Case Study One

Jordanian Case Study: Zai Water Treatment Plant, 1998

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Introduction

This paper has been prepared to explain a July 1998 incident in which the residents of the Amman west region complained of being supplied with discolored, smelly, and odorous water. The water was supplied from the Dabouq water reservoir, which receives its water from the Zai Water Treatment Plant (WTP). The Ministry of Water and Irrigation (MWI) and the Water Authority of Jordan (WAJ) treated the matter seriously and stopped the supply of water to all users. An investigation committee was formed to investigate the causes of the pollution, with assistance from the World Health Organization (WHO) and the U.S. Agency for International Development (USAID). These reports, however, were not made available to the public, as the matter was considered to be very delicate.

The Ministry of Health (MOH) announced precautionary measures, suggesting that citizens boil their water before use. Despite these actions the problem persisted through July and well into August. A number of Jordanian government agencies and international consultants investigated the problem and concluded that the taste and odor originated from algae in the water, and that the treatment plant processes and operations were insufficient to deal with the magnitude of the problem.

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Investigations were initiated to determine the source of the problem and identified live nematodes in the raw water and dead ones in the treated water. The nematodes were and are still likely to be originating from the Yarmouk River and could also be developing in silt and organic deposits in the bottom of the King Abdullah Canal (KAC), which supplies the Zai WTP. It was also believed that they could have been breeding in the plant's filters, and in wet weather could be washed from the soil into the canal.

On 19 July 1998, spokesmen from MWI and MOH confirmed to the Petra News Agency (PNA) that the water supplied to citizens from the Dabouq was drinkable. The causes of the recent scare had still not been identified, yet they further confirmed that laboratories had proved the water suitable for drinking, but still suggested, as a precautionary measure that the water be boiled for one minute before use.

Acronyms

MWI	Ministry of Water and Irrigation
MOH	Ministry of Health
Zai WTP	Zai Water Treatment Plant
KAC	King Abdullah Canal
WAJ	Water Authority of Jordan
JWSP	Jordanian Water Strategy and Policies
MCM/Yr	Million Cubic Meters Per Year
SWTP	Samra Wastewater Treatment Plant
DWR	Dabouq Water Reservoir
WHO	World Health Organization
PAC	Powdered Activated Carbon
CS	Caustic Soda
RSS	Royal Scientific Society
EPA	US Environmental Protection Agency

Background

The Hashemite Kingdom of Jordan is located to the east of the River Jordan. It has a number of variable topographical features. A mountain range runs through the country from north to south, and the ground slopes gently towards the eastern desert and steeply towards the Jordan Rift Valley. This valley extends from Lake Tiberias to the Red Sea at Aqaba, at a ground elevation of 220 meters below sea level. At about 120 kilometers south of Tiberias is the Dead Sea, which is approximately 405 meters below sea level. The Southern Ghore and Wadi Araba form the southern part of the Rift Valley. To the south of Aqaba, there is 25 kilometers of which stretches along the northern shores of the Aqaba Gulf.

The highland areas in the summer can reach maximum temperatures on average of 32°C (90°F), and 38°C (100°F) for the Jordan Valley and eastern desert. Highland

and desert areas in the winter have temperatures that average between 14 –17°C (57-63°F), and 21°C (70°F) in the Jordan Valley. The highland and desert areas in the winter can reach minimum temperatures on average of 1-4°C (34-39°F), with occasional snowfall, and a minimum of 8°C (46°F) in the Jordan Valley. Jordan's population was 5.2 million in 2000, with a growth rate of 2.8%. Approximately 91% of the population lives in the northwest region of the country, and 52% live in the Amman and Zarka area.

The Water Authority of Jordan (WAJ) was established under Law 18-1988 as an autonomous corporate body with financial and administrative independence and responsibility for water and sewage systems, as well as other related projects in Jordan.

Aim

The aim of this paper is to present the facts and actions that were related to the chemical incident and identify the remedial action taken to prevent any similar incidents occurring in the future.

Water Situation in Jordan [i]

The renewable water resource in Jordan is estimated at about 775 million cubic meters per year (MCM/Yr). This includes 275 MCM/Yr of ground water, and 692 MCM/Yr of surface water, of which 72% can be developed economically. An additional 140 MCM/yr comes from fossil aquifers and a further 50 MCM/Yr is expected to be accessible for urban uses after desalination. The following table shows the projected supply, demand and deficit of water in Jordan:

Year	**Supply**	**Demand**	**Deficit(MCM/Yr)**
1998	857	1.205	(348)
2005	1.042	1.321	(279)
2010	1.250	1.436	(186)
2015	1.283	1.536	(254)
2020	1.287	1.647	(360)

Jordan's Water Strategy and Policies (JWS) [ii]

The Ministry of Water and Irrigation (MWI) issued the JWS Document 10-1997, which provided the foundation and initiative to formally develop policies addressing specific issues facing Jordan's water sector. Four policies that have been developed are:

- Ground Water Management (GWM).
- Irrigation Water (IW).
- Utility Water (UW).
- Wastewater Management (WM).

The water policy's objectives are to outline in detail the statements contained in the JWSP, and set out the Jordanian Government's intentions concerning groundwater management. The aims focus on the development of water resources, its protection, management, and measures needed to bring the annual extraction of water from various renewable aquifers to a sustainable rate.

Water Resources

Water sources in Jordan consist of the following:

1. **Surface Water.** Surface water can be defined as water, which flows permanently in rivers, springs and flood flows. Permanent water flow in rivers, valleys and springs varies monthly. It is the quantity of and duration of rainfall that contributes directly to the quantity of ground water. Surface water resources average about 693 MCM/yr and are distributed unevenly in 15 basins, with high inter-seasonal and inter-annual variations. The collective long-term average base flow for all basins is approximately 359 MCM/Yr, and the flood flow is estimated at 334 MCM/Yr.
    a. The Yarmouk River Basin is Jordan's greatest source of surface water and amounts to approximately 40% of the annual total. This includes water flowing from Syrian territories within the Yarmouk Basin. The Yarmouk River is a major tributary of the King Abdullah Canal, which is considered to be the backbone of agricultural development in the Jordan Valley.
    b. Other surface water resources include the Zarka River and several wadis,[iii] where treated wastewater from As Samra Wastewater Treatment Plant (SWTP) and other treatment plants serves the Amman and Zarka regions. To date about 300 MCM/Yr of surface water has been developed for irrigation, municipal and industrial use. Full development has been impeded by regional considerations, related riparian rights of the Yarmouk River, and the high costs of developing and transporting the remaining sources of water, which are estimated at $11 per cubic meter.
    c. Priority has been given to the construction of dams and irrigation projects in the Jordan Rift Valley in order to maximize the utilization of its water resources before it is discharged to the Dead Sea or the Jordan River.
2. **Ground Water.** Ground water is considered to be the major, and in some areas of Jordan, the only water resource. There are eleven renewable ground water reservoirs in Jordan with a total sustainable yield of 275 MCM/Yr. Sustainable yield varies from one aquifer to another.[iv] Ground water can be divided into two types:
    a. Renewable groundwater resources. This is the quantity of water that percolates to aquifers through pores or cracks in rock formations. This water quantity has an annual average that depends on the annual rainfall, and on

the recharge surface area of the aquifer. Thus water abstraction from an aquifer has a direct or indirect effect on the natural discharge from that aquifer, including the spring flow. The long-term yield of renewable groundwater resources has been estimated at 275 MCM/Yr. Some of these renewable groundwater resources are presently being exploited to their maximum capacity and in some cases beyond the safe yield. Overexploitation of groundwater aquifers, beyond their annual potential renewable quantities, has and will contribute significantly to the degradation of ground water quality in the exploited aquifers, and endangers the sustainability of these resources for future use.

b. Nonrenewable groundwater resources. This is the water that is stored in aquifers inside the earth, and is sometimes found under renewable groundwater aquifers. The volume of this water depends on the thickness and storage capacity of the ground layer in which it is found, and on the horizontal layout of that layer. The main nonrenewable groundwater resource in Jordan exists in the Disi aquifer in the south, with a safe yield of 125 MCM/Yr for 50 years. Other nonrenewable groundwater resources are estimated at an annual safe yield of 18 MCM/Yr.

3. **Wastewater.** Treated wastewater is generated at 17 wastewater treatment plants, and is an important component of Jordan's resources. Due to the topography and the concentration of urban population above the Jordan Valley escarpment, the majority of treated wastewater is discharged into various watercourses flowing into the Jordan Valley, where it is used for irrigation. About 70 MCM/Yr of treated wastewater was discharged in 1999 in the watercourses or used directly for irrigation. As the volume of water used by Jordan's municipal and industrial sector increases, wastewater volumes will increase. By the year 2020, it is expected that the volume of treated wastewater available will amount to 230 MCM/Yr and will constitute a significant portion of the total irrigation demand and hence supplement the demand on renewable groundwater resources. Thus, treated wastewater is considered an essential element in Jordan's water strategy.

Water Quality and Environment

Jordan has adopted the Jordan Drinking Water specification #286. This is based on international water quality standards and guideline values developed by the WHO, United States Environment Protection Agency (EPA) and others. These standards are often stringent and are based on the worst-case assumptions, which may not be relevant to local conditions, or even affordable in some cases.

Jordan has witnessed some water quality deterioration during the past two decades due to various causes such as industrial pollution, overuse of agrochemicals, drainage water, over pumping of aquifers, and others.

Water Management in Jordan

Resource Management. The MWI has adopted an integrated approach to water resource management. Enhanced supply measures will be adopted for surface waters (e.g. surface /subsurface storage, reducing evaporation, seepage losses, and protection of water quality). Ground water abstractions will be controlled and reduced to within a safe yield of the aquifers and enforcement will be strengthened. Wastewater will be collected, and treated wastewater will comply with national standards so it can be used for agriculture and ground water aquifer recharge. A wastewater master plan will be developed for un-served areas of the country. The potential technical and economical feasibility of developing brackish ground water resources is continuing to be assessed throughout Jordan.

Wastewater Management. The WAJ has adopted a wastewater management policy, which addresses wastewater as a water resource and includes its development, management, collection, treatment, reuse and regulation.

This policy addresses many topics such as resource development, resource management, wastewater collection, reuse of treated effluent and sludge, pricing, legislation, institutional arrangements, standards, regulations, quality assurance, public sector participation, human resource development and finally, public awareness.

Water System Service Levels

Jordan's existing water distribution system and services are being improved and expanded. This improvement will include technical support and management. Old and damaged supply and distribution systems will be rehabilitated, and inadequacies will be corrected. Service issues include:

- Maintaining water quality in the distribution network.
- Frequency of water supply delivery to customers.
- Response time for repair of network leakage, etc.
- Reduction in waiting times for water and wastewater connections.
- Reduction in waiting time for resolution of customer complaints.

Water Supply Problems in Jordan

Within Jordan the areas that supply water for the country are scattered, which results in high costs for transfer systems in order to transport the water from one region to another. These long distances between supply locations can be up to 100 kilometers apart and therefore pipelines, pumping systems and electrical networks are required, which are costly. Deep-water aquifers can also reach depths of 300 meters, which causes problems by incurring high costs when drilling water wells. Consequently there is often a low productivity of water, which reduces drastically the supply of water being extracted from the sources.

Jordan also has difficult topography, which includes areas that are elevated 1000 meters above the mean sea level, as well as areas that are far below sea level. There are also rapid changes in the population density in certain regions, which can overload the water supply network. Consequently there is a continuous need for the renewal of water supply systems in order to cope with these changes and the growing demand on water.

Water Pollution

Water contamination can be defined as "the contamination of water by foreign matters such as microorganisms, chemicals, and industrial wastes, or sewage." Such contamination deteriorates the quality of the water and renders it unfit for use. Water pollution sources can be classified as:

1. **Municipal.** Municipal water pollution consists of wastewater from homes and commercial establishments.
2. **Industrial.** Industrial wastewater differs within and among industries. The impact of the industrial discharge depends on their collective characteristics such as biochemical oxygen demand, the amount of suspended solids, and the amount of specific organic and inorganic substances.
3. **Agricultural.** Agricultural contamination is the sediment from the erosion of cropland and the compounds of phosphorus and nitrogen that originate partly in animal wastes and commercial fertilizers. It also includes commercial livestock and poultry farming as a source of many organic and inorganic pollutants of surface and ground water.

Water Treatment

Water treatment is one of the ways of converting surface and ground water into drinking water. The Zai Water Treatment Plant (WTP) is the only water treatment plant in Jordan, and there are only six distillation plants for ground water treatment, which are scattered across the country.

The Incident

Issue

The Zai Water Treatment Plant's (Zai WTP) failure to produce drinkable water for the citizens of Amman and its supplying them water that was odorous and contaminated with algae.

Zai Water Treatment Plant (Zai WTP)

The Zai WTP is the only water treatment plant within Jordan, and is considered to be the main component of the Jordan Domestic Water Supply Project, constructed during the 1982–1985.

Location
The plant is located in the Zai region on the eastern heights near the city of Salt.[v]

Plant Objectives
The aim of the Zai WTP is to produce water that is chemically and bacteriologically safe for human consumption. The treated water should be aesthetically acceptable to the consumer and free from apparent turbidity, color, odor, and objectionable taste. The quality of produced water pumped from the Zai WTP should comply with Jordan's Drinking Water Specification #286-2001,[vi] Jordan's Specification #300/1980 and the World Health Organization (WHO) Drinking Water Directives and Regulations.

Zai WTP Water Sources
Raw water is conveyed to the Zai WTP through KAC[vii] and from the intake of the Pumping Station (PS) at Deir Alla in the Jordan Valley. The canal conveys water from:
1. The Yarmouk River[viii]
2. Wadi El-Arab Dam[ix]
3. Al Mukhaibeh well[x]
4. Lake Tiberias[xi], and
5. Ain Hazier, Al-Sharieah and a few other water springs and valleys

The physical treatment process consists of treatment by Clo2, rapid mixing, flocculation, sedimentation, intermediate chlorination, filtration, post chlorination, filters backwash system, metering, chemical feed systems, pumping units and controls.

Conveyance System
1. King Abdullah Canal Conveyance system conveys raw water from many sources and extends from the Yarmouk River in the north to the intake station at Deir-Alla (Sketch-1).
2. Deir-Alla – The Zai WTP Dabouq Conveyance System conveys raw water from the intake system in Deir Alla to Zai WTP, and treated water from the Zai WTP to the Dabouq Water Reservoir (Sketch-2).

Plant Design
Zai WTP has a nominal design capacity of 45 MCM/Yr (123.000 M^3/day), and a hydraulic capacity of 130% of its nominal design.[xii] The water is diverted from the KAC at Deir Alla, where it is screened, and then conveyed through a series of five pump stations, balancing tanks and pipelines to the Zai WTP. The treated water is then pumped to the Dabouq reservoir and from there conveyed by gravity into the city. This overall conveyance and treatment system is shown on the Schematic Diagram of the Deir Alla-Zai-Conveyance System (Sketch-2).

System Description

From the Zai WTP, the treated water proceeds through pump station 5, through a 1,200mm diameter pipe and on to the Dabouq (Terminal) reservoir. Water is then transmitted from the Dabouq reservoir via a 900mm pipe and then pumped into the Muntazah reservoir from where it flows by gravity.

The water in this canal is slow moving, and therefore the canal tends to accumulate silts, mud, and organic matter on its floor. This accumulation, combined with the long detention time and exposure to sunlight, promulgates algae growth. In order to reduce this algae growth, the addition of ferric chloride to the raw water at the head of the open canal has been initiated to precipitate out phosphorous in the water.

Phosphorous is one of the chemicals that enhance the growth of algae. The conveyance and treatment system is shown graphically in sketch-2. The balancing tanks at pump stations 1, 2, 3 and 4 are open to the atmosphere, and they float on the system; that is, the water is not routed through them. The water level simply rises and falls within them, depending on the imbalance between the water delivered and water pumped.

Consequently, the water in these tanks can stagnate and grow algae. This can result in slugs of water loaded with algae having a potential algae-secreted taste with odorous compounds entering the conveyance system and the Zai WTP. To minimize this algae-laden water entering the conveyance system and the Zai WTP, the operators regularly flush the water out via the reservoir overflows.

Water treatment processes are conventional and consist of:

1. Flow balancing and control.
2. Mechanical rapid mixers and flocculators for chemical coagulation and flocculation.
3. Rectangular and horizontal flow type sedimentation basins.
4. Dual-media rapid gravity filters.
5. Two-compartment treated water clear-wells.

Chemicals used include:

1. Potassium permanganate for pre-oxidation and as an aid in taste and odor control.
2. Powdered activated carbon (PAC) as the primary chemical for taste and odor control.
3. Aluminum sulfate (alum) as the primary coagulant.
4. Cationic polyelectrolyte (polymer) as a coagulant aid.
5. Anionic polymer as a flocculation aid; and chlorine to control aquatic growth, contribute to the control of taste and odor, and function as the primary disinfectant.

Provision was also included in the original design to add sodium hydroxide (caustic soda), but this chemical was found not to be needed and was never used. Provision was also made in the design for a spare chemical, which has never been used. The pH of the raw water is normally greater than 8.0. This is well above the optimum pH for alum coagulant. The pH of the water leaving the plant was 7 plus. This indicates that excess alum was being used to depress the pH closer to the optimum value. The anionic polymer had been relocated from the settled water application point to the last stage of flocculation to aid in the aggregation of particles.

Some experts did not recommend an increase to the dosage of chemicals used at the Zai WTP, with the exception of the PAC dose range. They agreed upon the need to increase the capacity of the PAC feeders and slurry pumps. The dosing capacities of the potassium permanganate, chlorine, and polymer feeders were adequate.

MWI and WAJ experts considered taking the Israeli approach to water treatment, including their pre-treatment methods. Israel's main water source is Lake Tiberias. They pump the water into a canal, which is then discharged into a large open reservoir. As the water enters the reservoir, a coagulant and an acid are added, and hydraulic flocculation follows. The water then traverses the reservoir, which is in fact a large sedimentation basin. At this point, other than the addition of chlorine, the water receives no further treatment.

The Israelis have conducted pilot plant studies and now plan to add ozonation and filters after the water has been in the settling reservoir basin. In effect, apart from the addition of ozone, the treatment process is the same as that used at the Zai WTP. In fact, the pretreatment at the Zai WTP is a more controlled and effective system than the Israeli pre-treatment system. The more concentrated the treatment processes are, the more manageable, effective, and efficient they will be. To diversify treatment processes complicates management, communication, and the control of the overall treatment process.

Potential Causes for the Taste, Odor and Nematode Problems[xiii]

The quality of the raw water sources and the warmer summer temperatures in early July 1998 initiated the taste and odor problems. Algae in the raw water sources, with the conveyance systems promoting their further development, along with the inability of the Zai WTP management and operators to treat the water at full plant capacity, was due to inexperience, and caused primarily by insufficient PAC metering capacity.

The taste and odor problems were far greater than any experienced before, but the plant's staff failed to respond quickly enough to avoid the catastrophe that resulted.

The plant had been running successfully for 10 years without an incident like this. At no time was more than 10 milligrams per liter (mg/L) of PAC needed. However, in this incident, regulations required that water production had to be cut back to allow the existing feeders to add 60mg/L of PAC and did not go into detail as to how this could be implemented. However, each of the two PAC volumetric feeders had been rated at 2.7 m3/d – about 10mg/L at the design flow of 123,000 m3/d. The PAC feeders therefore cannot feed PAC in excess of about 10mg/L at the design flow.[xiv] The plant had previously controlled taste and odor in the raw water (in 1997, for example) by using an average of only 10.2 mg/L of PAC, plus 10.3 mg/L of potassium permanganate and 2.8 mg/L of chlorine.

In one way, this incident did have the benefit of identifying nematodes as a future issue. Now that nematodes have been recognized as being present in the raw water and posing a potential health problem, they must be considered in all plant modifications to ensure their inactivation and removal.

The multiple water sources supplying raw water to the Zai WTP contained algae and nematodes. This is something that cannot be easily controlled or economically addressed. The scope of work relating to this incident is limited to the Deir Alla - Zai WTP – Water Conveyance System. However, the fact that the raw water sources do not contain algae and nematodes must be assumed as a given, and their impact on the treatment plant minimized, by limiting their growth in the conveyance systems. This is because the water in the KAC is primarily for irrigation purposes and the canal is only used to store water.

The water velocity in the canal is often slow causing silt, mud, and organic matter to accumulate on the canal floor. This then becomes a potential breeding ground for nematodes and a further source of bad taste and odor. Adding ferric chloride to precipitate out phosphorous, as is currently practiced, can actually exacerbate the situation. These algae blooms could therefore have the potential to cause severe taste and odor problems. Similarly, the resuspension of decaying organic deposits due to increased water velocities, or other reasons, could further add to the taste and odor problems with the water and the resuspended nutrients could encourage algae blooms.

The contributing factors for an algae bloom are complex. They include the correct combination of elements that contribute to an algal bloom, nutrients and their respective combination, water temperature, sunlight, and rainfall. These are consequently difficult to predict with any degree of accuracy. Storm run-off from the areas traversed by the canal can also contribute to waters with increased nutrients and therefore the potential for algae proliferation. These run-offs may also add to the nematode population in the canal water.

Both Giardia Lamblia and Cryptosporidium Pathogenic Protozoan organisms are possible contaminants in the Zai WTP surface water source. There are no water quality standards for these organisms in Jordan. Despite this, both of these organisms can be fatal to immune deficient people such as infants, the elderly, and those on kidney dialysis machines. However, these organisms can be inactivated and removed to acceptable levels through disinfections and good plant operation.

Analyses and Conclusions

1. There has been no history of catastrophic equipment failures, operating problems, or unsafe working conditions previously.

2. The incident had a large impact on Jordanian citizens living in the western Amman region, and had no international or regional relevance.
3. Plant operation was carried out within the standard operating procedures, and has been operating in the same manner for the last twelve years, with an accident free record.
4. There were no safety or maintenance violations that could have led to such an incident.
5. ZAI WTP is managed by the Jordan Water Authority (JWA), and had a clean, safe operational record. Despite this the then Minister of Water & Irrigation, Dr. Monther Hadadeen, made two conflicting press remarks. These indicated that the ZAI WTP staff had failed to react to the problem faced and were late to shut down the water supply, claiming that the plant had failed to cope with the problem sufficiently.
6. MWI and WAJ took a chain of actions. These included:
   a. Stopping the water supply to the Amman region.
   b. Providing citizens with clean drinking water from other supplies.
   c. Forming an investigation committee to pin point the causes of incident.
   d. Calling on the WHO and other specialized teams from Germany, Norway and the USA for analysis and recommendations.
   e. Maintaining a very close watch on all possible causes of the incident through monitoring raw water sources leading to the ZAI WTP.
7. Citizens of Amman were supplied with unpleasant water that had a bad smell and was contaminated with algae for few days
8. According to the Ministry of Health's official spokesman, there were no medical reports indicating any health problem suffered by citizens of the affected region.
9. The incident had no local environmental consequences and was limited to a specific region.
10. The incident did not have any economic affect on the community, apart from local citizens having to buy bottled drinking water for some time. In addition the government provided citizens with drinking water from other sources by tankers, and excused citizens in the affected region from paying their water bills for three months.
11. A more stringent monitoring system was enforced by JWA, to make sure that all drinking water supplied by its distribution system followed the Jordan Drinking Water Specification #286-2001.
12. WAJ has now contracted the Royal Scientific Society (RSS) Laboratory to monitor the water sources in Jordan. The contract covers the Zai WTP and its conveyance system.

Recommendations

1. Relocate PAC application points to the vault on the raw water line upstream with the regulating reservoir.
2. Use ferric sulfate for coagulation instead of the alum used in the plant.
3. Increase the capacity of powdered activated carbon feeders and slurry pumps to 35 mg/L each at full plant capacity.
4. Relocate the application of potassium permanganate to the raw water from the present location.
5. Add chlorine dioxide to the raw water at the intake pumping station as primary disinfectant and to aid in taste, odor and nematode control.
6. Add a perforated inlet wall to the fluctuation basin to reduce short-circuiting in the first stage, to improve fluctuation, and to make permanent the application points for flocculant polymer aid at the second and third stage flocculators.
7. Convert the existing mechanical electrical motor driven rapid mixer for the coagulant chemical and coagulant aid to hydraulic flash mixing. This would utilize the available head at the plant and creating savings in electrical and chemical costs.
8. Add perforated outlet walls in the sedimentation basin and abandon the finger weirs and troughs, to improve the basins effectiveness in removing fine floc and minimize carryover on to the filters.
9. Modify the filter operations and controls to allow for the elimination of the initial turbidity spikes immediately following the startup after the back-wash.
10. Use a filter aid polymer to help in the performance of the filters and in the removal of dead nematodes.
11. Replace the existing filter surface wash water system with an air scour method for full-depth filter media cleaning.
12. Convert the constant speed water recovery pumps to variable speed pumps.
13. Modify the piping for the storage tanks at four of the raw water pump stations, and add new piping to avoid stagnation and algae growth.
14. Add ferric chloride to the raw water at the head of the KAC to precipitate out phosphorous, one of the nutrients that algae depends upon.

References

i A comprehensive National Water Data Bank (NWDB) has been established and kept at the MWI, and will be aided by a Decision Support Unit. Additionally, this NWDB will be supported by a monitoring program, data collection system unit, data entry, update, data processing & dissemination, and will become a terminal regional data bank set up. (http:llwww.mwi.gov.jo/watersituationl.htm).

ii JWS has been issued since, and reviewed annually. For more see JWS/2000, or any newer edition.

iii Wadi is the Arabic name for valley.

iv JWS & P, pp18-19.

v Salt is 10 miles west of Amman.

vi Annex -2.

vii The KAC is an open concrete canal used primarily for irrigation, with a design capacity of (20) m3/sec at the initial entrance, reducing to (2,3)m3/sec. At the end of the canal, and is 100 km long, approximately 65 kilometers to the point of the Deir Alla intake. Conveys water from the different sources for agriculture purposes.

viii Yarmouk River. One of Jordan River sources, Yarmouk river flows through Syrian lands, and forms the Natural international boundaries between Jordan and Syria, meets with Jordan River about (5) km south of Lake Tiberius. Yarmouk River water is diverted to KAC through a receiving canal.

ix Wadi El-Arab Dam, is (82.5) meters high located 3 Km east of KAC. The Dam total capacity is (20) m m3 mainly used for irrigation of (12500) donums, providing population in the area with their need of drinking & house use water, Produce electrical power and supply KAC with raw water.

x AL-Mukhaibeh Wells. Wells are located at (8) km east of Adasiah Tunnel, Water is transferred through a 10 km long cement open canal, at a flow rate of (1.5)M3/Sec, to a point 500 meters from the tunnel. Total water supplied is about (16) MM3/Yr.

xi Lake Tiberias. After the Jordanian – Israeli Treaty was signed in 1994, Jordan started to about (50) MM3/Yr, from Lake Tiberias through a 32” pipe line from the lake to KAC entrance point.

xii The Japanese government has submitted a grant for the improvement of water supply system to the Greater Amman area, which included the improvement of Zai WTP to a capacity of (90)MCM/Yr.

xiii American Expert Michael Ring from Stanley Company has given an expert opinion on water incident in Jordan to press and said Zai WTP has been designed to treat running surface water only, and not stagnant water, of that kind that comes from lake Tiberias, this meant that the Zai WTP is not qualified to treat water with organs, materials, algae, or any other unidentified materials. Source: www.jordanembassyus.org.+zai+water+treatment.

Annex - 1

Algal Types Found in Clean Water and Polluted Fresh Water

Algal Group	Clean Water	Polluted Fresh Water	Wastewater Stabilization Ponds
Blue-Green	Aphanotheca Microcoleus	Phormidium Merismopedia Anabaena Oscillatoria Gloeocapsa Lyngbya Arthrospira	Spirulina Schizothrix
Green	Ankistrodesmus Ulothrix Staurastrum Lemanea Rhizoclonium Chladophora Micrasterias Hildenbrandia	Tetraedron Chlorococcum Spirogyra Chlorella Actinastrum Stigeoclonium Closterium	Closteridium Closterium Cosmarium Scenedesmus Golenkinia Polyedriopsis Planktospaeria Diacanthox Dictyosphaerium Chodatella Closteriopsis Schroederia
Flagellates	Rhodomonas Chrysococcus Phacotus Chromulina	Euglena Chlamydomonas Carteria Lepocinclis Pyrobotrys Phacus Chlorogonium	Chlamydomonas Massartia Pteromonas Cryptomonas Chroomonas Vacuolaria
Diatom	Surirella Cyclotella Navicula Meridion Pinnularia Cocconeis	Gomphonema Nitzschia	-------

Table 1-1

Algal Group	Algal Species	Odor when algae are		Taste
		Moderate	Abundant	
Blue-Green	Anabaena	Grassy, Musty	Septic	----
	Anacystis	Grassy	Septic	Sweet
	Gomphosphaeria	Grassy	Grassy	Sweet
	Oscillatoria	Grassy	Musty	----
	Rivularia	Grassy	Musty	----
	Aphsnizomenon	Grassy, Musty	Septic	Sweet
Green	Actinastrum	----	Grassy, Musty	----
	Chlorella	----	Musty	----
	Closterium	----	Grassy	----
	Cosmarium	----	Grassy	----
	Gloeocystic	----	Septic	----
	Pediastrum	----	Grassy	----
	Scenedesmus	----	Grassy	----
	Spirogyra	----	Grassy	----
	Staurastrum	----	Grassy	----
	Ulothrix	----	Grassy	----
Flagellates	Ceratium	Fishy	Septic	Bitter
	Chlamydomonas	Musty, Grassy	Fishy, Septic	Sweet
	Euglena	----	Fishy	Sweet
	Glenodinium	----	Fishy	----
	Peridinium	Cucumber	Fishy	----
	Synura	Cucumber,	Fishy	Bitter
	Volvox	Muskmelon	Fishy	----
		Fishy	Fishy	
Diatom	Cyclotella	Geranium	Fishy	----
	Diatoma	----	Aromatic	----
	Fragilaria	Geranium	Musty	----
	Synedra	Grassy	Musty	----
	Tabellaria	Geranium	Fishy	----
	Melosira	Geranium	Musty	----
	Asterionella	Geranium	Fishy	----

Table 1-2

Algal Group	Filter-Clogging Algae	Algae Interfering With Coagulation	Algae Causing Coloration of Finished Water (Color)
Blue-Green	Anabaena Anacystis Oscillatoria Rivularia	Anabaena Gomphosphaeria	Anacystis (Blue – Green) Oscillatoria (Purple-Red)
Green	Chlorella Closterium Palmella Spirogyra Tribonema Ulothrix	-----	Cholrella (Green) Cosmarium (Green)
Flagellates	Ceratium Peridinium Dinobryon Trachelomonas	Euglena	Ceratium (Rusty Brown) Chlamydomonas (Green) Euglena (Red)
Diatom	Cyclotella Tabellaria Cymbella Diatoma Fragilaria Navicula Nitzchia Asterionella Synedra Melosira	Synedra Asterionella	-----

Table 1-3

Annex - 2
Drinking Water Test Parameters & Limits

Unit	Parameter	#	unit	Parameter	#
SU	PH	2	°C	Water Temp	1
µs/cm	EC	4	Mg/L	DO	3
Mg/L	T – P	6	Mg/L	NO3	5
Mg/L	Br	8	Mg/L	PO4	7
Mg/L	Na	10	Mg/L	T.Kj - N	9
Mg/L	Mg	12	Mg/L	Ca	11
Mg/L	Cl	14	-	SAR	13
Mg/L	HCO3	16	Mg/L	B	15
Mg/L	TSS	18	Mg/L	TDS	17
MPN/100mL	TTCC	20	MPN/1oomL	TCC	19
Count/mL	Total Algae Count	22	Egg/L	Intestinal Nematodes	21
Mg/L	As	24	Mg/L	Al	23
Mg/L	Cd	26	Mg/L	Ba	25
Mg/L	Cr	28	Mg/L	Co	27
Mg/L	Fe	30	Mg/L	Cu	29
Mg/L	Li	32	Mg/L	Hg	31
Mg/L	Ni	34	Mg/L	Mn	33
Mg/L	Se	36	Mg/L	Pb	35
Mg/L	Mo	38	Mg/L	Zn	37

Test	Unit	Limit	Absolute Maximum Limit
Cd	mg/ L	0.003	--
Cr	mg/ L	0.05	--
CN	mg/ L	0.07	--
Hg	mg/ L	0.002	--
Ag	mg/ L	0.1	--
Ni	mg/ L	0.07	--
Sb	mg/ L	0.005	--
TCC	MPN/100 ml	< 1.1	--
TTCC	MPN/100 ml	< 1.1	--
Free Living Nematodes (Larvae)	Count / 5L	1 alive / L	--

Table – 2

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SO4	mg/ L	200	500
F	mg/ L	2.0	--
NO2	mg/ L	2.0	--
Al	mg/ L	0.1	0.2
Fe	mg/ L	0.3	1.0
Mn	mg/ L	0.1	0.2
Cu	mg/ L	1.0	1.5
Zn	mg/ L	3.0	5.0
As	mg/ L	0.01	--
Ba	mg/ L	1.5	--
Pb	mg/ L	0.01	--
Se	mg/ L	0.05	--
B	mg/ L	2.0	--

Test	**Unit**	**Limit**	**Absolute Maximum Limit**
pH	SU	6.5 – 8.5	--
Color	PCU	10	15
Turbidity	NTU	1.0	5.0
Cl2	mg/ L	0.2 – 1.0	--
TTHM's	mg/ L	150	--
ClO2	mg/ L	800	--
ClO3	mg/ L	--	--
NH4	mg/ L	0.5	0.5
NO3	mg/ L	50	70
TDS	mg/ L	500	1500
TH (as CaCO3)	mg/ L	300	500
MBAS	mg/ L	0.2	0.5
Na	mg/ L	200	400
Cl	mg/ L	200	500

King Abdullah Canal