Published online ahead of print August 24, 2012

Interfaces
Articles in Advance, pp. 1–16
ISSN 0092-2102 (print) | ISSN 1526-551X (online)

informs
http://dx.doi.org/10.1287/inte.1110.0622

Optimization of Water Resources Planning for Jordan's Aqaba Special Economic Zone

Abdelghani A. Elimam
Mechanical Engineering Department, American University, Cairo 11835, Egypt, aelimam@aucegypt.edu

Maurice A. Girgis
LTC Techno-Economics Research Group, Inc., Raleigh, North Carolina 27617, mauricegirgis@gmail.com

In this paper, we discuss the development of a water resources planning decision support system (DSS) for Jordan's Aqaba Special Economic Zone (ASEZ). Our objectives are to conserve fresh water supplies and minimize overall water production and delivery costs. Aqaba currently relies entirely on fresh water pumped out of the Disi aquifer, 63 kilometers away. We used water consumption patterns, demographic projections, planned investments, and water demands to forecast water demand. We also identified existing and potential water sources, including the potable Disi water, desalinated Red Sea water, and treated wastewater. The DSS includes a mixed-integer programming model that considers demand and system component capacity limitations on production, storage, treatment, and transportation. The DSS optimal plan involves increasing wastewater treatment capacity, expanding 8.5 kilometers of the Disi aquifer-ASEZ pipeline, and constructing a 7.5-million cubic meter (MCM) reverse osmosis desalination plant. The ASEZ adopted our recommendations, built the pipeline expansion, and issued a request for proposal to construct the desalination plant and build a 4.4-MCM wastewater treatment plant. In addition to improving the reliability of fresh water supplies, the cost savings exceed US $7.74 million in capital investments and US $0.661 million in annual operating costs, bringing the net present value of savings over 15 years to about US $12.77 million.

Key words: capacity expansion; integer programming; networks; decision support systems.
History: This paper was refereed. Published online in *Articles in Advance*.

Aqaba, a coastal town in the south of Jordan (see Figure 1), is the capital of the Aqaba Governorate, which was converted into the Aqaba Special Economic Zone (ASEZ) in 2001. Aqaba is strategically important to Jordan because it is the country's only seaport. The growing infrastructure and capital development led to an increase in the demand for water, without which the ASEZ cannot realize its full economic growth potential.

Realizing that water is an asset that must be efficiently and effectively managed, the ASEZ Authority (ASEZA), in partnership with the Ministry of Water and Irrigation (MWI), established the Aqaba Water Company (AWC) as a for-profit entity. Since its launch in 2004, AWC has completed studies to assess the availability of water resources in the ASEZ, which occupies 5 percent of the Governorate of Aqaba but has 80 percent of its population. Because of the fast pace of investment inflows in response to creating the zone, projecting future water demand has been challenging. Moreover, because of the long gestation periods of water projects, ASEZA was eager to forecast the demand for water. Therefore, it initiated a project to (1) identify the least-cost water resources allocation plan for the ASEZ, (2) reduce reliance on fresh water supplies from the Disi aquifer, and (3) develop a decision support system (DSS) for water resource planning. In this project, we developed and applied a DSS, which we based on a mixed-integer program (MIP), designed for water resource planning in the ASEZ.

Water resource planning has been addressed extensively in the literature. Goeller et al. (1985) developed an integrated system that contains 50 models for planning water resources in the Netherlands. The system was used to develop new national water policies, which led to hundreds of millions of dollars in savings. Miloradov (1992) reported on the

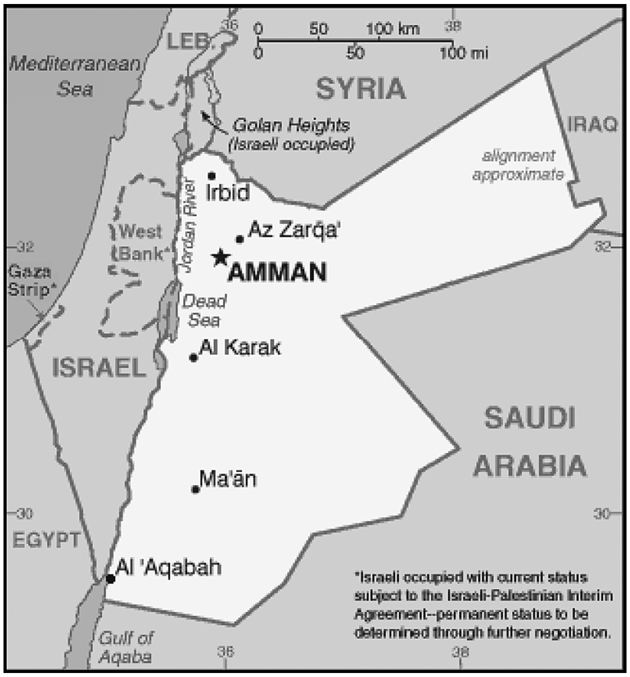

Figure 1: The map shows the location of Aqaba, Jordan.
Source. **http://upload.wikimedia.org/wikipedia/commons/b/bc/Aqaba_location.png.**

planning and management of water resource systems in developing countries. Al Alawi and Abdulrazzak (1994) identified water problems and provided perspectives for future developments in the Arabian Peninsula. Al-Tukhais (1997) discussed the status quo and the future of water resource usage and its impact on agricultural production in Saudi Arabia. Brimberg et al. (1995) reported on a zero-one MIP model for the optimal development of marginal water resources in Israel's Negev Desert. The model integrated the decision-making process at the regional and local levels. Quazi (2001) presented a strategic water resource planning framework for Bangladesh by solving a dynamic cost minimization model to compute the optimal investment needed in various water projects. He developed the minimum-cost solution, while considering the macroeconomic linkages of agriculture leading to different policy implications for optimal water planning. Bouhia (2001) discussed water in the macroeconomy and the integration of economics and engineering aspects into an analytical model in Morocco. Fisher et al. (2005) presented an economic approach for water management. Dawoud (2006) discussed the role of desalination in augmenting the water supply in the Gulf Cooperation Council countries, and attributed the shift in attention to the role of desalination in alleviating water shortages to the growing demand and to the reduction in desalination cost. Dawoud also suggested increasing investment in research and development to improve design and operations and reduce costs. Borowski and Hare (2007) presented the results of a two-year study, which the European Union funded, to identify the causes of the limited use of water management tools despite considerable investments in applied research in this area. They attributed the gap between water managers and researchers to a mutual misunderstanding of the functions of both communities. Such misunderstandings seem to revolve around these issues: the role and importance of model-based tools in water management; the transferability of models to new locations; the role of modeling in water management; the lack of confidence in model-based tools; the lack of simple system-user interfaces; and deficiency of model integration. The authors made several recommendations to minimize these misunderstandings and improve the utility of water resources planning models. Wu et al. (2009) illustrated the use of the generalized algebraic modeling system for water resource allocation in a Chinese province by optimizing the design of a water supply reservoir, pressure pipes, and related costs. Rosenberg and Lund (2009) used stochastic mixed-integer optimization to identify a portfolio of long-term and short-term supply and conservation actions for a municipal water system to cost-effectively accommodate a distribution of water shortages in Amman, Jordan. A detailed example for Amman considers 23 potential actions to conserve water and reduce leakage.

Our work is unique in that it deals with the major real-life characteristics of a water system and covers all possible water sources, including aquifers, desalination, treated or recycled water, pipelines, and storage tanks. Our DSS provides a tool that is flexible enough to generate any water system configuration needed to meet future demand or operate the existing water system. In addition to the usual capacity and demand constraints, the model considers establishing new facilities, expanding existing facilities, blending water qualities, recycling and treating wastewater, and sizing the pipelines required for water transportation among all producers or users.

This paper presents the results of the Aqaba water resources planning project and its impact on the ASEZ. Elimam et al. (2007) provide the details of the project. We organized this paper into the following sections. The *Demand for Water in the ASEZ* and *Water Supplies* sections summarize the status quo, including water consumption patterns, current supplies of water, and potential new supplies. *The Supply-Demand Gap*: *Projections Until* 2020 identifies the gap between supply and demand. *Water Resources Planning System* introduces the water resource planning system, including the basic structure and the optimization model and its DSS, and discusses the recommended plan of action. We discuss the results of our work in *Impact of Work* and finish with *Concluding Remarks*. The appendix describes the MIP model.

Demand for Water in the ASEZ

Water demand projections vary widely because of uncertainties and diversity in future investments. Moreover, population growth is problematic in Aqaba because of the anticipated rise in labor migration from within and outside Jordan.

Current Situation

Currently, the zone secures its fresh water supplies from the nonrenewable Disi aquifer. The MWI has limited withdrawal to a volume of 17.5 million cubic meters (MCM) per year, with the potential of reaching 20 MCM per year over a two-year period. Based on current demand and the MWI limit, an urgent need to introduce alternative water sources will exist unless this limit is lifted

In 2005, AWC completed the expansion and upgrade of the secondary treatment plant to provide tertiary-quality water (Dewiri 2007). In 2006, the Jordan Phosphate Mining Company (JPMC) substituted 2 of the 3.5 MCM per year of fresh water demand by tertiary-quality water. Based on current demand, a wastewater generation of approximately 3.8 MCM per year could be either tertiary or secondary treated. Currently, about 60 percent is treated to the tertiary level and the rest is processed through secondary treatment. Six principal sectors, including a sector within which water is unaccounted for (UFW), currently account for the total water consumed (see Table 1); however, four sectors represent about 98 percent of the total consumption. The industrial sector is the largest in terms of consumption, followed by the UFW, commercial and government, and finally residential use. Tourism represents approximately two percent; however, we expect that significant future growth will increase the demand for water in this expanding sector.

User (sector)	Consumption (MCM/yr)	Percent of total (%)
Residential	2.82	19.2
Commercial and govt.	2.68	18.3
Industrial	4.72	32.3
Local irrigation	0.02	0.1
Tourism	0.29	2.0
Unaccounted (UFW)	4.15	28.3
Total	14.68	100.0

Table 1: The table shows the pattern of water consumption in the ASEZ in 2005.
***Source*. AWC 2005 annual report (Aqaba Water Company 2005).**

Seasonality in Water Consumption

As Figure 2 shows, total water consumption in 2005 demonstrated a seasonal pattern. The Disi pipeline operates at its peak during June, July, and August; the winter months show much lower usage. It peaks at 19.43 MCM on an annualized basis. Because of this seasonality, the need to build up storage capacity to

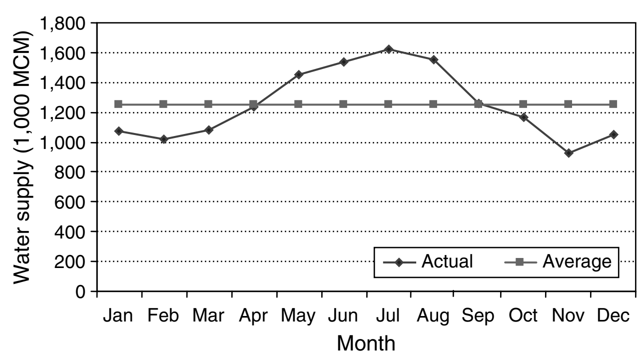

Figure 2: The graph shows the seasonal variation in water supply to the ASEZ in 2005.

Sector	2005*	2006*	2007	2010	2014	2018	2020	% Annual growth
Industrial	2.72	3.41	4.11	6.19	9.93	12.06	12.85	16.4
Residential	2.89	2.97	3.04	3.27	3.61	3.99	5.16	2.9
Commercial	2.72	2.85	3.21	3.83	4.12	4.43	4.60	3.3
Tourism	0.35	0.43	0.38	0.67	1.37	2.00	2.50	42.9
Agricultural	0.02	0.03	0.03	0.03	0.04	0.04	0.04	2.6
Unaccounted (UFW)	3.90	3.67	3.45	3.91	5.07	5.83	6.14	6.0
Total	12.61	13.36	14.22	17.89	24.14	28.36	30.32	8.7

Table 2: The table shows the fresh water demand forecast (MCM per year) from 2007 to 2020.
Source. **Fernandez (2007). Note that we also included the actual demand for 2005 and 2006. *Actual.**

help smooth supplies and improve the system's operational efficiency is apparent.

Demand Forecasting

Forecasting the demand in the ASEZ is challenging; many caveats and unknowns, specifically those listed below, could cast doubt on the accuracy of the results.

1. Water demand arising from planned investments that cover a wide range of projects (e.g., hotels, logistical facilities, golf courses, water parks, industrial plants, and commercial projects) is difficult to anticipate; in our situation, many of these projects were in their early development stages and had varied requirements.
2. Investors tend to inflate their future water needs.
3. Planned investments are often expanded, modified, delayed, or never materialize.
4. An unprecedented growth in investment activities is certain to increase migratory trends into Aqaba.

We relied on the demographic projections provided by the Aqaba Zone Economic Mobilization (AZEM), a USAID-funded project, and Jordan's National Department of Statistics, to project residential demand until 2020. The forecasting difficulties were instrumental in our decision to expand the project scope to develop a water resources planning DSS that would provide ASEZA with a permanent and flexible planning tool to accommodate future demand fluctuations. From the forecasts in Table 2, we can derive the following.

1. Future projects indicate that the total demand for fresh water could double from 2007 to 2020.
2. The industrial sector is expected to be the largest fresh water user by 2020 (42.4 percent).

In addition, we can observe that (1) new resorts and hotels are expected to fuel the largest growth for fresh water demand in tourism, (2) per capita water consumption is expected to show a slight increase over time, and (3) percent leakage is expected to decrease because of the planned pipeline network engineering enhancements and improved billing and collection efforts by AWC.

As Table 3 shows, the industrial sector is expected to be the largest consumer of tertiary water with tourism (landscaping) as the second largest. Because of the lower unit cost of tertiary water, it will replace the fresh water supply.

Sector	2005*	2006*	2007	2010	2014	2018	2020	% Annual growth
South industrial site	2	2	2.08	2.21	2.39	2.59	2.69	2.26
Industrial zone	0.20	0.20	0.75	2.10	3.07	4.50	5.45	47.87
Tourism in the city	0.20	0.20	0.20	1.05	1.28	1.55	1.71	58.09
South beach tourism	0.05	0.05	0.05	1.40	1.40	1.40	1.40	211.53
Landscape irrigation	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.00
Total recycled	2.65	2.65	3.28	6.96	8.34	10.24	11.45	19.12

Table 3: The table shows tertiary water demand projections (MCM per year) from 2007 to 2020.
Source. **Fernandez (2007). Note that we also included the actual demand for 2005 and 2006. *Actual.**

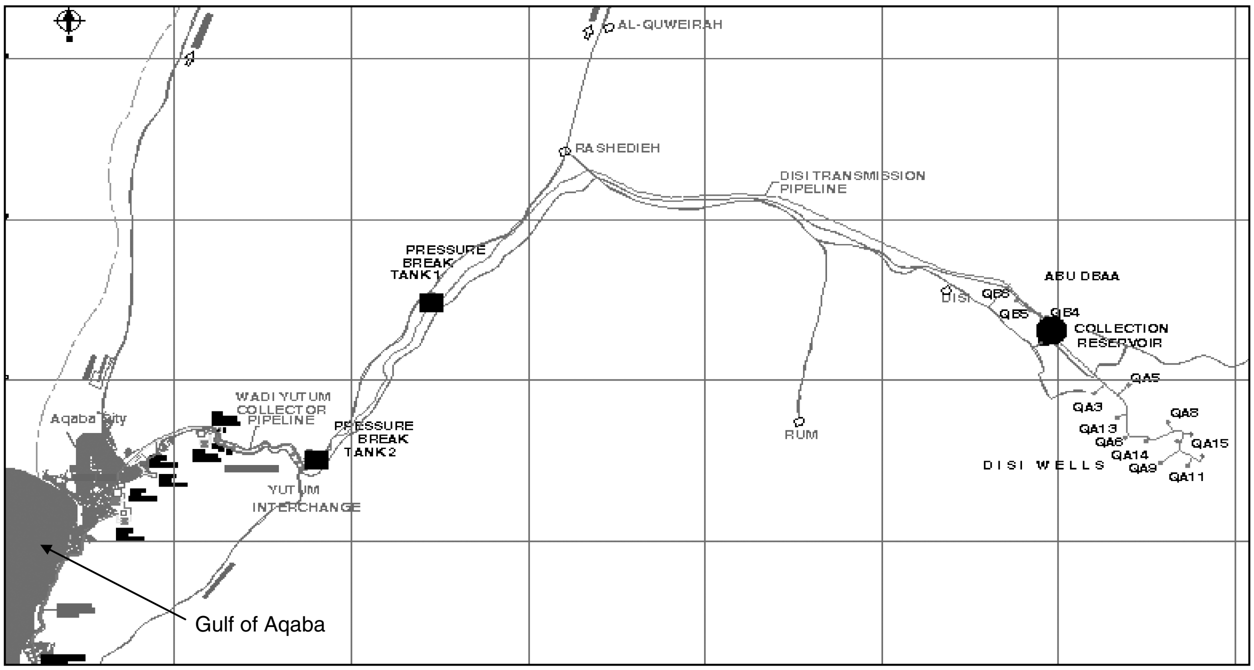

Figure 3: The map shows the location of the ASEZ in relation to the existing wells.
Source. **Dewiri (2007).**

Water Supplies

Current Water Supplies

Current water supplies include fresh water from the Disi aquifer and treated water used for landscaping for JPMC (see Figure 3).

Disi supplies the ASEZ with fresh water through a pipeline that has a capacity of about 19.5 MCM per year and a regulated capacity of 17.5 MCM per year. AWC pays the MWI 0.25 Jordan dinar (JD) per cubic meter (m^3) (\$1 US = JD 0.70) supplied to the ASEZ. The cost of Disi water includes depreciation, labor, maintenance, electricity, and water. In 2005, the unit cost of Disi supply to the ASEZ was 0.353 JD per m^3 (about \$0.50), which is the sum of the extraction (including the royalty paid to the government) and transportation costs—0.307 JD per m^3 and 0.046 JD per m^3, respectively.

In September 2005, the new wastewater treatment plant started operations to treat water for landscaping and industrial use for JPMC. According to AWC, the average daily wastewater generated in the ASEZ is approximately 10,800 m^3. Table 4 summarizes the technical specifications and the operating conditions of the tertiary wastewater treatment. The average resulting volume of 6,108 m^3 per day supplies JPMC with 2 MCM per year of tertiary-treated quality effluent at 0.7 JD per m^3 instead of the equal amount of fresh Disi water that JPMC previously bought from AWC at JD 1.4 per m^3 (including delivery and collection of wastewater). The cost of the reclaimed wastewater is 0.209 JD per m^3. Secondary-treated water is used in date-tree farms as agricultural reclaimed water (ARW). Subsequent to building the new tertiary treatment plant, AWC fed about 40 percent of effluent into the plant, which has an effluent capacity of 9,000 m^3 per day and produces water of a quality suitable for agriculture and landscaping. The effluent production rate is 1,380 m^3per day. The unit cost of producing ARW effluent is approximately 0.07 JD per m^3.

Potential New Water Supplies

Several studies identified new water supplies (Chemonics International 2005). Our analysis focused on verifying these sources and updating their cost estimates. Table 5 shows the four major categories into which we can group new water supplies.

Treatment factors	Tertiary	Secondary
Output (wastewater) input (fresh water) ratio	0.85	0.85
Ratio of effluent volume to influent	0.96	0.59
Maximum effluent capacity, m^3/day	12,000	9,000
Current effluent production, m^3/day	6,108	1,380

Table 4: The table shows wastewater treatment operating conditions.

Fresh groundwater sources include the following.

• New Disi aquifer-Aqaba pipeline: Recently, the MWI agreed to increase Aqaba's water allocation up to 35 MCM per year. Accordingly, AWC has tendered the design and construction document to build a parallel pipeline that would transport this amount. The project was divided into three phases. The first phase was completed in 2008. Based on the plans supplied by AWC, Phase I would increase the capacity by about 3MCM per year at a cost of about JD 3.57 million. Phases II and III would allow the pipeline to carry the full 35 MCM per year for an additional JD 19.43 million.

• Rehabilitated Wadi Yutum: Chemonics International (2005) suggested this potential water resource, which it expected to augment water supplies by at least 2.5 MCM per year. The expected unit cost of amortized capital investment and operation is approximately 0.26 JD per m^3.

• Exploration of brackish water at Wadi Araba (see Table 6).

The RO desalination option considers the installation of an RO desalination plant in the south and possibly a plant in the north, as needed. Water desalination using RO is becoming attractive, as evidenced by its widespread use, particularly in arid areas such as Saudi Arabia, Kuwait, Algeria, Israel, and Gaza. The following three factors could make estimating the capital cost of an RO desalination plant challenging.

	Capacity (MCM/year)		
Costs (JD/m^3)	2.0	5.0	7.5
Capital	0.31	0.24	0.23
Operations and maintenance	0.63	0.63	0.63
Total	0.94	0.87	0.86

Table 6: The table shows the unit costs of upgrading Wadi Araba at three capacity levels.

• Some elements of the capital cost depend on the plant's location; hence, capital costs cannot be accurately estimated in Aqaba without a complete feasibility study.

• Most of the reported RO desalination experiences deal with larger plant capacities, and at a much earlier time than we consider in this study. Nonlinearity of the cost function makes deriving a reliable cost estimate of downsized plants difficult.

• The bulk of desalination research points to the expected improvements in RO plants, leading to the continuous reduction in capital and operating costs.

We based the capital and operating costs of desalination plants on an extensive literature search, reported experiences with recently built RO plants in similar conditions, and the input of a major desalination plant manufacturer. The list of sources includes Sommariva (2004), Hee Kiang and Yong (2004), Glueckstern (2001), Bravo (2004), W. Harvey (pers. comm.), Medina (2004), Al-Jamal and Shoblak (2004), and Dreizin (2006). Glueckstern estimated that

Water category	New sources	Updated capacity (MCM/year)	Water type
Fresh groundwater	New Disi pipeline	35	Fresh
	Wadi Yutum rehabilitation	2.5–5	Blending, fresh
	Wadi Araba brackish nanofiltration	7.5	Desalinated, fresh
RO desalination	Seawater RO in south	5–15	Desalinated, fresh
Secondary wastewater	Upgrade secondary wastewater to tertiary treatment with the same capacity	3.28	Reclaimed
Tertiary wastewater	Expand tertiary treatment in two stages: Stage 1—to 18,000 m^3/day and Stage 2—to 24,000 m^3/day	Stage 1: 2.1 Stage 2: 2.1	Reclaimed

Table 5: The table shows potential new water sources in the ASEZ.

Tertiary treatment capacity		Capital cost (million JD)
m^3/day	MCM/year	
6,000	2.2	5.0
12,000	4.4	7.0

Table 7: Earlier estimates for tertiary treatment plants capital costs were given as JD 7 and JD 12 million for capacities of 2.2 and 4.4 MCM per year, respectively. However, AWC supplied data showing that technology improvements lowered these capital costs to JD 5 and JD 7, respectively.

the capital cost of desalination would fall from a range of \$3.0–3.5 per m^3 per year in 1998 to \$2.3–2.8 in 2005, a decline of about \$0.5 per m^3 per year in seven years. According to such expectations, a 5-MCM per-year plant capacity in the ASEZ would cost approximately \$12.75 million (\$2.55 × 5 MCM per year), which is equivalent to approximately JD 9.1 million. Likewise, a 7.5 MCM per-year RO plant would cost approximately JD 13.7 million. In the optimization model, we considered RO desalination plants ranging in capacity from 5 to 10 MCM per year, with an expected operations and maintenance (O&M) cost of about JD 0.26 per m^3. Energy costs would represent the major portion of this O&M cost (Del Castillo 2004, Chaudhry 2003).

The secondary wastewater option (i.e., the third category) includes upgrading or expanding the tertiary wastewater treatment capacity. Because of the substitutability of treated wastewater for fresh water supplies and the expected increase in water use, the tertiary wastewater option (i.e., the fourth category) introduces additional tertiary treatment capabilities to both treat more wastewater and to produce higher-quality effluents. By mixing (blending) brackish groundwater with fresh Disi water, water from Wadi Yutum or Wadi Araba can be used.

Table 7 illustrates tertiary treatment data.

The Supply-Demand Gap: Projections Until 2020

Based on the preceding analysis, we present demand and supply projections of fresh water from 2007 until 2020; our objective is to determine the year of equilibrium—the year at which demand will equal current supply. Assuming that no additional capacity is installed and made available beyond this time, we estimate the magnitudes of the expected water shortages.

Based on Figure 4, we note the following.

• The point of equilibrium at which fresh water demand meets the available supply is at 2012. Our analysis shows that AWC had sufficient time between 2006 and 2012 to develop long-term strategies, draw up annual plans, commission feasibility studies,

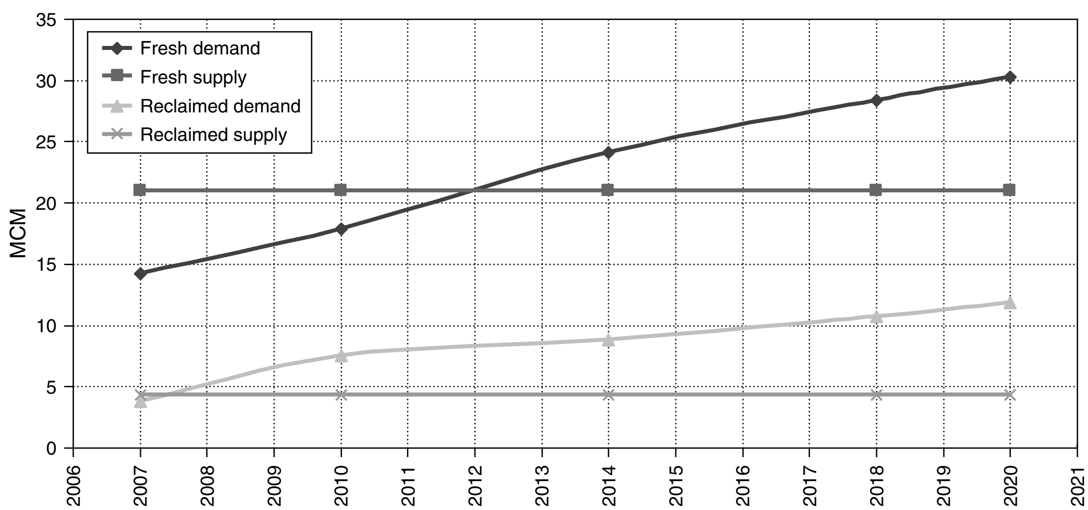

Figure 4: The graph illustrates the supply-demand gap for fresh and recycled water.

and construct new water supply augmentation facilities.

• Beyond 2012, water supply must rise gradually, reaching 30 MCG per year in 2020, including all types of water qualities.

• Demand for tertiary water exceeded the existing recycled water treatment capacities starting in late 2007.

AWC is well advised to build tertiary treatment wastewater plants immediately to dispose of residential effluent in an environmentally friendly manner, reduce the pressure on the demand for fresh water, and enhance customer satisfaction by providing lower-cost reclaimed water in place of the more expensive fresh water. However, the fresh water situation is different. Although the total quantity demanded is known, the numerous permutations that exist would lead to the same result using different water-quality categories. We could select one or more of these four options: rehabilitating Wadi Yutum, developing Wadi Araba, expanding the pipeline capacity from Disi to the ASEZ, or building new RO desalination plant(s).

Water Resources Planning System

In this section, we discuss the model's basic concepts and structure and explain, albeit briefly, the DSS we used to implement the MIP model (see the appendix).

Basic Concepts

The Aqaba Water Resources System (AWRS) (see Figure 5) includes the following elements.

1. Pure source nodes: Underground water supplies from Disi, Wadi Araba, and Wadi Yutum represent the existing pure source nodes (nodes 1, 2, and 3). Moreover, the model considers building an RO plant as a potential new source (node 4).

2. Pure sink nodes: Users who consume but do not recycle any water represent the pure sink nodes (nodes 9 and 10—industrial and irrigation).

3. Source-and-sink nodes: These nodes represent users who receive water from selected nodes and send it to other nodes in the system. These nodes include (1) all users, except industrial, agriculture, and landscaping users, and (2) AWC and wastewater treatment facilities. For example, AWC would receive water from Disi, treat it, and send it to residential,

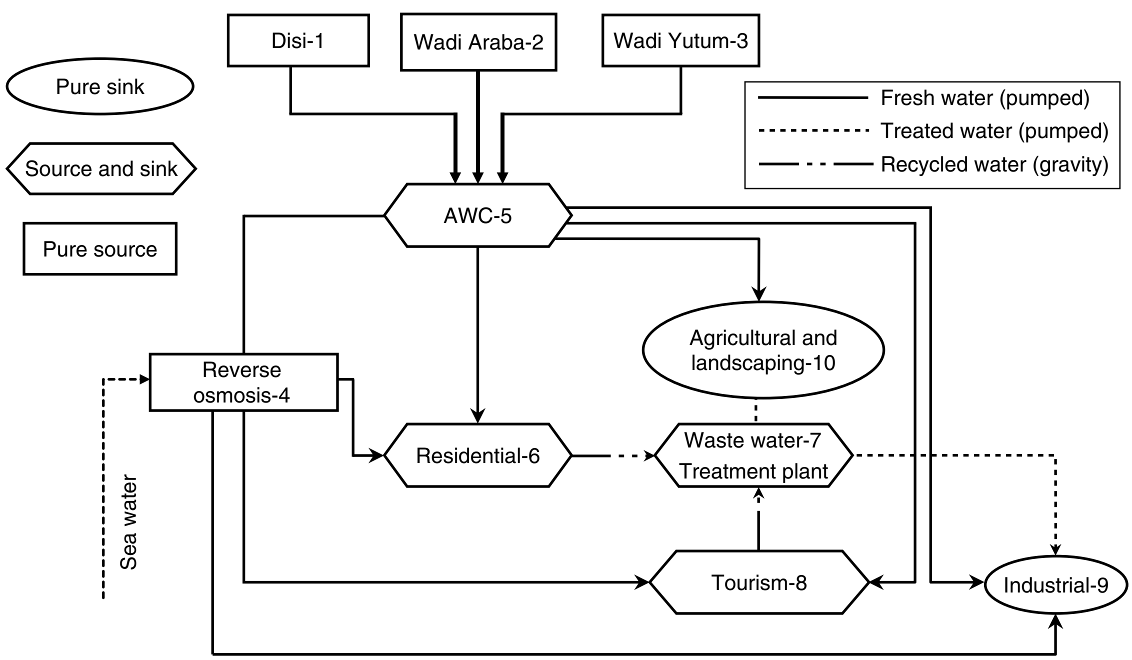

Figure 5: The schematic shows a flow diagram of the Aqaba water network.

industrial, governmental, tourism, and agricultural users. Part of this water flows again to the wastewater treatment plant, where it is recycled (nodes 5, 6, 7, and 8).

4. Pipelines: First, a pressure-pipe network transports water from pure source nodes to AWC facilities and from AWC to various users. This network also transports the wastewater from its treatment facility to the treated wastewater users. Second, a gravity-pipe network carries the wastewater from its generators to its treatment facility.

All existing sources in the system are characterized by their names, locations, production and storage capacities, and the quality of water used. The associated production and transportation costs are also required. In addition, the model allows the introduction of new facilities—whether water production plants or pipelines. The model also allows the user to assess the expansion of existing facilities by including the proposed capacity of the expanded facility, the capital cost of constructing the addition, and the lead time from construction to full operation.

We designed the model to run in two modes—a strategic policy-driven mode or operational mode. In policy-driven mode, the user runs the system annually for demands and capacities without regard to detailed monthly operations, and is interested in selecting the most attractive investments in new facilities to fulfill current and future water demand. The model allows the water planner to explore expanding existing water treatment, production, or building facilities. The system also allows the user to add large central RO facilities or satellite RO stations dedicated to specific major water users. Moreover, the model provides the water analyst with full flexibility to add new users. In operational mode, the system uses monthly demand and capacities, taking into account seasonal variations, to provide the minimum-cost allocations of existing water resources to satisfy user demand. In either mode, the system attempts to minimize the present value of the total cost, including capital, production, storage, and transportation costs.

Conceptual Model

We designed the planning system (see Figure 6) to use the existing or potential water supplies to meet consumer demands at minimum cost.

The DSS output includes the minimum-cost water resources plan, the size and timing of capacity expansions in new water sources, the amount of water produced, treated, or stored by each source, and the allocation of water to major users.

The model consists of a cost-minimization objective function and several linear constraints. The objective function minimizes the sum of the present value of the capital costs of investing in new water production, treatment, or storage facilities, building new pipelines, and the costs of O&M water production, treatment, storage, and transportation. The model includes constraints on demand for water by quantity and quality, capacity of water supplies, blending for matching quality, and water balance. The appendix shows the mathematical model.

Decision Support System (DSS)

The DSS (see Figure 7) includes the following elements.

Input interface: Two major input screens specify the water users and the sources available to satisfy their demand for water.

Data processor: The input data are preprocessed to prepare the cost and constraints coefficients used in the model.

Model builder: This module generates the cost-minimization objective function and the constraints, including capacity limitations on water production and treatment, pipelines, storage, demand, and balance of flow among various nodes of the system.

Premium SOLVER optimizer: We opted to use the professional version of the Premium SOLVER platform, which was affordable and interfaced well with Microsoft.NET.

Crystal report engine: We use this software to generate a variety of annual or monthly reports on production values, flow of water from source to user, user-to-source, and source-to-source requirements, and capacity expansion requirements.

Computational Work

The project team used the data in Tables 2–7 to generate the Aqaba water network (see Figure 5) and ran the DSS in strategic mode using 15 years—from 2006 to 2020. The resulting MIP included 600 $(0, 1)$ variables, 1,320 nonnegative variables, and 1,800

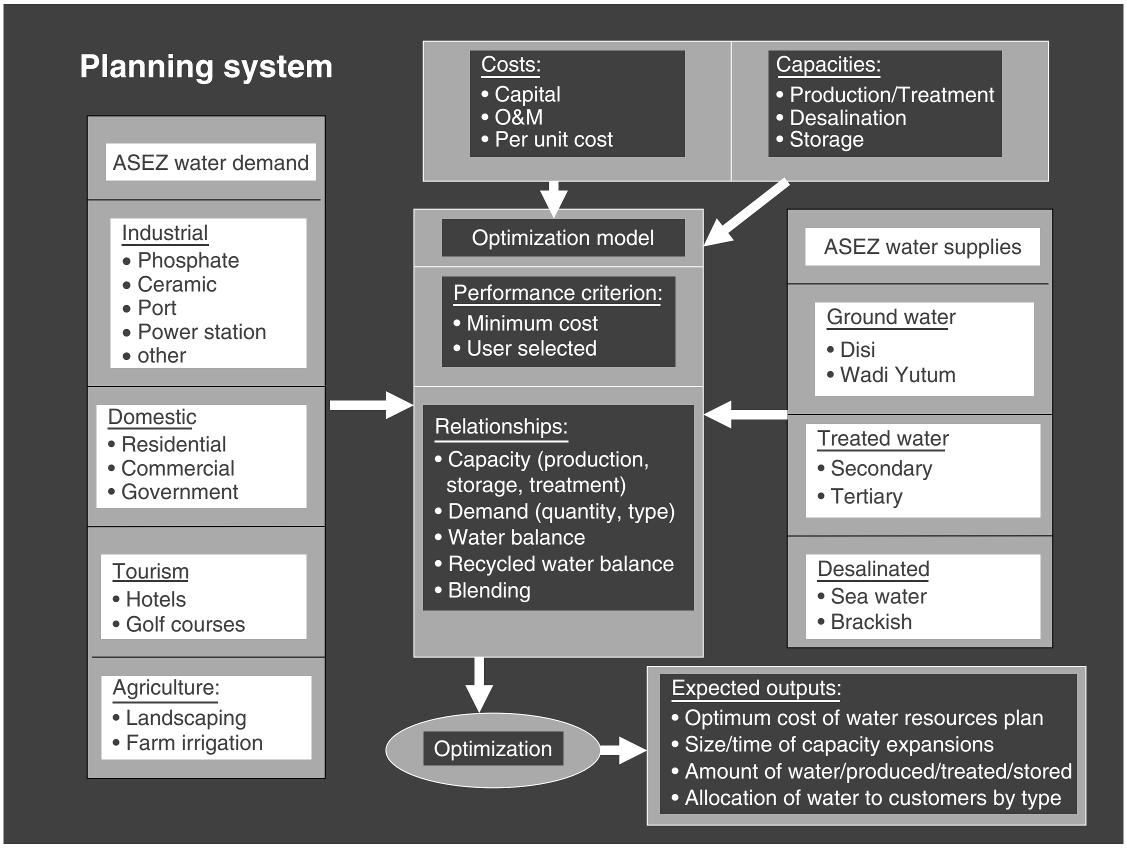

Figure 6: The flowchart shows an overview of the water resources planning system for the ASEZ.

constraints. We optimized the DSS using an Intel Core 2 Duo 2.4 GHz personal computer. All cases were solved in less than 1.4 CPU minutes. In operational mode, all $(0, 1)$ variables and constraint sets (6) and (7) on capacity updates (see the appendix) are excluded, thus leading to a pure linear programming formulation.

Table 8 summarizes the findings of the optimization model in light of the cost and capacity estimates

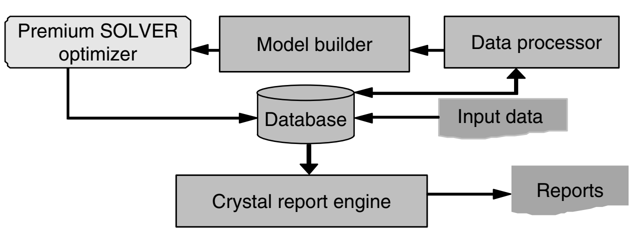

Figure 7: The flowchart shows the ASEZ water resources planning DSS.

made available by our team and AWC during January 2007. The table shows the required start production dates, annual production volume, and total capital costs using our project team estimates. Note that we assumed that all projects require a one-year lead time for completion. For example, if a project is scheduled to start producing water in 2010, its construction must start in 2009. Our demand projections were used throughout because AWC's projections were based on a tenuous, fixed extrapolation of 0.8 MCM annual increases, regardless of the well-known dynamic changes in the ASEZ. We developed three demand projection scenarios—basic, high growth, and low growth. The high-growth demand scenario assumed that all planned tourism and industrial enterprises would materialize. The low-growth demand scenario considered moderate growth only in the residential consumption because of conservative estimates of population increases in the ASEZ. We developed

Water type	Source option	Production		Capital cost, (million JD)
		Start date	Quantity (MCM/year)	
Using AWC estimates, including Wadi Yutum (5 MCM)				
Fresh	Wadi Yutum	2010	5.0	5.47
	Disi expansion I	2015	5.0	7.92
Total fresh water investment			10.0	13.39
Using AWC estimates, excluding Wadi Yutum				
Fresh	Disi expansion I	2012	5.0	7.92
	RO in the south	2015	5.0	12.00
Total fresh water investment			10.0	19.92
Using AZEM estimates, including Wadi Yutum (2.5 MCM)				
Fresh	Wadi Yutum	2010	2.5	3.47
	RO in the south	2013	7.5	14.20
Total fresh water investment			10.0	17.67
Using AZEM estimates, excluding Wadi Yutum				
Fresh	Disi expansion I	2012	3.0	3.98
	RO in the south	2014	7.5	14.20
Total fresh water			10.5	18.18
Tertiary water facilities using AWC or AZEM estimates				
Tertiary	Expansion I:	2010	4.4	7.00
	Expansion II:	2018	4.4	7.00
Total tertiary water			8.8	14.00

Table 8: The table shows optimal water resources investment options in the ASEZ.

the recommended plan assuming the basic scenario. However, we used sensitivity analysis to explore the impact of demand variation on the selected plan.

The optimum water resources plan includes Wadi Yutum and a 7.5 MCM RO desalination plant in the south. If we exclude Wadi Yutum, the solution consists of Phase I of the Disi pipeline expansion plus a 7.5 MCM RO plant in the south.

Sensitivity Analysis

The project team realized that several changes in input data would have a profound impact on the recommended plan. The team made several runs to alleviate the concerns of the ASEZ and AWC regarding the validity of our recommendations. Our analysis concentrated on exploring the impact of changes in the capital cost of constructing the RO plant and the Disi pipeline expansion and the variation in demand for fresh water. In these runs, we used a 10 percent discount rate, as ASEZA recommended, although the Central Bank of Jordan discount rate had varied between 6.5 and 7.50 percent over the preceding three years. However, after making several exploratory runs using these discount rates, we found that this rate did not affect the optimum water resources plant. The recommended plan of action is based on a 10 percent discount rate.

Impact of capital cost: AWC was surprised by our results, which recommended establishing an RO desalination plant as the most attractive source of fresh water. To convince the decision maker about the validity of the DSS results, we made other runs using AWC RO cost figures (see Table 8). Taking AWC's set of estimates as is, the least-cost options include rehabilitation of Wadi Yutum to produce an annual amount of 5 MCM and construction of Phase I of the Disi pipeline expansion (8.5 km).

However, when we eliminated Wadi Yutums, per AWC's request, the optimum water resources plan specified expanding the Disi pipeline in Phase I for 5 MCM and building a 7.5 MCM RO plant in the south.

Impact of demand levels: The project team repeated the same optimization runs for the high-demand and low-demand scenarios. The impact of such changes was only reflected on the timing of water production from each expanded or newly built water source. However, the DSS produced the same selections with altered dates. The low-demand scenario led to a delay of three years in constructing the Disi pipeline expansion and RO plant. However, the high-demand scenario optimization required that these projects be completed immediately.

Recommended Action Plan

The following results emerged from our water optimization model:

1. Phases II and III of the Disi pipeline expansion were not selected in any option, whether using AZEM or AWC data.

2. Wadi Yutum appears often in the results, thus indicating its economic feasibility. However, further exploratory engineering testing of the aquifer should be commissioned to ascertain its capacity and water quality.

3. Constructing an RO desalination plant in the south is a solid least-cost choice, even if the higher AWC capital cost estimates are used.

4. Phase I of the Disi pipeline expansion falls in the grey area because Wadi Yutum competes with it; however, it could be justified on the grounds that it would provide an emergency valve for the present pipeline network.

5. Tertiary expansion appears in all solutions. Therefore, it is not relevant in this comparative analysis.

To explain the rationale of the optimization model, we invited the decision maker at ASEZA to consider the capital and operating costs of the proposed Disi pipeline expansion versus the construction of an RO desalination plant. On the operating cost level, it currently costs about JD 0.35 per m^3 of Disi water (including JD 0.25 per m^3 for the royalty) supplied to Aqaba versus JD 0.26 per $m^3$of water produced by the RO plant in Aqaba. In terms of capital cost, the RO plant requires about JD 14.2 million for a 7.5 MCM, whereas the capital cost for Phases II and III of the Disi pipeline expansion was estimated to be about JD 19.43 million. However, we note that the capacity of these Disi pipeline expansions would increase the total transport capacity from Disi to about 35 MCM. Clearly, this excess capacity would not be useful until at least 2025.

In addition to the foregoing investment recommendations, the project team suggested that ASEZA take the following steps, which it classified into cost-and-demand data-related and system-related recommendations.

Cost-and-demand data-related recommendations:

1. Commission a detailed study seeking actual bids from potential suppliers of RO plants. The project team found that the capital cost estimates for the RO plant in Aqaba were controversial. Therefore, it had to do additional work to verify these cost estimates. The team used two studies (Chemonics International 2005, PUM Netherlands Senior Experts 2005) that had been conducted for AWC, and the team also sought actual cost figures from a major RO desalination plant supplier (W. Harvey, personal communication).

2. Update water demand estimates based on actual growth in the area. Although the project team made an extensive effort to estimate future demands on a project-by-project basis, we recommend that ASEZA update such demand figures annually.

3. Examine the issue of water pricing and subsidies in the ASEZ. AWC is currently charging customers more than the cost of fresh water produced by RO. Only AWC can produce and sell water in the ASEZ, making it difficult for investors to make full use of the potential competition that exits in a free market economy. AWC currently subsidizes users outside of Aqaba city and uses such subsidies to justify its pricing policy. We suggested that ASEZA make these subsidies transparent, compensate AWC for such subsidies, and then consider free market pricing strategies for water in the area.

Cost-and-demand system-related recommendations:

1. Train local engineers on using the DSS. The project team members spent a week in Aqaba training ASEZA engineers on the system's use.

2. Adopt the DSS as a strategic tool to help ASEZA select new water resources projects and as an operational tool to make monthly allocations among users while considering the seasonal variations in monthly demands.

Impact of Work

ASEZA has fully adopted the water resources plan recommended in this work and has proceeded with its implementation, with the following impacts.

1. ASEZA can identify water demand magnitude by type over the next 15 years.

2. The DSS can readily simulate water demand and supply imbalances under different development and demographic scenarios. This has enabled the AWC to identify the minimum-cost water production and delivery systems, thus leading to considerable savings in capital and operating costs for both AWC and its customers. For fresh water, the capital investment savings exceed JD 5.2 (US $7.74) million, and the operating costs decrease from JD 0.35 to JD 0.26 per m^3. The RO plant would initially provide 5 MCM per year, which would bring such savings to about JD 0.468 (about US $0.661) million per year. Based on a 10 percent discount rate, the net present value of these savings in operating costs will exceed US $5.03 million over the next 15 years. Thus, the net present value of savings over 15 years will be approximately US $12.77 million (7.74 million plus 5.03 million).

3. The proposed tertiary wastewater treatment plan would require the immediate expansion of the capacity of these facilities by 4.4 MCM in 2010, followed by another 4.4 MCM in 2018. In addition to the cost savings, this shift from fresh water to recycled water will help conserve scarce fresh water supplies to meet future demand.

4. The security and diversification of water sources represent a major concern for water resources planners in the ASEZ. Reliance on a single source of water, which is more than 63 km away from its place of consumption, introduces uncertainties to ASEZ future development. Investors in arid zones might question the reliability of such a distant water resource. In recent years, the ASEZ had no water for several days because of significant flash flooding, which caused an interruption of fresh water transportation from Disi to the ASEZ. The introduction of RO as a local source of fresh water would alleviate the major concerns of potential investors about the long-term availability of reliable fresh water supplies for their projects. Moreover, RO desalination provides a renewable source of fresh water, whereas the Disi aquifer provides a depletable supply. Without the availability of such a solution for water scarcity, potential investors will have little interest in new projects.

Concluding Remarks

The ASEZ water resources planning DSS demonstrated its ability to generate an investment plan for new water sources. In addition, the DSS can also be used for monthly operations. Because of the nature of the MIP model and its computational burden, we recommend limiting such operational runs to two to four years. The system is flexible in that it allows the user to introduce a variety of parameters to help in generating the most desirable water resources plan. It can also optimize over an extended planning horizon. To account for the time value of money, the system lets a user apply the prevailing discount rate to bring all costs to their present value. The DSS enables a user to specify any number of water consumers with their demand forecasts while introducing any number of water sources and their capacities, whether existing or proposed. Moreover, it allows a user to specify the pipelines connecting all water consumers to all suppliers, the distances among various water system elements, and the costs of capital, operations, transportation, and storage for water produced and consumed in the area. Because the optimization considers the quality of water produced or consumed in the area, the model is equally applicable to other parts of the world with similar water challenges.

Appendix. Mathematical Formulation

Input Parameters

NR Set of pure source nodes.
NK Set of pure sink nodes.
KR Set of nodes that can simultaneously be sources and sinks.
NB Set of customers accepting blended water.
N Set of all nodes in the water network, $N = NR \cup NK \cup KR$.
T Length of the planning horizon.
R Discount rate for time value of money (%).
$CC_{i(t-di)}$ Capital cost of adding production, treatment, or storage capacity to node i facility starting in period t, after d_i lead time (JD).
$CP_{ij[t-\delta ij]}$ Capital cost of constructing pipeline linking nodes i and j starting in period t, after δij lead time (JD/km).
DP_{ij} Distance from node i to node j (km).
CO_{it} Operations and maintenance cost of production or treatment of water at node i facility during period t (JD/m^3).
CS_{it} Storage cost at node i facility during period t (JD/m^3).
CT_{ijt} Cost of transporting one m^3 from node i to node j during period t (JD/km).
D_{it} Demand of customer in node i for water during period t (m^3).
PC_{ij} Existing pipeline capacity to transport water from node i to node j (m^3/period).
CE_{it} Existing production/treatment/storage capacity for node i during period t (m^3).
ICP_{it} Proposed production/treatment/storage capacity expansion node i facility in period t (m^3).
IPC_{ijt} Proposed (i, j) pipeline capacity expansion in period t (m^3).
P_j Quality level of water produced at node j.
q_j Required quality level of water at node j.
τ_j Recycling ratio of water leaving node j as a percentage of water flowing into this node.
β_j Amount of treated wastewater as a percentage of the input to node j treatment plant.

Decision Variables

$(0, 1)$ variables
$y_{i[t-di]}$ = 1 if capacity is added to node i for water production, treatment, or storage, constructed starting in period $(t - d_i)$;

= 0 otherwise.

$X_{ij[t-\delta ij]}$ = 1 if (i, j) pipeline is built in year $(t-\delta ij)$ to carry water starting in year t;
= 0 otherwise.

Noninteger Variables

WF_{ijt} Amount of water flowing from node i to node j during period t.

WP_{it} Amount of water processed (produced or treated) in node i during period t.

WS_{it} Storage level of water in node i by the end of period t.

NWP_{it} Updated production, treatment, or storage capacity at node i by the start of period t.

NWF_{ijt} Updated pipeline capacity from node i to node j by the start of period t.

Model Components

The objective function minimizes the sum of the present value of the capital costs of investing in new water production, treatment, or storage facilities and in building new pipelines in addition to the O&M water production, treatment, storage, and transportation costs. The objective function is mathematically represented as follows:

$$\text{Min} \sum_{t=0}^{T} \left[TCE_t + TCP_t + TPT_t + TCS_t + TCT_t \right], \qquad (1)$$

where

$$TCE_t = \sum_{i \in N} \frac{CC_{i[t-di]}}{(1+r)^{t-di}} \cdot y_{i[t-di]},$$

$$TCP_t = \sum_{i \in NR \cup KR} \sum_{j \in N,\, j \neq i} \frac{DP_{ij} \cdot CP_{ij[t-\delta_{ij}]}}{(1+r)^{t-\delta_{ij}}} X_{ij[t-\delta_{ij}]},$$

$$TPT_t = \sum_{i \in NR \cup KR} \frac{CO_{it}}{(1+r)^t} WP_{it},$$

$$TCS_t = \sum_{i \in NR \cup KR} \frac{CS_{it}}{(1+r)^t} WS_{it}, \quad \text{and}$$

$$TCT_t = \sum_{i \in NR \cup KR} \sum_{j \in KR \cup NK,\, j \neq i} \frac{DP_{ij} \cdot CT_{ijt}}{(1+r)^t} WF_{ijt},$$

subject to the following constraints.

Demand constraint

• The quantity of water supplied to each customer ≥ customers' water demand

$$\sum_{i \in NR \cup KR,\, i \neq j} WF_{ijt} \geq D_{jt} \quad \forall j \in KR \cup NK \quad \text{and } t = 1, \ldots, T. \qquad (2)$$

Blending constraint

• The quality of water supplied to a customer (expressed in water quality level) ≥ the required customer quality level. The summation over all types of water (percent of type 1 water ∗ quality parameter of type 1 water + percent of type 2 water ∗ quality parameter of type 2 water + ⋯ percent of type n water ∗ quality parameter of type n water) ≥ required water quality.

$$\sum_{i \in NR \cup KR} P_i \cdot WF_{ijt} \geq q_j \cdot WP_{jt} \quad \forall j \in NB,\ t = 1, \ldots, T. \qquad (3)$$

Capacity constraints

• Amount produced or treated of given water quality must be ≤ the production or treatment capacity for this water quality.

$$WP_{it} \leq NWP_{it} \quad \forall i \in NR \cup KR \text{ and } t = 1, \ldots, T. \qquad (4)$$

• Water flow from node i to node j ≤ capacity of pipeline from nodes i to node j.

$$WF_{ijt} \leq NWF_{ijt} \quad \forall i \in NR \cup KR,\ \forall j \in NK \cup KR,\ j \neq i \text{ and } t = 1, \ldots, T. \qquad (5)$$

Expand capacity or build a new facility

• Available capacity in a given period = the existing capacity + added capacity coming into production, treatment, or storage.

$$\begin{aligned} NWP_{i1} &= CE_{i1} \quad \forall i \in NR \cup KR, \\ NWP_{it} &= NWP_{i(t-1)} + ICP_{it} \cdot y_{i[t-di]} \\ &\qquad \forall i \in NR \cup KR \text{ and } t = 2, \ldots, T. \end{aligned} \qquad (6)$$

• Available pipeline capacity linking nodes i and j in period t = the existing (i, j) pipeline capacity + added capacity to pipeline (i, j) in period t.

$$\begin{aligned} NWF_{ij1} &= PC_{ij1} \quad \forall i \in NR \cup KR,\ \forall j \in KR \cup NK,\ j \neq i \\ NWF_{ijt} &= NWF_{ij(t-1)} + IPC_{ijt} \cdot X_{ij[t-\delta ij]} \quad \forall i \in NR \cup KR, \\ &\qquad \forall j \in KR \cup NK,\ j \neq i \text{ and } t = 2, \ldots, T. \end{aligned} \qquad (7)$$

Recycled water

• Amount of water recycled to be treated ≤ recycling ratio multiplied by the amount of water supplied to users generating recycled water.

$$WF_{jkt} \leq \beta_j \sum_{i \in NR} WF_{ijt} \quad \forall j \in KR,\ k \in NK,\ t = 1, \ldots, T. \qquad (8)$$

• Water generated by a production or treatment plant ≤ sum of water supplies to this plant.

$$WP_{kt} \leq \tau_k \sum_{j \in N,\, j \neq k} WF_{jkt} \quad \forall k \in NR \cup KR,\ t = 1, \ldots, T. \qquad (9)$$

Water balance

• This type of constraint monitors the flow of water throughout the system, namely, amount of water stored in period $t =$ (amount of water in period $(t-1)$ + the amount of water flowing in during period t − the amount of water flowing out during period t).

$$WS_{it} = WS_{it-1} + \sum_{k \in NR \cup KR,\, k \neq i} WF_{kit} - \sum_{j \in N,\, j \neq i} WF_{ijt}$$

$$\forall\, i \in NR \cup KR \quad \text{and } t = 2, \ldots, T. \qquad (10)$$

• Amount of water storage in a location ≤ the storage capacity in that location.

$$WS_{it} \leq NWP_{it} \quad \forall i \in NR \cup KR \text{ and } t = 1, \ldots, T. \qquad (11)$$

Acknowledgments

The paper is based on the work reported in the AZAM report that USAID financed. The authors wish to acknowledge the valuable assistance of Samir Dewiri, who helped in collecting the supply-side data, and Diego Fernandez, who collected and developed the demand and RO desalination cost data. Al Sherif Mostafa developed the software for the DSS, and Paul Kent provided the logistical support for the project.

References

Al Alawi, J., M. Abdulrazzak. 1994. Water in the Arabian Peninsula: Problems and perspectives. P. Rogers, P. Lydon, eds. *Water in the Arab World*: *Perspectives and Prognoses*. Harvard University, Cambridge, MA.

Al-Jamal, K. H., M. E. Shoblak. 2004. Costing a major desalination plant for Gaza on the Mediterranean region. *Proc. Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus.

Al-Tukhais, A. S. 1997. Water resources and agricultural production in Saudi Arabia: Present and future. *Proc. First Saudi Conf. Agricultural Sci., College of Agriculture, King Saud University, Riyadh, Saudi Arabia*, 25–27.

Aqaba Water Company. 2005. Annual report. Aqaba Water Company, Aqaba, Jordan.

Borowski, I., M. Hare. 2007. Exploring the gap between water managers and researchers: Difficulties of model-based tools to support practical water management. *Water Resources Management* **21**(7) 1049–1074.

Bouhia, H. 2001. *Water in the Macro Economy: Integrating Economics and Engineering into an Analytical Model*. Ashgate Publishing Limited–Gower House, Hampshire, UK.

Bravo, G. 2004. Trends of desalination bids for RO plants in North Africa: The case of Algeria. *Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus, 6–8.

Brimberg, J., A. Mehrez, G. Oron. 1995. Integrated model for the development of marginal water sources in the Negev desert. *Eur. J. Oper. Res.* **81**(1) 35–49.

Chaudhry, S. 2003. Unit cost of desalination. California Desalination Task Force, California Energy Commission, Sausalito, CA.

Chemonics International Inc. 2005. Review of Aqaba water demand and expanded evaluation of water resources. United States Agency for International Development, Washington, DC.

Dawoud, M. A. 2006. The role of desalination in augmentation of water supply in GCC countries. *Desalination* **186**(1–3) 187–198.

Del Castillo, J. 2004. Desalination costs at the Spanish Mediterranean Coast, the Bahía de Palma, Mallorca Case. *Proc. Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus.

Dewiri, S. 2007. Available and potential water supplies for the Aqaba Special Economic Zone (ASEZ). Technical report, AZEM, Aqaba, Jordan.

Dreizin, Y. 2006. Ashkelon seawater desalination project—Offtaker's self costs, supplied water costs, total costs and benefits. Accessed June 1, 2006, http://www.water.gov.il/Hebrew/Planning-and-Development/Desalination/Documents/Ashkelon.pdf.

Elimam, A., S. Dewiri, D. Fernandez, P. Kent. 2007. A water resource planning model for Aqaba. United States Agency for International Development, Washington, DC.

Fernandez, D. 2007. Water demand forecast in ASEZ. Aqaba Special Economic Zone (ASEZ). Technical report, AZEM, Aqaba, Jordan.

Fisher, F. M., A. Huber-Lee, I. Amir, S. Arlosoroff, Z. Eckstein, M. J. Haddadin, S. G. Hamati, et al. 2005. *Liquid Assets*: *An Economic Approach for Water Management and Conflict Resolution in the Middle East and Beyond*. RFF Press, Washington, DC.

Glueckstern, P. 2001. Desalination: Current situation and future prospects. Accessed July 1, 2011, http://www.biu.ac.il/Besa/waterarticle1.html.

Goeller, B. F., S. C. Abraham, A. F. Abrahamse, J. H. Bigelow, J. G. Bolten, D. M. de Ferranti, J. C. De Haven, et al. 1985. Planning The Netherlands water resources. *Interfaces* **15**(1) 3–33.

Hee Kiang, F., W. Yong. 2004. Supply of desalinated water by the private sector 30 mgd Singapore seawater desalination plant. *Proc. Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus.

Medina, J. A. 2004. 20 years evolution of desalination costs in Spain. *Proc. Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus.

Miloradov, M. 1992. Planning and management of water-resource systems in developing countries. *J. Water Resources Planning Management* **118**(6) 603–619.

PUM Netherlands Senior Experts. 2005. Mission report, Aqaba Water Company (AWC). PUM Netherlands, The Hague, The Netherlands.

Quazi, R. M. 2001. Strategic water resources planning: A case study of Bangladesh. *Water Resources Management* **15**(3) 165–186.

Rosenberg, D. E., J. R. Lund. 2009. Modeling integrated decisions for a municipal water system with recourse and uncertainties: Amman, Jordan. *Water Resources Management* **23**(1) 85–115.

Sommariva, C. 2004. Approaches to desalination project budgeting. *Proc. Internat. Conf. Desalination Costing*, Middle East Desalination Research Center, Limassol, Cyprus.

Wu, J., D. Tang, X. Ge. 2009. Application on optimized design of water resource allocation system with GAMS. *Proc.* 2nd *Internat. Conf. Modelling Simulation* (*ICMS*2009), *Vol.* 2, 187–191.

Dr. Bilal Bashir, Chief, Development Zones Commission, Amman, Jordan, writes: "I am pleased to write this letter to verify the impact of the work reported in the subject paper by Drs. Elimam and Girgis.

"This work was commissioned by the Aqaba Special Economic Zone Authority in Aqaba (ASEZA), Jordan, in 2006 and in my capacity then as the Commissioner for Environmental Affairs, I was the officer most interested in the study and its applicability to the situation at hand in Aqaba.

"The authors developed and applied a water resources planning decision support system to identify the optimum water resources development plan for the Aqaba Special Economic Zone (ASEZ). I am pleased to inform you that we at ASEZA have fully adopted, and started implementing, the water resources plan recommended by the authors. Such a plan resulted in the following significant impact on ASEZ and its future development:

1. Identification of the magnitude of demand for water by type over the coming 15 years,

2. Development of a system that can readily simulate water demand and supply imbalances under different development and demographic scenarios. This new decision support system is able to mitigate against selecting the more expensive water production and delivery systems and thereby saving costs to water consumers and saving unnecessary capital spending to the water company.

3. Reduction of capital investments from JD 19.43 million to about JD 14.2 million, leading to a cost saving of about JD 5.23 million (about $7.7 million). The operating cost would also decrease from JD 0.35 per cubic meter, of Disi water supplied to Aqaba, to JD 0.26 per cubic meter of water produced by the RO plant in Aqaba. Assuming the RO plant output reaches an average of 5 MCM per year, this would translate into $661,000/year saving per year for at least 15 years. Assuming 10% interest, this would bring the total NPV of savings to about $5.03 million. Therefore, the total capital and operating cost savings are expected to exceed $12.7 million over the next 15 years.

4. Enhancement of the water supplies reliability by moving from relying on a depletable and finite water source in a water poor country (the Disi aquifer) to another source with unlimited water supply. This would reduce the risks associated with sudden huge flash floods and rain storms and their destructive impact on the water conveyance system running some 63 kilometers from Disi to Aqaba city as it happened during January 2006.

"As you know, water is the lifeline of development. Not only did this work lead to cost savings but it also enabled ASEZA to provide reliable sources of water for future investments in touristic, urban development and industrial projects. Without the availability of such resolution for water scarcity, the ASEZ would suffer from lack of interest on the part of new investors."