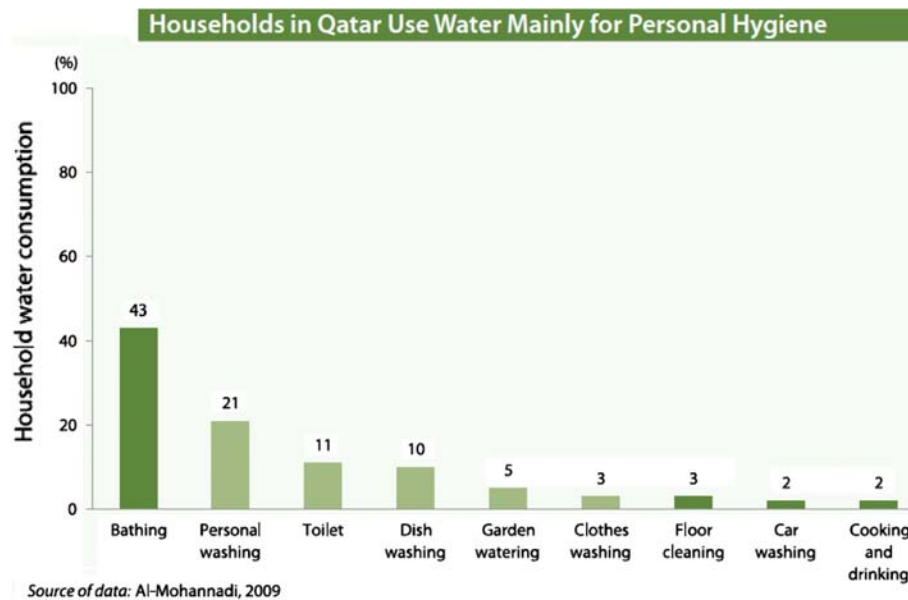


Fig. 9. Distribution of household water in Qatar [2].

assuming a 35% average efficiency due to part-time operation that prevails most of the time with low efficiency, the consumed fuel energy by the CPDP is 366.3 MGJ. This 366.2 MGJ is equivalent to 61.03 million barrels of oil (bbl), or 348.9 billion cubic feet (BCF) of NG. The heat content of one bbl is assumed equal to be 6 GJ, and of 1,000 cubic feet (CF) of NG is 1,050 kJ. Since Qatar produced 3,154 BCF of NG in 2009, while consumed 745 BCF. So, the CPDP consumed NG is more than 11% of its NG total production in 2009, and about 40% of total NG consumption.

The mass of fuel burned in the CPDP (366.2 BCF) is equal to $366.2 \times 0.0,208 = 7.602$ M tons of NG, with the contribution of 1.6 M tons by the DW. The CO₂ produced due to burning 7.602 M tons of NG is: $7.602 \times 0.75 \times 44/12 = 20.922$ M tons. The contribution of DW to this amount stands at 1.6 M tons, indicating that the production of 1 m³ of DW causes an emission of 11.23 kg/m³ CO₂. In brief, desalting 373 Mm³ in 2010 (1.02 Mm³/d) causes the burning of 1.6 tons of NG and an emission of 4.4 M tons of CO₂.

It worth mentioning here that the choice of seawater reverse osmosis (SWRO) to desalt seawater in place of the MSF system can save as much as 75% of the fuel used and reduce the CO₂ emission by the same ratio. The average SWRO energy consumption with devices used for brine energy recovery is 5 kWh/m³.

Desalination impact on marine environment. Besides polluting the air and emission of CO₂ by burning the NG fuel to produce DW, the MSF desalting process

has negative effects on marine environment by: (i) affecting the seawater intake and impingement of marine species on intake screens, (ii) brine discharge of high salinity brine with chemicals used in pre-treating the feedwater, and (ii) thermal discharge to the sea by high-temperature brine and cooling seawater. For an MSF unit of capacity D , the intake to the heat rejection section of the MSF as cooling water, M_c , is about six times D , or $6D$. Part of M_c (after being heated) is treated to become the makeup F ($F \cong 3D$). The balance ($M_c - F$), $\cong 3D$ is discharged back to the sea through the outfall; say at $\cong 11^\circ\text{C}$ higher than the seawater temperature and with the same seawater salinity. Part of F becomes the distillate D , and the balance is brine B ($\cong 2D$). B is rejected back to the sea through the outfall. The rejected brine B has, say at 11°C higher than the seawater temperature and salinity about 50% higher than that of the sea salinity. So, the MSF outfall flow rate stands at $5D$ and at 11°C higher than that of seawater. The high flow rates of seawater intake in MSF intensify the negative effect on the marine species by impingement; increase the chlorine discharge due to the chlorine added to seawater at the intake, and its overall negative effect on marine life. As an example, the RAF A desalting plant of 70 MIGD (318,220 m³/d) has an intake flow rate of 92,814 m³/h and an outfall flow rate of 79,555 m³/h.

In the year 2010, the produced DW in Qatar was 1.02 Mm³/d; the heat rejected to the sea was at the rate of 3.1 GW. It may be noted that the heat discharged to

the sea is almost equal to the thermal energy added to the desalting units. This can be checked by ascertaining that the thermal energy used by the MSF is in the range of 270 MJ/m^3 , then the heat added to produce $1.02 \text{ Mm}^3/\text{d}$ ($11.8 \text{ m}^3/\text{s}$) is 3.18 GW .

3. Water storage

In 2010, the water storage capacity stood at 2.673 Mm^3 , mainly in the reservoirs located in the CPDP (1.31 Mm^3), and 1.36 Mm^3 in other locations, and the balance stored in high towers and ground tanks (see Table 2). The daily DW production (and consumption) was more than $1 \text{ Mm}^3/\text{d}$ in 2010. The capacity water storage increase from 2006 to 2010 is shown in Fig. 8, indicating that the storage capacity is less than three times the daily consumption. This can create a critical situation if the vulnerable desalting plants become non-operational for any reason. A strategic water storage is required to augment water demand for several weeks.

4. Water consumption

The strategy in water consumption adopted in Qatar is to use GW for agriculture, DW to provide potable municipal water, and the reclaimed TWW for the irrigation of forage crops and landscaping. The agriculture areas are scattered where the GW of reasonable salinity is available for farming. Extraction of GW from the NGW and SGW Basins was 220.2 Mm^3 in 2004/2005.

Municipal water of potable quality is mainly DW, with slight contribution from the desalting GW. In 2010, the consumption of municipal water of potable quality is $1.02 \text{ Mm}^3/\text{d}$ ($373 \text{ Mm}^3/\text{y}$), while the population was 1.7M. This gives 600 liters per day per capita (l/d.ca) potable water consumption, one of the highest worldwide. The main reason for such a high consumption of potable water is the

politically motivated low or even no prices paid by the consumers. The Qatari nationals get water without any payment, while the expatriates (about 80% of population) pay a highly subsidized price of about $\$1.2/\text{m}^3$, about 35% of the real cost. An example of government water subsidization in 2003 is illustrated in Table 3.

As mentioned before, the average annual GW extraction between 2004 and 2005 was 220.2 Mm^3 . If this extraction was kept the same in 2010, then the daily per capita consumed GW is $3551/\text{d.ca}$. The effluents of the TWW plants in Doha were $129 \text{ Mm}^3/\text{y}$ ($354,520 \text{ m}^3/\text{d}$ or $2081/\text{d.ca}$). So, the total daily consumption of water is $1,1631/\text{d.ca}$, extremely high. In 2003, the ratio of residential water consumptions (for Qatari's and non-Qatari) was 74%, Table 3. So, the water demand management program should be imposed to reduce the household water consumption. The distribution of household water in Qatar is given in Fig. 9.

The contribution of agriculture to economy is negligible, as it represents less than 1% of the GDP (gross domestic product). However, it consumed about 60% of the country's water in 2005. The development of the agricultural sector is hampered by several factors, such as scarce water resources, low water quality, unfertile soils, and harsh climatic conditions. All these factors have contributed to low crop yields and have resulted in the importation of most agricultural products, dates being the only exception.

In 2005, the total water withdrawal was estimated to be 444 Mm^3 , of which 262 Mm^3 or 59% was used for agricultural purposes, 39% for municipal purposes, and 2% for industrial use. Of the totally reused TWW of 43 Mm^3 (an increase of more than 70% since 1994), 26% was supplied to Doha to be used for landscape irrigation, the remaining part conveyed via pipelines for the irrigation of forage crops in two farms (see Table 4). All the water used for the irrigation was pumped from the wells and from the sewage treatment plants to the farms and to Doha. There was no pricing system and the water was given free to the farmers, all what they had to pay was the cost of pumping. Measuring and limiting the abstraction should be implemented.

The picture should have been changed in 2010, as the DW became $373 \text{ Mm}^3/\text{y}$ (compared to $180 \text{ Mm}^3/\text{year}$ in 2005 or a 207% increase in 5 years). Similarly the TWW was increased from $43.3 \text{ Mm}^3/\text{y}$ in 2005 to $129.4 \text{ Mm}^3/\text{y}$ in 2009, almost 300% increase in 4 years. The GW withdrawal is restricted by the government. If the GW were limited to

Table 2
Water storage capacity in Qatar in 2007 [2]

Storage facility	Storage capacity	Percentage
Reservoir	1,927,542 ^a	97.2
Ground tank	25,167	1.3
Elevated tank	2,987	0.1
Water tank	27,640	1.4
Total	1,983,336	100

^aExcludes non-Operating reservoir Under refurbishment or maintenance.

Source: KAHRAMAA, 2008.

Table 3
Qatar 2003 water consumption and government subsidy [2]

Sector	Subsidy per unit (QR/m ³)	Total consumption (Mm ³)	Total subsidy MQR	% distribution of subsidy
Residential (Qatari)	10	52.3	524	63
Residential (non Qatari)	5.6	24.6	138	17
Commercial	5.6	10	56	7
Government	10	3.6	36	4
Industrial	5.6	13.4	75	9
Total	8.0	103.9	829	100

200Mm³/y, then the total water withdrawal would stand at 702.4Mm³/y. The percentage water withdrawals in 2010 can be about 53.1% for DW, 18% for TWW, and 27.9% for GW.

5. Water sustainability

The sustainability of water in Qatar is at risk. The extracted GW is several times its replenishment rate. The first sustainability condition is that the rate of a consumed renewable resource should be less than its replenishment rate. The municipal water supply depends almost entirely on the DW. The used desalting process is energy-intensive and costly. The fuel consumed, NG, is finite and non-renewable. The second sustainability condition is that the rate of a consumed non-renewable resource (NG here) should be less than the rate of developing another alternative; and no alternative here. Burning fuel to produce DW emits gases, which pollutes the air, contributing to the greenhouse gases causing a climate change. The desalting process also negatively affects the marine environment. The third sustainability condition is that the polluting gases should be treated to render them unharmed to the environment, which is not the case here. The use of TWW is limited to some agriculture and landscaping, and at a low rate compared to the potable

water consumption (about 25%). The WW is a water resource after being reclaimed, and most of it is wasted here.

6. Measures to be considered

There are clear advantages of seriously considering some measures such as:

- (1) Conservation of water is the best resource. Raising public awareness and education, using water conservation measures, and restructuring water prices are to be used for water conservation.
- (2) Most WW in Qatar is treated to the tertiary level and is used for irrigation. The dissolved organic compounds and any other contaminant present in the tertiary-treated effluent are known or are suspected to be detrimental to various reuse applications and still limit the full utilization of this valuable resource. The quaternary treatment is defined and used as the treatment for producing potable water quality to meet unrestricted residential uses and industrial applications requiring ultra-pure water. Membranes of different pore sizes are usually used in the quaternary treatment process such as micro-filtration (MF), ultrafiltration

Table 4
Water withdrawal by different sectors in Qatar in the year 2005 [2]

	Agriculture		Domestic		Industry		Total	
	Mm ³ /y	%	Mm ³ /y	%	Mm ³ /y	%	Mm ³ /y	%
GW	218	83.5	2.4	1.4	–	–	22.7	49.7
Treated sewage water	43.2	16.5	–	–	–	–	43.2	9.7
Desalinated water	–	–	171.8	98.6	8.4	100	180.2	40.6
Total	261.5	100	174.2	100	8.4	100	444.1	100
% by sector	58.9		39.2		1.9		100	

(UF), nano-filtration (NF), and hyper-filtration reverse osmosis (RO) in a descending pore diameter order. As a general rule, the MF is suitable for the removal of suspended solids, including larger micro-organisms such as protozoa and bacteria. The UF is required for the removal of viruses and organic macromolecules even down to a size of around 20 nm. Smaller organics and multivalent ions may be removed by the NF, while the RO is even suitable for the removal of all dissolved species. However, direct human consumption of this treated effluent may be objectionable owing to psychological and probably religious reasons, although it can satisfy the potable water requirements and can be used for human consumption in many parts of the world. The quaternary treated water is used as a direct potable water or is recharged to aquifers for storage and then extracted for potable purposes in many parts of the world. Example of such types are given in Ref. [7]. An example is the Sulaibiya WW treatment and reclamation plant in Kuwait [8], which uses UF and RO to produce potable water quality from a tertiary municipal WW effluent. The RO removes all the dissolved salts and any other harmful contaminant, including bacteria, viruses, and chemicals. The plant is the largest facility of its kind in the world that uses RO and UF membrane-based water purification method to decontaminate water. The plant had an initial daily capacity of $0.375 \text{ Mm}^3/\text{d}$ and has been designed to reach a daily capacity $0.6 \text{ Mm}^3/\text{d}$ in the future. Its output can be used without any limitation for agriculture, industry, and some buildings' application. The output can also be used for aquifer storage charge to saving the GW from depletion and deterioration, especially in the NGW Basin.

- (3) Increasing natural recharge of aquifer by the drilling of wells (with a special design including a perforated casing and graded gravels) in depressions to recharge water from occasional storm through the wells to depths that reach the water-bearing formations to accelerate the natural recharge of floodwater.
- (4) Decrease the losses between municipal water supply and the TWW, which represents only 25% of the municipal water supply, and should be at least 60%.

7. Conclusion

In addressing water security concerns, Qatar needs to take a serious step to conserve water and to develop an integral water management program. The following steps should be considered such as:

- Formulating Integrated water resources management.
- Capacity building and institutional strengthening.
- Looking for innovative desalination technologies that minimize both the cost of water production and the environmental impact should be further investigated.
- Promote the technology of WWT.
- Promote the use of TWW for agricultural and industrial use.
- Promoting the storage of treated wastewater in aquifers as strategic water storage.
- Expanding the use of a Dual distribution system: one for the distribution of potable quality water for drinking and cooking purposes, and the other for the distribution of water with lesser quality intended for landscaping, flushing of toilets, etc.
- Managing Water Demand, a more effective way against water scarcity, risk, and vulnerability.
- New water pricing: Water pricing needs to reflect the scarcity value of water, so that governments do not end up subsidizing the depletion of an essential natural resource and polluting the environment.
- Formulating education and training programs which could result in considerable water saving primarily through behavioral change and good ethical and moral practices.
- Relying on renewable energy for desalting water and WWT.
- Developing programs to optimize and monitor the collection and distribution of water resources from rainfall, GW, desalination, aquifers, and recycling, and direct each of these to its most appropriate and efficient use.
- Expanding the capacity of water storage facilities to ensure reliable supply of water, especially potable water, for months instead of merely days.
- Demand-side considerations include: developing a strategy to manage the demand and ensure the efficiency of use in all sectors, coordinating and integrating the work of water agencies, eliminating wasteful practices, adopting advanced and appropriate technology, and constraining extravagant or unnecessary consumption.

Nomenclature

BCF	— billion cubic feet
ca	— capita
d	— day
DW	— desalted seawater
EP	— electric power
FAO	— Food and Agriculture Organization of the United Nations
G	— giga (10^9)
GJ	— giga Joules (10^9 Joule)
GT	— gas turbines
GW	— giga Watt
GWh	— giga Watt hours (1 GWh = 3,600 GJ)
GTCC	— gas turbines combined cycle
GW	— groundwater
HRSG	— heat recovery steam generator
kWh	— kilo Watt hour (1 kWh = 3,600 kJ)
M	— million (10^6)
mg/l	— milligram per liter
MIGD	— million imperial gallons per day (4,546 m ³ /d or 62.62 kg/s)
MSF	— multi-stage flash desalting
MW	— megawatt (10^6 Watt)
MCF	— million cubic feet
NG	— natural gas
RO	— reverse osmosis
ST	— steam turbine
SWRO	— seawater reverse osmosis desalting system
TWW	— treated wastewater
WW	— wastewater

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