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Ag and Biosystems Engineering

The University of Arizona

Planning for Demonstration Site for Mafraq Treated Wastewater

and

Water Balance for City of Aqaba

For

International Arid Lands Consortium

December 15 – December 22

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I. Activities for Peter Waller, Dec 13 – Dec 22.

December 13 – Saturday - Left US
December 14 – Sunday – travel and arrive in Amman at night -
December 15 – Monday - met with Dr. Akrum Tamimi and Dr. Ramzi Touchan for dinner –worked on Aqaba and Mafraq proposals. I was scheduled to meet with Badia personnel in afternoon, but they were out of town
December 16 – Tuesday - Visited Mafraq from 8 am to 2 pm with Faisal and Dr. Akrum Tamimi. - met with Dr. Akrum Tamimi from 6-9 pm that evening to work on Mafraq proposal and make further plans for Aqaba.
December 17 – Wednesday - Met with Mr. Jamal Rashdan from WAJ in morning. Met with Dr. Mohammed Shahbaz, Dr. Akrum Tamimi, and Dr. Amal Hijazi from 2-4 pm. Took flight to Aqaba in evening.
December 18 – Thursday. Met with Dr. Salim Al-Mugrabi from ASEZA from 8:30-9:30. Met with Taiseer from PA consulting until 2:00 to gather information already compiled by PA on Aqaba water situation. Also visited PA Consulting demonstration site. Met with Mr. Bilal Assi from WAJ in the afternoon. Bilal Assi is the operations manager and we discussed water usage and supply in Aqaba
December 19 – Friday. Worked on reports all day. Summarized and modified Mafraq proposal and observations. Started Aqaba report.
December 20 – Saturday. Worked on report in morning. Met Osama (landscaping and irrigation supervisor for ASEZA) and arranged meeting for next day. Went with PA to print documents and observe irrigation start up. Late afternoon. Worked on internet to find crop coefficients for date palms and Poinciana. Discussed Mafraq soils and irrigation with Taiseer from PA in evening.
December 21 – 8:30-9:00 Met with Thair from ASEZA. 9:00-10:30 Met briefly with director of Aqaba WAJ (Imad Zurekat), then met with wastewater engineer Jamal Reyati and customer service manager (engineer) Naem A. Saleh. 1:00-2:30 Met with Osama and Nabil from ASEZA (agricultural engineers / agronomists). Osama has a landscaping background and Nabil is fresh out of school and is designing the irrigation systems. These people are designing and installing the irrigation systems in Aqaba.
December 22 – 8:30-9:15 Met with Ismael Bazian. He as happy to hear that we are working with Isam Jaradat. He had the opinion that just using a hose is better than irrigation “network”. I told him that I will be doing an economic assessment of different methods of irrigation in Aqaba and he was happy to hear that. Met with Isam and Ahmed (head of landscaping) from 9:30 – 1:20. Discussed the fact that bubblers is usually a better choice for the individual palms and that inline drip emitters are better for hedges and ground cover. Went out with Isam to the Marina site and discussed various aspect of the irrigation and landscaping. Also drove to Farouq Shrer and discussed irrigation and landscaping along this street. The landscaping phase is moving ahead of the planning phase. Trees are being put in at a very rapid pace. We also discussed the fact that an irrigation training course is needed for the “agricultural engineers” who are working for the landscaping department. We discussed a one or two week course next summer (or sooner if possible). In addition, they will be sending me drawings of landscaped sections

(as AutoCad files) and I will design irrigation systems for these sections over the next few months.

Left for the airport in Aqaba to fly to Amman at 6:00 p.m on the 22^{nd} . Caught plane in Amman at 1:30 am. Caught plane in Paris at 11:45 am. Caught plane in Atlanta at 6 pm. Landed in Tucson at 9 pm, December 22.

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Ahmed
Isam Jaradat's assistant, probably head of landscaping

III. Mafraq observations and proposal

1. Observations.

a. Soils and irrigation

Mafraq is Northeast of Amman in a dry, hot, desert near the Syrian border. The city has approximately 100,000 people. Rain fed wheat and pasture are typically grown in the area. Rainfall is minimal so yield is low.

Soil is extremely gravelly and rocky silty clay. Previous infiltration tests (reference in Appendix C in CH_2MHill report on Mafraq WWTP) on a nearby field indicate that the infiltration rate is low (5 mm/hr). Soils are "filled with rocks and cobbles of limestone" (40 %). Cobbles of limestone are probably caliche. Thus, water holding capacity is reduced from what is normally expected for a silty clay (14 %) to approximately 9 %. Last year the farmer ripped the soil to 70 cm depth in order to improve infiltration. Presently, the farmer irrigates every 2 to 3 days because of a lack of ability to get a good quantity of water in the soil. I assume this is because he cannot get water passed a caliche layer. As expected in the desert, the soil is calcareous. Taiseer from PA said that soils in that area are highly variable and that there may be good and bad regions in the field. Extra effort should be made to map the soils in order to find the best spots for farming.

For a crop with 1 m rooting depth and 50 % management allowable depletion, the readily available water is approximately 50 mm, and infiltration time would be approximately 10 hours at a 5-mm/hr-infiltration rate. Thus, irrigation time would be approximately 12 hours. For a crop with 2 m root depth, infiltration time would be approximately 24 hours. Thus, it is likely that alfalfa will be irrigated for 24 hours with 8 to 10 days between irrigation events (12 mm/day ET) and wheat and corn will be irrigated for 12 hours every 5 days. As stated in the CH_2MHill report, further analysis of infiltration and soil water holding capacity is required before the irrigation system design is conducted. It is likely that water penetration problems and impenetrable layers in the soil will require creative soil management and irrigation solutions.

It is likely that WAJ and USAID will break the property into parcels with outlets from the mainline for individual farmers. CH_2MHill has surveyed the entire property and has produced a topographic map with 0.5 m elevation contours. This should be sufficient for irrigation mainline design. Part of the property is level, part of the property has a gentle slope suitable for furrow irrigation, and part of the property has a steeper slope and is probably unsuitable for any type of surface irrigation. It is possible that sloping furrow irrigation will be unsuitable because of water penetration problems.

The property has a 2.5 m elevation drop from south (near the road) to north (down by the Wadi). The proposed storage reservoir is located at the north (lower) end of the property. A second, smaller storage reservoir should be constructed at the south end (highest elevation) of the property in order to provide water to the irrigation system with a constant gravity head. A device in the upper reservoir should trigger a pump in the larger, lower reservoir whenever the water level in the upper reservoir drops below a given elevation above the ground surface (approximately 1 to 2 m).

Because of the fact that the wastewater plant produces excess water in winter when crop ET is low, it is likely that more land should be planted in wheat or other winter crops than is planted in summer. Thus, some land should lie fallow in summer and have a crop in winter. Possibly, WAJ can charge no money for water that is utilized in winter.

b. Current wastewater treatment plant and wastewater use on forage

The wastewater treatment plant is operated by the Water Authority of Jordan (WAJ). It is a series of treatment ponds and is overloaded. Thus, the effluent is of low quality and does not meet the Jordanian criteria for application of secondary effluent on forage crops. Approximately 75 % of homes in Mafraq are connected to the sewer system, and the rest are connected to septic tanks. The plant effluent flow rate is approximately 2,400 m^3/day (check this).

The plant director, Faisal, attempts to discharge all water to the farm or to evaporation ponds; however, if all else fails, excess wastewater must sometimes be discharged to the nearby Wadi. Although the wastewater is not suitable for application to forage based on Jordanian standards, WAJ has determined that application of this effluent to forage is preferable to discharge of the effluent to the Wadi. The plant provides 2,400 m^3/day effluent to a farmer who irrigates approximately 20 ha with the wastewater. The following calculation indicates that the farmer applies an average of approximately 12 mm/day to the 20 ha area.

$2{,}400\ m^3/day * 1/10{,}000\ ha/m^2 * 1{,}000\ mm/m\ /\ 12\ mm = 20\ ha.$

The irrigation system includes a series of small level basins (approximately 5 m by 10 m) within fields (approximately 2 ha). Water fills one basin and then overflows to other basins in the field. Small channels within the field also help distribute water to the basins. As a result of sequential basin filling, irrigation is probably inefficient and nonuniform. One of the treatment plant operators stated that the irrigation is inefficient.

Crops appear healthy, and the farmer feeds the crops (berseem (alfalfa), corn, sudan grass, and wheat) to cattle and sheep on his nearby farm.

Most farming appears to take place with manual labor rather than with automated equipment. Laborers were cutting wheat by hand on the day of our visit.

c. New wastewater treatment plant and projected flow rate.

The current plant will be replaced by a new wastewater treatment plant to be constructed by 2005 or 2006. Approximately 75 % of Mafraq residences are connected by sewers to the wastewater treatment plant; however, it is expected that the connection of industries to the sewer system will increase the influent load to the treatment plant to approximately 6,000 m^3/day.

The new wastewater treatment plant will use a mechanized treatment process rather than ponds. The effluent will be treated to secondary (check this) effluent standards. The wastewater will be discharged to a 90,000 m^3 pond for storage. This should provide at least 10 days of irrigation capacity.

2. Proposed activities in Mafraq

a. Economic analysis

Decisions on type of irrigation system, depth of irrigation water application, and farm area to be irrigated should be based on economics and the environment. An economic analysis of irrigation alternatives for the Mafraq wastewater reuse farm will be conducted.

It is likely that the proposed irrigation systems in this project will include

i) Low head bubbler with level basins
ii) Gated pipe irrigation of level basins
iii) Subsurface drip
iv) Sloped furrows with gated pipe (recycled water)

Level basins may include a furrowed system or a flat system. A furrowed system would reduce the contact between plants and irrigation water.

The expected capital costs and annual costs and benefits (labor, energy, and water, and yield) will be compared between systems in order to make recommendations for the most appropriate system for individual farmers. It is possible that the selection criteria will be different for each farmer.

Crop water production functions express yield as a function of applied water. Thus, the economic benefit of adding more irrigation water can be assessed. Based on this analysis, a chart will be developed that recommends planted acreage of crops vs. amount of water available and type of irrigation system. A soils map of the farm will be used to perform economic analysis and to prioritize areas of the farm.

b. Wastewater reuse demonstration site

A smaller demonstration site with an area approximately equal to one hectare is proposed. It is likely that the demonstration site will be conducted at a location just to the East of the new wastewater treatment plant. However, soil type will be a strong consideration and may necessitate moving the site to another part of the farm. The demonstration site will include demonstration and monitoring components. The main purposes of the demonstration site will be to evaluate crop yield vs. type of irrigation system and to evaluate environmental and crop contamination in treatments with different irrigation systems.

Three irrigation treatments will be included in the monitoring section of the demonstration site. The fourth treatment is considered as the control.

i) Low head bubbler with level basins (recycled water)
ii) Subsurface drip (recycled water)
iii) Sloped furrows with gated pipe (recycled water)
iv) Low head bubbler with level basins (ground water)

Four hypotheses will be evaluated

- Furrowed systems have less crop contamination than level basins but have more crop contamination than subsurface drip.
- There is an effect on milk and beef cattle from using recycled water in irrigating forage.
- Water use efficiency (yield vs. applied water) is improved with pressurized irrigation.
- Environmental contamination is reduced with pressurized irrigation systems.

In hypotheses 3 and 4, the bubbler system is considered pressurized and the gated pipe are considered unpressurized. However, each treatment will be evaluated for significant differences vs. all other treatments. Each treatment will include 3 replicates. Thus, there will be 12 plots in the monitoring section. T-tests or Anova will be used determine significance between treatments. All of the monitoring experiments will include alfalfa (2 years) and corn/wheat (1 year) in rotation. It is possible that Sudan grass or wheat will be required during the first year in order to prepare the soil (leach the salt) before other crops are planted.

Environmental contamination will be evaluated by monitoring water and contaminant transport through and below the root zone. Water transport will be evaluated with neutron probes. Four soil cores in each monitoring plot will be collected twice each year. Four neutron access tubes will be installed in each plot. Neutron probe access tubes will be installed to 3 m depth. Soil cores will be collected at 0.5, 1, 1.5, 2, 2.5 m depths. Soil cores will be evaluated for pathogens, nutrients, salinity, and heavy metals.

Possible pathogenic crop contamination will tested by analyzing crop samples in the laboratory.

Citrus (subsurface drip) and cactus (surface drip) will be grown for demonstration but will not be included in the irrigation monitoring experiments. Pathogen contamination of these crops will be evaluated.

Based on demonstration site experiments, the team will determine crops, and appropriate irrigation and management methods that can be used when the new Mafraq wastewater treatment plant is constructed in 2006 and its effluent is ready to be used in the Mafraq production farms.

Field days will be conducted once each year in order to educate farmers at the site on the use of wastewater. Field days will include presentations by project personnel as well as a tour of the site. In addition, researchers and government personnel will be invited to tour the site as well as to hear a summary of the project results at the conclusion of the 3-year project.

c. Develop irrigation management scheme for Mafraq

AZSCHED is a software program that utilizes weather data to recommend irrigation depths to farmers. AZSCHED irrigation scheduling software will be modified for use in the Mafraq area. The name of the modified software will be Jordsched. The modifications will include two things: evapotranspiriation parameter modifications and translation into Arabic. Use of AZSCHED in real time for crop watering does not require any modification because the model depends on measured heat units and measured reference ET.

However, in order to use AZSCHED for predictive purposes, three things are required: average daily minimum temperature, maximum temperature and reference ET for each day of the year. Reference ET can be estimated based on weather parameters, but it is best to install a weather station designed for agrimeteorology. For this reason, and for crop management, the proposal will recommend installation of an agricultural weather station.

As a result of the implementation of AZSCHED and the weather station, recommended watering schedules will be placed on a bulletin board. In addition, up to date information on real time crop water needs and recommended irrigation frequency will be posted.

The wastewater treatment load decreases in summer and increases in winter due to winter storms and increased summer evaporation from ponds and summer scarcity of water and resulting low consumption. The project will develop recommended planting schedules and recommended areas to be planted in winter and summer based on observed ET rates and plant effluent rates.

The possibility of automatic control of some irrigation systems at the site will be investigated. It is possible that farmers will choose to have project personnel automatically irrigate their farm based on AZSCHED results. This will only be possible with some irrigation systems. It is unknown at this time whether this is a wise solution or will lead to problems. It is also unknown whether a radio controlled system or conventional solenoid valves connected to a central controller by buried wires is the best choice. The possibilities and possible ramifications will be evaluated. Recommendations will then be made for the final irrigation system design.

IV. Aqaba water balance

A water balance should include the following terms, In (water source), out (water demands), internal generation of water (reclaimed water), and change in storage. A summary of these terms is given below. A more detailed description of each of the terms follows.

The major water source in Aqaba is the Disi aquifer. The aquifer is extensive; however, the Country of Jordan has signed an agreement with Saudi Arabia that limits the Jordanian withdrawal from the aquifer. Under the agreement, ASEZA has been limited to 20 million m^3/year, and the rest of the Jordanian water allotment will be piped to Amman. The present Aqaba water system capacity is 17.5 million m^3/year.

A second planned source of water is the construction of desalination plants in the Gulf of Aqaba. Future demand that is above 20 million m^3/year will be met by these desalination plants. Private companies will build the plants and sell the water. The first desalination plant will have a capacity of 11 million m^3/year.

The water demands on potable water in Aqaba include residential, hotels, industrial, and landscape irrigation. The current potable water use is 17 million m^3/year. The primary industrial users are phosphate plants. The water use is divided as follows.

45 %	Industry
35 %	Residential
20 %	ASEZA, hotels, and tourist industry

A golf course and large development are planned for the south coast area. I expect that the golf course would use approximately 500,000 m^3/year. Projected water demand for ASEZA landscape irrigation in the next 5 years is approximately 500,000 m^3/year. The largest water user is the phosphate plants: I estimate this water use is nearly 7 million m^3/year, and will increase to nearly 11 million m^3/year.

ASEZA will generate water internally with the reclaimed water plant. The tertiary (mechanical treatment) part of the plant will treat 12,000 m^3/day (4.5 million m^3/year). It is expected that the total wastewater load will increase from 12,000 m^3/day to 18,000 m^3/day between now and 2020. The excess wastewater will be treated in the present treatment ponds that are being lined. I don't expect much water from these treatment ponds in the summer since most of the water will evaporate (4,000 m^3/day).

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 overpumped, then Aqaba is not sustainable without further construction of desalination plants.

1. Out

The current demand on the Aqaba water system exceeds the supply in the summer. The yearly billed water use is 14-15 million m^3/year. Unaccounted for water is approximately 28 %. It is unknown whether this is due to illegal withdrawals of water or due to leakage, but it is expected that most of the unaccounted for water is due to leakage. In comparison, the unaccounted for use of water in Amman is 52 % of the supply.

a. Residential

Residential water use is approximately 35 % of the Aqaba water system (5.5 million m^3/year). The per capita water use is 170 L/day. The owner of a 120 m^2 flat could expect to pay 15 JD/month. Because of new construction, I estimate that projected use with expansion will be 7,000,000 m^3/year

b. ASEZA irrigation

ASEZA's primary irrigation water demand is 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).

Stopping irrigation on low water use plants (desert plants) does not usually result in plant death in some desert areas such as Tucson, but stopping irrigation often results in a poor visual appearance. However, Aqaba, without Tucson's summer monsoon season and sporadic winter rains, must continue to irrigate all plants if they are to survive. Because of the continued irrigation requirements in Aqaba, a more robust irrigation system than drip irrigation may be required. Drip irrigation systems tend to degrade in the urban environmnent.

Landscape plants can be categorized as low, medium, and high water users, and they use these lists to regulate the planting of trees in new landscapes. The Tucson list is found at

http://www.water.az.gov/adwr/Content/Conservation/LowWaterPlantLists/TucsonAMA/Files/DesertGuideTUC.pdf

Low water use plant lists often divide plants into the following categories

The City of Tucson has further divided the low water use plant list into four categories.

1. No supplemental irrigation once established.
2. Irrigate once a month during the growing season once established.
3. Irrigate twice a month during the growing season once established.
4. Irrigate once a week during the growing season once established.

The following discussion provides a starting point for estimating irrigation requirements of some of the landscape plants that are prevalent in Aqaba.

Date palms

Date palms are listed on the low water use plant list under category 3. This category indicates that the crop coefficient for date palms is approximately 0.5. The FAO lists the crop coefficient for date palms as 1.0; however, this crop coefficient is for irrigation of date palms on a production agriculture date palm farm. The date palms in Aqaba have less canopy density than date palms on a date palm farm. Isam Jaradat stated that approximately 100 L/day are applied to mature date palms in summer. Mature date palms in Aqaba average approximately 7 m diameter. The expected daily water requirement (liters per day, LPD) for mature palm trees (with a little bit extra for leaching salts) with a crop coefficient of 0.22 is 100 LPD.

$$LPD = \left(\frac{12\ mm}{day}\right)\left(\frac{m}{1{,}000\ mm}\right)\left(\frac{\pi D^2\ m^2}{4}\right)\left(\frac{1{,}000\ L}{m^3}\right) * 0.22 = 2.2D^2 = 2.2 * 7 * 7 = 100\ LPD$$

There are 10,000 date palms that are planted in the City of Aqaba. The expected irrigation requirements during the summer quarter are

$$\left(\frac{100\ L}{day}\right)\left(\frac{90\ days}{quarter}\right)\left(\frac{m^3}{1{,}000\ L}\right) * 10{,}000\ trees = 90{,}000\ m^3\ /\ summer\ quarter$$

Assuming that irrigation efficiency of the date palms is 90 %, then the actual depth of water applied during summer will be

$90{,}000\ m^3 / 0.6 = 100{,}000\ m^3$/summer quarter

Ponciana

The President of Egypt recently gave 3,000 ponciana trees to King of Jordan for planting in Aqaba The flame ponciana is not listed on the Low Water Use Plant List in Tucson. In addition, the lack of a waxy cuticle on the leaves indicates that evapotranspiration from these trees will be relatively high. Isam Jaradat stated that the flame poncianas use approximately the same volume of water as the palm trees. The average width of the flame ponciana is 6 m. There are 3,000 flame ponciana trees being planted. Thus, the water requirements will be

$$\left(\frac{100\ L}{day}\right)\left(\frac{90\ days}{quarter}\right)\left(\frac{m^3}{1{,}000\ L}\right) * 3{,}000\ trees = 27{,}000\ m^3\ /\ summer\ quarter$$

Assuming that irrigation efficiency of the date palms is 90 %, then the actual depth of water applied during summer will be

$27{,}000\ m^3 / 0.9 = 30{,}000\ m^3$/summer quarter

The water requirements of the palms and ponciana are approximately half of summer requirements in spring and fall and approximately one quarter in winter. Estimated water requirement during each quarter is tabulated in table 1.

Table 1. Estimated cumulative water requirements (m^3) of different tree species in Aqaba.

	Jan,Feb,Mar	Apr, May, Jun	Jul, Aug, Sep	Oct, Nov, Dec	Year
Palm	20,000	60,000	90,000	20,000	190,000
Ponciana	10,000	25,000	30,000	10,000	75,000

Summary of discussion of trees in Aqaba

Isam Jaradat stated that there are 50,000 trees and shrubs in Aqaba. Because of the observed low water use, it seems that the current practice of irrigating manually with hoses and with water trucks results in an efficient irrigation system for the City of Aqaba. It is probably more efficient than long term irrigation with a drip system. The problem with manual irrigation is the labor involved, and the destruction of some shrubs due to washing the soil away from the roots. There has been a high plant death rate for shrubs, but the trees seem to do well under hose irrigation.

The history of water deliveries for irrigation to ASEZA during the last five years is shown in figure 1. The interesting part of the data is that the water deliveries have been much lower than the expected demand. The data in figure 1 were derived from billing records at WAJ. The total water consumption by irrigation in the last full year of billing, 2002, is 187,000 m^3. This is approximately equal to the estimated water requirements for the palm trees. Based on this data, it is likely that the palm trees receive less than 100 LPD in the summer and less than the estimated amounts in table 1 during other parts of the year. It appears that the estimate by Jaradat that the palms use approximately 100 LPD may be slightly high. During a meeting with Jaradat, his assistant, Ahmed, estimated that the palms use 100 L every 3 days.

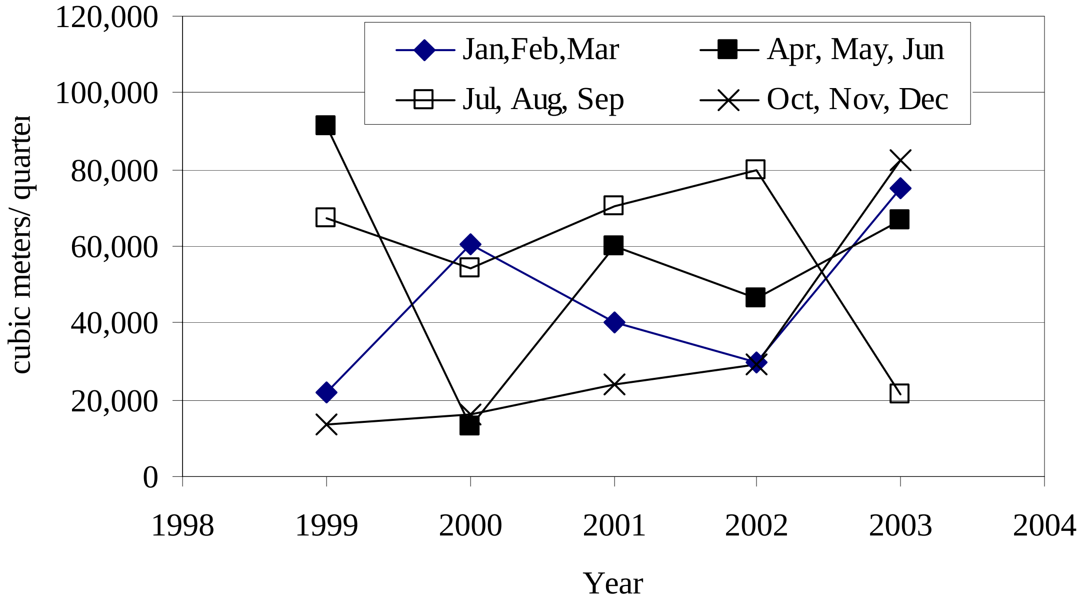

Figure 1. Quarterly water use for irrigation by ASEZA.

The following estimation of projected water requirements in the next five years under the greening of Aqaba program was compiled by Bakir.

Short term :

The city is divided into 5 sectors of which 4 are on the Northern part of the city and 1 to the south on the main Coastal Road towards (Yamanieh Heights). Landscaped areas are as follows.

Northern sector: 4 zones:
Area 1 = 192698 sqm
Area 2 = 51 886 sqm
Area 3 = 187107 sqm
Area 4 = 59743 sqm
Total = 491434 sqm = 49.14 ha

The number of trees required and crop water requirements for the Northern sector will be as follows:

.	Number	Crop water requirements CM/year		
		1 to 3 years	3 to 5 years	More than 5 yr
Palm trees	1750	32,000	45,000	64,000
Ficus	1750	32,000	45,000	64,000
Poinciana (flame tree)	5100	37,000	56,000	75,000
Total		**101,000**	**146,000**	**203,000**

Southern sector: 4 zones:
The area comprises the coastal road to the south towards (Yamaniah heights) including Medians, sidewalks, parking lots and buffer zones.

Buffer area = 280870 sqm
Island area = 37393 sqm

Total = 318262 sqm = 31.83 ha

The number of trees required and crop water requirements for the Southern sector will be as follows:

	Number	Crop water requirements CM/year		
.		1 to 3 years	3 to 5 years	More than 5 years
Trees and Shrubbs (Yucca)	10,000	73,000	110,000	146,000
Palm trees	1750	32,000	45,000	64,000
Ficus	1750	32,000	45,000	64,000
Poinciana (flame tree)	5500	41,000	61,000	81,000
Total		**178,000**	**261,000**	**355,000**
	Number	Crop water requirements		
Trees and Shrubbs (Yucca)	10,000			
Palm trees	1750	25,000 m3/ha/an		
Ficus	1750	20,000 m3/ha/an		
Poinciana (flame tree)	5100	20,000 m3/ha/an		

It appears that the trees and shrubs in Aqaba may have a crop coefficient in the neighborhood of 0.25. Mr. Jaradat made the statement that palms in landscapes can be irrigated with minimal irrigation water because there is no need to produce fruit. It appears that he is right and that the palms are a low water use tree as grown in Aqaba.

This ends the information compiled by Bakir on landscape water requirements.

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

c. Reference evapotranspiration in Aqaba

It is important to estimate reference evapotranspiration in Aqaba because of the influence of reference evapotranspiration on water use. Aqaba is located on the Gulf of Aqaba and has a very hot climate with high reference evaporanspiration in summer and much lower evapotranspiration in winter. Reference evapotranspiration (ET) values for Aqaba were compiled for ASEZA with the Penman-Montieth method by Patricia Bakir from Ecodit under a subcontract from PA consulting. Data from a weather station at the Aqaba airport that was used in the calculation includes max and min temperature, mean relative humidity, sun hours/day, and wind distance (km/day). Bakir estimated max ET_0 (reference evapotranspiration) as 12 mm/day in summer and 3 mm/day in winter. These figures are almost the same as Tucson and Phoenix.

Minimum relative humidity (midday) in Aqaba ranges from 22 % in summer to 40 % in winter. The humidity is quite low in summer and the reported average wind speed is very high. The average reported wind speed (24 hour average) is 6 m/sec (20 ft/sec or 13 mph) in summer and 3.5 m/sec in winter. However, locals say that there is very little wind in summer. The sun hours used in the calculation ranged from a maximum of 12 hours in summer to a minimum of 6 hours in winter (????). The temperature regime (maximum = 38.4 C in June and 21 C in Winter) and humidity regime is very similar to Tucson, Arizona. Bakir's maximum calculated ET_r for Aqaba in summer was 12 mm/day, and max ET_r in Tucson is approximately 12 mm/day. Likewise, winter ET_r in Tucson is ¼ that of summer ET_r (Winter ET_r = 3 mm/day in Tucson), and this result is also seen in Bakir's calculation of ET_r in Aqaba in winter (3 mm/day). **Thus, the attached guidelines that were developed for landscape irrigation in Tucson should be appropriate for Aqaba**.

There are many citrus and other fruit trees in residential gardens in Aqaba. Water use by fruit trees can be estimated by reference evapotranspiration and crop coefficients. The crop coefficient is the adjustment to reference ET for different plants species:

$$ET_{crop} = ET_r * K_c$$

where

ET_{crop}	=	evapotranspiration from an individual crop, mm/day,
K_c	=	crop coefficient, dimensionless,
ET_r	=	reference evapotranspiration, mm/day.

Crop coefficients for agronomic plants grown in the Aqaba Pilot Water Reuse Project were reported by Patricia Bakir. The crop coefficients were taken from FAO publications are based on the area between trees (tree spacing) rather than the canopy area of the tree. In order to adjust these crop coefficients for calculation of evapotranspiration from individual trees in a landscaped area, they must be adjusted as described below.

FAO crop coefficients for all citrus ranged from 0.65 in winter to 0.75 in summer. The crop coefficient for an individual orange tree in a landscaped areas in Tucson is generally assumed 1.0 in summer. FAO crop coefficients for grapes, olives, pomegranates, papaya, and guava were similar to citrus. If trees are in a shaded area, then evapotranspiration may be reduced based on the percent hours that the tree is in direct sunlight. All of the trees listed above would be categorized as a high water use plant in the attached guidelines for landscape irrigation.

d. Turf and golf courses

There are plans to build at least one golf course in the Aqaba area. Estimated water requirements for a golf course in the desert are listed below. Because of the similarity of the Aqaba climate to the Tucson and Phoenix climates, water use for Arizona golf courses will be used to estimate water use in Aqaba turf areas.

Golf courses in Tucson and Phoenix, Arizona irrigate 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). If reference ET in summer in Aqaba is 12 mm/day, then depth of water applied to the course (70 % irrigation efficiency and 10 % leaching fraction (LF)) in summer is

$$ET_{ref} * K_c / (\text{Irr eff} * (1 - LF)) = 12 \text{ mm/day} * 0.7 / (0.70 * 0.9) = 13.2 \text{ mm/day}$$

The winter water requirement is

$$ET_{ref} * K_c / (\text{Irr eff} * (1 - LF)) = 3 \text{ mm/day} * 0.8 / (0.70 * 0.9) = 3.8 \text{ mm/day}$$

Water requirement in summer is

$$\left(\frac{13.2\ mm}{day}\right)\left(\frac{32\ ha}{course}\right)\left(\frac{10{,}000\ m^2}{ha}\right)\left(\frac{m}{1{,}000\ mm}\right) = 4{,}200\ m^3 / day$$

Water requirement in winter is 1,219 m^3/day

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_{grass} with no extra water for leaching. This has resulted in soil salinization, and golf course managers are beginning to have a difficult time keeping the course green. Salinization should not be a problem with Disi groundwater due to low salinity; however, golf courses irrigated with saline recycled 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 overirrigation. For example, a typical golf course in Tucson, Arizona that is connected to the reclaimed water system spends approximately $500,000 / year on irrigation water. A typical championship golf course in Tucson with cactus species between fairways covers 80 acres (32 ha). The State of Arizona regulated depth of applied irrigation water to golf courses is 4.5 ft/year (1.37 m/year). It is expected that golf courses in Aqaba would use slightly more water than Arizona because they do not have a summer monsoon season (assume 5 ft/year or 1.5 m/year). Thus, the volume applied to an individual golf course would be 1.5 m/year * 32 ha * 10,000 m^2/ha = 500,000 m^3/year. If the cost of fresh water delivered to the golf courses is 1.0 JD/m^3, and the golf course has a well-maintained and efficient irrigation system, then golf courses can expect to pay **500,000 JD /year** for irrigation water (similar to the water expenses for golf courses in Tucson, Arizona). If the course uses recycled water sold at a rate of 0.7 JD/m^3 and the golf course is forced to apply 15 % excess water for leaching, then the cost of water for the golf course would be approximately $400,000 / year. If the golf course uses potable water and has an inefficient irrigation system with 50 % efficiency, then the course can expect to pay **1,000,000 JD/year** for irrigation water.

One alternative might be to allow the golf course to use recycled water or Disi water depending on the availability of the different sources. Because the government regulates the annual supply of water to Aqaba rather than the daily flow rate, the golf course may drill a new well and irrigate with Disi water when reclaimed water is not available. The intermittent use of Disi water may allow the golf course to effectively flush salts from the root zone.

e. TWW use in palms and landscaping.

There are several palm farms, some of which produce dates, and others produce palm trees to be used in landscaping. The following data was largely compiled by Akrum Tamimi and Patricia Bakir.

The Al-Haq farm produces dates. This farm was started by the government in order to utilize (dispose) the secondary treated wastewater from the present treatment plant. They were charged nothing for the water because they were doing a service by disposing of the water, and they are still not charged for this water. Patricia Bakir estimated that Al-Haq farms uses 456,000 m^3/year with a 1,000 m^3/day demand in winter and a 1,500 m^3/day demand in summer. Akrum Tamimi noted that the farm utilized 1,744 m^3/day in April, 2003. Taiseer said that the farm has had trouble with their drip emitters because of the low quality water. There may be an opportunity to help this farm with Geoflow emitters, bubblers, or some other solution that resists clogging by biological growth. Patricia Bakir noted that the farm manager said that they use much more water than they are given credit for, and that they intend to increase their irrigated area by 50 %. It sounds like the Al-Haq farms wants to make sure that their water use is not restricted by the new projects.

The Al-Salam (peace) farm produces palm trees for the future road between Israel and Jordan that will be established in Aqaba. Taiseer said that the planned road would go right by the Aqaba wastewater reuse pilot project (the 100 dunnum farm with fruit and ornamental trees and shrubs that will be irrigated with wastewater). The farm is not irrigated well at this point (according to Bakir) and trees are underwatered and look water deficient. There may be an opportunity to design an irrigation system for this farm. The farm presently uses approximately 400 m^3/day (150,000 m^3/year). I think that a low head bubbler system or pressurized bubbler system may be appropriate here.

The Al-Nakheel farm produces date palms for the city of Aqaba greening program. There are currently 5,000 palms on the site, and it uses 1,250 m^3/day (500,000 m^3/year). Approximately 20 palms per day are removed and planted, and 2,000 palms have been planted so far. The average water use/tree at the Al-Nakheel farm is 1,250 m^3 / day / 5,000 palms = 0.2 m^3 / palm / day = 200 L/day. Because of the health of the palms at Al

Nakheel farm, it may be reasonable to expect that palms may need somewhere in the range of 200 m^3/day (including inefficiencies of the irrigation system).

ASEZA is currently irrigating landscapes on the north side of town with the secondary treated wastewater. Bakir estimated that the current use for this system is 800 m^3/day in winter and 1,200 m^3/day in summer. Total water use is approximately 400,000 m^3/year.

Current TWW use for date palm farms and landscaping in Aqaba is shown in table 2.

Table 2. Treated wastewater use in Aqaba during 2003 (m^3/day).

	Summer	Winter
Al Salaam	400	400
Al Haq	1,000	1,500
Aseza	800	1,200
Al Nakheel	1,250	1,250
Total	3,400	4,100

f. Evaporation from treatment ponds

The treatment ponds have an area of 20 ha. Jamal Reyati stated that maximum pan evaporation in Aqaba (airport weather station) was observed to be 20 mm/day. Thus, he stated, the maximum evaporation from the ponds is 4,000 m^3/day. Based on the similarities in climate between Aqaba and Phoenix, I expect that the evaporation rate decreases in winter to approximately ¼ the summer evaporation rate or 1,000 m^3/day.

Total evaporation during the year from seepage ponds, assuming that fall and spring evaporation are ½ of summer, and winter evaporation is ¼ of summer evaporation is

$$4{,}000 * 90 + 2{,}000 * 90 + 2{,}000 * 90 + 1{,}000 * 90 = 810{,}000 \text{ m}^3\text{/year}$$

Thus, the total expected evapotranspiration from treatment ponds is over four times the annual water use by landscapes.

Because the new wastewater treatment plant will not include ponds, evaporation from treatment ponds will be neglected 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.

g. Seepage from treatment ponds

The ponds are currently being lined by Montgomery so this value should decrease to zero.

h. Fertilizer plants

The three current phosphate plants each use a maximum of approximately 500 m^3/hr. I estimate that the yearly water use by the phosphate plants is approximately 7 million

m^3/year, based on proportion of Aqaba water use by industry (45 %). If they used their full capacity of water, then they would use nearly the entire ASEZA allotment (17 million m^3/year). The new planned phosphate plant that will use TWW will use 6,000 m^3/day. A second new phosphate plant is also planned, but this one will not use TWW. Yearly water use of each of these plants should be approximately 2 million m^3/year.

Phosphate plants pay 1 JD/m^3 for potable water (check this). It is expected that the new phosphate plant will pay 0.7 JD/m^3 for tertiary treated wastewater.

2. Water sources

The major water source in Aqaba is the Disi aquifer. The aquifer is extensive; however, the Country of Jordan has signed an agreement with Saudi Arabia that limits the Jordanian withdrawal from the aquifer. Under the agreement, ASEZA has been limited to 20 million m^3/year, and the rest of the Jordanian water allotment will be piped to Amman. The present Aqaba water system capacity is 17.5 million m^3/year and is controlled by WAJ (Water Authority of Jordan). 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 production is approximately 0.5 JD/m^3 of water. Hotels, ASEZA, and industry are all charged 1.0 JD/m^3. ASEZA will be charged 0.1 JD/m^3 for irrigation water from the tertiary treatment plant and will continue to be charged 1 JD/m^3 of potable water. The palm farms presently pay nothing for the TWW.

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 1 JD/m^3, 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^3/year, and that this plant will be completed in 2005. The first phase of this plant will produce 5.5 million m^3/year.

WAJ has allotted 1.5 million m^3/year for irrigation by ASEZA.

3. Reclaimed water (internal generation)

ASEZA will generate water internally with the reclaimed water plant. The tertiary (mechanical treatment) part of the plant will treat 12,000 m^3/day (4.5 million m^3/year). It is expected that the total wastewater load will increase from 12,000 m^3/day to 18,000 m^3/day between now and 2020. The excess wastewater will be treated in the present treatment ponds that are being lined. I don’t expect much water from these treatment ponds in the summer since most of the water will evaporate (4,000 m^3/day).

Table 3 was compiled by Patricia Bakir. It shows the monthly treatment plant influent and use of the effluent. The excess in evaporation ponds should be available to new projects. However, the mechanical treatment plant will not have evaporation or seepage. Thus, 6,000 m^3/day should be available for the new phosphate plant if it is required.

There will be little excess water until the wastewater influent to the treatment plant increases.

Table 3. Aqaba wastewater treatment plant statistics for 2003.

Month	Inflow (m^3/day)	Seepage (m^3/day)	Evaporation (m^3/day)	Outflow (m^3/day)	Total consumptive use of WWTP effluent Use (m^3/day)	Excess in Evaporation ponds (Excess)(m^3/day)
January	10694	600	1078	9016	3750	5266
February	10385	600	1394	8391	3750	4641
March	10767	600	1941	8226	3750	4476
April	11929	600	2691	8638	4650	3988
May	11914	600	3359	7955	4650	3305
June	12272	600	4261	7411	4650	2761
July	11580	600	4269	6711	4650	2061
August	11874	600	4002	7272	4650	2622
Septemper	12286	600	3360	8326	4650	3676
October	11600	600	2374	8626	3750	4876
November	10892	600	1772	8520	3750	4770
December	10653	600	1229	8824	3750	5074
Total (m^3/yr)	4,163,672	219,000	967,364	2,977,308	1,533,450	1,443,858

4. Projected water balance for Aqaba after completion of tertiary treatment plant.

Values compiled in section four are summarized in table 4. These are estimates based on 5 days research in Aqaba, and the numbers should be confirmed by WAJ and ASEZA. However, the table is a starting point.

The projected TWW use (4,050,000) is approximately equal to the projected production. Thus, there does not appear to be much benefit to encouraging urban residents to use TWW in their gardens. There also does not appear to be extra water available to the golf course. The reduction in palm gardens due to planting of palms in the city landscapes should be offset by the planned expansion of Al Haq farms.

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

Table 4. Water balance for Aqaba.

In	Potential (m^3/year)	Estimated delivery efficiency	Delivery (m^3/year)
Disi aquifer	20,000,000	72 %	14,400,000
Desalination plant	11,000,00	72 %	8,000,000
Total in			**22,400,000**
Internal generation			
TWW	5,000,000	80 %	4,000,000
Total Int. Gen.			**4,000,000**
Out			
Old phosphate plants			7,000,000
New phosphate plant on potable water			2,000,000
ASEZA (hotels etc (20 %)			3,000,000
Golf course			500,000
Residential			7,000,000
Total potable water use			**19,500,000**
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 TWW			2,000,000
Total TWW use			**4,050,000**
Change in Storage			**0**

V. Brief Economic Analysis

The Water Authority of Jordan's (WAJ) selling price of treated wastewater to commercial users is understood to be 0.7 JD/m^3. The selling price of tertiary treated wastewater for ASEZA irrigation is proposed to be 0.1 JD/m^3. Currently, ASEZA pays WAJ 1.0 JD/m^3 for potable water. This implies that WAJ will gain more economic benefit from selling treated wastewater to commercial users than by selling the treated wastewater to ASEZA. Also ASEZA will likely pay a lot more for potable water than treated wastewater (m^3/year water in Central Aqaba * (l.0 - 0.1 = 0.9 JD/m^3)). 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^3. WAJ may then be able to reduce the cost of potable water to ASEZA to the cost of production (0.5 JD/m^3) rather than the 1.0 JD/m^3 that it currently charges. In this way WAJ would still earn more revenue overall 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 Central Aqaba versus potable water. If irrigation water use in Central Aqaba is approximately 200,000 m^3/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 costs for the wastewater distribution network for municipal and small users will add considerably to ASEZA's and to WAJ's costs.

VI. Conclusions

Because of the considerable number of potential large-scale users of treated wastewater (expansion of Al Haq farm, planned golf course, planned expansion of the phosphate plant, 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 higher risk.

Treated wastewater would likely increase irrigation system maintenance, would probably require expensive pressure regulators, and would pose a potential health risk to residents if the operation and maintenance of the WWTP were to temporarily fail. 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. WAJ could probably make more money piping the treated wastewater to golf courses and phosphate plants rather than essentially giving the water away to ASEZA and palm farms.

VII. Future activities in Aqaba

Isam Jaradat has requested help with irrigation system design in Aqaba and with training Aqaba landscape personnel in irrigation system design. The following projects were discussed with Isam while there.

A landscape irrigation course will be conducted this summer if that is agreeable to USAID and ASEZA.

An economic study of different irrigation systems proposed for Aqaba will be conducted (drip, bubbler, or hose irrigation). An evaluation of the wisdom of using the tertiary water in urban landscapes will also be conducted.

The distribution system from the reclaimed water plant to the landscape areas in Aqaba will be constructed. Help is needed to connect irrigation systems to this distribution system and to design reliable and easy to operate and maintain irrigation systems.

Finally, I adapted several irrigation publications for use in Aqaba that were originally developed for use in Arizona. These publications detail methods of irrigation operation calculations. Publications were given to Isam Jaradat. This process will continue.

Two abstracts have been submitted for the Water Management Conference in May, 2004. The first abstract focuses on economic analysis of reclaimed water in Aqaba. The second abstract is an economic assessment of different irrigation systems in Aqaba.