Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2012.700034

51 (2013) 38–43
January

Taylor & Francis
Taylor & Francis Group

Combined desalination, water reuse, and aquifer storage and recovery to meet water supply demands in the GCC/MENA region

Noreddine Ghaffour*, Thomas M. Missimer, Gary L. Amy

Water Desalination and Reuse Center, King Abdullah University of Science and Technology (KAUST), Thuwal, Makkah Province, Saudi Arabia
Email: noreddine.ghaffour@kaust.edu.sa

Received 1 March 2012; Accepted 29 May 2012

ABSTRACT

Desalination is no longer considered as a nonconventional resource to supply potable water in several countries, especially in the Gulf Corporation Countries (GCC) and Middle East and North Africa (MENA) region as most of the big cities rely almost 100% on desalinated water for their supply. Due to the continuous increase in water demand, more large-scale plants are expected to be constructed in the region. However, most of the large cities in these countries have very limited water storage capacity, ranging from hours to a few days only and their groundwater capacity is very limited. The growing need for fresh water has led to significant cost reduction, because of technological improvements of desalination technologies which makes it an attractive option for water supply even in countries where desalination was unthinkable in the past. In the GCC/MENA region, operating records show that water demand is relatively constant during the year, while power demand varies considerably with a high peak in the summer season. However, desalination and power plants are economically and technically efficient only if they are fully operated at close to full capacity. In addition, desalination plants are exposed to external constraints leading to unexpected shutdowns (e.g. red tides). Hybridization of different technologies, including reverse osmosis and thermal-based plants, is used to balance the power to water mismatch in the demand by using the idle power from co-generation systems during low power demand periods. This has led to consideration of storage of additional desalinated water to allow for maximum production and stability in operation. Aquifer storage and recovery (ASR) would then be a good option to store the surplus of desalinated water which could be used when water demand is high or during unexpected shutdowns of desalination plants. In addition, increased reuse of treated wastewater could bring an integrated approach to water resources management. In this paper, the power to water demand mismatch in the GCC/MENA region as well as the feasibility of using ASR technology as an option for providing large-scale storage is assessed.

Keywords: Desalination; Water reuse; Aquifer storage and recovery (ASR); Integrated water resources management (IWRM); Hybrid systems

*Corresponding author.

Presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, 23–26 April 2012, Barcelona, Spain

1. Introduction

One of the most significant water supply problems within the Gulf Corporation Countries (GCC) and the Middle East and North Africa (MENA) region is the lack of sufficient potable water storage for large population centers. According to the authors' survey of the managers of main large-scale desalination plants and decision-makers managing distribution systems, between only 12 h and 3 days of potable water storage are available in the major population centers of the GCC/MENA region. This lack of storage and the growing capacity of individual desalination facilities being used to supply water are increasing the security risk to the growing populations of the major cities [1]. Damage to large water conveyance pipes or major damage to a single desalination facility could leave a large population center without a viable water supply in one of the driest regions in the world. To resolve this issue, a multi-faceted water management approach is required that involves the need to create more water storage (both ground-storage and aquifer storage and recovery [ASR]), increase the capacity of desalination, and increase water reuse. The water management approach needs to be coordinated, perhaps within a framework of integrated water resources management (IWRM).

Rapid population and economic growth within the GCC/MENA region has led to a growing need to increase freshwater supplies. Limited existing fresh groundwater has been essentially depleted and can only be used to sustain supplies for small villages and farms within wadi systems [2] and at locations where regional aquifer systems still have some productive capacity of fresh water. Only two sources of new water supply have the potential to meet future water supply demands; desalination and water reuse (treated wastewater effluent reuse). Capture and storage of stormwater has some potential to be used for water supply, for primarily irrigation. These water supplies and the small amount of existing fresh groundwater should be managed within the concept of IWRM. To optimize the management of all water resources within the context of seasonal demand variations, emergencies, and drought occurrences, storage of water must be considered as another key factor within IWRM [3].

Addition to the freshwater supply in the GCC/MENA region continues to be developed as increased desalination capacity, which is no longer considered to be a nonconventional source of water supply [4]. Desalination of seawater is rapidly growing in capacity [5]. Technological advances in the desalination processes have been responsible for this growth to meet the increasing water demands. These advances have led to a significant reduction in desalinated water cost to a level that has made it a viable option for potable water supply [6–8]. It is now technically and economically feasible to generate large volumes of water of suitable purity through the desalination of seawater and brackish water. Continued reductions in desalination costs are anticipated based on the enhanced use of renewable energy sources and the use of hybrid facilities to help reduce overall energy consumption [9–12].

Membrane treatment of wastewater and aquifer recharge and recovery (ARR) are also capable of increasing the viability and safety of reusing domestic wastewater. A very small part of the wastewater generated in the GCC is being reused in a useful manner. In Saudi Arabia, only about 10% is being reused [13]. As the capacity of desalination increases, the amount of generated wastewater will increase proportionately, thereby creating another viable source of water supply.

The efficiency and cost of desalination is linked fully to power generation and consumption. Greater efficiency in coordinated desalination and power systems must be achieved to maintain sustainable growth in water supplies. A key strategy is to create more potable water storage linked with both power generation and desalination in a manner to increase combined facility efficiency and to provide greater water supply security [14,15]. Generated electricity cannot be stored; however, desalinated water can be stored. Utilizing ASR can provide storage of desalinated water during seasonal low-energy usage to improve electric power generation efficiency and to create large in-ground strategic reservoirs for security purposes [16].

2. Water storage and seasonal imbalances of power and water production

There are a number of operational issues that plague the utilities with the GCC/MENA region. First is the lack of storage within the distribution systems, particularly in large cities. Second is the operational inefficiency of the combined power and water production cycles with power production being quite seasonal and water demand being more constant.

Rapid population growth stimulated by internal economic development, external immigration to fill jobs, and internal migration of people from rural areas to cities has contributed to the rapid increase in urban water demand. Water suppliers are tasked with adding new capacity to cities that already have limited access to potable water by expanding distribution systems and adding additional capacity to meet new demand. Also, distribution system losses contribute to the need to increase water supplies in the older cities of the GCC/MENA region. While desalinated water is the primary source being sent to the cities, the internal distribution systems have little ground storage capacity to meet fire flow and general emergency conditions. Virtually, no city in this region has more than 3 days of system storage and many have less than 12 h of storage in the event of the primary water supply system failure. Within distribution systems, the lack of elevated and ground storage causes the occurrence of very low line pressures, which can lessen water delivery to customers and can allow contaminated water inflow into the distribution system, thereby, causing potential health issues.

A major security issue is that the large desalination facilities are located adjacent to the sea and some of the larger cities are located inland at considerable distances from the potable water sources, thereby, necessitating the construction and maintenance of large-diameter pipelines [1]. In the event of a major pipeline or desalination plant failure, no potable water would be delivered to the population centers [16]. Disastrous results could occur with only a few days of supply interruption. Implementation of distribution system storage of desalinated water could not practically resolve this large-capacity storage problem. However, the implementation of strategically located ASR systems could be used to solve this problem [17]. The concept of strategic storage of large volumes of desalted water, up to one year of plant capacity, is currently being implemented at two sites in the United Arab Emirates (UAE) [17].

Both increases in distribution system storage and strategic storage using ASR are required to meet water supply system reliability considerations and security needs. However, ASR cannot be used as a substitute for ground storage within a distribution system because of the necessary high rate of production required within a short-time frame for fire flow use. Also, strategic storage of large water volumes cannot be economically developed using ground storage.

Another unique feature of the GCC power/water demand pattern is that power demand has a very seasonal fluctuation, while water demand is relativity constant in comparison. Therefore, there is a general inefficiency within the power production component of the nexus. Power generation is most cost effective during times of continuous facility operation at near maximum capacity, but electrical power can be generated, but not effectively stored. However, desalinated water can be stored using ASR, creating a link between the stored desalinated water with power plant operations, leading to greater operational efficiencies for both facilities and lower costs [14,15].

2.1. Ground storage improvements

Distribution system ground storage is a fundamental part of all well-managed water conveyance systems. Typically, ground storage needs to be strategically placed at key locations in the conveyance and distribution system, beginning with storage at the treatment plant and at locations corresponding to special demand requirements and special needs, such as high-volume fire flows. Perhaps, a reasonable target for ground storage would be three days of overall supply within the system. This assumes that the ground storage system is being operated primarily to meet daily variations in demand associated with peak factors and that system water losses are under 10% of the overall system water input rate. There is no other substitute for ground storage within the daily operational time frame and for fire flow. ASR cannot be used to provide this function.

2.2. Strategic storage of desalinated water

ASR is a strategic storage option in countries relying on costly desalted water as a primary supply. Desalinated water production may be interrupted due to many reasons, such as calamities like earthquakes, wars, and contamination of feedwater, i.e. red tide [18] or operational failures [19] including equipment breakdown. In the GCC/MENA region, desalinated water storage could play an important role in providing uninterrupted water supply to consumers since desalinated water is mainly produced for domestic water supply. Recent experience shows that several desalination plants in the region were shutdown for several weeks during red tide season [20,21].

The average available desalinated water storage capacity in various large GCC cities varies between few hours such as in Sharjah in the UAE to few days (Abu-Dhabi, Dubai, Bahrain, Riyadh, Jeddah, Doha, Muscat (2 days), and Kuwait (5 days) [22].

To mitigate long-term water supply failures, ASR could be a good option to use for providing large-scale storage. The water required for ASR could come from the existing desalination plants by operating them throughout the year at maximum load or constructing new reverse osmosis (RO) plants that utilize the idle power in the winter from the co-generation systems instead of operating the power plant at a lower load due to lower electricity demand. In all cases, the placement of water into storage does require that the water treatment facility must have excess capacity during part of the year.

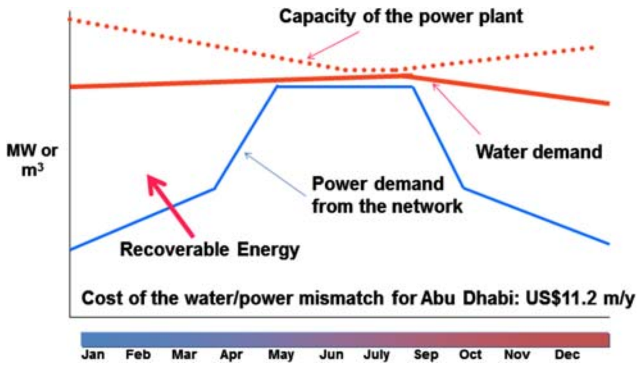

Fig. 1. Seasonal variation of water and power generation capacities in Abu Dhabi [22,24].

2.3. Seasonable disparity between water and power production

Operating records from desalination and power plant facilities in the GCC/MENA region show that water demand is relativity constant during the year, but the production of power shows considerable seasonal variation. While Fig. 1 was developed for water and power demands for the City of Abu Dhabi, UAE, a similar pattern is observed in many other GCC/MENA cities. The seasonality is related primarily to the summer demand for air conditioning in this very hot and dry region [23].

Moreover, water demand growth is higher than that of electricity in the GCC with water being 11% per year and electricity only 4% [24]. During low power demand periods, when power plants are not operating at full load, the steam used to operate thermal desalination plants is commonly supplied by auxiliary boilers instead of from turbines. This operational mode is quite costly.

Large-scale storage of desalinated water must be achieved by using ASR technology. Storage is also required for both operational and emergency needs to achieve the most economic mode of operation and a high degree of water security. Plants are capable of economically producing water seasonally in excess of immediate demand, because most of the desalinated plants in the GCC/MENA region are thermal-based desalination processes and coupled to power plants (co-generation). Storage capacity also plays an important role in coordinating the optimal design power and desalination plant capacities. Generally plants are designed to meet the peak day demand, causing much of the treatment capacity to lie idle during a large part of the year. The use of operational ASR would allow the desalination plants to be constructed at a lower capacity, thereby saving considerable capital and operational and maintenance costs.

3. The role of water reuse in reducing desalination demand

Production of potable water from seawater desalination is costly and energy intensive regardless of the process used; membrane or thermal. Beneficial reuse of domestic wastewater and perhaps industrial wastewater is necessary to reduce the demand for desalinated water used for nonpotable uses, such as landscape irrigation, agricultural irrigation, and industrial uses including cooling water. The driving force for wastewater becoming a water source has been the increased cost to dispose of it. Therefore, the motivation to recycle is economic and in many case related to real and perceived environmental impacts. Also, the use of desalted potable water for irrigation is more costly than reusing treated wastewater.

Conventional wastewater treatment using primary, secondary, and tertiary processes gives policy- and decision-makers a choice in cost vs. product and product vs. use. Membrane technology offers different treatment options. Wastewater can be treated to a very high quality, above potable water standards, by microfiltration (MF) or ultrafiltration (UF), or by a membrane bioreactor which uses MF or UF submerged membranes, followed by RO and Ultraviolet. However, the cost of this treatment is very high and no developing country can afford to do this unless the water must be used as a direct potable supply, such occurs at Windhoek, Namibia [25]. Although highly treated wastewater could be used for drinking water, this is rarely acceptable from a cultural standpoint. However, it can also be utilized for potable purposes in an indirect way by letting the treated water flow into rivers and then, downstream people use this water for potable purpose [22]. It can also be injected into aquifers for further treatment and used later for potable purposes (ARR), but only when there is adequate separation between the injection system and the withdrawal location [26]. It should be noted that the use of aquifers in the treatment process, such as ASR, may require that the injected water meet potable standards before being injected for storage under US Environmental Protection Agency rules that have similar counterparts in other countries [17].

4. ASR systems for desalination and water reuse optimization

ASR has been used in conjunction with desalination in many systems located around the world to improve operational efficiency [27] and for large-scale strategic storage in the UAE [28,29]. The strategic ASR systems being designed and constructed in the UAE at Liwa and Schwaib will hold approximately one full year of a coastal desalination plant capacity or over 100 million cubic meters of stored desalted water. Investigations are currently being conducted in Kuwait to assess both operational and strategic ASR storage potential for desalination water.

Storage of large quantities of desalinated water in the ground requires that the hydrogeology of the storage aquifer is suitable to allow storage and recovery of the water with minimal losses and at a quality that can be used for drinking water. Not every location can support the development of a successful ASR project [17].

ASR systems can also be developed to store reclaimed water and surface water, which are both important in the GCC/MENA region. The feasibility of using wadi aquifers in Western Saudi Arabia for storage, treatment, and reuse has been recently investigated [25]. Also, reclaimed water ASR systems are being investigated or considered in Kuwait, Oman, and Qatar within the GCC region.

ASR is the only reasonable alternative for large-scale storage of treated water. Ground storage facilities can have a unit capital cost of up to \$130/m^3. The use of reservoirs may be perhaps on the order of \$50, but water losses in the GCC/MENA could severely reduce the effectiveness of reservoirs or necessitate the use of a cover, therefore, increasing the cost by at least 40%. A comparative cost of ASR development is perhaps on the order of \$20/m^3 for very high capacity systems. Lower capacity systems would have a higher cost per unit volume stored. The final numbers for construction of a mega-scale strategic storage ASR system are not precisely known.

The operational cost of ASR is also an issue that must be considered. While treated water placed into storage tanks remains of high quality, the stored water in an ASR system comes in contact with both the framework matrix of the storage aquifer and the native groundwater contained within it. If adverse chemical reactions occur that alter the quality of the stored water, it could become impaired, requiring post-storage treatment that may make the system infeasible. Therefore, great care must be taken in the selection of the ASR site and an awareness of the risks involved must be considered [17]. Any ASR system should allow the storage of treated water and recovery of that water for its intended use without significant additional treatment with the exception of disinfection [17].

5. Desalination, water reuse, and ASR within the framework of IWRM

The primary focus of this paper has been on the development of cost effective potable water supplies and storage of potable water within the arid lands of the GCC/MENA region. However, the largest water user in this region as well as globally is agriculture. The role of desalination and reuse of reclaimed water must be considered within the framework of overall water use, not solely potable and industrial uses.

IWRM is a philosophical approach to water management that seeks to incorporate all potential sources of water supply and match them with the most economically beneficial users inside a framework of sustainability. Within the GCC/MENA arid region, the highest value water use is for drinking and industrial uses with agricultural water use having a very low economic return. Therefore, under IWRM planning the further development of desalination along with reuse should be the primary supplies of water to meet all potable and industrial requirements. Reuse and the capture and storage of ephemeral stormwater would likely be the primary uses to meet agricultural demands without the use of desalinated water. Economic considerations may limit the use of water for agriculture and the in-country production of food crops, thereby requiring the importation of food as "virtual water" within the context of IWRM [30,31].

6. Conclusions

Desalination capacity is expected to increase significantly in the next decade to meet the water needs especially in GCC/MENA region where water demand is increasing. To satisfy this increased demand in water and power simultaneously, more megasize plants including hybrid systems are expected to be constructed in the region. However, most of the big cities in these countries, relying mostly on desalinated water for their potable water supply, have very limited water storage ranging from few hours to few days. On the other hand, operating records show that water demand is relatively constant during the year while power demand varies considerably with a high peak in the summer, mainly due to the full operation of air-conditioning systems in this very hot and dry region. During low electricity demand season, use of the idle power from co-generation systems could be a good option to produce additional desalinated water using RO technology. ASR could then be to store the surplus of desalinated water which would be used when water demand is high or during an unexpected shutdown of desalination plants.

Also, improvements to the economics of using reclaimed water need to be made. This will include reuse of treated wastewater and the capture, storage, treatment, and use of stormwater. The use of natural systems filtration methods will likely need to be implemented to increase the use of these resources.

References

[1] N. Drouiche, N. Ghaffour, M.W. Naceur, H. Mahmoudi, T. Ouslimane, Reasons for the fast growing seawater desalination capacity in Algeria, Water Resour. Manage. 25 (2011) 2743–2754.

[2] R.G. Maliva, R. Herrmann, F. Winslowand, T.M. Missimer, Aquifer storage and recovery of treated sewage effluent in the Middle East, Arab. J. Sci. Eng. 36 (2011) 63–74. doi: 10.1007/s13369-010-0011-y.

[3] R.G. Maliva, R.E. Griswold, M.M. Autrey, and T.M. Missimer, Aquifer storage and recovery and the optimization of reclaimed water reuse in coastal areas—Destin water users system, in: Technical Program & Proceedings of the 85th Annual Florida Water Resources Conference, Orlando, FL, May 16–19, 2010, 12 p.

[4] N. Ghaffour, The challenge of capacity-building strategies and perspectives for desalination for sustainable water use in MENA, Desalin. Water Treat. 5 (2009) 48–53.

[5] Global Water Intelligence (GWI/WDR), Market profile and desalination markets, 2011 yearbooks and GWI website. Available from: http://www.desaldata.com/.

[6] K.V. Reddy, N. Ghaffour, Overview of the cost of desalinated water and costing methodologies, Desalination 205 (2007) 340–353.

[7] R. Borsani, S. Rebagliati, Fundamentals and costing of MSF desalination plants and comparison with other technologies, Desalination 182 (2005) 29–37.

[8] C. Sommariva, H. Hogg, K. Callister, Cost reduction and design lifetime increase in thermal desalination plants: Thermodynamic and corrosion resistance combined analysis for heat exchange tubes material selection, Desalination 158 (2003) 17–21.

[9] H. Mahmoudi, A. Ouagued, N. Ghaffour, Capacity building strategies and policy for desalination using renewable energies in Algeria, Renew. Sustain. Energy Rev. 13 (2009) 921–926.

[10] M.F.A. Goosen, H. Mahmoudi, N. Ghaffour, Water desalination using geothermal energy, Energies 3 (2010) 1423–1442.

[11] H. Mahmoudi, N. Spahis, M.F.A. Goosen, S. Sablani, S. Abdul-Wahab, N. Ghaffour, N. Drouiche, Assessment of wind energy to power solar brackish water greenhouse desalination units: A case study from Algeria, Renew. Sustain. Energy Rev. 13 (2009) 2149–2155.

[12] L. Awerbuch, Hybridization and dual purpose plant cost considerations, in: MEDRC International Conference on Desalination Costing, Conference Proceeding, Lemesos, Cyprus, December 2004.

[13] M. Al-Saud, Managing the water sector of Saudi Arabia, in: Keynote Lecture of the Deputy Minister, Ministry of Water and Electricity (personal communication), King Abdullah University of Science and Technology (KAUST), Saudi Arabia, 2010.

[14] T.M., Missimer, R.G. Maliva, Efficiency improvement of co-located electric power and seawater desalination plants using aquifer storage and recovery technology, in: Singapore Water Week 2010, Sustainable Cities: Clean and Affordable Water, June 28–July 2, 2010, Singapore, 7 p.

[15] T.M. Missimer, R.G. Maliva, Improving the efficiency of seawater desalination: Use of alternative intakes and aquifer storage and recovery, in: Proceedings of WEX 2010, The Water and Energy Exchange, February 2–4, 2010, Limassol, Cyprus, 9 p.

[16] H. Mahmoudi, N. Saphis, M.F. Goosen, N. Ghaffour, N. Drouiche, A. Ouagued, Application of geothermal energy for heating and fresh water production in a brackish water greenhouse desalination unit: A case study, Renew. Sustain. Energy Rev. 14 (2010) 512–517.

[17] R.G. Maliva, T.M. Missimer, Aquifer storage and recovery and managed aquifer recharge, in: Planning, Hydrogeology, Design, and Operation: Methods in Water Resources Evaluation Series No. 2, Schlumberger Corporation, 2010, 578 p.

[18] T.M. Missimer (with contributions by I. Watson, R.G. Maliva, T. Pankratz), Water supply development, aquifer storage, and concentrate disposal for membrane water treatment facilities, in: Methods in Water Resources Evaluation Series No. 1, Schlumberger Water Services, Houston, TX, 2009, 390 p.

[19] W. Arras, N. Ghaffour, A. Hamou, Performance evaluation of BWRO desalination plant: A case study, Desalination 235 (2009) 170–178.

[20] H. Faujour, 2008–2009 red tide in Fujeirah: Pretreatment trains to cope with algal blooms, in: MEDRC Expert Workshop on Red Tides and HABs: Impact on Desalination Plants, February 8–9, 2012, Muscat, Oman.

[21] S. Bertrand, Sensitive areas to algal blooms and impact on desalination plants, in: MEDRC Expert Workshop on Red Tides and HABs: Impact on Desalination Plants, February 8–9, 2012, Muscat, Oman.

[22] K. Quteishat, Desalination and ASR in Integrated Management of Water, Schlumberger Symposium, Artificial Recharge and Water treatment for Sustainable Development of Groundwater Aquifers, Muscat, 2006.

[23] R.K. Jassim, N. Ghaffour, T. Khir, Thermoeconomic optimization of the geometry of an air conditioning precooling air reheater dehumidifier, Int. J. Energ. Res. 30(4) (2006) 237–258.

[24] K. Quteishat, Hydrorop conference 2001, provided by Suez, Marseille, France.

[25] T. Pankratz, MEDRC workshop on Membrane Technology Used in Desalination and Wastewater Treatment for Reuse, Muscat, Oman, March 2008.

[26] T.M. Missimer, J. Drewes, G. Amy, R.G. Maliva, S. Keller, Restoration of wadi aquifers by artificial recharge with treated waste water Ground Water. doi: 10.1111/j.1745-6584.2012.00941.x.

[27] T.M. Missimer, C.W. Walker, F. Bloetcher, Use of aquifer storage and recovery technology to improve membrane water treatment plant efficiency, Collier County, FL, Desalination 87 (1992) 269–280.

[28] Schlumberger Water Services, Strategic aquifer storage and recovery (ASR) project for the Eastern Region of the Emirate of Abu Dhabi, Feasibility Report (August, 2004): Abu Dhabi, United Arab Emirates, Schlumberger Water Services, 2004, 77 p.

[29] Schlumberger Water Services, Strategic aquifer storage and recovery (ASR) project for the Eastern Region of the Emirate of Abu Dhabi, Final Report: Abu Dhabi, United Arab Emirates, Schlumberger Water Services, 2004, 73 p.

[30] J.A. Allan, Virtual water: A strategic resource, Global solutions to regional deficits, 1998.

[31] J.A. Allan, "Virtual water" as an essential element in stabilizing the political economies of the Middle Eastern natural environments: Legacies and lessons, Yale School of Forestry and Environmental Studies, Bulletin 103 (1998) 141–149.