

# Analysis of Water Allocation in Aqaba

Peter Waller, Associate Professor  
Agricultural and Biosystems Engineering Department  
The University of Arizona, Tucson, Arizona 85721 USA  
[Pwaller@ag.arizona.edu](mailto:Pwaller@ag.arizona.edu)

Akrum H. Tamimi, Assistant Professor  
Department of Sustainable Natural Resources and Management  
Hebron University, PO Box 40, Hebron, West Bank, Palestine  
Project Coordinator for the Sustainable Development of Drylands in Asia and the Near East  
International Arid Lands Consortium, Office of Arid Lands Studies  
The University of Arizona, Tucson, AZ, 85719 USA  
[akrumt@email.arizona.edu](mailto:akrumt@email.arizona.edu)

## Abstract

The City of Aqaba is growing fast. Irrigated areas, industrial capacity, and tourist facilities are expanding at the same rate as the City of Aqaba. As a result, water demand will increase, and new sources of water must be found. At the present time, all of the water supply comes from the Disi aquifer. Through a treaty with Saudi Arabia Aqaba is entitled to 20 million m<sup>3</sup>/year from the Disi aquifer.

Two of the planned sources of new water are reclaimed wastewater and desalinization of seawater. The new desalinization plants are expected to deliver 11 million m<sup>3</sup>/year while treated wastewater production is expected to reach 6.6 million m<sup>3</sup>/year in 2020.

At the present time Aqaba's water use is divided as follows: 45% to industry, 35 % to residential, and 20 % to Aqaba Special Economic Zone Authority (ASEZA), hotels, and the tourist industry. The largest industrial user of water is the phosphate plants in Aqaba.

Allocating new water sources between users should incorporate both economic and environmental criteria. Three water allocation decisions are addressed in this study from both an environmental and economic perspectives: using treated wastewater for irrigation of municipal landscapes within the City of Aqaba, using treated wastewater for irrigation of a proposed golf course in Aqaba, and, finally, the construction of new phosphate plants with planned use of treated wastewater.

## Introduction

The City of Aqaba is situated at the head of the Gulf of Aqaba on the Red Sea and at the southern end of Wadi Araba. It is an important commercial center in Jordan with expansion being accompanied by a rapid growth of industrial development along The Jordanian coastline. Having an arid climate, water supply has been a major constraint for Aqaba's regional development. The Disi aquifer located 50 km northeast of Aqaba is the main source for the water supply. The Disi is a nonrenewable (fossil) aquifer with a low total dissolved solids ranging between 300 ppm and 400 ppm.

This research study assesses the different demands and sources of water in Aqaba. Then cost and risk associated with the water demands are evaluated; and recommendations on allocation of reclaimed wastewater are made based on minimizing risks.

The two factors that make this analysis important are the construction of a new wastewater treatment plant and delivery system and rapid expansion and development projects of Aqaba. The reclaimed water should be put to its best use, and the city must consider water sources and costs as the city expands.

Aqaba Special Economic Zone Authority will generate tertiary quality water internally. The new wastewater treatment plant will produce tertiary quality water (mechanical treatment) and will have a maximum allowable load of 12,000 m<sup>3</sup>/day (4.5 million m<sup>3</sup>/year).

It is expected that the total rate of reclaimed wastewater will increase from 12,000 m<sup>3</sup>/day to 18,000 m<sup>3</sup>/day between now and 2020. The excess wastewater will be treated in the existing Aqaba wastewater treatment plant ponds that are being lined. There shouldn't be much available water from these treatment ponds during the summer months since most of the water will evaporate. Evaporation rate from those ponds is calculated at 4,000 m<sup>3</sup>/year.

There is no long term storage in Aqaba other than the Disi aquifer. Because the withdrawal of water from this aquifer is regulated by the treaty between Jordan and Saudi Arabia, the degradation of the aquifer is not a concern of this study. However, if the aquifer is over-pumped, then Aqaba is not sustainable without further construction of desalination plants.

## **Water Demand**

Water is used in Aqaba for residential consumption, agricultural irrigation and for industry. The current demand on the Aqaba water system exceeds the supply during the summer months due to high irrigation requirements. The yearly billed water use is 14-15 million m<sup>3</sup>/year with unaccounted-for-water being approximately 28 %. It is unknown whether this is due to illegal withdrawals of water or due to leakage. However, it is expected that most of the unaccounted-for-water is due to leakage in the distribution network since the unaccounted-for-water in Amman is about 52 % of the supply.

### **Residential**

Residential water use is approximately 5.5 million m<sup>3</sup>/year which represents 35% of the Aqaba water system. The per capita water use is 170 liters per day and the owner of a 120 m<sup>2</sup> apartment could expect to pay JD15 per month. Because of new construction, projected use with expansion is expected to reach 7 million m<sup>3</sup>/year in 2005.

### **Agricultural Irrigation**

#### **ASEZA Irrigation Requirement**

The primary irrigation water requirement for ASEZA is irrigating ornamental trees. The most prevalent ornamental trees are date palm and Washingtonia (palm), flame ponciana, and ficus. In general, irrigation of low water use plants is based on a crop coefficient of 0.25 and irrigation of medium water use plants is based on a crop coefficient of 0.5 (based on plant canopy area).

The history of water deliveries for irrigation to ASEZA during the last five years is shown in figure 1. The data in this figure were derived from billing records at Water Authority of Jordan, WAJ. Based on ASEZA records, it was indicated that the applied volume of irrigation water for palm trees to be 100 liter per day. However, the total water consumption for irrigation in the last full year of billing, 2002, is 187,000 m<sup>3</sup> which is the amount needed to irrigate palm trees at a rate of 100 liters per day. Hence the data shows that the water deliveries have been much lower than the expected demand concluding that it is likely that the palm trees received less than 100 liters per day in the summer and less than the estimated amounts shown in table 1 during other parts of the year. It appears that the estimates indicated by ASEZA's records that the palm trees use approximately 100 liters per day may be slightly high.

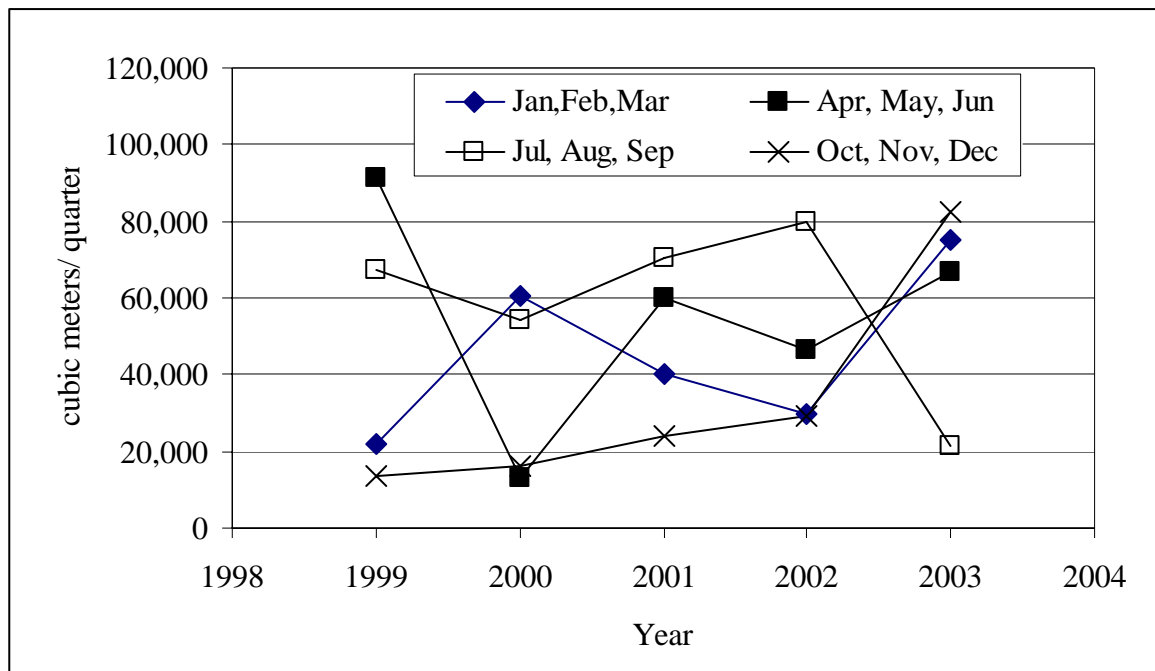


Figure 1: Quarterly Water Use for Irrigation by ASEZA.

Water use for all landscaping in Aqaba appears to be less than 300,000 m<sup>3</sup>/year and is projected to be in the range of 550,000 m<sup>3</sup>/year within the next 5 years.

### **Determining Evapotranspiration in Aqaba**

It is important to estimate reference crop evapotranspiration in Aqaba because of the influence of reference crop evapotranspiration on water use. Aqaba has a very hot climate with high reference crop evapotranspiration in the summer and much lower reference crop evapotranspiration in winter.

Weather data from the Aqaba airport meteorological station includes maximum and minimum air temperature, mean relative humidity, sun shine hours, and daily wind speed. The Penman-Montieth method for calculating reference crop evapotranspiration, ET<sub>0</sub>, has been used to estimate the ET<sub>0</sub> for the summer and the winter months in Aqaba. The maximum and minimum ET<sub>0</sub> has been calculated to be at 12 mm/day for the summer and 3 mm/day for the winter. These results agree favorably with unpublished estimates produced by Ecodit Company under a subcontract from PA Consulting Inc. acting as a subcontractor for the US Agency for International Development, USAID, in the bilateral wastewater reuse implementation project in Aqaba.

It should be mentioned here that these maximum and minimum  $ET_0$  values have almost the same magnitude as those for the city of Tucson and Phoenix in the State of Arizona, USA.

### **Irrigation Requirements for Future Turf and Golf Courses**

There are plans to build at least one golf course in the Aqaba area. Because of the similarity of the Aqaba climate to the Tucson and Phoenix climates and due to the similar values of  $ET_0$ , water use data for Arizona golf courses will be used to estimate water use for Aqaba turf areas.

Golf courses in Tucson and Phoenix are irrigated based on turf crop coefficients ( $K_c$ ) that are 0.7 for summer grasses (Bermuda) and 0.8 for winter grasses (rye grass). A typical championship golf course in Tucson with cactus species between fairways covers 80 acres (32 ha or 320 dunums). If reference crop evapotranspiration,  $ET_0$ , in the summer in Aqaba is 12 mm/day, then depth of water that is required to be applied to the course with 70 % irrigation efficiency and 10% leaching fraction (LF) is:

$$ET_{Bermudagrass} = \frac{K_c ET_0}{E_i(1-LF)} = \frac{0.7(12\text{mm/day})}{70\%(1-10\%)} = \frac{0.7(12\text{mm/day})}{0.7(0.9)} = 13.3\text{mm/day}$$

While for the winter the required applied depth is:

$$ET_{Ryegrass} = \frac{K_c ET_0}{E_i(1-LF)} = \frac{0.8(3\text{mm/day})}{70\%(1-10\%)} = \frac{0.8(3\text{mm/day})}{0.7(0.9)} = 3.8\text{mm/day}$$

Therefore, during the summer and for a 32 ha golf course the water requirement can be calculated as 4,256  $m^3/day$  and as 1,216  $m^3/day$  during the winter months.

Imposing strict regulations on golf course water use may adversely affect golf course appearance. Because of State of Arizona water regulations for golf courses, many golf course managers have watered based on  $ET_0$  as indicated above but with no extra water for leaching resulting in salt accumulation in the soil. Hence golf course managers are beginning to have a difficult time keeping the golf courses green.

Salinization of soil should not be a problem when using the Disi groundwater due to its low salinity level. However, golf courses irrigated with saline recycled water from the Aqaba Wastewater Treatment Plant with tertiary quality water should not be overly restricted in their water use in order to avoid soil salinization. The cost of water should be enough to encourage golf course managers to avoid over irrigation reducing deep percolation. During the design of the golf courses a drainage system should be considered and designed to reduce the amounts of deep percolation that might seep into the waters of the Gulf of Aqaba to avoid coral reef damage.

### **Irrigation Requirements for Palm Farms and Landscaping**

There are several palm farms in Aqaba, some of which produce dates, and others are nurseries producing palm trees to be used in landscaping. All these farms have been using recycled wastewater from the Aqaba Wastewater Treatment Plant. Table 1 shows the

amounts of recycled wastewater that are being used for the year 2003 by the different stakeholders and average usage for yearly demand (Tamimi, 2003).

**Table 1: Irrigation Usage of Recycled Wastewater in Aqaba**

<b>Farm Name/ Irrigation Purpose</b>	<b>Purpose</b>	<b>Winter 2003 Usage (m<sup>3</sup>/day)</b>	<b>Summer 2003 Usage (m<sup>3</sup>/day)</b>	<b>Average Usage (m<sup>3</sup>/year)</b>
Al-Salam	Nursery for palm trees	400	400	150,000
Al Haq	Planted with date palm trees	1,000	1,500	456,000
Al-Nakeel	Produces date palms for the City of Aqaba greening program	1,250	1,250	500,000
ASEZA's Landscaping	Greening North Aqaba and landscaping	800	1,200	400,000
<b>Totals</b>		<b>3,450</b>	<b>4,350</b>	<b>1,506,000</b>

### **Evaporation Loses from Aqaba Wastewater Treatment Ponds**

The Aqaba wastewater treatment ponds have an area of 20 ha. According to the Aqaba airport weather station data, the maximum measured pan evaporation in Aqaba during the summer months is estimated at 20 mm/day. Thus, the maximum evaporation from the ponds is 4,000 m<sup>3</sup>/day.

The evaporation rate decreases in winter to approximately ¼ that of the summer evaporation rate and reduces to ½ of the summer rate during spring and autumn months. Therefore, assuming that each season has 90 days the yearly evaporation rate from the treatment ponds can be calculated to be 810,000 m<sup>3</sup>/year

Because the new wastewater treatment plant will not include ponds, evaporation from treatment ponds will be ignored in the final water balance. In addition, when the tertiary plant is overloaded and excess water is diverted to treatment ponds, there will be very little effluent from the treatment ponds for the first several years because nearly all of the water diverted to the ponds will evaporate.

### **Phosphate Producing Factories**

There are three existing phosphate plants in Aqaba each of which requires a maximum water consumption rate of 500 m<sup>3</sup>/hr. Based on this rate and on the assumptions that each phosphate plant operates 12 hours per day, 6 days per week and on a water conveyance efficiency of 75%, the total yearly use for the three phosphate plants is approximately 7 million m<sup>3</sup>/year. This rate is comparable to the 45% industrial water use proportion of the entire ASEZA allotment of 17 million m<sup>3</sup>/year. If the three phosphate plants operate at full capacity, i.e. 24 hours per day, 7 days per week then they require the entire ASEZA allotment of water.

There are two newly planned phosphate plants to be constructed in Aqaba. The management of one of the plants has signed a contract to reuse recycled effluent of tertiary quality. This requires approximately 6,000 m<sup>3</sup>/day totaling 2 million m<sup>3</sup>/year, based on the above operational assumptions.

All phosphate plants in Aqaba pay JD1.0/m<sup>3</sup> for potable water. It is expected that the new phosphate plant that will reuse recycled tertiary quality effluent will pay 0.7 JD/m<sup>3</sup> for tertiary treated wastewater causing a saving of JD600,000 per year for the phosphate plant.

## **Water Sources**

The Disi aquifer located 50 km northeast of Aqaba is one of the main sources for the water supply in Jordan. The Disi is a nonrenewable (fossil) aquifer with a low total dissolved solids ranging between 300 ppm and 400 ppm. However, the Government of Jordan has signed an agreement with Saudi Arabia that limits the Jordanian withdrawal from the aquifer. Due to the agreement, ASEZA has been limited to 20 million m<sup>3</sup>/year from the Disi and the rest of the Jordanian water allotment will be piped to Amman. The present Aqaba water system capacity is 17.5 million m<sup>3</sup>/year and is controlled by the Water Authority of Jordan, WAJ. Five new wells are planned for Aqaba, and it is expected that the capacity of the Aqaba water system will be increased by 50 %.

The current cost of water production is approximately JD0.5/m<sup>3</sup>. Hotels, ASEZA, and industry are all charged JD1.0/m<sup>3</sup>. ASEZA will be charged 0.1 JD/m<sup>3</sup> for irrigation water from the tertiary treatment plant and will continue to be charged JD1.0/m<sup>3</sup> for potable water. The palm farms presently pay nothing for the treated effluent.

A second planned source of water is the construction of desalination plants in the Gulf of Aqaba. Future demand will be met by these desalination plants. Private companies will build the plants and sell the water. The current cost of desalinated water production is approximately JD1.0/m<sup>3</sup>, and that is the price that ASEZA expects to pay for the water. It is expected that the first desalination plant will produce 11 million m<sup>3</sup>/year, and that this plant will be completed in 2005. The first phase of this plant will produce 5.5 million m<sup>3</sup>/year. Water Authority of Jordan has allotted 1.5 million m<sup>3</sup>/year for irrigation to be sold to ASEZA.

### **Reclaimed water (Internal Generation)**

ASEZA will generate water internally with the reclaimed wastewater plant. The tertiary (mechanical treatment) part of the plant will treat 12,000 m<sup>3</sup>/day (4.5 million m<sup>3</sup>/year). It is expected that the total wastewater load will increase from 12,000 m<sup>3</sup>/day to 18,000 m<sup>3</sup>/day between now and 2020. The excess wastewater will be treated in the present treatment ponds that are being lined.

## **Projected Water Balance for Aqaba**

Table 2 summarizes the demands and sources of water in Aqaba after the completion of the tertiary wastewater treatment plant. The projected recycled wastewater reuse (4,050,000 m<sup>3</sup>/year) is approximately equal to the projected production. Thus, there does not appear to be much benefit to encouraging urban residents to use recycled wastewater in their gardens.

In addition, it does not appear that there will be extra water available to the golf course and hence the golf course has to be irrigated using potable water.

The expected total potable water demand (19,500,000 m<sup>3</sup>/year) is slightly less than the expected supply (22,000,000 m<sup>3</sup>/year). Thus, there does not appear to be a lot of extra water and major expansion will require construction of additional desalination plants.

**Table 2: Water Balance for Aqaba**

<b>Water Source</b>	<b>Potential (m<sup>3</sup>/year)</b>	<b>Estimated Conveyance Efficiency</b>	<b>Estimated Conveyance (m<sup>3</sup>/year)</b>
Disi aquifer	20,000,000	72 %	14,400,000
Desalination plant	11,000,00	72 %	8,000,000
<b>Total In</b>			<b>22,400,000</b>
<b>Internal Generation</b>			
Recycled Effluent	5,000,000	80 %	4,000,000
<b>Total Recycled Effluent</b>			<b>4,000,000</b>
<b>Potable Water Demands</b>			
Old phosphate plants			7,000,000
New phosphate plant on potable water			2,000,000
ASEZA (hotels etc ...)			3,000,000
Golf Course			500,000
Residential			7,000,000
<b>Total Potable Water Demand</b>			<b>19,500,000</b>
<b>Recycled Water Demand</b>			
ASEZA irrigation			550,000
Al Haq farm			456,000
ASEZA irrigation (north and airport)			400,000
Al Nakheel farm			500,000
Al Salam farm			150,000
New phosphate plant on Recycled Effluent			2,000,000
<b>Total Recycled Effluent Demand</b>			<b>4,050,000</b>
<b>Difference in Storage</b>			<b>≅ 0</b>

## **Economic Analysis**

The Water Authority of Jordan's selling price of treated wastewater to commercial users has been designated to be JD0.7/m<sup>3</sup>. The selling price of tertiary treated wastewater for ASEZA irrigation is proposed to be JD0.1/m<sup>3</sup>. Currently, ASEZA pays WAJ JD1.0/m<sup>3</sup> for potable

water. This implies that WAJ will gain more economic benefits from selling treated wastewater to commercial users than by selling the treated wastewater to ASEZA. Also ASEZA will likely pay JD0.90/ m<sup>3</sup> more for potable water than treated wastewater which is an incentive for ASEZA to reuse recycled effluent. An alternative might be that WAJ sells all the treated wastewater to commercial users at the same price as it does today of 0.7 JD/m<sup>3</sup>. Water Authority of Jordan may then be able to reduce the cost of potable water to ASEZA to the cost of production (0.5 JD/m<sup>3</sup>) rather than the 1.0 JD/m<sup>3</sup> the price that is currently beign charge. In this way WAJ would still earn more overall revenue if they then sold the treated wastewater to commercial users, and the residents of Aqaba would benefit from reduced costs of water.

Related to this issue is the decision to use treated wastewater in residential Central Aqaba versus potable water. If irrigation water use in residential Central Aqaba is approximately 200,000 m<sup>3</sup>/year, then ASEZA will pay an extra 200,000 \* (0.5 JD - 0.1 JD) = \$80,000/year for the potable water. ASEZA should examine whether the extra cost of having treated wastewater in Central Aqaba is more or less than \$80,000/year. The distribution and maintenance cost for the wastewater distribution network for municipal and small users will add considerably to ASEZA's and to WAJ's costs.

## Conclusions

Because of the considerable number of potential large-scale users of treated wastewater (expansion of the different palm farm, planned golf course, planned expansion of the phosphate plant, using treated wastewater in the newly planned phosphate plants, landscaping on road to airport, landscaping plan for peace Highway between Jordan and Israel, and landscaping of South Coast), it is difficult to justify bringing treated wastewater into central Aqaba. Residential use where residents could come into direct contact with the water, such as in parks and places where children play would be both at higher cost and at higher risk.

Treated wastewater would likely increase irrigation system maintenance costs and would require the installation of more expensive components. Reusing of treated wastewater in residential areas such as neighborhood parks and public parks would pose a potential health risk to residents if the operation and maintenance of the wastewater treatment plant were to temporarily fail or the quality of the treated effluent is not properly tested. The cost of routing dual-pipe systems in central Aqaba would also be expensive. In addition, the new requirement of using purple piping for treated wastewater systems, although necessary, would be unsightly in central Aqaba. This is especially true given the current practice of running polyethylene pipe along the ground surface in irrigation systems.

It should be carefully determined whether the cost and risk of using treated wastewater is justified in residential Central Aqaba. Water Authority of Jordan could probably make more money piping the treated wastewater to golf courses and phosphate plants.



## References

- Jensen M.E., R.D. Burman, and R.G. Allen (Editors). Evapotranspiration and Irrigation Water Requirements. American Society of Civil Engineers. 345 East 47th St. New York, NY 10017. 1990
- Metcalf & Eddy, Inc. Wastewater Engineering, Treatment and Reuse. Fourth Edition, McGraw-Hill Companies, Inc. New York. 2003.
- Steel E.W. and Terence J. McGhee. Water Supply and Sewerage. Fifth Edition. McGraw-Hill Companies, Inc. New York. 1979.
- Tamimi, A. (2003). Sustainable Development of Drylands in Asia and the Near East: Jordan Component. Technical Report submitted to The University of Arizona/International Arid Land Consortium.