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Water-supply augmentation options in water-scarce countries

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Growing demand for water resources due to increased population and improved living standards, have prompted public agencies and others in the Fertile Crescent (FC), a semi-arid region, to seek better ways to manage water. This paper discusses water supply-augmentation options (e.g., desalination, water importing, wastewater treatment, recycling, water conservation, reducing evapotranspiration and storage) to alleviate water scarcity generally, and in the FC countries in particular. Introduction of conventional and non-conventional measures to augment water supplies as well as narrowing of the gap between water supply and demand in water-scarce countries and regions was done. A conceptual supply augmentation method operationalized with secondary data suggests water supply augmentation is feasible in this region. Marginal cost (MC) principle was used to demonstrate optimal water supply by step-wise adoption of the supply-augmentation methods with the lowest MC. Three supply-augmentation options were most promising in the FC: (1) desalination of brackish water, (2) reducing evapotranspiration, and (3) water conservation. These three options can potentially add as much as 630 million cubic meter (MCM) over the next two decades, helping to solve the water-scarcity problem while considering sustainability and water quality for present and future uses.

Key words: Water scarcity, Fertile Crescent (FC), supply-augmentation options, marginal cost (MC).

INTRODUCTION

Water is a vital component for all life forms and necessary for human and economic development. Water is essential to food security. It is required for a quality environment for humans and other life forms. However, water scarcity is a critical resource constraint for economic growth and development of the Fertile Crescent (FC), [1]the Arabian Peninsula[2] and Egypt (Haddadin, 2002). Water resources in the FC consist of ground (renewable and non-renewable) and surface water, with treated wastewater used increasingly for irrigation. Development of water resources has been hindered by regional political considerations and the high costs of water transportation infrastructure (Taha, 2006).

Water shortages constrain economic development, negatively impact urban industries and adversely affect the environment (United Nations, 2003). Further, many FC countries lack an integrated and comprehensive approach to address water shortages. Securing additional water can ameliorate water scarcity, *ceteris paribus*. However, reducing evapotranspiration, capturing rainwater with micro- and macro-storage dams (building dams), desalination of seawater and brackish groundwater, wastewater reuse and importation of water from neighboring countries via virtual water can all augment water supply. Conservation, or using current water supplies more efficiently, can also augment water supply. However, in the real world, sustainable supply-augmentation options must adhere to economic principles by considering costs, benefits, and constraints.

Water situation in the FC countries

More than half of the countries in the FC are ranked in the world's lowest 10% of annual, per capita total renewable water resource availability (Table 1). Of the FC countries, Iraq has the greatest supply of total annual

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[1] Including Iraq, Syria, Lebanon, Jordan, Palestine and Israel.

[2] Including the Republic of Yemen and the Gulf Cooperation Council members which are the State of Kuwait, the Kingdom of Bahrain, the State of Qatar, the United Arab Emirates, the Sultanate of Oman and the Kingdom of Saudi Arabia.

Table 1. Water availability in the FC.

Country	Ranking*	Total renewable water resources (MCM/cap/year)	Total internal renewable water resources (MCM/year)	Surface water: Produced internally (MCM/year)	Groundwater: Produced internally (MCM/year)
Palestinian territories	179	52.0	500	0.00	500
Jordan	170	179.0	680	400	500
Israel	167	276.0	750	250	500
Lebanon	149	1,261.0	128,500	97,300	49,300
Syria	141	1,622.0	7,000	4,800	4,200
Iraq	108	3,287.0	35,200	34,000	1,200

*****Rank of FC countries among 182 countries according to their annual, per capita total renewable water resource availability from the least (182) to the most (1). Source: Adapted from World Water Development Report (WWDR, 2003).

renewable water resources per capita at 3,287 MCM/cap/year (Table 1). The Palestinian territories have the least total annual renewable water resources per capita in the FC with only 52 MCM/cap/year. Jordan and Israel also have fewer than a million MCM/cap/year in renewable water resources. Lebanon and Syria have 1.2 and 1.6 MCM/cap/year, respectively. Lebanon has the greatest internal renewable water resources in the region with more than 1.2 MCM/year. The surface water and groundwater together are about 146,600 MCM/year which means that the water situation in Lebanon is better than the other FC courtiers. The Palestinian

METHODOLOGY

Three overall categories of options for increasing water supply in the FC include (1) reallocating water to its highest and best use, (2) finding actual substitutes for water, and (3) augmenting water supply. Herein we consider the water supply augmentation options, including reducing evapotranspiration, capturing rainwater with micro and macro dams, conserving water, desalinating seawater and brackish water, treating wastewater, and importing water from neighboring countries. However, all these options must be assessed based on both efficiency and geopolitical feasibility. The marginal cost (MC) principle is used to select the order in which supply-augmentation options could be implemented efficiently. The marginal cost (MC) principle helps to achieve economically optimal water supply by adopting the supply-augmentation method with the lowest MC first. In brief, the option where the next unit of water can be obtained at the least cost is the most efficient.

Conceptual model

To illustrate the conceptual model we assume there are two supply-augmentation options (A and B). Factors that affect option A and B are held constant. Also, the model assumes options A and B are already in operation at some level, so there are no additional start-up costs. A practical issue with water supply is the ability to either scale-up existing supply options or to start from nothing with a new water supply option which usually includes heavy initial costs. Thus, hereafter we have assumed scaling-up an existing option, rather than investing in a start-up.

Both options A and B provide an optimal quantity of water (q1) (Figure 1). The switch point is reached by allocating water to the least cost use at the margin, until the costs equal the marginal benefits of an additional unit of water. At the switch point, efficient choice is to switch to the supply-augmentation option with a lower MC per unit.

We used water cost and marginal cost data for supply-augmentation options from the literature. The cost data used to operationalize the conceptual supply augmentation model came from several studies (FAO, 2009; Al-Mutaz, 2005; El-Sadek, 2010; World Bank, 2007; United Nations, 2003). Secondary water data at the country or regional scale are generally not sufficiently robust to employ precise optimization methods.

Reducing evapotranspiration

Water that evaporates from soil, water, or artificial surfaces is removed by plants through transpiration is a bio-physical phenomenon called evapotranspiration (ET). Reducing ET could help alleviate water-poverty. ET is influenced by several factors including rainfall patterns, air and soil temperature, wind speed, soil characteristics and type of vegetative cover. About 85% of total surface water initially available for use in the FC is lost to ET (Shannag and Al-Adwan, 2000), illustrating a potential place to 'save' water. Annual evaporation volumes at high temperatures and under direct exposure to the sun in the Middle East may reach 1.5 to 2.5 m^3/m^2 of water surface (Varma, 1996). In Israel, 70 to 80% of average annual precipitation evaporates (Shevah, 2008).

ET can be feasibly reduced in the FC on a small, localized scale. Building dams and reservoirs in deep valleys with a correspondingly smaller surface area to overall volume ratio can reduce water loss to ET. Mechanical wind fences and parasol-type floats could also be used to prevent water loss due to evaporation (Gökbulak and Özhan, 2006; Segal and Burstein, 2010). Segal and Burstein (2010) concluded that parasol-type floats reduced water loss in proportion to the protected surface area.

Subsurface storage has also been shown to reduce ET and lower the risk of surface water contamination (Hut et al., 2008).

Monolayers have been used to reduce water evaporation from large dams when the conditions are favorable. Monolayers are thin chemical films as little as one molecule thick which produce a diffusion barrier on the water surface reducing evaporation (Barnes, 2008). Barnes (2008) used findings from small projects to estimate monolayer costs. The potential volume of water gain was about 15.18 MCM. The average total cost (ATC) was estimated to be $1.92/$m^3$, average variable cost (AVC) was $0.82/ m^3 and the

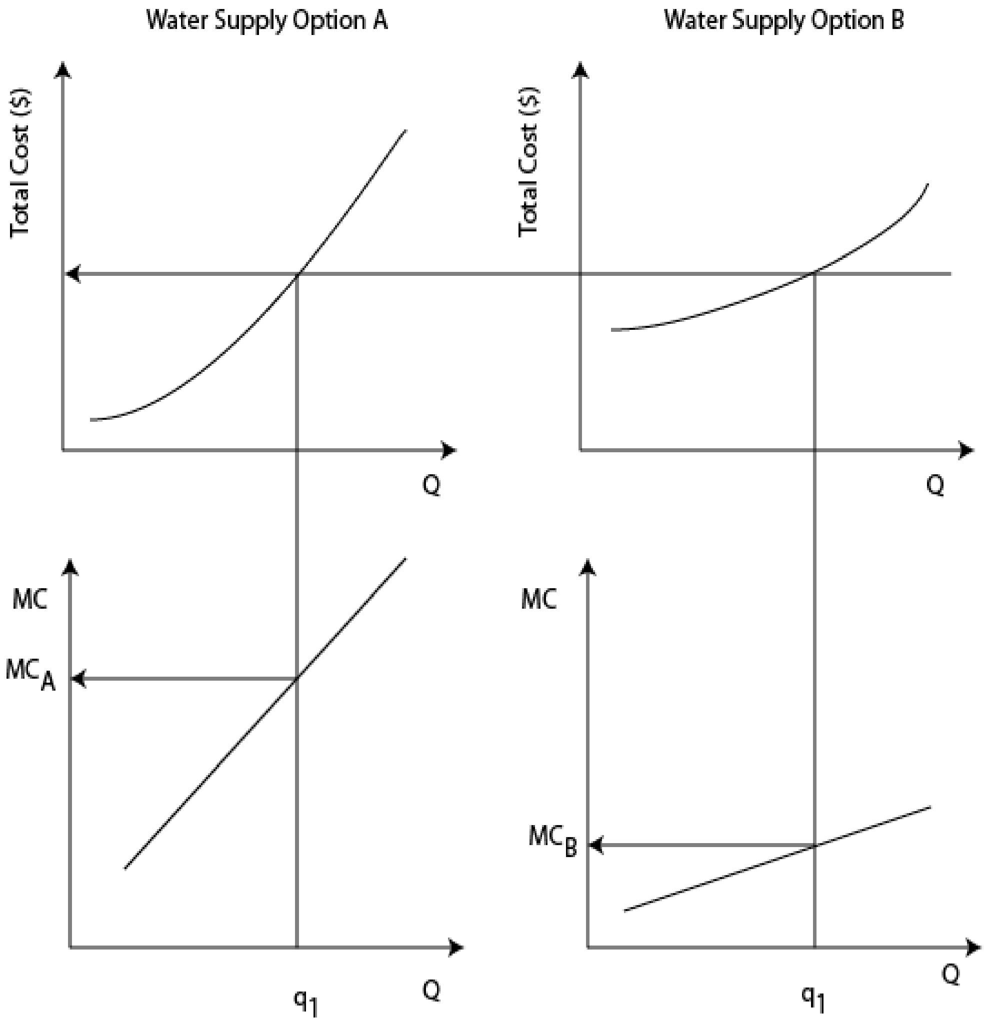

Figure 1. Conceptual Water-Supply Augmentation Model for Two Options (A and B).

marginal cost was \$0.83 /m^3 (McJannet et al., 2008). Davenport et al. (1976) estimated the cost of reducing ET was about \$1.3/m^3 while Gay (1988) estimated the cost to reduce ET would be \$0.8/m^3.

The main constraint to reducing ET is technology. Additional research is needed to develop technologies and reduce the cost of ET reduction techniques. Reducing ET could potentially conserve as much as 50 MCM by year 2030 in the FC.

Capturing runoff by building dams

Reservoir storage is a time-tested supply augmentation tool (Tullos et al., 2009). Reservoirs behind dams collect water in one time period for use in a future time period and function as storage pools to provide water during periods of water shortages. Dams (water storage) in the FC region provide water for agriculture, commercial, municipal, hydropower and recreation uses (World Commission on Dams [WCD], 2000). However, dams and dam construction have biophysical, socioeconomic, geopolitical and environmental impacts (Adams and Hughes, 1986). Dams can negatively affect ecosystems, hydrology and water quality and disrupt existing cultural and economic institutions (Poff and Hart, 2002). Applying the MC principle to reservoirs would involve increasing storage at existing sites through operational changes, rather than developing new sites.

Sub-surface groundwater dams also capture rainfall and store it for livestock, irrigation and domestic use (Hut et al., 2008). A subsurface dam stores groundwater with a “cut-off wall” across a groundwater channel. The sub-surface technology is preferred for numerous reasons including increasing the capacity of traditional wells, simplicity and less expensive to construct, replicable and easily maintained by the community, and less contamination of water. For example, sand dams have made a substantial impact on more than 100,000 people in Kenya. Sand dams are a relatively low cost measure that improves individuals’ access to water (Lasage et al., 2008). A sand dam is a subsurface dam built across a seasonal river. Sand and gravel are accumulated upstream of the dam, which is raised progressively before each rainy season until it reaches an appropriate height to provide water storage.

The Al-Wehdah dam project on the Yarmouk River, the border between Syria and Jordan, is an FC example of reservoir storage. The project was funded by the government of Jordan, the Arab Fund for Economic and Social Development, and the Abu Dhabi Fund for Development in 2003. Dam capacity was about 1,144,000 m^3. Construction costs were \$135 million (Molle et al., 2008) and operation and maintenance (O&M) costs were about $7.03 million/year. The operation and maintenance (O&M) costs include labor, administration, clean-up operations, electricity, rehabilitation and resettlement, environmental and forest aspects, the catchment area treatment and drainage system cost, and others. Average total cost (ATC) was $4.72 /m^3, average variable costs (AVC) were $0.25/m^3 and the marginal cost was $1.87 /m^3 (Molle et al., 2008).

The feasible potential quantity of water that can be gained annually from building surface and subsurface dams in the FC is 280 MCM by 2030 (FAO, 2009). The lack of research and development about the importance of dams as well as the high costs of construction and operation of dams are the main constraints to the dam-building option. However, micro and groundwater storage dams may be readily adopted in the next two decades.

Desalination

Among the options for water-supply augmentation is desalination of saline groundwater, brackish drainage water and seawater. Desalination in the FC is receiving considerable attention from scientists, resource planners, policy-makers and other stakeholders. Desalination removes dissolved minerals from seawater and brackish water. Desalination is not a new technology; in fact studies from centuries ago discussed distillation of drinking water from seawater by Mediterranean and Near East civilizations (Abu Zeid, 2000). Water desalination in the FC can be a technically and economically efficient option to produce additional quality water (Ammary, 2007). Desalination of Red Sea water by reverse osmosis (RO) and brackish groundwater desalination by nano-filtration could be technically viable and economically feasible (Afonso et al., 2004). RO is a relatively low MC option, reducing the content of organic and inorganic matter in water at a relatively low marginal cost ($0.36/m^3) (Afonso et al., 2004).

The existing Ashkelon desalination facility in Israel is expected to operate for 25 years, from 2002 to 2027. Facility production is expected to rise to 750 MCM by 2020 (de la Torre, 2008). The total cost of desalinated water from the Ashkelon plant, consisting of contracted total water price and the government's own project-related costs, is $0.53 /m^3. About 42% of the water cost covers energy costs, variable O&M costs, membranes and chemicals costs. The remaining 58% covers capital expenditure and fixed costs. The average total cost (ATC) is about $1.00/m^3, average variable cost (AVC) is $0.85/m^3 and the marginal cost is $0.53/m^3 (de la Torre, 2008; Kronenberg, 2004).

In 2010, water desalination provided 30 MCM in the FC, and by 2030, desalination is projected to provide about 170 MCM (Al-Mutaz, 2005; El-Sadek, 2010; World Bank, 2007; United Nations, 2003). In the FC, the marginal cost of treated brackish water ranged from US$0.30 to US$1.00, while, for seawater desalination, this cost ranged from US$0.84 to US$1.70 (Glueckstern, 2004). Use of desalination technologies in the FC is quite new when compared to the Gulf States where it has been used since 1957, but interest is growing as conventional water resources became fully allocated. Desalination is currently used primarily in industrial and tourism sectors because of the high cost of seawater desalination. The use of desalination for other purposes (agriculture and municipal) will depend on technological improvements that result in reduced overall and marginal costs.

Wastewater reuse

The U.S. Environmental Protection Agency (EPA) defines wastewater reuse as reusing treated wastewater in agricultural and industrial processes. In the FC, water reuse is an existing tool for managing scarce water resources. Overtime, wastewater reuse has changed from simply irrigating field crops with untreated wastewater to a sophisticated reclamation process for agricultural, industrial and domestic reuse (Durham et al., 2005).

Wastewater treatment and reuse as a tool for addressing food and water security in the Middle East and North Africa (MENA) was introduced by Faruqui (2002). The most practical solution for water scarcity is reuse of domestic wastewater for some non-potable municipal purposes, such as flushing toilets, irrigating green spaces, and for agriculture. Reusing wastewater is cheaper than developing new water supplies and protects existing sources of valuable fresh water from overexploitation (Faruqui, 2002).

The As-Samra wastewater treatment plant in Jordan was funded by USAID to replace the existing wastewater treatment plant. The project budget was $169 million, with half from USAID and the rest from the Jordanian government (Al-Zboon and Al-Ananzeh, 2008). The As-Samra plant is the largest wastewater treatment plant in Jordan and can treat about 75% of the 267,000 m^3 of wastewater collected each day (Ammary, 2007). The project began in 2000 and was completed in 2007. The plant is expected to be viable until 2025.

The government buys water from the As-Samra plant for approximately $1.1 /m^3 (Al-Zu'bi, 2007). The average cost for O&M of treating wastewater in waste stabilization ponds ranges from $0.15 to $0.9 /m^3. The total cost of the As-Samra wastewater treatment plant includes depreciation, salary, electricity, operation and maintenance, chemicals, sludge disposal and contracted testing. The average total cost (ATC) is about $1.51 /m^3, average variable cost (AVC) is $0.53 /m^3 and the marginal cost is $1.23 /m^3 (Mohsen, 2007).

Wastewater treatment is assumed to become much more widely adopted in the next two decades because it is an applicable and feasible technology (Mohsen, 2007). However, the main constraints for wastewater recycling in Israel and the Palestinian territories for irrigation and other appropriate industrial and municipal uses are potential contamination and long term reliability (Yaron, 1999). Investment and operation costs for wastewater treatment and reuse are high. However, treated wastewater is increasingly being used for agricultural irrigation. Many efforts, such as increasing awareness and information campaigns, are needed to encourage participatory approaches.

Importation of water from neighboring countries and virtual water

Water importation in the FC can be actual, physical water or virtual water. Virtual water is importing food with high water use in its production, thereby having the burden of the water input borne by the food producing country. In addition to processed food, it may be rational to import high water-consuming crops (that is, virtual water) from countries with adequate water (Shuval, 2006). For example, Israel's annual 'virtual' water imports are approximately three times its available internal water resource (Phillips et al., 2006). Israel also imports about 80% of its food and the Palestinians import over 65% of their food.

Israel and Turkey signed an agreement in 2004 that allowed Israel to import 50 MCM/year of fresh water from the Manavgat River system in Turkey for the next 20 years. The net cost of these physical water imports was estimated at US$0.73 to US$1.36 per m^3. That cost covers the tankers, bags and loading and unloading terminals (Yedioth, 2004; Friedman, 2004). The total minimum Manavgat River flow recorded was 60 m^3/s (that is, 1892.16 MCM per year). In other words, a volume of up to 1,892 MCM per year may be available from the Manavgat River (Friedman, 2004).

Many studies indicate that political conflict will be the main limiting factor for water-importation, especially physical water. Political uncertainty limits multi-national projects in the region. Strong collaborative institutions, at both national and regional

Table 2. Water-supply augmentation cost, potential volume (MCM) for different years and constraints for each option.

Supply augmentation options	Average prices (2008)* ($/M^3)	Expected prices 2030	Potential volumes (MCM)		Constraints
			2010	2030	
Brackish desalination	0.54	Decreasing	30	170	High cost and ecological impact
Sea water desalination	1.70	Decreasing			
Water importation	1.55	Increasing	60	140	Geopolitical, technical, high cost and pollution concern
Building storage dams	1.87	Increasing	120	280	High cost and little of research
Wastewater Reuse	1.23	Decreasing	80	230	High cost and water quality
Water conservation	0.85	Increasing	10	60	Low social incentive, cost and unorganized plan
Reducing ET	0.83	Decreasing	0	50	Global climate change

*Prices from different years were adjusted to 2008 using the GDP deflator. Source: Al-Mutaz (2005), Alrosoroff (2004), Friedman (2004) and Mohesn (2007).

levels, will be required for transboundary water agreements in the FC (Swedish Ministry for Foreign Affairs [SMFA], 2001). There is hope, that, through transboundary cooperation, local stakeholders' participation and policy-makers' regional analysis, the conflict can be recognized and people can resolve disputes. Political conflicts will limit water imports over the coming decades, but importing water as food products (virtual water) is an efficient option. The potential volumes of water from importation in 2030 could be 140 MCM.

Water conservation (demand management)

Water conservation increases the water available for all uses and can expand water availability and improve water quality. The main constraint for water conservation in the FC countries, or its potential for savings, is that consumers, water authorities, are unorganized and lack sufficient incentives. There are many water losses and other forms of waste in the FC. There is a lack of national and international water conservation plans to address the many examples of water loss through wasteful processes. For example, farmers in the FC consider the cost of adopting new irrigation techniques as a part of a water-conservation system to be high. That belief tends to discourage adaptation of more efficient irrigation systems (Helming, 1993). The farmers have neither appropriate nor adequate incentives to consume water in an efficient way.

Water conservation through water demand-supply management can take many forms, including provisions to reduce losses through technical measures that will improve the efficiency of water consumption. Rationing programs to increase public awareness together with incentives may also promote water conservation. A water-conservation management plan for the Jordan basin region will likely need to incorporate both supply- and demand-oriented measures to maximize economic and environment efficiencies (Berkoff, 1994).

The approximate marginal cost of water from all water conservation measures is about $0.85/m^3 and the projected potential quantity of water that can be obtained is about 10 MCM. By 2030, the projections for water conservation in the FC could be 50 MCM (Arlosoroff, 2004). By 2030, the challenges of inefficient water pricing mechanisms and the lack of public awareness about conservation could be solved resulting in more water from conservation.

RESULTS AND DISCUSSION

Three specific supply-augmentation options were most promising in the FC: (1) desalination of brackish water, (2) reducing evapotranspiration and (3) water conservation. These three options have the lowest marginal costs among all options reviewed. MC of reducing evapotranspiration was $0.83/m^3, for water conservation was $0.85 /m^3 and for brackish desalination was $0.54 /m^3. Additional research is needed to address technical and economic constraints.

The potential volume of water that could be added by each method varies (Table 2) based on both technology and the principle of increasing marginal cost. That is, there becomes a point where option A's MC becomes higher than option B's MC (that is, the switch point). Marginal cost (MC) also varies across space and over time for each option. The following plan considers the MC of each supply-augmentation option to assist decisions makers to prioritize choices. Furthermore, precise economic analysis involving AFC, ATC and AVC; technical analysis, and socio-political assessments will be necessary as plan components are implemented over time.

Assuming a perfect market where Price (P) = Marginal Cost (MC); the costs of water-supply augmentation options are adjusted to 2008 (Table 2). Desalination was the lowest marginal cost option to reduce water scarcity. Total water supply in 2010 was about 300 MCM from all sources. By 2030, the total water supply could feasibly be increased by about 630 MCM in the FC (Figure 2).

Conclusion

With continuing world population growth and a widening gap between water supply and demand, supply-augmentation options, such as water importation,

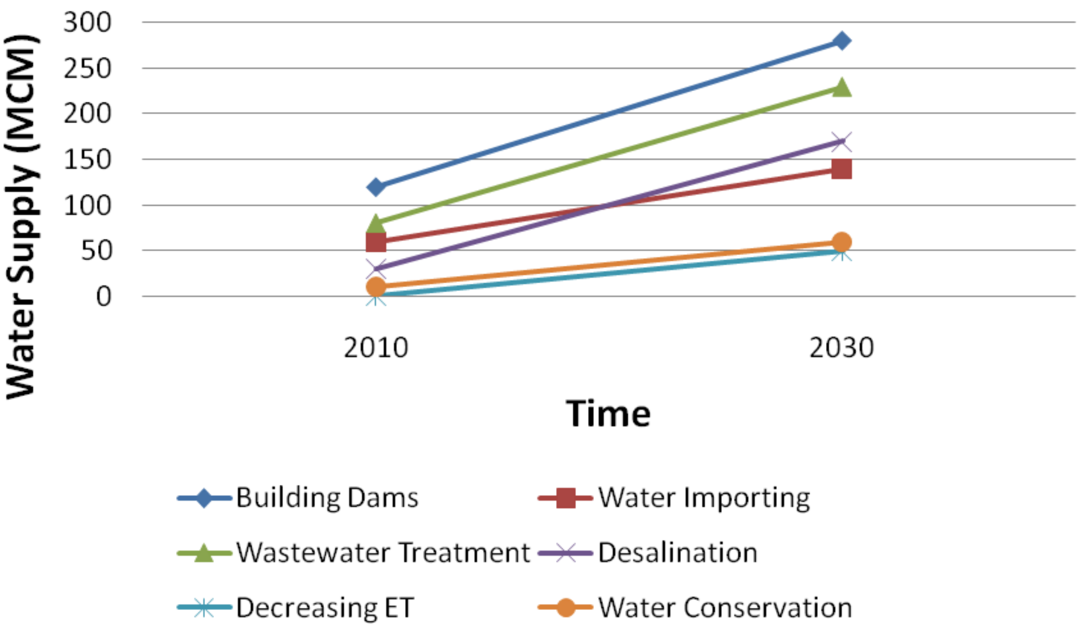

Figure 2. Water-supply augmentation amounts (MCM) from six options over time (2010 and 2030) in the FC countries.

wastewater treatment, desalination of brackish water and seawater, water storage in dams and water conservation will be implemented to help address water-scarcity worldwide.

Brackish desalination, reducing evapotranspiration and water conservation are least costly, at the margin, at this time in the FC. FC countries may need to cooperate to overcome water shortages. Supply-augmentation options require transboundary support and regional cooperation. Policy-makers might start using supply-augmentation options efficiently not only to overcome water shortages, but also to resolve long-standing political conflicts and to invigorate economic growth and promote stability in the region.

The development of options with high capital investments is further limited by environmental and ecological impacts along with public awareness. The FC countries currently lack resources and face technological issues to implement most of supply-augmentation options.

Dams and water importation systems are examples of supply-augmentation options limited by high cost and other political and economic constraints. An efficient mix of water-supply augmentation options will eventually likely be adopted. Most of the literature showed that the major mission given to the engineers was to evaluate the effectiveness and efficacy of various options. The assessment of supply-augmentation options would help extend the process of identifying packages of implementation options and help proceed with the plan.

A comprehensive approach is needed. A broad strategy can highlight the need for improving and managing the available water resources and for finding new water-supply options. This broad, general approach is the necessary groundwork for a more detailed strategic plan that could feasibly add as much as 630 MCM over the next two decades, helping solve the water-scarcity problem while considering sustainability and water quality for present and future uses.

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