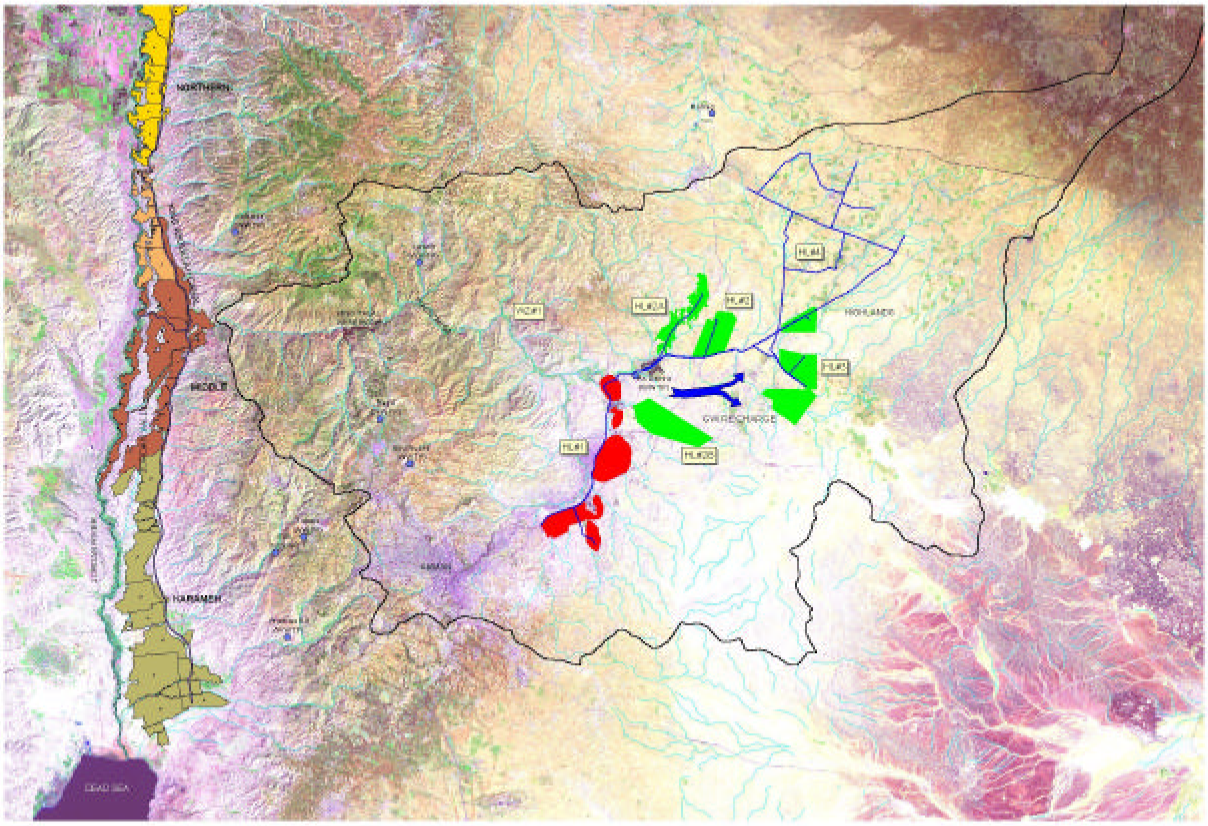
MINISTRY OF WATER AND IRRIGATION
Water Resource Policy Support

WATER REUSE COMPONENT

PLAN FOR MANAGING WATER REUSE IN THE AMMAN–ZARQA BASIN AND THE JORDAN VALLEY



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ABBREVIATIONS

AES	Agricultural Extension Service
AMO	Agricultural Marketing Organization
AZB	Amman–Zarqa Basin
BOD_5	Biochemical Oxygen Demand, Five Day
COD	Chemical Oxygen Demand
DEH	Directorate of Environmental Health
DFS	Directorate of Food Safety
DO	Dissolved Oxygen
EUREP	Euro-Retailer Produce Working Group
FCC	Fecal Coliform Count
GAP	Good Agricultural Practices
I&M	Industrial & Municipal
IAS	Irrigation Advisory Service
JV	Jordan Valley
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
km^2	Square kilometers
KTR	King Talal Reservoir
Li	Lithium
m^3	Cubic meter
M&I	Municipal and Industrial
MCM	Million cubic meters
Mn	Manganese
Mo	Molybdenum
MOA	Ministry of Agriculture
MOH	Ministry of Health
MWI	Ministry of Water and Irrigation
NCARTT	National Center for Agriculture Research and Technology Transfer
NIR	Net Irrigation Requirements
NRA	Natural Resources Authority
TDS	Total dissolved solids
TO	Task Order
USAID	United States Agency for International Development
V	Vanadium
WAJ	Water Authority of Jordan
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

The Hashemite Kingdom of Jordan has a critical shortage of water resources. Water use per capita is among the lowest in the world, and the urban population continues to grow, with increasing water demand and, subsequently, increased volumes of wastewater. The majority of the treated wastewater is already reused indirectly in agriculture. As such, reclaimed water has become a major component of the national water budget, particularly in the densely populated Amman–Zarqa Basin (AZB) and Jordan Valley (JV). With the supply of freshwater being very limited and the demand expected to continue to increase, it is vital that the anticipated increases in reclaimed water be managed to meet, at least in part, national and regional demands.

The key policy objectives of this draft water reuse management plan are to use reclaimed water, where practical, to exchange for present and future uses of freshwater; and to maximize the returns from the reclaimed water resource. In addition, the plan has to consider other requirements such as protecting the public, conserving resources (water, soils/land, natural vegetation, etc.), complying with international treaties, and ensuring environmentally sound practices.

The planning process consisted of four major elements:

1. Develop an understanding of the past, present, and future situation;
2. Identify and characterize options for using additional supplies of reclaimed water;
3. Develop practical scenarios (combinations of prioritized options) for allocating reclaimed water; and
4. Investigate and define supporting actions for the sustainable management of water reuse.

The development of this plan has been iterative, incorporating continuous input and feedback from stakeholders, the review of available data and information, and the implementation of specific technical studies.

The Quantity and Quality of Reclaimed Water Resources

The volume of reclaimed water available in the AZB is expected to grow from approximately 61 MCM/year in 2000 to almost 180 MCM by the end of the planning period, 2025. Over 90% of this will originate from the As Samra facilities, which include the rehabilitation of the existing As Samra wastewater treatment plant (WWTP) and the planned Zarqa WWTP downstream.

The quality of the reclaimed water is expected to improve with the implementation of the new facilities at As Samra. However, of the main constituents now of concern in irrigated agriculture in the AZB and JV - salts (specifically chlorides), microbiological contamination, and nitrogen (at sensitive growth stages of certain crops) - only nitrogen will be significantly reduced at point of use. The improvements at As Samra will reduce the microbiological contamination, but other secondary sources will continue to significantly contaminate the water in wadi Zarqa.

From the available data, the levels of trace elements and heavy metals in the effluent are lower than those specified by the relevant Jordanian standards, which, with the exception of zinc and boron, are as stringent as the United States Environmental Protection Agency’s water reuse guidelines (EPA, 1992). Anticipated growth in industrial development within the AZB could increase the levels of these constituents in the wastewater.

Present Use of Reclaimed Water

The reclaimed water of the AZB is used in three ways: planned use for agriculture and trees within the immediate vicinity of the wastewater treatment facilities; unplanned use for agriculture in the wadi downstream; and indirect use for agriculture, after mixing with natural surface water supplies and freshwater supplies from the King Abdullah Canal, in the Middle and Karameh (southern) Directorates of the JV.

Future Options for Using Increased Volumes of Reclaimed Water

Other than using reclaimed water for intimate domestic purposes, which was not considered viable because of sociological/psychological public acceptance issues, a broad range of options was considered: commercial irrigation (agriculture, ornamental nurseries, and forestry); municipal (landscape, recreational, and residential); industrial; and others such as hydropower, artificial groundwater recharge, meeting international treaties, and environmental enhancement.

The highlands, Wadi Zarqa, and the JV areas were each examined to determine which options were practical and at what scale. The planning process ensured that potential options were not rejected without careful consideration. Also, the process was iterative, adding in variations of options as investigations revealed additional opportunities for using reclaimed water.

Detailed investigations (pre-feasibility level studies) were conducted on potential options. Early iterations determined that pumping and conveying reclaimed water from As Samra to the highlands for commercial irrigation were not economically viable, and could be justified only where it was to be exchanged for present groundwater use. In addition, although sites for artificial groundwater recharge appear technically feasible in the highlands, the importance of the underlying aquifer makes it unsuitable for consideration in the planning time frame (up to the year 2025). Artificial groundwater recharge in the JV was found to have merit as a more drought-resistant alternative to surface storage.

From the investigations, seven priority options were identified and detailed:

1. Exchange with groundwater in the Dhuleil–Hallabat area in the highlands;
2. Exchange with groundwater, and meet future demands by industrial and municipal reuse, in the Hashemite–Zarqa area;
3. Intensification of irrigated agriculture in Wadi Zarqa;
4. Intensification and expansion of irrigated agriculture in the Karameh (southern Directorate in the JV;
5. Intensification of agriculture in the Middle Directorate in the JV;
6. Exchange with surface water in the Northern Directorate in the JV; and
7. Development of commercial irrigation at the minor WWTPs.

The characteristics and conclusions from the investigations of these options are summarized in Table ES-1.

Table ES-1. Summary of Characteristics and Conclusions from Analysis of Priority Options

OPTION	DESCRIPTION	DEMAND FOR RECLAIMED WATER	FRESHWATER CONSERVED		CAPITAL COSTS	ECONOMICS OF AGRICULTURE	INSTITUTIONAL RESPONSIBILITY	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION ISSUES	PRIORITY
		MCM	Volume MCM	Cost fils/m^3	JD million						
Dhuleil–Hallabat Irrigation Network.	Exchange with groundwater for agriculture in the highlands.	9.5	9.5	610	35	Not viable unless exchange with groundwater considered.	WAJ. Water user organizations.	Conserves groundwater.	Risk of contaminating important aquifer.	Effluent quality. Ensure O&M costs available. Farmer involvement.	Moderate.
Industrial Reuse in Hashemite –Zarqa area.	Exchange with groundwater. Meet future demands.	13	13	400	13	Economics for use in industry are very good.	Industries. Private ownership of network. Government as facilitator.	Conserves groundwater. Power plant required to use reclaimed water.	Cooling system discharge could increase salt discharges to wadi.	Reliable effluent quality. New power plant by 2004. Stakeholder coordination vital.	High.
Wadi Zarqa.	Intensification of agriculture.	3.3	0	N/A	0	Good.	Farmers.	Low cost.	Health risk. No freshwater conserved.	Cooperation from farmers on health risk.	
Karameh Directorate	Intensification/ expansion of agriculture.	40	0	N/A	4.2	Moderate net return JD3.5 million.	JVA. Farmers.	Low-cost. Infrastructure exists.	No freshwater conserved.	None.	High.
Middle Directorate	Intensification of agriculture.	6	0	N/A	0	Good. Net return JD2.2 million.	JVA. Farmers.	Very low cost.	No freshwater conserved.	None.	High.
Northern Directorate	Exchange with freshwater used for agriculture.	57	57	430	87	Break even.	JVA. Farmers.	Volume of water conserved. Sustain agriculture.	Changes to cropping pattern. Potential loss of market. Difficult to implement. Resistance by water users.	Decision needed. User cooperation. Technical support. Phase in.	High.
Minor WWTPs.	Expand/intensify agriculture in vicinity of plant.	6.6	2			Low to moderate.	WAJ. Farmers.	Could replace freshwater. Progressive projects.	Potential contamination of important aquifers. Urbanization.	Must be high-value crops. Wait until other options satisfied.	Low.

Prioritizing Options

Before allocating reclaimed water resources, the existing obligations, which are assumed to take priority, have to be accounted for. There are two elements to preexisting obligations. One is that existing uses of reclaimed water will continue to be met at least at the same levels. These existing uses are in the JV (the Middle Directorate, and stage offices 6 of the Karameh Directorate) and in Wadi Zarqa. The second element is to fully meet the needs of preexisting allocations that have not yet been met. These are the options to allocate further reclaimed water to the Middle Directorate, Wadi Zarqa, and the Hashemite University. Except for the latter, these options will produce increased net returns with little investment. In the case of Wadi Zarqa, the projected increase in water consumption will occur if markets for irrigated produce improve. It is, therefore, prudent to include this in the scenario analysis.

To prioritize options according to the objective of conserving freshwater, the three relevant options are the Northern Directorate, the Dhuleil–Hallabat network, and industrial and municipal reuse in the Hashemite–Zarqa area. The total costs, including those for supplying the reclaimed water and developing the freshwater for domestic use, are summarized in Table ES-2.

Table ES-2. Summary of Costs for Conserving Freshwater

Option	Capital Cost (JD)	Freshwater (MCM)	Cost (fils/m^3)
Northern Directorate	87 million	57 million	430
Dhuleil-Hallabat	35 million	10 million	490
Industrial	13 million	13 million	630
New freshwater sources			> 700

The Northern Directorate is clearly a very attractive option since very large volumes of freshwater are conserved and made available for domestic use at relatively low costs. However, the resistance by water users, which was clearly restated in the MWI Water Resources Policy Support stakeholder workshop on June 11, 2001, is considerable.

From the point of view of prioritizing options that maximize returns from the resource, allocation of increased supplies of reclaimed water should favor industry over agriculture. The expected revenues for the relevant agricultural options are summarized in Table ES-3. The Northern Directorate option presented in this table assumes that its existing freshwater supplies have diminished (e.g., through transfer of these supplies to domestic use) and redevelopment of the area has to be justified in terms of irrigated agriculture alone.

Table ES-3. Summary of Economics of Irrigated Agriculture Options

Option	Capital Cost (JD)	Reclaimed Water (MCM)	Net Revenues (JD)
Middle Directorate	0	6 million	2.2 million
Karameh Directorate	4.2 million	40 million	3 million
Northern Directorate	87 million	57 million	Break even
Highlands Agriculture			Not viable

Assuming that the present resistance to using reclaimed water in the Northern Directorate remains, the basic prioritization of options is:

Scenario 1

- Industrial and Municipal (I&M) reuse in the Hashemite–Zarqa area;
- Expansion in the Karameh (Southern) Directorate;
- Exchange in Dhuleil–Hallabat Irrigation Network; and
- Reuse at minor WWTPs.

However, should the Northern Directorate be considered, the basic prioritization of options is:

Scenario 2

- I&M reuse in the Hashemite–Zarqa area;
- Exchange in Northern Directorate;
- Expansion in the Karameh (Southern) Directorate;
- Exchange in Dhuleil–Hallabat Irrigation Network; and
- Reuse at minor WWTPs.

Analysis of Scenarios

Water quantity

The methodology for allocating reclaimed water assumed a conservative estimate of the natural hydrology (65% of the long-term average), and allowed for gradual sedimentation of King Talal Reservoir (KTR), reach losses and a blending ratio of 20% freshwater to reclaimed water. The schedule for fully satisfying the demands of Scenario 1 is presented in Table ES-4. The schedule where the projected supply of reclaimed water is 15% less is also shown.

By the year 2016 the needs for all viable options, other than the Northern Directorate, will have been met. This includes exercising the option to develop irrigated agriculture at the minor WWTPs.

Table ES-4. Schedule for allocating reclaimed water to Options (Scenario 1)

OPTION	Year Fully Met	
	Reclaimed water supply as projected	Reclaimed water supply 15 % less than projected
Preexisting demands	2005	2006
Industrial (HL #1)	2006	2007
Karameh Directorate	2014	2019
Dhuleil–Hallabat	2015	2020
Other WWTPs	2016	2021

If the Northern Directorate is included (Scenario 2), the schedule, as shown in Table ES-5, is quite different. The implementation of the Northern Directorate precludes the Karameh Directorate getting its full allocation before the year 2030. However, if the exchange for freshwater is considered, the Northern Directorate is a much more attractive option.

Table ES-5. Schedule for allocating reclaimed water to Options (Scenario 2)

Option	Year Fully Met
	Supply as Projected
Preexisting demands	2005
Industrial	2006
Northern Directorate	2017
Karameh Directorate	2030
Dhuleil–Hallabat	-
Other WWTPs	-

Water quality

Using reclaimed water for irrigated agriculture can risk human health and can harm crops, soils, and the management of the irrigation system. Also, the quality of the reclaimed water constrains its use in industry.

From a human health perspective, the implementation of the new As Samra facility will reduce the present fecal coliform levels in the effluent being discharged in Wadi Dhuleil. However, the contamination of the wadi from secondary fecal sources will mean that the wadi water still presents an unacceptably high risk if used to irrigate raw-eaten crops.

At present, the KTR will continue to facilitate the die-off of the fecal coliforms, and levels in the releases from the dam will be generally low. The exception is when contaminated runoff from the highlands in the wet season coincides with low water levels in the reservoir. The subsequent residence time is inadequate. In addition, secondary fecal contamination from the downstream of the reservoir raises the fecal coliform levels in the water before it reaches the JV.

With respect to the health of crops and soils, the implementation of the new As Samra facility will significantly reduce the total nitrogen (TN), which, at certain times of the growing season, can harm certain crops. However, total dissolved solids (TDS), chlorides, and total phosphorous (TP) will remain relatively unchanged. As it does with fecal coliforms, the KTR will continue to reduce the pH levels reaching the JV. TDS and chlorides are expected to increase gradually over the planning period as reclaimed water becomes more dominant in the overall water balance. Reducing TDS and chloride levels in the urban water supply and further managing discharges of salts into the sewers or wadis are the most practical solutions.

Total suspended solids (TSS) will be reduced in the wadi, thereby alleviating some of the irrigation system clogging problems experienced by farmers there. Now, TSS levels in releases from the KTR will be low, except when residence time is short, but will be increased before diverting to the JV.

From the available data, the levels of trace elements and heavy metals in the effluent are lower than those specified by the relevant Jordanian standards, which, with the exception of zinc and boron, are as stringent as the United States Environmental Protection Agency's water reuse guidelines (EPA, 1992). Anticipated growth in industrial development within the basin could increase the levels of these constituents within the wastewater.

Supporting Actions

No matter how the reclaimed water is allocated, there are a number of supporting actions that need to be implemented to sustain the management and reuse of water in the AZB and the JV.

The challenges facing irrigated agriculture in using this reclaimed water resource cannot be overemphasized. It has been shown in these investigations and, more significantly, by the farmers, that this is technically and economically feasible. However, despite the presence of a few farmers with very high levels of management expertise in the JV, to sustain irrigated agriculture in the future requires that the majority of farmers improve their skills and knowledge.

The interrelated actions to support the use of reclaimed water in the JV and Wadi Zarqa can be listed as follows, in approximate order of priority:

- Support the farmers to improve on-farm water management, especially to deal with the water quality-related issues. This needs a major integrated extension and applied research effort.
- Enhance information management, especially with regard to information on water quality, and make it available to farmers. Regular monitoring and reporting of soil and crop health needs to be introduced.
- Reduce further the health risk associated with irrigation practices in Wadi Zarqa. This must be done in cooperation with the farmers.
- Control secondary fecal contamination sources in the basin.
- Enhance the Jordanian standards and guidelines for water reuse.
- Control hazardous discharges to sewers and wadis more strongly.

Details on each of these supporting actions are provided in this document, and in the associated working papers.

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Stephen Luxton – Civil Engineer
Bahman Sheikh – Water Reuse, and Standards, Regulations & Legislation
Garry Grabow – Water Quality & Water Resources
Andrew Alspach – Database & Information Management
Hani Rashid – Irrigation
Stephen Grattan – Crops, Soils & Water Quality
Willis Shaner – Economist
Kenneth Edworthy – Artificial Groundwater Recharge
Barnes Bierck – Industrial Reuse & Hazardous Emissions
Howard Wong – Water Chemistry & Database
James Fitch – Marketing
Amer Jaberin – Marketing

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We especially thank the farmers of Wadi Zarqa and the JV, who patiently provided their insights into irrigated agriculture with reclaimed water and voiced their concerns about water use and water reuse. Faced with the challenges of irrigation management under water-short conditions and poor water quality, they took time to relate their experiences and concerns.

Finally, the support of the United States Agency for International Development (USAID) Mission in Jordan and the ARD, Inc. team, in Jordan and Vermont, is highly appreciated.

I. INTRODUCTION

This document presents the plan for managing water reuse in the Amman–Zarqa Basin (AZB) and Jordan Valley (JV). Included here is the background to water reuse in the basin; the present and anticipated quantity and quality of reclaimed water; a review of the present uses and potential options for reuse in the basin; assessments of the potential scenarios for allocating reclaimed water over the next 25 years; and the other requirements considered necessary for the successful management of water reuse in the basin.

I.1. Background

The Hashemite Kingdom of Jordan has a critical shortage of water resources. Water use per capita is among the lowest in the world, and the urban population continues to grow, with increasing water demand. Today the majority of the treated wastewater is reused. As such, water reuse has become a major component of the national water budget, particularly in the densely populated AZB.

The AZB is located in the north of Jordan and extends to over 2,400 km^2 (see Figure 1). It slopes downward from within the Syrian border in the east to the JV in the west, where the natural course of the Wadi Zarqa meets with the Jordan River and eventually discharges into the Dead Sea at 400 m below sea level (see Figure 2). The AZB is relatively densely populated, including the two largest urban centers in Jordan, Amman and Zarqa. These urban centers require increased water supplies and subsequently generate increasing levels of effluent from treating the wastewater. The water demands have been largely met by a combination of groundwater, from the AZB and adjacent basins, and surface water from sources that were originally developed to irrigate the JV.

Figure 1. Drainage basins of the Hashemite Kingdom of Jordan

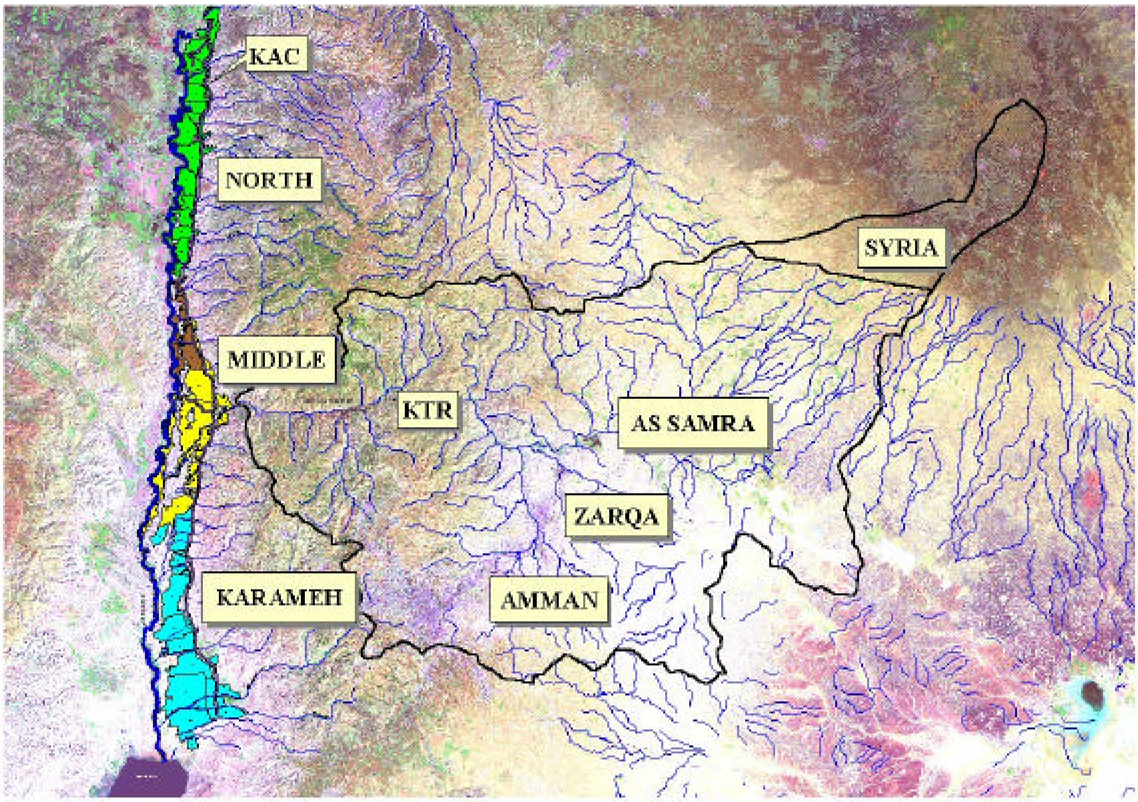

Figure 2. AZB and the three irrigation directorates of the JV.

Abstraction of groundwater for irrigation and urban water use has depleted the highland aquifers, thereby reducing their contribution to the natural base flow in the wadi. To date, the increasing supplies of treated effluent have offset the reduced freshwater supplies reaching the JV.

Reuse of water, albeit indirectly, is already a necessary component of water resources management in the AZB and JV. With the supply of freshwater being very limited and the demand expected to continue to increase, it is vital that the anticipated increases in water available for recycling be managed to meet, at least in part, the national and regional demands.

I.2. National Strategy and Policy Setting

The relevant strategy and policy framework within which this plan is being developed includes the National Water Strategy (MWI, 1997); the National Irrigation Policy (MWI, 1998a); and the National Wastewater Management Policy (MWI, 1998b).

The National Water Strategy (MWI, 1997) recognizes that population pressure in Jordan has already caused a chronic deficit in available freshwater, which has resulted in overabstraction of groundwater. The limited opportunities to develop new freshwater sources are expensive, with high operating costs. Given this, treated wastewater is to be considered as a resource that, with due care for health and the environment, should be reused for agriculture and other non-domestic purposes, including groundwater recharge.

The National Wastewater Management Policy (MWI, 1998) states that reuse for irrigation is to be given a high priority, and that reclaimed water is to be sold at prices that, at a minimum, cover the operation and maintenance costs of delivery. However, leaching water is to be provided free-of-charge in the wet season where reclaimed water is used for irrigation.

The policy also allows for the Jordanian Standards on water reuse (Nazzal et al., 2000; MWI/ARD, 2001c) to be periodically examined to account for ambient conditions, end uses, socio-economics, environment, and local conditions.

Considering the national water strategy and policies, the realities in the AZB, and the specific needs for successful water reuse, the overall objectives of water reuse management within the AZB are to:

- Meet some of the present and future water demands in the basin; and
- Maximize returns from the resource.

Furthermore, there are conditions that any such developments must comply with, including:

- Protect the public;
- Conserve resources (water, soils/land, natural vegetation, etc.);
- Comply with international treaties; and
- Ensure environmentally sound practices.

I.3. Objectives

The objective of this document is to present plans for water reuse management in the AZB and JV during the next 25 years.

I.4. Planning Process

The process used in developing the plan has five primary facets:

1. Understand the past, present, and anticipated future situation (see Section II);
2. Identify, review, and refine to pre-feasibility level, options for using reclaimed water (see Section III);
3. Develop practical scenarios, composed of prioritized options, for allocating reclaimed water (see Section IV);
4. Identify and include stakeholders in developing the plan; and
5. Investigate and define requirements for the successful management of water reuse (see Section V).

Aspects of the five facets have been implemented concurrently, with various iterations of the options and the scenarios, as more detailed information was made available and as the plan began to take form and gradually come into focus.

I.5. Documentation Structure

The planning process included development of a number of working papers that allowed the many complex aspects of the issue to be incorporated and provide for constructive feedback. The final versions of these reports, which provided the foundation for the management plan, are as follows:

- Water Reuse for Agriculture and/or Forestry in the Amman–Zarqa Highlands (MWI/ARD, 2000b);
- Monitoring and Information Management Pertaining to Water Reuse in Jordan (MWI/ARD, 2000c);
- Impact of Increasing Supplies of Reclaimed Water on Crops, Soils, and Irrigation Management in the Jordan Valley (Grattan, 2000);
- Economics Study for Water Reuse for Agriculture and/Forestry in the Amman–Zarqa Highlands (Shaner, 2000);
- Water Reuse in Wadi Zarqa and from Other Amman–Zarqa Sources (MWI/ARD, 2001b);
- Standards, Regulations, and Legislation for Water Reuse in Jordan (MWI/ARD, 2001c);
- Characterization of Wastewater Effluent in the Amman–Zarqa Basin (MWI/ARD, 2001d);
- Water Reuse Options in the Jordan Valley (MWI/ARD, 2001e);
- Storage, Conveyance, Blending, and Analysis of Preliminary Scenarios for Water Reuse in the Amman–Zarqa Basin (MWI/ARD, 2001f);
- Options for Artificial Groundwater Recharge with Reclaimed Water in the Amman–Zarqa Basin and Jordan Valley (MWI/ARD, 2001g);
- Identification and Pre-Feasibility Analysis on Non-Agricultural Reuse Options for Reclaimed Wastewater from As Samra (MWI/ARD, 2001h);
- Controlling Harmful Discharges to Wadi Zarqa (MWI/ARD, 2001i);
- Economics Study for Managing Water Reuse in the Amman–Zarqa Basin and the Jordan Valley (Shaner, 2001);
- Information Management—Data Migration of Water Quality Data from WAJ and RSS to MWI WIS (MWI/ARD, 2001k); and
- Marketing Jordanian Vegetables and Fruits in the Context of Irrigation with Reclaimed Water (Fitch and Jaberin, 2001).

Copies of the above working papers are included on the attached CD, along with the electronic version of this document.

II. RECLAIMED WATER RESOURCES

Section II presents the quantities and qualities of effluent, or reclaimed water, that are expected from the wastewater treatment plants (WWTPs) in the AZB over the planning horizon, which is through year 2025. Details of the relevant analysis and results are presented in MWI/ARD (2001d)[1]. Section II also presents an overview of the present uses of reclaimed water generated in the AZB.

II.1. Expected Reclaimed Water Resources

There are presently four wastewater treatment facilities: Abu Nuseir (activated sludge), As Samra (waste stabilization ponds), Baq'a (trickling filters), and Jerash east (extended aeration) located in the AZB. A further two, Jerash (west) and Zarqa, are planned. Section II presents the current and expected quantity and quality of effluent. For future projections, the As Samara and planned Zarqa WWTPs are considered together. The planned Zarqa plant is to be located downstream of the As Samara facility.

II.1.1. Quantity

As detailed in MWI/ARD (2001d), the gross quantity of effluent generated in the AZB is expected to rise from the present 61 MCM/year to nearly 180 MCM/year by 2025. The relatively sharp increase in volume between 2005 and 2010 depicted in Table 1 and Figure 3 is due to an anticipated 29% increase in per capita water supply to the urban areas (JICA, 2000), achieved by the development of new water sources. This requires an aggressive development of new water sources. In the event that one or more of these new developments is delayed, the actual effluent volumes in the future are likely to be lower.

Table 1. Projection of Total Effluent (MCM Annual Flow) to be Discharged to the AZB

Treatment Plant	2000	2005	2010	2015	2020	2025
As Samra–Zarqa	56.2	77.0	104.7	120.7	137.9	157.6
Jerash	0.6	1.3	3.9	4.5	5.0	5.8
Abu Nuseir	0.5	0.5	0.6	0.7	0.7	0.8
Baq'a	3.8	5.3	8.4	9.7	10.9	12.4
Total	**61.1**	**84.1**	**117.6**	**135.6**	**154.6**	**176.6**

The majority (93%) of the effluent discharging into the AZB now originates at the As Samra WWTP. By 2025 the proportion of the effluent discharging from both the As Samra and the Zarqa WWTPs will be 90%.

II.1.2. Quality

For each treatment facility where data were available, the water quality parameters were tabulated and compared with the Jordanian Standards for discharge to wadis.

In the case of As Samra, the levels of trace elements and heavy metals in the effluent are much lower than those specified by the standards. With the exception of zinc and boron, the standards are as stringent as the United States Environmental Protection Agency's water reuse guidelines (EPA, 1992). Other parameters, however, are not in compliance with the respective Jordanian Standards: five day biochemical oxygen demand (BOD_5); chemical oxygen demand (COD); total suspended solids (TSS); fats, oils, and greases (FOG); NH_4 - N; total nitrogen (TN); PO_4 - P; Cl;

1. Water Reuse Component Working Paper – "Characterization of Wastewater Effluent in the Amman-Zarqa Basin."

HCO_3; and fecal coliforms. Except for PO_4 - P, the planned improvements at As Samra are expected to address these parameters, reducing them to at least the Jordanian Standards and, most likely, below. The specifications for the BOD_5, TSS, and TN from As Samara are set at 30 mg/l, which is more stringent than the Jordanian standards.

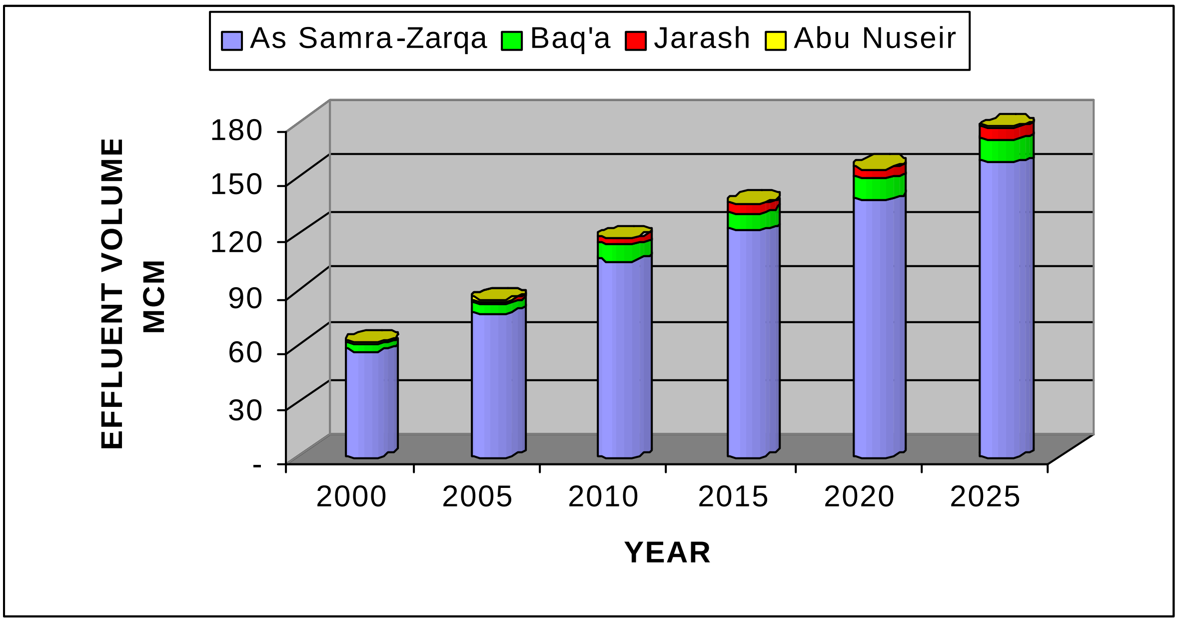

Figure 3. Projection of total effluent (MCM annual flow) to be discharged to the AZB.

At Jerash (east) site, Cl, SO_4, and HCO_3 are not recorded regularly. The records for NO_3-N, NH_4-N, PO_4-P, B, and fecal coliform count (FCC) are sparse, and those that do exist suggest that none of these parameters are in compliance with the Jordanian standards. Single readings observed in September 1999 for Cu, Fe, Mn, Cd, Zn, Fe, Mn, and Zn were well within the Jordanian standards, and Cd was at the standard. However, Cu was not in compliance. BOD_5, COD, dissolved oxygen (DO), TDS, TSS, and pH are all in compliance with the Jordanian standards. There are no plans for further development of the wastewater treatment facility at Jerash (east); therefore, there should be no major changes in the quality parameters. Although the total contribution of Jerash to the AZB is relatively small, the noncompliance of certain parameters is of concern, particularly as most of the present effluent stream is being used for irrigated agriculture nearby.

At Abu Nuseir, the Water Authority of Jordan (WAJ) monitors BOD_5, COD, DO, TDS, TSS, and pH. All are in compliance with the Jordanian standards. Because the rate of influent increase at Abu Nuseir is expected to be relatively low, and the present plant has the capacity to treat projected influent loads through the planning horizon, it is expected that quality parameters will not deteriorate. The monitoring program at this plant needs to be enhanced if water is to be reused adjacent to the site.

At Baq'a, the WAJ monitors BOD_5, COD, TDS, and TSS. Despite the Baq'a facility's being relatively effective at lowering the values of the monitored parameters in the influent, only the TDS in the effluent complies with the Jordanian standards for discharge to wadis. The present facility is overloaded (WAJ, 2000). The new plant, which uses trickling filters, was completed in the last quarter of 2000. The situation at Baq'a will, therefore, improve. Before considering reuse options using Baq'a effluent, it would be prudent to determine the levels of the other parameters, trace elements, and heavy metals.

II.2. Present Use of Reclaimed Water

There are now basically three uses of reclaimed water in the AZB: planned use within the immediate vicinity of the wastewater treatment facilities, unplanned use in the wadi downstream, and indirect use, after mixing with natural surface water supplies and freshwater supplies from the King Abdullah Canal, in the Middle and Karameh (southern) directorates of the JV. In addition, there is the planned use of 1.5 MCM/year at the Hashemite University.

II.2.1. Local use at the WWTPs

The use of reclaimed water in the immediate vicinity of the WWTPs is generally under the jurisdiction of the WAJ. Raw-eaten crops are not allowed. The microbiological quality of the water does not meet the respective Jordanian standard, and presents a potential health risk to the field workers. Also, these sites are generally pilot projects with some research, with limited commercial viability. These irrigated areas are included in the areas discussed in the next section.

II.2.2. Unplanned use in the wadis

From interpretation of satellite imagery and field visits (MWI/ARD, 2001b)[2], it was determined that as much as 17,000 dunums of irrigated crops use some portion of reclaimed water to meet the water supply needs. Of this, up to 4,400 dunums are estimated to be vegetables, some raw-eaten. The microbiological quality of the water, not all of which is associated with inadequately treated wastewater, presents a serious health risk.

II.2.3. Indirect use in the JV

The majority of the reclaimed water generated in the AZB is, after flowing down Wadi Zarqa and passing through the King Talal Reservoir (KTR), used in the JV, primarily in the Middle Directorate and, to a lesser extent, the Karameh Directorate (MWI/ARD, 2001e)[3]. The management of the water from KTR to the farm gate is under the jurisdiction of the Jordan Valley Authority (JVA).

II.2.4. Planned use at the Hashemite University

The University has obtained a permit to use 1.5 MCM of reclaimed water from As Samra, and is in the process of implementing the project, which will develop approximately 500 dunums of olives and forest trees.

2. Water Reuse Component Working Paper – "Water Reuse in Wadi Zarqa & from Other Amman-Zarqa Sources."
3. Water Reuse Component Working Paper – "Water Reuse in the Jordan Valley."

III. OPTIONS FOR WATER REUSE

Section III presents an overview of the process used for identifying and characterizing potential options for water reuse in the AZB and presents the final versions of the more viable, or working, options.

As already stated, water reuse is already practiced in the AZB, and a number of other options have been previously proposed, from sending reclaimed water into the eastern desert to developing a separate reclaimed water supply system in Amman. Apart from using reclaimed water for intimate domestic use, which is *not* viable because of sociological/psychological public acceptance issues, a broad range of options was considered:

- Irrigation (agriculture, ornamental nurseries, and forestry);
- Municipal, including landscape, recreational, and residential;
- Industrial; and
- Others (hydropower, artificial groundwater recharge, meeting international treaties, and environmental enhancement).

The highlands, Wadi Zarqa, and the JV were examined to determine which options were practical and at what scale. The planning process was biased toward being inclusive—that is, to not reject potential options without careful consideration. Also, the process was iterative, adding in variations of options as investigations revealed additional opportunities for using reclaimed water.

The main options examined were:

- **Highlands**
  - Irrigated agriculture;
  - Industrial and municipal; and
  - Artificial groundwater recharge.
- **Wadi Zarqa**
  - Intensification of irrigated agriculture.
- **Jordan Valley**
  - Intensification and expansion of irrigated agriculture in the Karameh Directorate;
  - Intensification of irrigated agriculture in the Middle Directorate;
  - Replacement of freshwater now used for irrigation in the Northern Directorate; and
  - Artificial groundwater recharge.

In addition, similar, much smaller scale options were considered at the minor WWTPs (Abu Nuseir, Baq'a, and Jerash, and the planned Jerash West facility).

III.1. Screening of Options

During the planning process, it became evident that in the case of irrigation in the highlands and artificial groundwater recharge, the basic options could be refined. This subsection presents the rationale for these two situations.

III.1.1. Irrigated Agriculture in the Highlands

The basic options, detailed in MWI/ARD (2000b)[4] and Shaner (2000)[5] and shown in Figure 4, were:

- Developing new irrigated lands with reclaimed water (HL #2);
- Supplying reclaimed water to an existing irrigation project (Duhleil) to exchange with the present groundwater supply (HL #3); and
- Supplying reclaimed water to individual farms now using groundwater from private wells (HL #4).

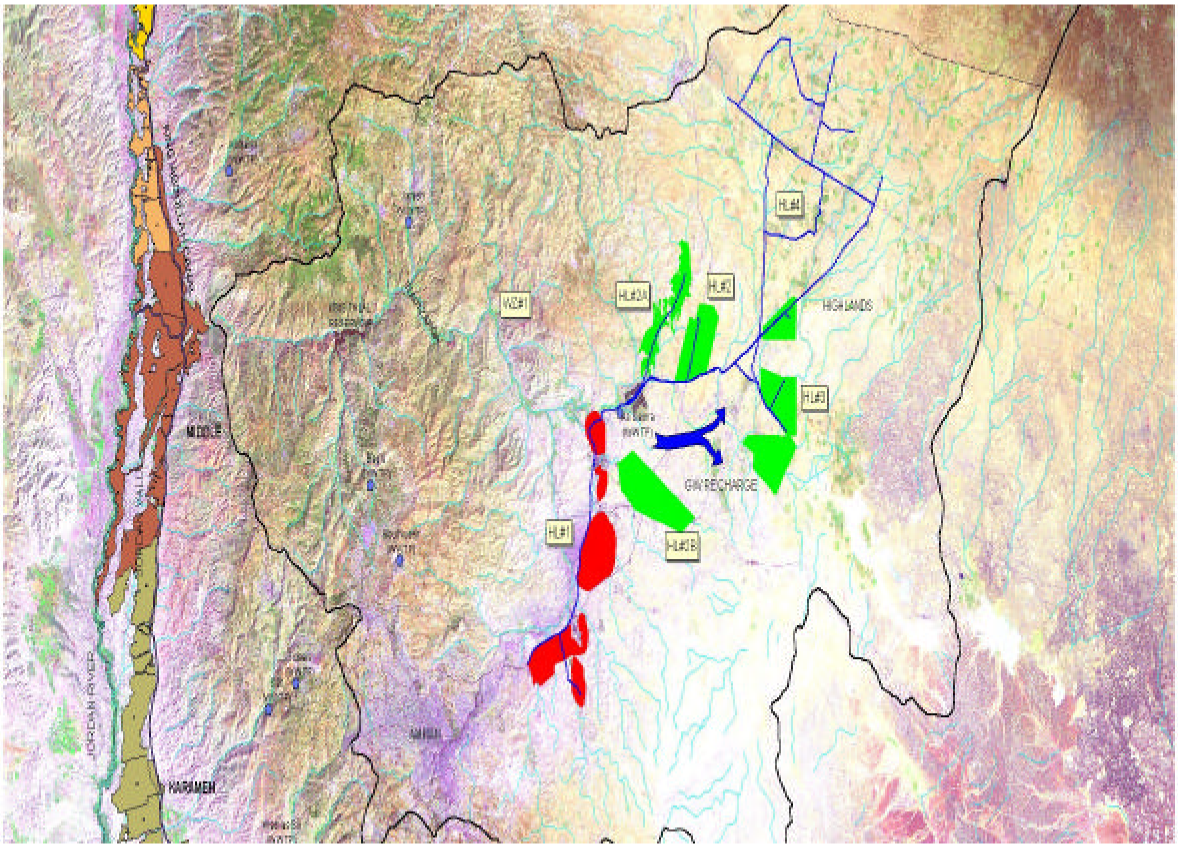

Figure 4. Location of options for water reuse in the highlands of the AZB.

All of these options require pumping facilities at As Samra, conveyance pipelines to the project areas, distribution networks, and either complete or enhanced on-farm systems.

From these investigations it was clear that using reclaimed water in the highlands could not be justified on agricultural benefits alone. HL #2 and its variants (HL #2a and HL #2b) were therefore not viable (MWI/ARD, 2000b; Shaner, 2000).

Where existing irrigated agriculture is using groundwater, the costs of pumping and conveyance of reclaimed water into the highlands can be offset against the value of the groundwater. Over 60% of the farmers sampled in the highlands expressed an interest in using reclaimed water in

4. Water Reuse Component Working Paper "Water Reuse for Agriculture and/or Forestry in the Amman-Zarqa Highlands."
5. Water Reuse Component Working Paper "Economics Study for Water Reuse for Agriculture and/or Forestry in the Amman-Zarqa Highlands."

exchange for groundwater (MWI/ARD, 2001j)[6.] The majority of farmers were located toward the south of the AZB in the Dhuleil and Hallabat areas. Those farmers located in the north of the AZB, where the quality and quantity of the groundwater are good, are generally not interested in using reclaimed water.

The option of delivering reclaimed water in the highlands (HL #4) is considerably more expensive than the other options. The pumping and conveyance costs alone are estimated to be 650 fils/m^3 (MWI/ARD, 2000b), which, by itself, is close to the cost of developing new freshwater supplies for municipal use (Shaner, 2001). This, and the lack of interest by the users in exchanging reclaimed water for the groundwater, makes this option not viable at this time.

Supplying reclaimed water to the Dhuleil project (HL #3) could replace the 2.5 MCM of groundwater used at present (MWI/ARD, 2000b). However, this groundwater is already saline (2,500–3,000 mg/l). A variation of this option, which will allow for economies of scale and exchange with better quality groundwater, is to include individual farms in the Dhuleil and Hallabat areas, where the total annual consumption of groundwater is about 30 MCM/year. This working option is presented in detail below.

III.1.2. Artificial Groundwater Recharge

Opportunities for using reclaimed water for groundwater recharge were examined for the AZB and the JV areas (MWI/ARD, 2001g)[7]. Recharge using surface infiltration, or soil-aquifer treatment (SAT), is the most robust technique and is suitable for use with secondary effluent with no special requirements for pretreatment. Possible locations where artificial recharge could be utilized in the basin include two areas to the east of As Samra, and within the alluvial areas along the margin of the JV, as indicated in Figure 5.

Well recharge could in principal be applied widely, since there are several potential aquifers into which recharge could be done. However, artificial recharge through wells demands comprehensive pretreatment and is technically more complex to manage.

Cost comparisons show that the cost of surface and well recharge facilities is likely to be of the same order, but the additional costs of the essential comprehensive pretreatment, at an estimated 0.4 JD/m^3, make well recharge expensive. Together with the comparative complexity of using the technique, well recharge is unattractive at present.

SAT systems or infiltration lagoons, though considered technically feasible in the highlands, appear unlikely to meet with official or public acceptance at present because public water supplies are drawn from the same areas. In contrast, similar schemes in the JV appear likely to gain ready acceptance as a clearly useful approach, making best use of resources.

Artificial groundwater recharge in the JV does present an opportunity for improving the storage of excess flows in the wet season and in wet years that, unlike surface storage facilities, could carry over multiple years. This could be a useful drought-alleviation technique for irrigation in the JV. In this case, artificial groundwater recharge is not a competing demand that needs to be considered in the basin level scenarios, but a storage facility that will improve the reliability of the irrigation options being considered for the JV. Artificial groundwater recharge in the highlands is technically feasible, but, due primarily to acceptance issues, it is not envisioned that such an option would be implemented in the planning time frame (i.e., before 2025).

6. Groundwater Component Working Paper "Study of Groundwater Use and Users in Northeastern Amman–Zarqa Basin Highlands."
7. Water Reuse Component Working Paper "Options for Artificial Groundwater Recharge with Reclaimed Water in the Amman-Zarqa Basin & Jordan Valley."

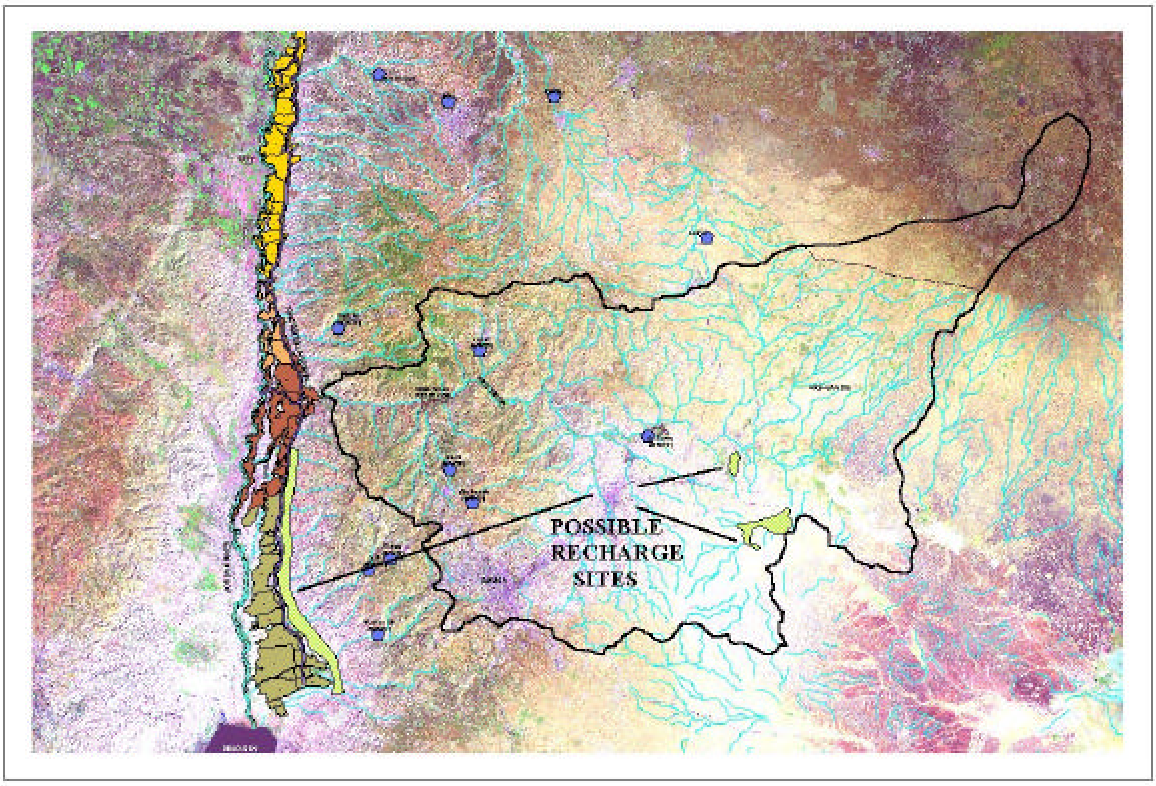

Figure 5. Locations of possible artificial recharge sites in the AZB and JV.

III.2. Dhuleil-Hallabat Irrigation Network (HL #3a)

III.2.1. Description

This option, depicted in Figure 6, would deliver reclaimed water via pipeline to an area 14 km east of As Samra in order to exchange with present groundwater use within the existing Dhuleil project and individual farms in the Dhuleil and Hallabat area.

The existing Dhuleil irrigation project provides farmers with groundwater pumped from deep wells, delivered to a storage reservoir, and distributed to their fields (MWI/ARD, 2000b)[8]. The system was designed to serve up to 8,000 irrigable dunums, but at present irrigates around 2,000 dunums because of the falling watertable and increased salinity of the groundwater, which is around 2,500–3,000 mg/l. The individual farmers surrounding the Dhuleil irrigation project draw from private wells, indicated as dots on Figure 6. The salinity levels in these wells are generally lower than those in the Dhuleil project, especially toward the east. The combined abstraction from the private and Dhuleil project wells in this area exceeds 30 MCM. From the groundwater component survey of the farmers using groundwater in the highlands, more than 60% indicate an interest in using reclaimed water (MWI/ARD, 2001j).

8. Water Reuse Component Working Paper “Water Reuse for Agriculture and/or Forestry in the Amman-Zarqa Highlands.”

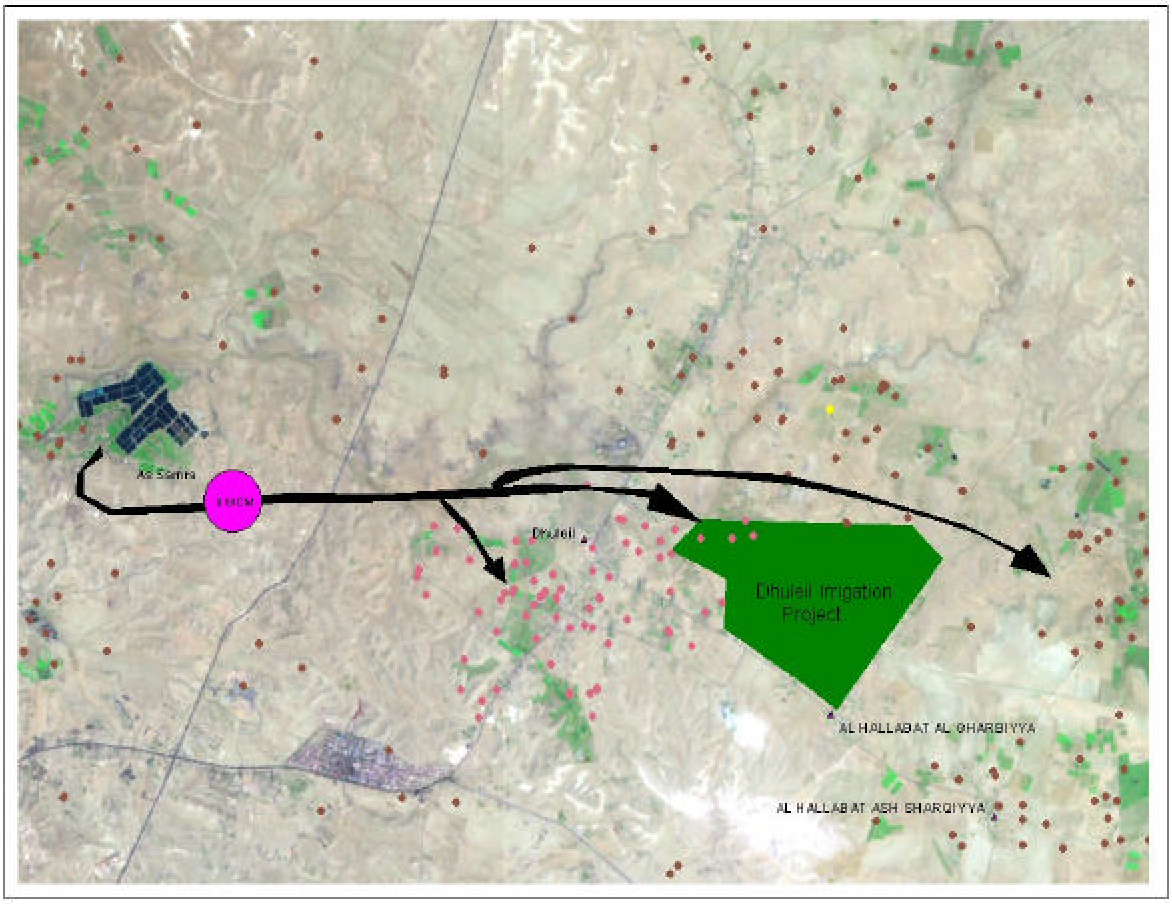

Figure 6. Dhuleil/Hallabat Irrigation Network (HL #3a).

III.2.2. Reclaimed water requirements and freshwater saved

This option would provide approximately 9.5 MCM (2.5 MCM to the Dhuleil project and 7.0 MCM to surrounding farms) of water/year, freeing up an equivalent quantity of groundwater. The quality of the groundwater ranges from 650 to 2,500 mg/l, which, if it were to be used for municipal supplies, would need desalination.

III.2.3. Investment costs and economics

The total capital cost for the pumping, conveyance, and storage to Dhuleil, and the network to deliver to the individual farms, is estimated to be JD35 million, including on-farm improvements in the Dhuleil project and contingencies. The total annualized costs are JD4.5 million. Accounting for the need to desalinate some of the groundwater before it can be used for municipal supply, and allowing for an on-farm internal rate of return of 12%, the cost of providing 1 m^3 of water by exchange with the reclaimed water is approximately 610 fils (Shaner, 2001)[9].

III.2.4. Implementation and institutional arrangements

The existing Dhuleil project is operated by the WAJ. The individual farms are privately owned. The primary benefit from this project is conservation of groundwater; therefore, the Government

9. Water Reuse Component Working Paper - “Economics Study for Managing Water Reuse in the Amman-Zarqa Basin & the Jordan Valley.”

will have overall responsibility for facilitating and financing it. In addition to the construction costs, a significant part of the annual operation and maintenance (O&M) budget must come as a transfer payment from the Government.

A key objective must be to make the farmers collectively responsible for the O&M of the infrastructure. The detailed feasibility study and pre-design will require that the farmers and the communities be closely involved within the project area.

III.2.5. Environment and other issues

The key concern with such a development is the potential impact on the underlying aquifer from the use of reclaimed water for irrigation, especially since this aquifer is an important source of water for municipal supply.

The proximity of urban communities and their encroachment into the area is another important factor. Even with the new facilities at As Samra, the quality of the reclaimed water would require that access to the irrigated fields be restricted (MWI/ARD, 2001c)[10].

III.2.6. Overall assessment of option

- Advantages
  - Technically and, if value of conserved groundwater is included, economically viable;
  - Exchange with approximately 10 MCM of groundwater; and
  - Sustains irrigated agriculture in the Dhuleil-Hallabat areas.
- Disadvantages
  - High operating costs for pumping and conveyance;
  - High capital costs;
  - Some of the conserved groundwater will need desalination to be used for domestic purposes; and
  - Risk of groundwater contamination of an important municipal aquifer.
- Key implementation issues
  - As Samra must be reliably producing better quality effluent (2004); and
  - Ensure financial sustainability to cover O&M costs in the future.
- Relative priority
  - Moderate.

10. Water Reuse Component Working Paper - "Standards, Regulations & Legislation for Water Reuse in Jordan."

III.3. Industrial/Municipal Reuse in the Hashemite-Zarqa area (HL #1)

III.3.1. Description

The present power plant and oil refinery obtain their water supply from the groundwater in the immediate vicinity. This groundwater is already quite saline (~3000 mg/l), and has to be desalinated for use as process and cooling water, at an approximate cost of 500 fils/m^3. In addition, the oil refinery and the power plant are charged 250 and 350 fils/m^3 respectively for the right to abstract the groundwater. The municipal water supply in Zarqa is unable to supply these demands.

The water reuse option involves building a pipeline to convey reclaimed water 17 km to the Hashemite–Zarqa area where it would be stored and then delivered by spur lines to a few principal locations (see Figure 7). The new power plant and the refinery would use the reclaimed water for industrial cooling, with an annual demand of 5.5 and 3.9 MCM, respectively. Lesser annual demand could come from the east Zarqa Planning Area (2.0 MCM), other industries (1.0 MCM), and the existing power plant (0.6 MCM). These amounts total 13.0 MCM, which would otherwise be pumped from the underlying aquifer (MWI/ARD, 2001h)[11].

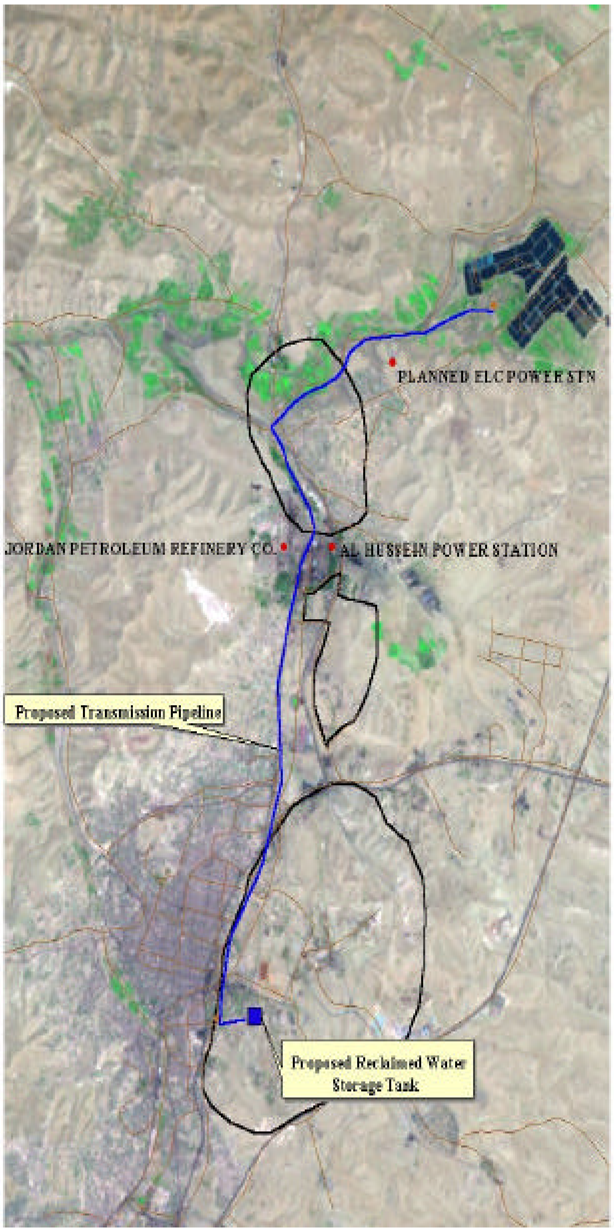

Figure 7. Proposed pipeline alignment for Industrial & Municipal reuse.

The managers of the existing power plant and the refinery have expressed interest in using reclaimed water, but have reservations over the reliability of the effluent quality.

According to the Ministry of Power & Energy, the new power plant, which is to be completed by the end of 2004, will be required to use reclaimed water for cooling. This presents a good opportunity to meet the needs of the new and existing facilities, and further encourage the use of reclaimed water instead of groundwater.

Treatment of the expected effluent from As Samra would be required. For industrial cooling, this would entail phosphorous removal and the addition of scale, corrosion and bio-fouling

11. Water Reuse Component Working Paper “Identification & Pre-feasibility Analysis on Non-Agricultural Reuse Options for Reclaimed Wastewater from As Samra.”

inhibitors. Phosphorous removal would be most economically done at the As Samra end of the pipeline. For other industrial processes, further treatment will be required at the specific industry site.

III.3.2. Reclaimed water requirements and freshwater saved

At start up (2004), the demand for reclaimed water is estimated to be 6.6 MCM, of which 0.6 MCM would replace groundwater now used at the refinery, 5.5 MCM would meet the needs of the new power plant, and a further 0.5 MCM for other industrial and municipal uses. By the year 2015, the envisioned facility would supply a total of 13 MCM of reclaimed water, which would replace 4.5 MCM of existing groundwater abstractions and a further 8.5 MCM of projected abstractions for industrial and municipal users.

III.3.3. Investment costs and economics[12]

The system capital cost is estimated to be JD13 million, which would provide the necessary infrastructure for expected demands to 2015 (MWI/ARD, 2001h). The option will supply 13 MCM of reclaimed water to replace existing use of groundwater and meet future demands. The annualized cost of the investment for the reclaimed water system plus the annual O&M is estimated to be JD1.8 million, or 136 fils/m^3 delivered to the industry. With tertiary treatment, required to produce reclaimed water suitable for cooling and costing 250 fils/m^3, the expected total cost is around 400 fils/m^3. This level of treatment will be sufficient for the first phase of the option (6.5 MCM). In the future, for other non-cooling industrial processes, further specific treatments will be required. To provide the reclaimed water as above and make the groundwater available for urban use, the total cost for the water exchanged is 630 fils/m^3. This is without considering the economic value to industry. Further details are included in Shaner (2001).

The value of water to industry is considerably higher than that for agriculture because the amount of water required is less than in agriculture, industry usually contributes higher values of output per unit of input (including water), and it plays a key role in a country's development strategy. This does not mean that agriculture is not important. It has its place as a provider of considerable employment for the relatively unskilled and in reducing the country's dependence on imported foodstuffs. Administratively, this means that the Government should favor industry's claim to reclaimed water over agriculture's claim as long as demand for reclaimed water exceeds supply.

III.3.4. Implementation and institutional arrangements

The major prerequisites for the implementation of this option are the completion of at least one treatment train of the upgrade of the new As Samra wastewater treatment facilities, and convincing the managers of the existing power plant and the refinery that the quality of the reclaimed water will be reliable. The first treatment train of the new As Samra facilities is expected to begin operation in 2004.

The fact that the new power station is required to use reclaimed water presents an opportunity to develop this broader reclaimed water option with minimal additional costs. This power station is scheduled to be implemented in the same time period as the As Samra improvements, although this will also depend on the completion of the new gas pipeline from Egypt, which is to be the source of energy.

12 Further investigations have shown that phosphorous removal will be required for reclaimed water used for cooling purposes. Details are included in the final draft of (MWI/ARD, 2001h). The change in costs does not affect the economic analysis.

This option would be best implemented as a private concern, with the users collectively owning and operating the facility. The Ministry of Water and Irrigation (MWI) should facilitate the development process by completing the feasibility study, which needs to be done in cooperation with the representatives of the potential users, including the managers from the existing power plant and refinery, and the consultants for the new power plant.

III.3.5. Environment and other issues

There do not appear to be any significant negative environmental impacts of this option. Indirectly, the possible attraction of further industry into this area could lower the quality of the water reaching Wadi Zarqa, unless regulations are strictly enforced. Further details on this issue are presented in (MWI/ARD, 2001i)[13]. Also, the evapoconcentration of the salts in the discharge water from the cooling towers could increase the TDS levels in the reclaimed water.

III.3.6. Overall assessment of option

- Advantages
  - Economically and technically viable;
  - Developers of new power plant have been required to use reclaimed water;
  - Could be developed as a private venture, but will need external encouragement; and
  - Potential to demonstrate industrial reuse and, with bulk reclaimed water facility, municipal reuse.
- Disadvantages
  - Evapoconcentration in cooling process could increase salt loads in the sewers or wadi.
- Key implementation issues
  - As Samra must be reliably producing better quality effluent (2004);
  - New power plant to come on line in late 2004; and
  - Stakeholder coordination needs to be facilitated.
- Relative priority
  - High.

III.4. Wadi Zarqa (WZ #1)

III.4.1. Description

Farmers, who have established rights to use waters from Wadi Zarqa and its tributaries, at present irrigate a total of 24,000 dunums (see Figure 8). Of this, approximately 17,000 dunums have access to water from Wadi Zarqa that includes reclaimed water originating from the As Samra WWTP. Many of these same farmers also have access to spring water and shallow wells. In addition to the 17,000 dunums, there is estimated to be a further 3,000 dunums of land that has been historically irrigated (MWI/ARD, 2001b)[14] that farmers say they would irrigate if prices for produce improved or the restrictions on irrigation of vegetables were lifted.

13. Water Reuse Component Working Paper - “Controlling Harmful Discharges to Wadi Zarqa.”
14. Water Reuse Component Working Paper - “Water Reuse in Wadi Zarqa and From Other Amman–Zarqa Sources.”

III.4.2. Reclaimed water requirements and freshwater saved

In addition to the present use of reclaimed water in the wadi, if future conditions allow, there could be a further 3,000 dunums irrigated. This would require approximately 3.3 MCM of reclaimed water. Freshwater would not be conserved.

III.4.3. Investment costs and economics

The farmers would irrigate these historically irrigated areas, if the market and regulatory conditions allowed. The on-farm costs would be similar to those for the highlands projects (Shaner, 2000).

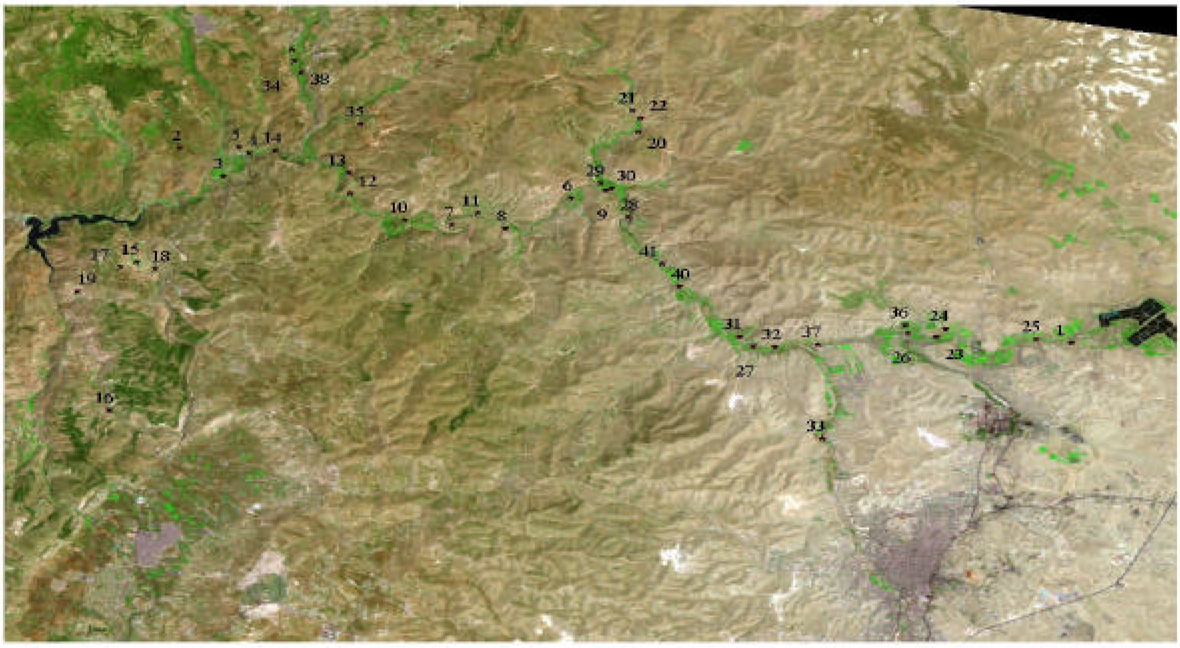

Figure 8. Locations of 41 farmers interviewed in Wadi Zarqa and irrigated land identified using satellite imagery (MWI/ARD, 2001b).

III.4.4. Implementation and institutional arrangements

If conditions prevail, implementation will be by the farmers. However, the potential health risk to the consumers of irrigating raw-eaten vegetables is a major issue. Considerable efforts have been exerted to alleviate this problem. It is recommended that a new effort be made, in cooperation with the farmers in the wadi. This is detailed in Section V.

III.4.5. Environment and other issues

Because the land areas along the wadi are relatively small, there is a plentiful supply of water, and the soils are reportedly free-draining, the risk of soil salinization is less than with other options. The issue of concern with the present irrigated farming and the future expansion (option) in Wadi Zarqa is the high fecal coliform levels in the water supply. Note that reducing the fecal coliform levels in the effluent from As Samra, as will occur with the new facilities, will not resolve the high fecal coliform levels in the wadi. This issue, which appears to be caused by secondary contamination from human activities in the catchment, is detailed and analyzed in MWI/ARD (2001f)[15] and addressed in Section V of this document.

15. Water Reuse Component Working Paper - "Storage, Conveyance & Blending, and Analysis of Preliminary Scenarios."

III.4.6. Overall assessment of option

- Advantages
  - Costs for development are low and overall economic returns are moderate.
- Disadvantages
  - Does not free up freshwater.
- Key implementation issues
  - No external intervention is required. However, this potential demand for additional water needs to be considered in the basin level scenarios of the water reuse plan.
- Relative priority
  - Preexisting right that is not being fully utilized at present.

III.5. Karameh (Southern) Directorate (JV #1)

III.5.1. Description

The Karameh Directorate is the southernmost directorate in the JV (see Figure 9), located immediately north of the Dead Sea. The Directorate comprises three Stage Offices: 6, 9, and 10. The water reuse option in the water-short Karameh Directorate is to use more reclaimed water for irrigated agriculture (MWI/ARD, 2001e)[16]. In the case of Stage Office 9, this would be irrigating lands that are now not assigned an official water allocation, although some areas are irrigated with brackish groundwater and others by tailwater from King Abdullah Canal (KAC). The physical infrastructure has been developed to farm-unit level.

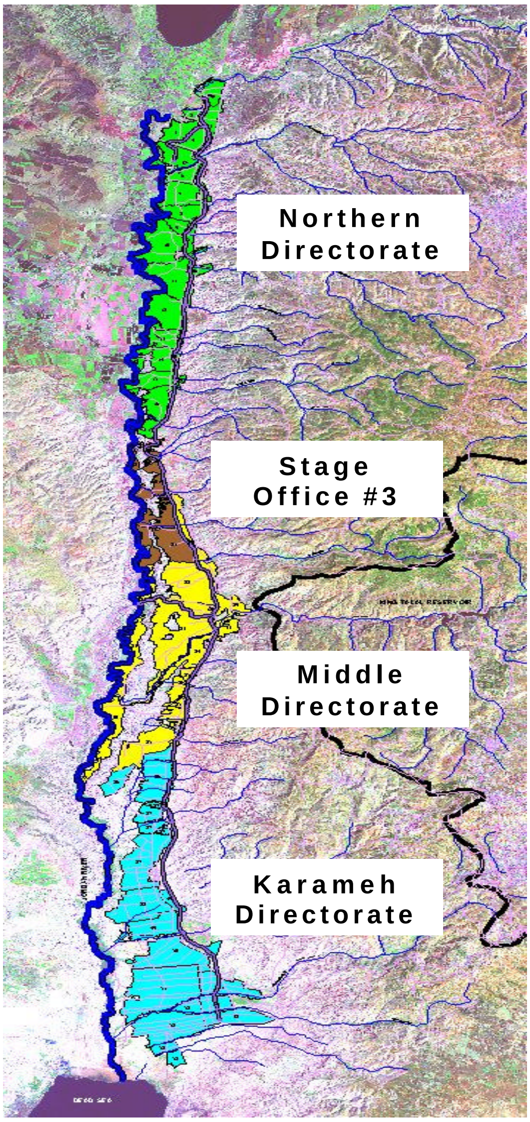

Figure 9. Irrigation Directorates in the JV.

In the case of Stage Office 10, further reclaimed water would supplement existing water sources (Kufrein dam, Wadi Hisban, and shallow groundwater), and in Stage Office 6 it would be added to the present blend of the KTR and Yarmouk (fresh) water.

Being at the tail end of the KAC system, Karameh farmers in Stage Offices 6 and 9 frequently do not receive the water they need, especially during the second half of the calendar year. The result is generally lower yields and cropping intensities than the other two directorates, which, according to Shaner (2001)[17], explains the low net revenues for Karameh farmers. The alternative source of water is the relatively brackish groundwater, which

16. Water Reuse Component Working Paper - “Water Reuse Options in the Jordan Valley”
17. Water Reuse Component Working Paper - “Economics Study for Managing Water Reuse in the Amman-Zarqa Basin & the Jordan Valley.”

a few farmers are using. Farmers in this Directorate are very interested in increased water supplies from KTR.

III.5.2. Reclaimed water requirements and freshwater saved

The estimated total water requirements for the Karameh Directorate is 76 MCM (MWI/ARD, 2001e). To satisfy this will require allocation of a further 40 MCM of reclaimed water. This will allow expansion onto 34,000 dunums and intensification on a further 5,600 dunums.

No fresh water will be saved. The existing Kufrein water supply is not considered suitable for transfer to municipal use (MWI/ARD, 2001e).

III.5.3. Investment costs and economics

The required investments to implement this option are those for on-farm development in Stage Office 9, a pumping facility, and a 5.5-km pipeline to convey water from KAC to Stage Office 10. These costs are, respectively, JD2.7 million and JD1.5 million (MWI/ARD, 2001e; Shaner, 2001), giving a total capital cost of JD 4.2 million.

The expected increase in net returns from this expansion and intensification is JD3.1 million after all costs have been accounted for.

III.5.4. Implementation and institutional arrangements

With respect to Stage Offices 6 and 9, the process for implementing this option is essentially in place and requires no further intervention. When sufficient water supplies are available, the land will be allocated by the JVA to farmers. The required on-farm investments are the responsibility of the farmers.

The JVA would be responsible for development of the 5.5-km conveyance line to Stage Office 10. This Stage Office is water-short, and the addition of reclaimed water will alleviate this. However, at least some of the farmers within this stage office are reluctant to introduce reclaimed water into the water supply.

Improving the productivity of agriculture will require further development of the farmers' skills to effectively manage the water and deal with the quality aspects of the reclaimed water (Grattan, 2000)[18]. The necessary extension and applied research capabilities are discussed in Section V.

III.5.5. Environment and other issues

The primary environmental concern is the potential contamination of the underlying groundwater by the use of reclaimed water for irrigation. However, unlike the highlands, the groundwater is not a significant source of municipal supply, much of it is already more saline than the proposed irrigation water, and irrigation with reclaimed water is already practiced in the area.

III.5.6. Overall assessment of option

- Advantages
  - Costs for development are low and overall economic returns are moderate.
- Disadvantages

18. Water Reuse Component Working Paper - "Impact of Increasing Supplies of Reclaimed Water on Crops, Soils and Irrigation Management in the Jordan Valley."

    - Does not free up freshwater.
- Key implementation issues
    - Development of the proposed conveyance line to Stage Office 10 should be considered as a stand-alone project, comparing the stage office level benefits and costs; and
    - Large water requirement, which limits options elsewhere.
- Relative priority
    - Moderate.

III.6. Middle Directorate (JV #2)

III.6.1. Description

The Middle Directorate (see Figure 9) comprises Stage Offices 4, 5, and 8. In addition, Stage Office 3 is managed as part of this Directorate. However, because this stage office receives no reclaimed water, it has been included in the Northern Directorate analysis below.

The water reuse option in the Middle Directorate is to use more reclaimed water for irrigated agriculture in Stage Offices 4, 5, and 8 through intensification.

The present irrigated area in the Middle Directorate extends to a total of around 43,000 dunums (MWI/ARD, 2001e). The quantity supplied to the Directorate is less than needed to meet demand. With further increases in supply of reclaimed water, the irrigated area in the Directorate could be expanded to a total of 49,000 dunums, a 6,000-dunum increase. Also, the cropping pattern would be more intensive.

III.6.2. Reclaimed water requirements and freshwater saved

The annual water requirements for an intensified cropping pattern in the Middle Directorate, excluding Stage Office 3, are estimated to be 52 MCM (MWI/ARD, 2001e). With 20% of this supplied as freshwater from the KAC, the total water allocation from KTR is 43 MCM, which is 6 MCM higher than 1998, the base year used in developing this plan. The additional reclaimed water requirements for the Middle Directorate are, therefore, 6 MCM.

Although there is some use of freshwater from KAC water in this directorate, the opportunity for exchange with reclaimed water is very limited, since it generally is available during high-flow months when the municipal demand is being met.

III.6.3. Investment costs and economics

There are no anticipated capital investments required. The increase in net revenues to the farmers is expected to be around JD2.2 million, less any minor investments the farmers must make (MWI/ARD, 2001e; Shaner, 2001). This option qualifies as a strong contender for additional reclaimed water when it becomes available in the JV.

III.6.4. Implementation and institutional arrangements

Improving the productivity of agriculture will require further development of the farmers' skills to effectively manage the water and deal with the quality aspects of the reclaimed water (Grattan, 2000). The necessary extension and applied research capabilities are discussed in Section V.

III.6.5. Environment and other issues

No additional environmental impacts are anticipated. As mentioned above, further enhancement of the farmers' skills to manage this quality of irrigation water is required to, among other things, avoid salinization of the soils.

III.6.6. Overall assessment of option

- Advantages
  - Costs for development are very low and overall economic returns are good.
- Disadvantages
  - Does not free up freshwater.
- Key implementation issues
  - None.
- Relative priority
  - Preexisting allocation that is not fully met.

III.7. Northern Directorate (JV #3)

III.7.1. Description

The Northern Directorate (see Figure 9) comprises Stage Offices 1, 2, and 7. Also Stage Office 3, which is now managed as part of the Middle Directorate but has been included in some of the documentation in the Northern Directorate, is included here in the Northern Directorate. All four Stage Offices are at present supplied with what is essentially freshwater from the Yarmouk, Mukhaiebeh wells or the side wadis. The cropping pattern in the Directorate is dominated by salt-sensitive crops, specifically citrus (Grattan, 2000)[19].

This Directorate is a major user of freshwater that, as demonstrated in MWI/ARD (2001e), is normally water-short in the summer months. Development of dams in the Yarmouk basin and the recent drying trends in the natural hydrology have raised concerns over the dependability of the supply. In addition, the ever increasing need to meet the basic water requirements of the urban population threaten to jeopardize the reliability of the supply. Reclaimed water presents a potential alternative water supply for all or part of the Directorate.

Considering this Directorate as an option is a contentious issue. Water users in this Directorate are opposed to the use of reclaimed water, but some recognize that the freshwater supplies are not guaranteed and that reclaimed water presents an alternative water supply. As presented in Grattan (2000), using reclaimed water in this directorate would have a significant negative impact on the cropping pattern resulting in a reduction in the net revenues for the farmers (Shaner, 2001). Also, the introduction of reclaimed water into this directorate would jeopardize its marketing advantage.

If freshwater supplies to the Northern Directorate are secure, this option need not be considered. However, if the present trends persist, such an option needs attention.

The water reuse option is to transfer water, by gravity, from Wadi Zarqa northward to the pumping stations serving the northern directorate (see Figure 10). As detailed in MWI/ARD

19. Water Reuse Component Working Paper - "Impact of Increasing Supplies of Reclaimed Water on Crops, Soils and Irrigation Management in the Jordan Valley."

(2001e), it would require the construction and operation of a gravity pipeline that would carry reclaimed water from Wadi Zarqa downstream of the KTR to the upper reaches of the Northern Directorate.

III.7.2. Reclaimed water requirements and freshwater saved

This option would require up to 57 MCM of reclaimed water and could replace up to the equivalent amount of freshwater. This assumes that 20% of the overall water supply to the directorate would come from freshwater and a further 10 MCM of reclaimed water would be supplied from Irbid (MWI/ARD, 2001e).

III.7.3. Investment costs and economics

The capital investment required to develop a gravity transfer pipeline from Wadi Zarqa to all pumping stations in the Northern Directorate is estimated to be JD87 million (MWI/ARD, 2001e). There will be additional costs associated with changes in irrigation equipment and changing cropping patterns. Also, the loss of productivity and markets will require some form of compensation to the affected farmers. The facilities to transfer a further 45 MCM of freshwater from the valley to the highlands are already under development. If this is to come from the 57 MCM discussed above, capacity for pumping and conveyance of the remaining 12 MCM would have to be developed. These factors have been incorporated in the economic analysis (Shaner, 2001).

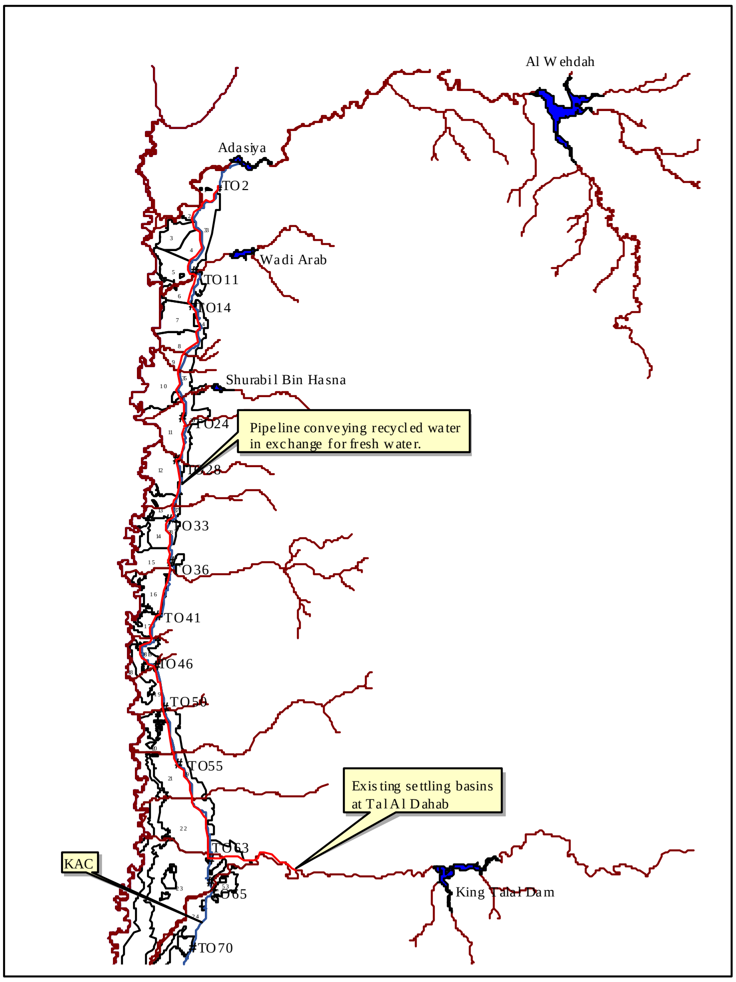

Figure 10. Schematic of reclaimed water transfer line to the Northern Directorate.

This option can be considered from two economic perspectives: the economic returns from agriculture and the value of the freshwater transferred to domestic use.

The former case would occur sometime in the future when the quantity of freshwater in the Northern Directorate has diminished and sufficient reclaimed water resources can be secured. The transfer pipeline would have to be justified on agricultural returns alone and, as detailed in Shaner (2001), would be a break-even development.

The latter case, which would occur if the option were to be developed in conjunction with the transfer of freshwater to domestic use, would cost 430 fils for each m^3 of freshwater transferred and delivered to the Zai treatment plant (Shaner, 2001). The cost of developing the least expensive alternative new water resources for urban water supply is estimated to be no less than 700 fils/m^3.

III.7.4. Implementation and institutional arrangements

Implementation of this option depends on the final acceptance by the present water users in the directorate. Considering the expected increase over time in demand for the freshwater and resultant increase in reclaimed water resources, the phasing of the implementation, either by stage office or pump station, would be appropriate. However, the capacity of the transfer line should be sufficient to meet the built-out demand.

The JVA would be the responsible agency. Significant support, most likely by a strengthened Irrigation Advisory Service (IAS), will be required in supporting the farmers to change cropping patterns and water management practices.

III.7.5. Environment and other issues

The environmental considerations for this option are significant, particularly the risks of groundwater contamination, soil salinization, reduced productivity, and lost markets.

III.7.6. Overall assessment of option

- Advantages
    - Economically viable if value of freshwater included;
    - Technically feasible;
    - Potential to exchange up to 57 MCM of freshwater; and
    - Sustains irrigated agriculture in the Northern Directorate.
- Disadvantages
    - Severely impacts present cropping pattern;
    - Loss of marketing advantage;
    - Large cost of physical works;
    - More difficult to manage on-farm;
    - Potential impact on groundwater;
    - Relatively large volume of reclaimed water; and
    - If not implemented in conjunction with declining freshwater supplies and presently unallocated reclaimed water supplies, the economic viability of redeveloping the area is marginal.
- Key implementation issues
    - Decision on allocation needs to be made in the near future. If Karameh continues to develop as supplies become available, this option cannot be implemented.
    - Interest and cooperation of present water users.
    - Compensation for loss of farm production capacity.
    - Technical support for water users to manage reclaimed water.
    - Phase in as reclaimed water supplies become available.
- Relative priority
    - High.

III.8. Reuse at Minor WWTPs in the AZB

III.8.1. Description

The existing minor WWTPs in the AZB are Jerash (east), Abu Nuseir, and Baq'a (MWI/ARD, 2001b)[20]. There are further WWTPs planned for Jerash (west) and for Zarqa, located downstream of the As Samra plant. The Zarqa plant is considered as part of water reuse associated with the As Samra plant in the main Wadi Zarqa and, therefore, has already been discussed.

At Jerash, reclaimed water is already effectively being used downstream of the WWTP to irrigate a variety of fruit trees (MWI/ARD, 2001b). There are some small areas of irrigation downstream of the Baq'a facility, but nothing associated with the Abu Nuseir plant, although a site has been identified (JICA, 2000). Excess effluent from all these plants continues downstream to the KTR.

In addition to the potential site at Abu Nusier, there is limited land at Baq'a, Jerash, or Jerash west for further development of irrigated agriculture. However, at Jerash, with the development of the springs upstream in the wadi for domestic supply, the farmers now irrigating with freshwater are likely to seek alternative sources. Also, immediately to the east of the Baq'a facility is the Baq'a valley, where irrigated vegetables (around 4,000 dunums) are produced using groundwater. This presents a potential opportunity for exchange of recycled water with reasonable development costs, thereby freeing up fresh water for domestic use. There are many issues with such a development, including the potential threat to an important aquifer, marketing concerns, impact on cropping patterns, and the acceptability by the present users. However, the value of the groundwater would justify investment in further treatment of the wastewater, farmer education, and so forth. This may present an opportunity to develop a high-quality effluent and promote unrestricted use, as proposed in MWI/ARD (2001c)[21].

III.8.2. Reclaimed water requirements and freshwater saved

The present use of reclaimed water from the minor WWTPs is approximately 0.6 MCM. This could rise by a further 6.6 MCM by the year 2025, if a major effort was made in the Baq'a area. This could conserve up to 2 MCM of groundwater/year.

III.8.3. Investment costs and economics

This is a mixture of potential developments. However, the main sub-option is Baq'a. This sub-option would require a high-quality effluent. Conveyance and pumping costs would be moderate. If accepted by the existing farmers, the economics would be good. However, such options cannot economically compete with the JV if the irrigated crop has low returns, such as commercial forest.

III.8.4. Implementation and institutional arrangements

Other than Jerash, where farmers are likely to seek a replacement water source, the development at or near these minor WWTPs will require intervention. The costs for further treatment, pumping, and conveyance will be moderate to high. It is unlikely that Abu Nusier can

20. Water Reuse Component Working Paper - "Water Reuse in Wadi Zarqa and From Other Amman-Zarqa Sources."
21. Water Reuse Component Working Paper - "Standards, Regulations & Legislation for Water Reuse in Jordan"

compete with the JV. However, once the JV receives its full allocation, these options should be more attractive.

III.8.5. Environment and other issues

There is potential for increased groundwater contamination. This is a particular concern in the Baq'a area, which is underlain by a small but important aquifer. Also, exchange with present groundwater will have significant impact on cropping patterns and management requirements.

III.8.6. Overall assessment of option

- Advantages
  - Costs for development are moderate to high;
  - Potential to free up to 2 MCM of freshwater; and
  - Could be sites for innovative reclaimed water developments.
- Disadvantages
  - Economics are marginal unless exchanging with groundwater;
  - Potential for contamination of important aquifer (Baq'a);
  - Area becoming urbanized; and
  - Irrigation of low-value crops (commercial forest) does not justify the investment.
- Key implementation issues
  - Needs intervention by the Government; and
  - Appropriate to wait until the JV is satisfied.
- Relative priority
  - Low.

III.9. Summary of Options

A summary of the characteristics and conclusions from the detailed investigations of the priority options is presented in Table 2.

Table 2. Summary of Characteristics and Conclusions from Analysis of Priority Options

OPTION	DESCRIPTION	DEMAND FOR RECLAIMED WATER	FRESHWATER CONSERVED		CAPITAL COSTS	ECONOMICS OF AGRICULTURE	INSTITUTIONAL RESPONSIBILITY	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION ISSUES	PRIORITY
		MCM	Volume MCM	COST fils/m^3	JD million						
Dhuleil–Hallabat irrigation network	Exchange with groundwater for agriculture in the highlands	9.5	9.5	610	35	Not viable unless exchange with groundwater considered	WAJ. Water user organization	Conserves groundwater	Risk of contaminating important aquifer	Effluent quality. Ensure O&M costs available. Farmer involvement.	MODERATE
Industrial Reuse in Hashemite –Zarqa area	Exchange with groundwater for cooling. Meet future demands.	13	13	400	13	Not applicable. Economics for use in industry are very good.	Industries. Private ownership of network. Government as facilitator.	Conserves groundwater. Power plant required to use reclaimed water.	Cooling system discharge could increase salt discharges to wadi.	Reliable effluent quality New power plant by 2004 Stakeholder coordination vital	HIGH
Wadi Zarqa	Intensification of agriculture	3.3	0	N/A	0	Good	Farmers	Low cost	Health risk No freshwater conserved	Cooperation from farmers on health risk	
Karameh Directorate	Intensification/ expansion of agriculture	40	0	N/A	4.2	Moderate Net return JD 3.5 million	JVA Farmers	Low cost Infrastructure exists	No freshwater conserved	None	HIGH
Middle Directorate	Intensification of agriculture	6	0	N/A	0	Good. Net return JD2.2 million	JVA Farmers	Very low cost	No freshwater conserved	None	HIGH
Northern Directorate	Exchange with freshwater used for agriculture	57	57	430	87	Break even	JVA Farmers	Volume of water conserved. Sustain agriculture	Changes to cropping pattern Potential loss of market Difficult to implement Resistance by water users	Decision needed User cooperation Technical support Phase in	HIGH
Minor WWTP	Expand/intensify agriculture in vicinity of plant	6.6	2			Low to moderate	WAJ Farmers	Could replace freshwater Progressive projects	Potential contamination of important aquifers Urbanization	Must be high value crops Wait until other options satisfied	LOW

IV. SCENARIOS FOR MANAGING WATER REUSE

Section IV presents the approach used in developing the scenarios (combinations of options) for allocating the projected increased volumes of reclaimed water in the AZB over the next 25 years. The final scenario (No. 1) is presented as well as an alternative scenario (No. 2) that considers the consequences of allocating reclaimed water to the Northern Directorate. In addition, the impacts of any increased storage capacity, potential shortfall in reclaimed water supply, and natural climate variability are examined. Finally, the water quality implications of implementing these scenarios are considered.

IV.1. Strategy

As presented in Section I, the key policy objectives for allocation of future reclaimed water in the AZB are exchange with existing use of freshwater (1) to meet future demands that would have been met with freshwater and (2) to maximize the economic returns from the resource.

The scenarios presented in this chapter are the result of an iterative process as the future options for water reuse were developed, preliminary scenarios were examined (MWI/ARD, 2001f)[22], and feedback was received from key stakeholders.

Considering the chronic national water deficit and the Government’s policy to exchange effluent for freshwater resources, it is highly unlikely that further freshwater sources will be available for irrigated agriculture. Where reclaimed water is used to develop new irrigated agriculture, no freshwater resources will be available, except where excess freshwater cannot be transferred to a higher use, as is the present case with some of the Yarmouk water in the wet months (MWI/ARD, 2001e).

IV.1.1. Preexisting obligations

There are two elements to preexisting obligations. One is that existing uses of reclaimed water will continue to be met in the future at least at the same levels. These existing uses are the Middle Directorate, Stage Office 6 of the Karameh Directorate, and Wadi Zarqa. As yet, Stage Office 9 of the Karameh Directorate has not been allocated water. The second element of preexisting obligations includes the options, as discussed in the previous section, to allocate further reclaimed water to the Middle Directorate for intensification and to Wadi Zarqa. The options to allocate more water to the Middle Directorate and to Wadi Zarqa will produce increased net returns with little investment. In the case of Wadi Zarqa, the projected increase in water consumption will occur if markets for irrigated produce improve. Figure 11 shows the estimated present usage of reclaimed water, in purple, and the average freshwater allocations, in blue.

22. Water Reuse Component Working Paper – “Storage, Conveyance and Blending, and Analysis of Preliminary Scenarios for Water Reuse in the Amman-Zarqa Basin.”

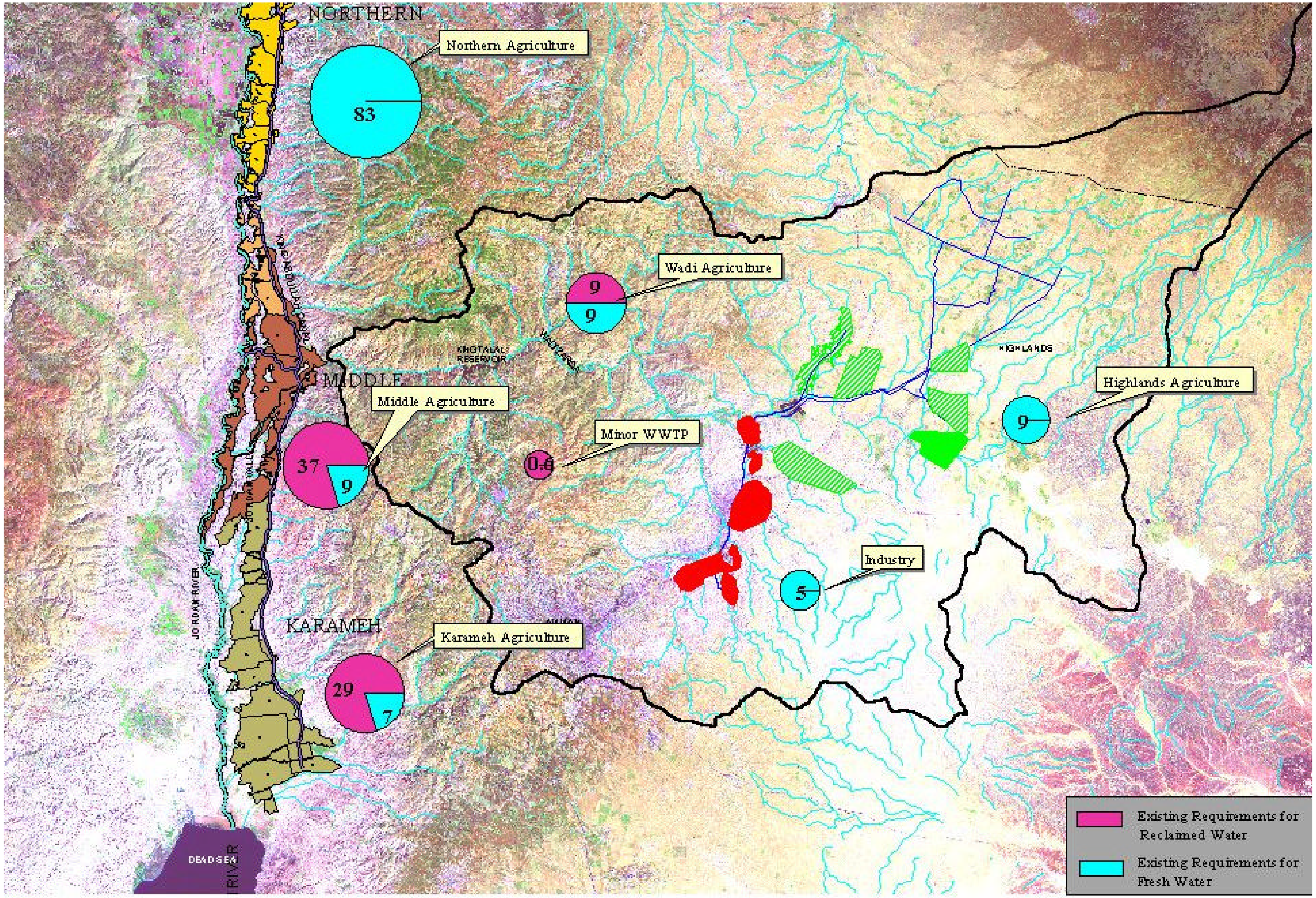

Figure 11. Summary of existing reclaimed and freshwater use.

In addition, the WAJ has issued a permit to the Hashemite University to utilize up to 1.5 MCM of reclaimed water/year. Although the University has yet to develop the necessary infrastructure to utilize this resource, it has been included as an obligation to be met before further allocation of reclaimed water.

IV.2. Prioritization of Options

As detailed in the previous section, the options are:

- Exchange with groundwater with the Dhuleil–Hallabat irrigation network (HL #3a);
- Industrial and Municipal (I&M) reuse in the Hashemite–Zarqa area (HL #1);
- Intensification in Wadi Zarqa (WZ #1);
- Intensification and expansion in Karameh (Southern) Directorate (JV #1);
- Intensification in the Middle Directorate (JV #2);
- Exchange with freshwater in the Northern Directorate (JV #3); and
- Reuse at other WWTPs.

The potential reclaimed water requirements to fully satisfy these options are shown in Figure 12 in purple. The expected freshwater allocation is shown in blue.

IV.2.1. Comparisons between options

Table 3 summarizes the costs of conserving freshwater for the relevant options (Shaner, 2001)[23]. All three options present opportunities to provide freshwater at costs lower than anticipated for the least expensive new freshwater projects. In terms of quantity of water and unit costs, the Northern Directorate is the most significant option.

Table 3. Summary of Costs for Conserving Freshwater

Option	Capital Cost (JD)	Freshwater (MCM)	Cost (fils/m^3)
Northern Directorate	87 million	57 million	430
Dhuleil-Hallabat	35 million	10 million	490
Industrial	13 million	13 million	630
New freshwater sources			> 700

In addition to freeing up freshwater, the industrial reuse option provides water to industry, which is of greater economic value than using it for irrigated agriculture (Shaner, 2001) See Table 4.

Table 4. Summary of Economics of Irrigated Agriculture Options

Option	Capital Cost (JD)	Reclaimed Water (MCM)	Net Revenues
Middle Directorate	0	6 million	JD2.2 million
Karameh	4.2 million	40 million	JD3 million
Northern Directorate	87 million	57 million	Break even
Highlands Agriculture			Not viable

23. Water Reuse Component Working Paper - "Economics Study for Managing Water Reuse in the Amman-Zarqa Basin and the Jordan Valley."

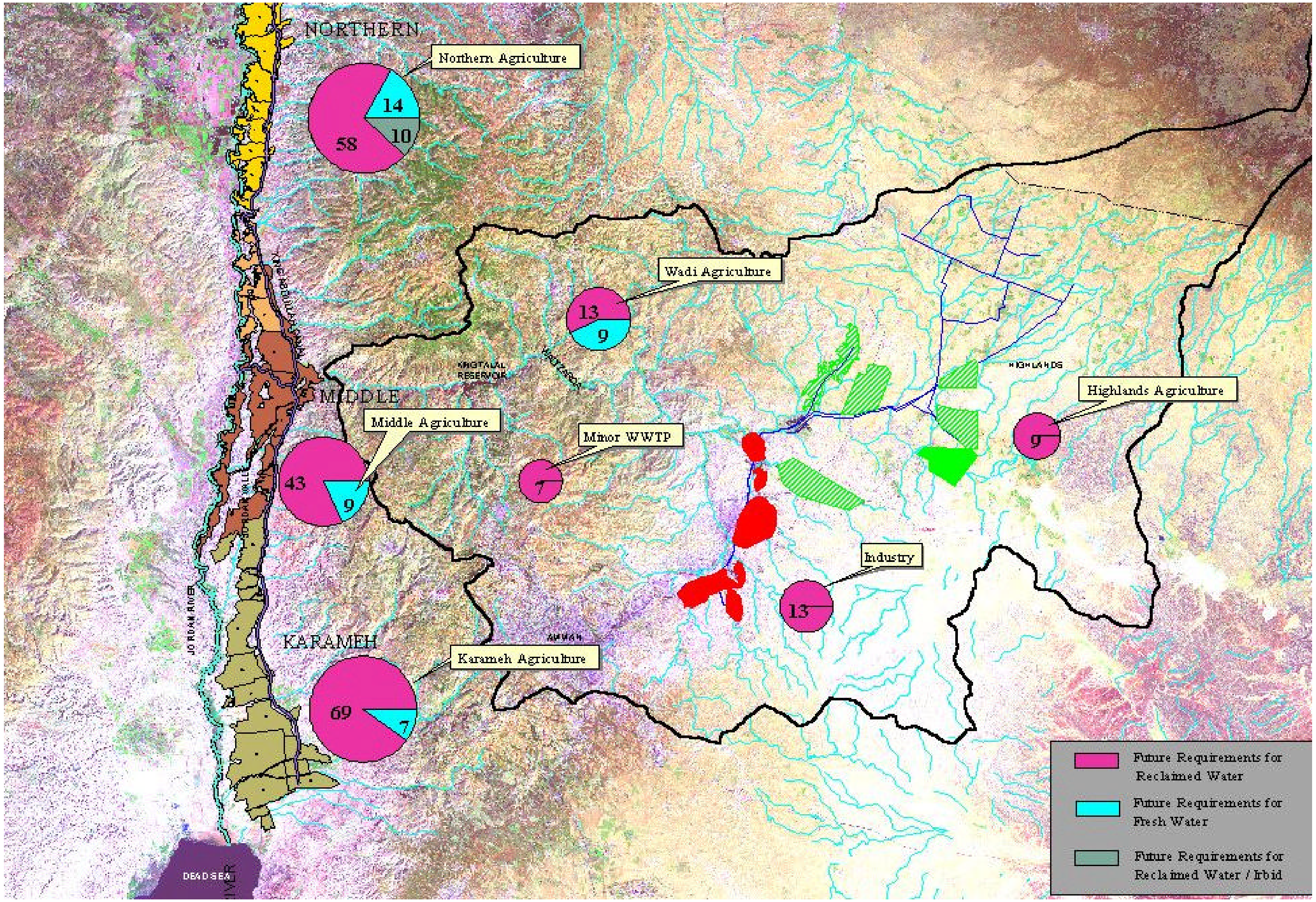

Figure 12. Summary of potential reclaimed and freshwater use for each option.

Intensification of irrigation in Wadi Zarqa, where additional investment costs will be very low, will yield a similar result to the Middle Directorate. For the other WWTPs, where the necessary conveyance, delivery, and application systems have to be developed, and further treatment may be required, the net returns will be low unless high-value crops are produced.

IV.2.2. Selection of priority options

Assuming that the present resistance to using reclaimed water in the Northern Directorate remains, and following feedback from stakeholders, the basic prioritization of options is:

1. I&M reuse in the Hashemite–Zarqa area (HL #1);
2. Karameh (Southern) Directorate (JV #1);
3. Dhuleil–Hallabat irrigation network (HL #3a); and
4. Reuse at other WWTPs.

However, should the Northern Directorate be determined to be a priority, the basic prioritization of options is:

1. I&M reuse in the Hashemite–Zarqa area (HL #1);
2. Northern Directorate (JV #3);
3. Karameh (Southern) Directorate (JV #1);
4. Dhuleil–Hallabat irrigation network (HL #3a); and
5. Reuse at other WWTPs.

In investigating the above scenarios, it is assumed that all existing unfulfilled obligations (Middle Directorate, Wadi Zarqa, and the Hashemite University) are met.

IV.3. Analysis of Scenarios

This subsection presents the analysis of scenarios for allocating reclaimed water in the AZB and JV. Details of the scenario analysis methodology and the results from a range of conceivable scenarios are presented in detail in MWI/ARD (2001f)[24].

The analysis of scenarios used the projected effluent supplies (Section II, above) and a conservative estimate of the natural hydrology of the basin (65% of the long-term average). The initial analysis for a given scenario assumed no additional storage. For each scenario, the aim was to determine the most aggressive schedule (start date for each option) without creating a large deficit. The objective function in this analysis was to have no annual deficit in the 25-year planning period exceed 5% of the total expected annual demand.

In addition to the conservative hydrology, the basic assumptions in balancing the supplies with the demands were:

- Sedimentation occurs in KTR at an average annual rate of 0.65 Mm^3 (Harza, 1996);
- Reach losses of 10%;
- KTR has an initial capacity at the beginning of the simulation period of 15 Mm^3 and a total live capacity of 75 Mm^3; and
- Blending ratio at the mixing point at KAC is 20% freshwater.

24 Water Reuse Component Working Paper "Storage, Conveyance & Blending, and Analysis of Preliminary Scenarios."

IV.3.1. Results

For the scenario based on the first prioritization above, the schedule of when reclaimed water can be allocated to each of the options is presented in Table 5. The graph of the final run of the allocation model (MWI/ARD, 2001f) is depicted in Figure 13.

Table 5. Schedule of Allocation for Prioritization (Northern Directorate not Included)

Option	Year Fully Met	
	Reclaimed Water Supply as Projected	Reclaimed Water Supply 15% Less Than Projected
Preexisting demands	2005	2006
Industrial (HL #1)	2006	2007
Karameh Directorate	2014	2019
Dhuleil–Hallabat	2015	2020
Other WWTPs	2016	2021

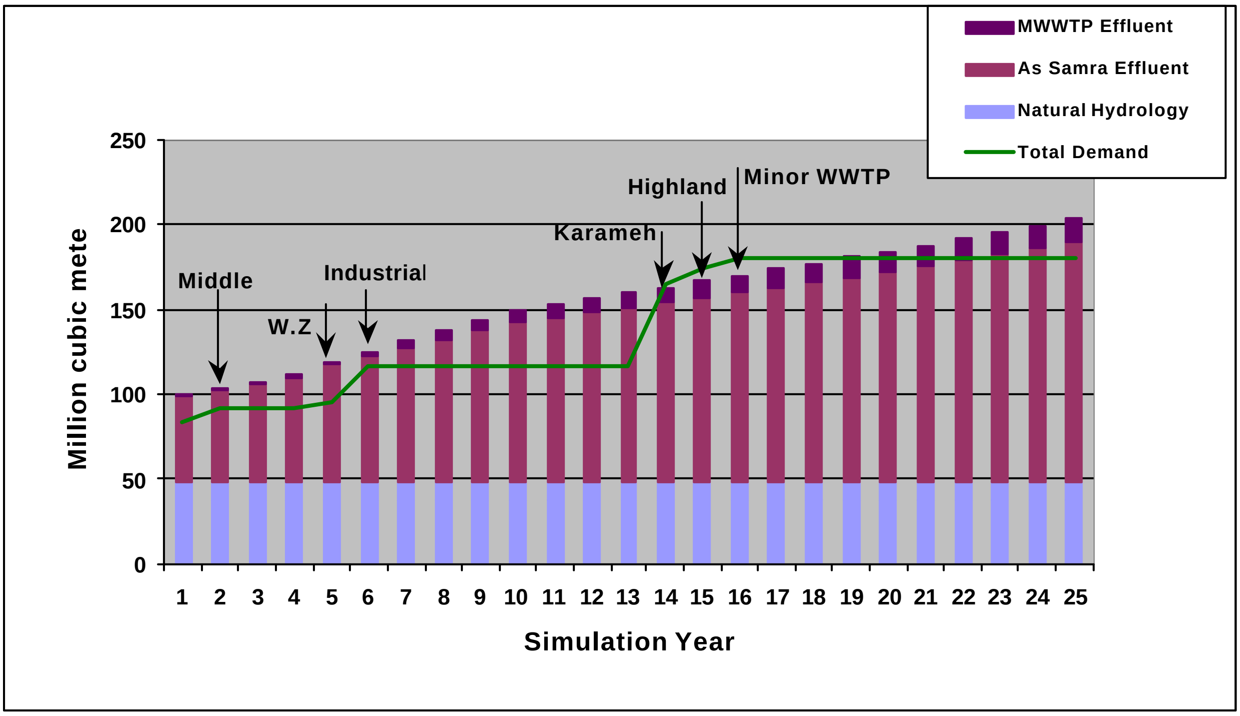

Figure 13. Output from allocation model.

By the year 2016, the needs for all viable options, other than the Northern Directorate, will have been met. This includes exercising the option to develop irrigated agriculture with well treated effluent at the other WWTPs.

As discussed in Section II, the estimated volumes of reclaimed water in the future are based on the development of new water supplies for the urban areas. If these new supplies are delayed, the volume of reclaimed water produced will be lower than projected. Table 5 also presents the schedule for allocations should the volume of reclaimed water by 2025 be 15% less than predicted. The result is a delay in the schedule of around five years. This also represents the situation should demands be 15% higher.

Table 6 shows the schedule for allocation of reclaimed water where the Northern Directorate is given priority. In this case, the implementation of the Northern Directorate after the industrial option precludes the Karameh Directorate getting its full allocation before the year 2030.

Table 6. Schedule of Allocation for Prioritization (Northern Directorate Included)

Option	Year Fully Met
	Supply as Projected
Preexisting demands	2005
Industrial	2006
Northern Directorate	2017
Karameh Directorate	2030
Dhuleil–Hallabat	-
Other WWTPs	-

IV.4. Increased Storage Capacity Requirements

As reclaimed water becomes more dominant in the hydrology of the basin, the total supply from all sources will be more reliable. However, as future options are developed in the AZB and JV, and the KTR gradually loses capacity owing to sedimentation, additional storage capacity could further improve the reliability of water supplies.

IV.4.1. Opportunities for increasing storage capacity

Opportunities to develop storage capacity in the AZB and JV include:

- Excavation of sediment from the KTR;
- The existing Karameh Reservoir;
- An in-stream dam downstream of the existing KTR;
- Groundwater recharge in the JV;
- Off-stream storage inside wadis in the JV; and
- Off-stream storage inside wadis of Wadi Zarqa.

With the exception of the off-stream storage, these opportunities have been examined as part of the planning process.

Large-scale dredging to remove the sediment from the KTR does not appear advisable because of the costs associated with removing it (MWI/ARD, 2001f). The levels of trace elements and heavy metals in the sediment do not present a major risk, and keeping them in situ in the reservoir is the best course of action (MWI/ARD, 2001f).

The 50 Mm^3 Karameh reservoir is intended to store excess water available from the Yarmouk and not water from the KTR. However, since the dam was completed in 1996, there have been limited opportunities to divert excess flows from the Yarmouk. The salinization of the reservoir from springs upstream and strata within the reservoir and the effect of evapoconcentration have, to date, resulted in stored water with salinity levels too high to be practical for irrigation. The utility of the reservoir can be determined only when more dam operational experience is obtained under more favorable hydrological conditions.

According to the JVA, development of a further in-stream dam on the Zarqa has been previously discussed. No studies are available. Examination of existing contour maps suggest that an 85-m-high dam upstream of Tal Al-Dahab weir would produce a reservoir capacity of 22 Mm^3. No geological or geotechnical assessment has been performed.

Artificial recharge of groundwater may present an opportunity to improve, in terms of quantity and quality, shallow groundwater supplies available in parts of the Karameh and Middle Directorates (MWI/ARD, 2001g)[25] These resources could be accessed during dry periods when surface water supplies are low.

IV.4.2. Impact of increasing storage capacity

Using the same conservative average hydrological conditions as in the analysis above, the allocation model was run multiple times with increasing volumes of storage (MWI/ARD, 2001f). This storage could come from either of the two surface storage facilities described above. The results showed that the scenarios could be implemented more aggressively. In the first scenario presented above, the Karameh Directorate would be fully satisfied by the year 2010 compared with 2014 if the storage capacity were increased by 20 MCM. Further increases in storage volume produced little advantage in the schedule for allocating to options. In addition, increased storage capacity could improve the overall management of the system.

IV.5. Impact of Climate Variability

Variation in the natural hydrology in the AZB creates severe challenges to productively manage the water resources. The recent drying trend, where the average runoff and base flow (excluding effluent) for the past six years has been only 65% of the long-term average, has been particularly difficult for irrigated agriculture in the JV. The increasing dominance of reclaimed water in the total water supply will improve the reliability in the long term, but the development of options as described above places additional demands on the system.

For Scenario 1 above, a series of 30 different synthetically generated flow series, based on an average of 65% of the long-term average hydrology, was developed. For each simulation run, the probability of a given shortage over the planning period (25 years) was determined. From this analysis, it was concluded that for all 30 simulations, the 10-year return period shortage will most likely be less than 12% of the total demand (MWI/ARD, 2001f). This is more conservative than would normally be designed into an irrigation allocation, where normal practice is to meet demand four years out of five. However, in the case of the JV, where drought years are often consecutive and the water quality dictates that irrigating under deficit conditions for multiple seasons will be difficult to manage, it is appropriate to be conservative.

IV.6. Water Quality Implications

The water quality constituents of primary interest with respect to water reuse in the AZB are those that would impact agriculture or, to a lesser extent, industry. In the case of irrigated agriculture in the AZB and the JV, these are total salts and chloride. In addition, at certain times of the season, excess nutrients, in the form of nitrogen and phosphorous, can promote excessive vegetative growth rather than additional fruit yield (Grattan, 2000). Furthermore, microbiological contamination, expressed in terms of FCC, can present a serious risk to human health. These constituents were included in the allocation model (MWI/ARD, 2001f). Other

25. Water Reuse Component Working Paper - "Options for Artificial Groundwater Recharge with Reclaimed Water in the Amman-Zarqa Basin and Jordan Valley."

constituents, including heavy metals and suspended solids, have also been investigated, and are discussed below as to their expected levels in the future.

The results discussed below are meant to show trends and relative changes as various scenarios are implemented. Natural variability in the physical system, as well as model uncertainty, mean that values generated by the model should be treated as a "best estimates" and not considered as "100% accurate." The results reported here assume that the quality of the effluent produced from As Samra will be as expected from the new facilities.

IV.6.1. TDS and Chlorides

The TDS and chloride levels reaching the JV from the AZB are expected to trend slightly upward on account of the increasing influence of the reclaimed water (MWI/ARD, 2001f)[26]. Because the present TDS (see Figure 14) and chloride levels (1,200 and 350 mg/l, respectively) are already creating management challenges (Grattan, 2000), this increase is a serious concern. However, should the quality of water supply to Amman improve through the development of new sources from Zara–Main, Disi, and KAC, the TDS and chloride level in the effluent will decline.

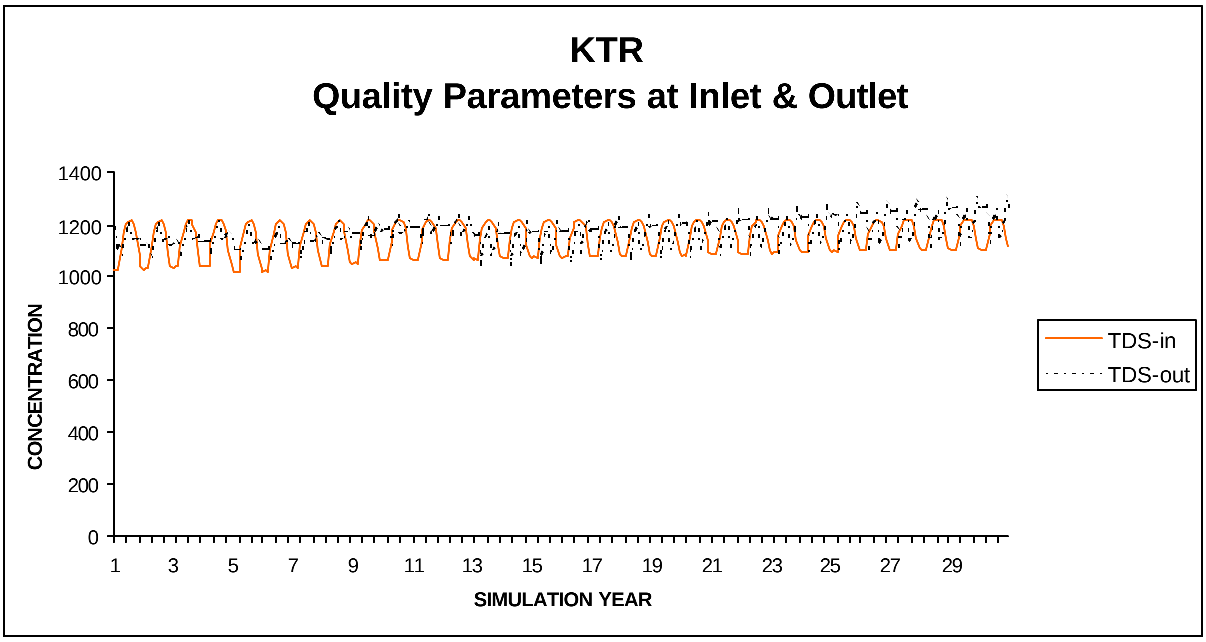

Figure 14. Projected TDS concentration in KTR inflow and outflow.

IV.6.2. Total Phosphorus

TP levels are expected to remain as they are now, and will continue to cause algae blooms in the KTR (MWI/ARD, 2001f). TP concentration in the outflow from the KTR and from any proposed reservoir is expected to be lower than inflow concentrations. This is primarily due to soil-adsorbed phosphorus and sedimentation within the reservoir. Additionally, some uptake of dissolved phosphorus is expected from algae or aquatic vegetation. TP reduction is decreased by shorter retention times.

26 Water Reuse Component Working Paper - "Storage, Conveyance & Blending, and Analysis of Preliminary Scenarios."

IV.6.3. Ammonium and Nitrate

Ammonium is expected to decrease in the reclaimed water as it moves downstream because of oxidation to nitrite and nitrate. By the same reasoning, nitrate is expected to be higher downstream. Travel time from As Samra to the KTR is normally about 18 hours (Harza, 1996). During this relatively short period, very little organic nitrogen is expected to be converted to an inorganic form (ammonium). As such, the sum of ammonia-N and nitrate-N is expected to remain relatively constant moving downstream. Inputs of nitrogen from side wadis would change the mass balance. Little denitrification is expected to occur in Wadi Zarqa as it is fairly well aerated for most of its course.

Within the KTR, consumption of ammonia and nitrate by algae and aquatic vegetation is expected to reduce TN. In addition, some denitrification will contribute to the loss of nitrate. Nitrate is expected to dramatically decrease to below 3 mg/l between inflow and outflow from the KTR or any proposed reservoir, as it has historically through KTR. Ammonium levels are expected to remain around 8 mg/l. Reservoir level has an impact on TN and the form of nitrogen. As reservoir levels decrease, nitrate reduction within the reservoir lessens (MWI/ARD, 2001f).

The implementation of the new As Samra facilities, with TN levels below 30 mg/l, will mean that the overfertilization of crops in the JV will no longer be a problem.

IV.6.4. Total Suspended Solids

TSS can present a problem for irrigated agriculture, especially for drip irrigation, in the form of physical clogging. Present TSS levels at the As Samra outlet are above 100 mg/l, but the inflow into the reservoir has average TSS levels of around 70 mg/l. The average TSS levels drop further through the reservoir to less than 30 mg/l, which present a minor potential for clogging. However, after release from the reservoir, the TSS levels rise again as the water flows downstream, most likely owing to scouring and discharge from the side wadis. The reported problems with TSS (JVA - Middle Directorate, 2000) appear to be due to the increased levels during conveyance from the dam to the diversion points and when the residence time in the reservoir is low. The implementation of the new facilities at As Samra will reduce the BOD and, therefore, reduce the TSS levels at the discharge point into the wadi. This will alleviate the clogging problem with farms in the wadi (MWI/ARD, 2001b)[27] and with the development of highlands options, such as Dhuleil-Hallabat. However, for reasons not directly related to the reclaimed water, TSS will remain an issue at the field level in the JV, and this will need to be addressed by either filtration systems or the management of filtration systems (MWI/ARD, 2001f).

IV.6.5. Fecal Coliform Count

Fecal coliform levels from As Samra will be lower (MPN 1000) once the new facilities are developed. However, the contamination of the water in the wadi from secondary sources will continue to be consistently higher (see Figure 15). As is the case now, the fecal coliforms of the water discharged from the reservoir will be significantly lower (Figure 15), but will rise again before reaching the JV.

The exception to the above is when demands downstream cause the reservoir levels to be low during the wet winter months. The residence time in the reservoir is not sufficient. As shown in

27. Water Reuse Component Working Paper – “Water Reuse in Wadi Zarqa and from Other Amman-Zarqa Sources.”

Figure 16, the elevated fecal coliform levels discharging from the reservoir also mean elevated levels reaching the JV.

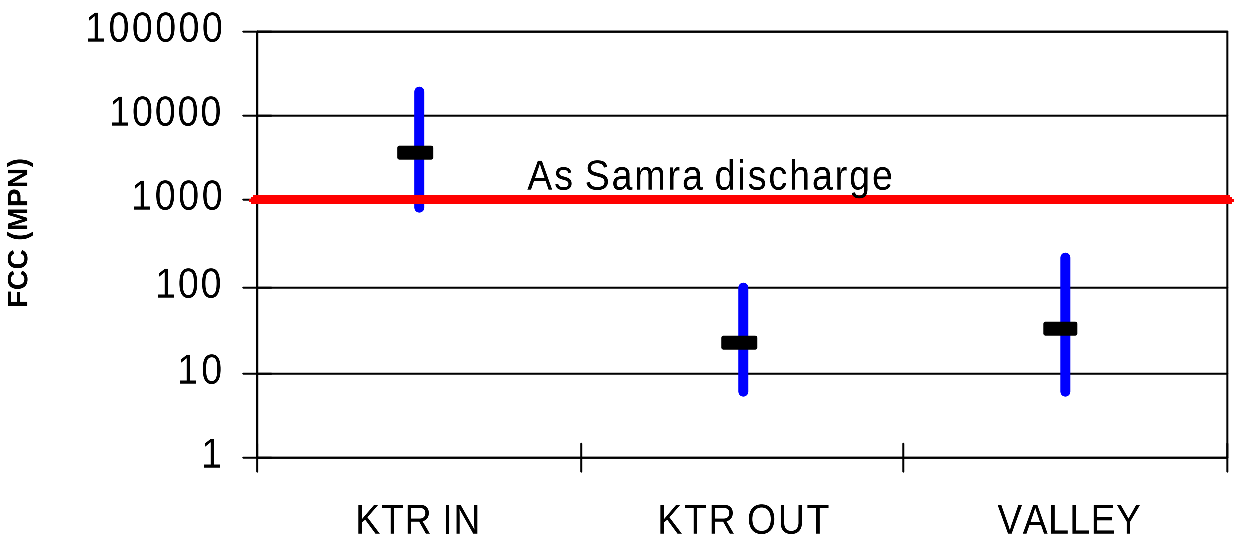

Figure 15. Expected range of fecal coliform levels along Wadi Zarqa.

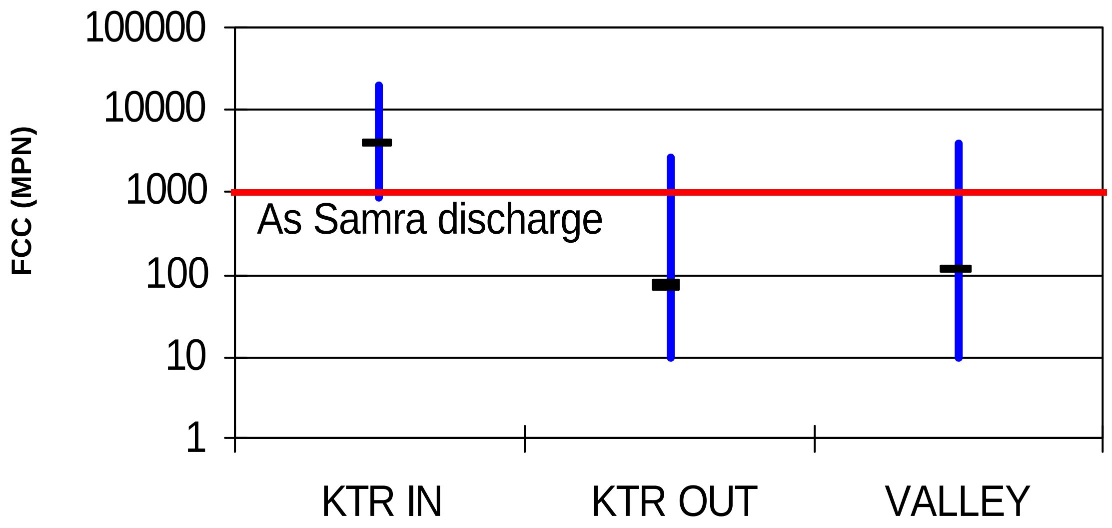

Figure 16. Expected range of fecal coliform levels along Wadi Zarqa if reservoir levels are low in the wet months.

IV.6.6. Metals

From the available data, none of the metals present in As Samra effluent or present in Zarqa runoff are in concentrations sufficient to affect crop yield (Grattan, 2000). This is consistent with the relatively low level of industrialization within the basin. The few metals that do pass through the As Samra WWTP generally settle in the KTR and are adsorbed to the bottom sediments.

Despite the above, water users in the JV are concerned and cite a number of cases. Brief investigations of specific cases were conducted (Grattan, 2001). Detailed investigations are required. The sustainable management of reclaimed water depends on such cases being fully addressed and added to a rational knowledge base. Grattan (2000) identified four elements that are at levels that merit regular monitoring. These are manganese (Mn), molybdenum (Mo), lithium (Li), and vanadium (V).

V. PREREQUISITES AND ACTIONS FOR SUSTAINABLE WATER REUSE

There are a number of prerequisites and actions that need to be implemented to sustain the management of water reuse in the AZB and the JV. These interrelated actions include:

- Support the farmers to improve on-farm water management, especially to deal with the water quality-related issues. This needs a major integrated extension and applied research effort.
- Enhance information management, especially with regard to information on water quality and making it available to farmers. Regular monitoring and reporting of soil and crop health needs to be introduced.
- Reduce further the health risks associated with irrigation practices in Wadi Zarqa. This must be done in cooperation with the farmers.
- Control secondary fecal contamination sources in the basin.
- Enhance the Jordanian standards and guidelines for water reuse.
- Enhance the control of hazardous discharges to sewers and wadis.

V.1. Improving On-Farm Water Management

The challenges facing irrigated agriculture in using this reclaimed water resource cannot be overemphasized. It has been shown in these investigations and, more significantly, by the farmers, that this is technically and economically feasible. However, despite the presence of a few farmers with very high levels of management expertise in the JV, to sustain irrigated agriculture in the future requires that the farmers' skills and knowledge be significantly improved.

In the JV, water supply is often less than the demand (MWI/ARD, 2001e), and there are a number of water-quality parameters that will affect the crop, irrigation management, and system maintenance (Forward, 1999; Grattan, 2000). Farmers already have to manage within a very limited margin of safety. In addition to the constraints and management challenges of TDS and chloride levels in the irrigation water, farmers in Wadi Zarqa and the JV have to contend with clogging agents in both the KTR and KAC water and limited information or even misinformation on the impact of specific water-quality constituents on their crops. Furthermore, farmers, particularly in Wadi Zarqa, need to be aware of appropriate practices for irrigating with microbiologically contaminated water.

Farmers must understand how to effectively manage water for their specific situation and be able to access information on existing and emerging issues concerning water quality. To develop, maintain, and disseminate this information requires an effective extension service and applied research capability that not only considers management of water quantity, but also water quality's relationship with the soil and crops.

The objectives of improving on-farm water management are to improve agricultural returns, to ensure sustainability, and to reduce risks associated with the microbiological contamination of the water in Wadi Zarqa.

The required actions are enhancements of both the extension services and the applied research capabilities. The extension services and applied research must be integrated and focused on solving the actual problems faced by the farmers, particularly concerning the water quality.

For farmers to be able to optimize management, maintenance, and crop performance, an overall understanding of irrigation systems, irrigation management, and crop/soil/water quality relations is essential. Special care needs to be taken to maintain a favorable environment in the crop root zone when irrigating with poor-quality water. The skill level of the farmer needs to be upgraded considerably in order to utilize water supplies of higher salinity (i.e., the KTR water) successfully. *The current salinity level in the KTR is on the margin such that a slight change in irrigation management could have devastating consequences*. The grower needs to know crop water requirements, crop differences in sensitivity to salinity, and basic principles on irrigation management and salinity control. Therefore, the grower or irrigation manager needs to adopt practices that use these principles and carefully monitor the soils for salinity build-up and be able to remedy adverse conditions.

Nationally the Ministry of Agriculture (MoA) is responsible for providing extension services to farmers. However, the MoA has no responsibilities within the JV; in areas where they are responsible, such as the highlands and Wadi Zarqa, they have limited capabilities on irrigation water management.

Within the JV, the IAS of the JVA is responsible for information and technology transfer to the grower, and they deal specifically with on-farm water management. The IAS is a USAID-funded project (Hagan and Scott, 2001). They interact directly with the growers and conduct on-farm activities, such as soil moisture monitoring. There has been relatively high staff turnover, most likely because the service is not viewed as a permanent part of the JVA. As a means of improving the institutional setting for the IAS, it has been recommended that it become part of the MWI (Hagan and Scott, 2001).

Extension services also exist in the private sector, as private consultants or within companies providing farm inputs such as fertilizers. Private consultants are and will be an important component of future extension services, although they are generally not accessible to all but the larger farmers. Also, in the case of fertilizer companies, the objective is to sell more fertilizer, which is not necessarily consistent with improving the returns of agriculture.

Relevant applied research is now being conducted by the Brackish Water Project and, to a limited extent, the IAS within JVA; the National Center for Agriculture Research and Technology Transfer (NCARTT) within MoA; and individual universities. Within these organizations there is already a considerable knowledge base. However, that which is of utility to farmers is not readily accessible.

As indicated above, the actual water quality relationship to the soils and crops in the JV is complicated, and is further confused by misinformation. Effective extension services need to be backed up by supportive applied research that is responsible for problem solving, and by developing viable solutions to complicated site-specific situations. Ideally, extension agents should conduct field research that will help with the other portion of their job, extending or transferring knowledge. To be effective, the agent must have applied research experience such as what would be obtained under graduate education from a credible university.

Such research should focus on troubleshooting and developing technology and recommendations that support the extension service. Such efforts should include further efforts in developing and introducing on-farm filter methodologies suitable for the JV; using drip systems with larger emitters (bubblers); interpretation of water quality information for specific crops; and reexamination of crop water requirements in the JV to account for salt-stressed crops and narrow row spacing.

Specific goals of extension and applied research programs to improve on-farm management skills may include:

- Understanding salt balance, leaching, and drainage;
- Measurement and monitoring soil salinity under drip irrigation;
- New technologies in soil water measurement;
- Salt movement patterns under drip irrigation;
- Understanding crop response to salinity and specific ions;
- Selecting appropriate crops based on tolerances to salinity and chloride;
- Interpretation of water quality reports;
- Irrigation strategies using saline water;
- Measure irrigation uniformity and practical methods to improve it;
- Measuring applied water under different systems;
- Determining crop water requirements;
- Improve filtration practices; and
- Troubleshooting.

There is already considerable experience with these skills within Jordan. In addition, farmers should be exposed to water reuse practices and experiences in the region.

Despite many of the basic skills being available within Jordan, there is a lack of coordination and cooperation between the relevant extension and research institutions. The institutional question is perhaps the biggest constraint facing the realization of an effective extension service and applied research program that is focused on developing the necessary skills and knowledge of the farmers in the JV and Wadi Zarqa. There is no single solution. All parties must participate in focusing the required effort.

The institutional disconnect cannot be easily addressed, if at all. However, for irrigated agriculture with reclaimed water to be sustained in the JV, it is vital that a major effort be made to provide the required skills and knowledge to the farmers. Many of the basic capabilities are available within Jordan, but they need to be developed to a level that can address the complexity of the issues.

The first step toward developing these capabilities will be to bring all parties together, including the farmers, in the form of a workshop or conference focused on addressing the institutional disconnects and laying out the extension and applied research requirements and goals for the next five years. This conference should include four or five carefully prepared keynote papers that present the latest state of knowledge on irrigated agriculture using the KTR water. Subjects should include best management practices, water quality, emerging constituents, and marketing, all related to the present and future of irrigated agriculture with the KTR water. These papers, which will require external assistance to develop, should be presented in Arabic.

V.2. Monitoring and Information Management

Generally, the level of monitoring implemented in the AZB and JV is adequate (MWI/ARD, 2000c; MWI/ARD, 2001f; MWI/ARD, 2001k). However, the data are being gathered by a number of different agencies and, even if they are processed, sharing and dissemination of the relevant information is rare.

Changes are needed in the way water quality data are collected, managed, and routed to the Ministry and other agencies with an interest in water quality data and information (MWI/ARD, 2000c[28;] MWI/ARD, 2001k[29]). The reason for change is to improve the efficiency and to standardize methods of monitoring and information management. At the same time, monitoring needs to be better coordinated among the organizations (e.g., MWI, WAJ, JVA, RSS, MOH, and MOA) that are responsible for data collection. In some cases, monitoring needs to be done more frequently and /or expanded to include more parameters and locations. In other cases, there may be redundancy in the parameters measured regarding location and time. Better coordination would help reduce overlap and at the same time develop a standardized sampling procedure that could be followed by all groups.

The RSS water quality parameters listed in MWI/ARD (2000c) are, for the most part, sufficient for water quality assessment in regard to suitability for irrigation. In addition to these it would be advisable to include Mn, Mo, V, and Li. These trace elements are included because either their concentrations were found to be close to the Jordanian standards or, as in the case with the latter, is toxic to citrus at concentrations lower than the existing standard (i.e., 0.075 mg/L) (Grattan, 2000).

A mechanism is needed for representatives from the various groups responsible for monitoring water quality to work together, revise and/or better coordinate efforts, and develop and implement a countrywide monitoring plan. This may require institutional changes, changes in job descriptions, financial incentives, and a source of funds to develop and implement the monitoring plan.

V.3. Marketing

The fact that reclaimed water is used for irrigation, even if only indirectly, creates a problem for marketing fresh vegetables and fruits grown in Jordan. Saudi Arabia, which had been one of the major buyers, has banned the importation of all fresh vegetables from Jordan. While other international buyers have not imposed bans, the fact that reclaimed water is used in some areas creates a problem for producers who want to sell to foreign buyers in upper income countries or to buyers with higher quality standards in other regions. Foreign buyers or domestic consumers often cannot be sure that fresh vegetables and fruits grown in Jordan have not been grown with contaminated water. Alternatively, they cannot be sure that suitable practices have been followed to ensure that the products are safe to eat without being cooked. Uncertainty about the safety of vegetables and fruits grown in Jordan presents a serious marketing problem.

The strict enforcement of the unauthorized use of reclaimed water in Wadi Zarqa is a prerequisite to improving the marketing uncertainty. The indirect use of reclaimed water in the JV still leaves uncertainty about the safety of fresh vegetables grown in Jordan. Several additional measures are required to improve the safety and quality of Jordan's vegetables:

- Clarify the regulatory responsibility for food safety in fresh vegetables;
- Improve management and availability of information on water quality and food safety;
- Initiate applied research to clarify the relationship between water quality and the sanitary condition of fresh vegetables in Jordan;
- Establish microbiological testing of fresh vegetables to check for pathogens;
- Incorporate practices for safe use of irrigation water in Good Agricultural Practices (GAPs) for production of fresh vegetables and fruits and promote their use; and
- Promote the establishment of a grower certification system and/or accredited product marketing organizations that meet international standards.

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28. Water Reuse Component Working Paper - "Monitoring and Information Management Pertaining to Water Reuse in Jordan."
29. Water Reuse Component Working Paper - "Information Management – Migration of Water Quality Data from WAJ and RSS to MWI WIS."

Details of each of the six components are presented in Fitch and Jaberin (2001)[30]. An overview is presented below.

The Directorate of Food Safety (DFS) and the Directorate of Environmental Health (DEH) in the Ministry of Health (MOH), and the Agricultural Marketing Organization (AMO) of the MOA have responsibilities related to food safety of raw-eaten crops. It is recommended that the responsibility to monitor for potential biological contamination be assigned to AMO.

Water quality information that is collected is not being managed in a way that is designed to promote food safety or enhance marketing. Improvement in the management of water testing and quality information is required to help farmers be more effective in their irrigation water use and so that the implications for product safety can be taken into account in production and marketing.

Insufficient information is available on the relationship between water quality and food safety in Jordan. Research is needed on a number of issues, including comparisons between biological counts in Jordan's irrigation water and elsewhere in the world; relationships between microbiological risks and the specific climatic conditions; and the validity of the hypothesis that use of drip irrigation under plastic mulch for many raw-eaten crops reduces levels of microbiological contamination of crops. In addition, general research is needed to establish the relationship between management practices and the presence or absence of pathogens on raw-eaten crops.

The applied research efforts described above should design a practical, cost-effective system for routine microbiological testing of fresh fruits and vegetables, to detect possible pathogens. In designing this new program, provisions should be made for tracing the product back to the producer. The pathogen-testing program should be administered by AMO as a regular part of its food safety program for fresh fruits and vegetables.

Jordan has a system for developing GAPs as a part of the ongoing research and technology development program of NCARTT. It is important, however, that safe irrigation practices be explicitly incorporated in the GAPs. Safe practices should incorporate the required practices in the standards and regulations, and the findings of the applied research. Furthermore, the mandate of the extension services [Agricultural Extension Service (AES) or the IAS], as discussed in Section V could be expanded to include safe irrigation practices that take water quality into account.

Throughout the world there is a growing demand for quality assurance and improved food safety. The main driving force in establishing procedures to increase food safety is the large private sector buyer organizations. The clearest example of this is the Euro-Retailer Produce Working Group (EUREP), an organization formed by major European retailers. This group is in the process of developing a set of GAPs and related procedures known as EUREPGAP that will soon be required of domestic and foreign producers and marketers in order to be accredited to sell to members of the Group.

The focus of EUREGAP is on process control, meaning that they seek to ensure that the production and marketing environment is safe. This is accomplished by requiring that growers follow GAPs and that packers and shippers maintain clean environments. However, it must be recognized that there is currently not a great demand for improved product quality or safety in

30. Water Reuse Component Working Paper – "Marketing Jordanian Vegetables and Fruits in the Context of Irrigation with Reclaimed Water."

Jordan. Nevertheless, if Jordan wishes to increase its exports to high-value markets such as Europe and upper-echelon retailers in the Gulf, it will need to have more producers and marketers that qualify for EUREPGAP or similar accreditation.

Jordan has held discussions with the World Bank to obtain support for an Export Promotion Project in which MOA would take the lead. One of the objectives of this program would be to help establish modern quality standards, including a National Scheme for Quality Assurance and an Accredited Export Farmer Scheme. If this project is implemented, it would be a logical way to implement the plan described above.

V.4. Risk Reduction in Wadi Zarqa

Irrigated agriculture has been practiced for generations and at present is an important source of agricultural products and ornamental plants. Many of these farms have a traditional water right, and have successfully adapted to irrigating with the degraded quality of the water in the wadi.

Despite ongoing efforts by the Government, there is a clear risk associated with using water from the upper reaches of Wadi Zarqa to irrigate vegetables, many of which are eaten raw (MWI/ARD, 2001i). The perception to the general public jeopardizes domestic and export markets. Few farmers will admit to such practices, arguing that vegetables grown in the wadi were done so by spring water and shallow groundwater. However, there is strong evidence to the contrary. If current standards are adhered to, the level of risk to which the public and farm workers are exposed would be many orders of magnitude lower than at the present time. Furthermore, the proximity of water in the wadi, which smells and looks foul, and the irrigated vegetable crops on the riparian lands leaves even the most casual observer with a very poor impression of the produce that is likely reaching the markets.

Concurrent to the efforts to improve the quality of effluent from the WWTPs and reduce the microbiological contamination from secondary sources, an initiative to work with the farm community to further alleviate the health risks needs to be undertaken. This initiative, which must be separated from attempts to enforce the ban on growing raw-eaten vegetables, should:

- Work with the farm community to reduce the production of all raw-eaten vegetables or fruits whose edible parts may contact the irrigation water, whether irrigated with wadi, spring, or well water. Or, as described in the marketing section above, develop a certification program that certifies that crops are grown in a safe, pathogen-free environment.
- Implement a training program for farm workers to minimize their exposure to pathogens associated with irrigation from the wadi.

Offsetting measures to facilitate the viability of irrigated agriculture in Wadi Zarqa include:

- Develop and disseminate information on the relative suitability of specific crops using Wadi Zarqa water, such as varieties of citrus better able to withstand the prevailing salinity, nitrogen, and chloride levels in the wadi water. Note that with the improvements scheduled for As Samra, the nitrogen levels will be reduced.
- Develop and disseminate information on best management practices to control salinity

V.5. Controlling Secondary Fecal Contamination Sources

Separate from a standard monitoring plan described above, an aggressive short-term monitoring effort is recommended to control primary and secondary sources of fecal contamination in the AZB, and develop a plan to remove them.

Sources other than the WWTP are contaminating Wadi Zarqa (MWI/ARD, 2001f), both upstream and, to a lesser extent, downstream of the KTR. The reservoir itself plays a major role in reducing the level of fecal coliforms reaching the JV. Upstream of the KTR, the health risk remains high. Potential contamination sources include spillage from overflowing sewage and septic systems, animal wastes for intensive livestock operations, or illegal dumping of septage.

It is recommended that an aggressive effort be pursued for a year. The FCC will need to be monitored at a number of points in the basin in addition to existing monitoring points. This will provide valuable additional information about sources of secondary contamination. The frequency of measurements needs to be increased particularly in winter months, when flows are the highest since this source of pollution is highly flow dependent (MWI/ARD, 2001f). The sampling must be done frequently enough to not miss storm events. The frequency of samples depends on the duration of the storm event. During such an event, multiple samples may need to be collected each hour (MWI/ARD, 2001f). If the year selected for this extensive monitoring program falls in a year of less than average annual precipitation, maximal flows may not be reached and an additional year of monitoring may be necessary. The data will need to be evaluated by trained personnel shortly after the data are collected so that corrective measures can be taken.

Once secondary sources of contamination have been located, corrective measures need to be taken to (1) eliminate the sources of contamination and (2) patrol the basin to make sure potential contaminant sources are avoided in the future. Citations should be issued to individuals, groups, or operations that contaminate or that can potentially contaminate the irrigation water supply.

V.6. Enhance the Jordanian Standards and Guidelines for Water Reuse

An important reason for review and revision of the current water reuse standards is the unequivocal statement in the Jordan Water Strategy—adopted by the Jordanian Council of Ministers—stating: "*Wastewater shall not be managed as 'waste'; It shall be collected and treated to standards that allow its use in unrestricted agriculture and other non-domestic purposes, including groundwater recharge".* Current standards for water reuse specifically prohibit unrestricted use of reclaimed water for irrigation of vegetable crops (MWI/ARD, 2001c)[31].

There are additional reasons for revising the existing standards, including:

- The need to review and update existing standards, periodically;
- Desire to reflect the state of knowledge about use of reclaimed water;
- Necessity of reflecting the importance of water reuse in Jordan, as part of its overall integrated water resources;
- Bringing focus on safe implementation of water reuse, protecting the public health, leaving other important considerations (environmental protection, soil characteristics, agricultural productivity) to the discretion of customers and other governmental entities;
- Need to simplify compliance with uniform standards by all involved; and
- Need to streamline enforcement of the standards.

For Jordan, an important objective is the protection of the export market against restrictions imposed by importers, based on the poor microbiological quality of the irrigation water. The existing standards for water reuse were reviewed and compared with similar standards in effect

31. Water Reuse Component Working Paper – "Standards, Regulations & Legislation for Water Reuse in Jordan."

in neighboring countries (MWI/ARD, 2001c), and in other regions of the world, with similar climatic conditions and water shortage situations. In the course of developing the proposed new standards, discussions were held with various stakeholders in the MWI, WAJ, JVA, and MOH. Several stakeholder presentations were made, including one to the WAJ Committee on Sewerage and Treatment Plants, currently working on revisions to Jordanian water reuse standards.

A three-tiered set of criteria is recommended (MWI/ARD, 2001c). The first tier would encompass only the legally enforceable water reclamation standards, primarily aimed at protecting the public health and the workers' health. This would be accomplished through regulation of parameters that (1) ensure optimal performance of the WWTP, (2) indicate microbiological safety of reclaimed water, and (3) can be controlled at the WWTP.

A second tier of criteria is aimed at protection of the soil and crop yields, critically important concerns in water reclamation and reuse. Parameters dealing with these concerns are assigned limits in "guidelines"—not legally enforceable standards—for critical judgment of suitability of the reclaimed water for any given use. Agronomic and other users' concerns are critical, but most of the constituents of agronomic concern cannot be controlled or adjusted in a typical water reclamation plant. They are best handled technically and managerially by source control, and by the users of reclaimed water, in collaboration with the appropriate governmental agencies, including those producing reclaimed water from wastewater. It would be an unreasonable (if not impossible) burden on the treatment plant operations personnel to be responsible for every parameter that might affect soil and crop productivity or for industrial applications of water reuse, under all conditions. This concept is a major departure from existing standards, which attempt to regulate all parameters.

Finally, the third tier of criteria addresses a relatively new concern, called "emerging" contaminants, including synthetic organic compounds; various pharmaceutical products, such as veterinary and human antibiotics, sex, and steroidal hormones; and other endocrine disruptors. These constituents are of greatest concern in the drinking water supply. Their relevance in water reuse arises from the fact that some reclaimed water (or wastewater effluent discharged to water bodies) may end up in the domestic water supply through the aquifers or surface water sources. The best way to manage these substances is through source control and with well-designed research programs conducted in appropriate academic institutions.

On the basis of the above, a regulatory framework is proposed primarily to ensure protection of the public and workers' health, while sending a clear message to the importers of Jordanian food crops about the safety of crops grown with reclaimed water. Qualitatively, tradeoffs between cost and strictness of standards were weighed. Also, risk levels were weighed against treatment standards, in a qualitative way. This report presents the rationale for the content of the framework and offers the framework as a tool for discussion and stimulation of ideas. It is expected that these ideas and reactions to the proposed framework will form the basis for a forum at which the stakeholders can build the elements of a new set of standards for water reuse. The proposed regulatory framework consists of eight separate elements:

1. Definitions;
2. Sources of reclaimed water;
3. Uses of reclaimed water;
4. Use of area requirements;
5. Monitoring requirements;
6. Reporting and operational requirements;
7. Design requirements; and
8. Reliability requirements.

Numerical standards for intensive monitoring, control, and legal enforcement of the tier 1 criteria are proposed to be limited to those in Table 7. These parameters would be monitored by the WWTP personnel, as feedback to control strategies, and for maintaining a complete record of plant performance. Intensive monitoring of the primary control parameters (fecal coliform, *Helminth* eggs, turbidity, BOD_5, TN, and residual chlorine) is critical to reliability of production of safe reclaimed water. Monitoring for the primary process control parameters should be intense, to give quick feedback to treatment plant operators about problems that need correction and adjustment. Criteria in the last column of Table 7, if adopted, would remove the restrictions imposed in the current standards on irrigation of raw-eaten vegetables.

Other important parameters are placed in the second tier, or "guidelines," sampling and monitoring for which would be conducted by other governmental agencies, such as WAJ, JVA, MOH, MOA, and the RSS, as well as universities and other organizations. It is recommended that data generated by all these organizations be coordinated and shared. Further, it is recommended that all data on water quality be managed and displayed in user-friendly formats and made easily available to anyone interested in the safety of uses of reclaimed water. Second, guideline parameters should be monitored monthly by agencies other than the treatment plant operators.

Table 7. Proposed Tier 1 Standards for Jordanian Water Reuse Regulation

Process Control Parameter	Maximum Level For Use in Restricted Irrigation of:		Maximum Level For Use in Unrestricted Irrigation of:
	Orchards, Forest, Fodder, Industrial Crops, Grains	Vegetables Eaten Cooked, Processed	Vegetables Eaten Raw, Public Parks, Other Urban Uses
Fecal coliform	1,000	200	23
Nematode eggs	1	1	1
BOD	100	50	15
Turbidity	12	10	2
TN	45	45	30
Residual chlorine	NR	NR	0.5

Note—Tier 1 includes parameters that can be controlled directly, by WWTP operators.
NR=Not Required.

It is recommended that the existing standards and the framework offered in the Water Reuse Component Working Paper (MWI/ARD, 2001c) be used as a basis for eventual development of two sets of separate standards, one for treatment plant discharge requirements and another for water reclamation and reuse. The standards for treatment plants emissions to the environment would be largely the same as the existing standards 893/1995 as specified for "Discharge to water bodies and catchment areas." The separate standards for treatment plants would be based on the framework presented in MWI/ARD (2001c), with three distinct tiers of criteria. Only the top tier of criteria should be the responsibility of treatment plant operators.

It is recommended to limit the scope of legally regulated water reuse standards to the primarily public health parameters and provide for requirements and prohibitions that protect the health of field workers and the general public. These requirements should be legally enforceable, providing for measured and appropriate penalties for violations.

V.7. Controlling Hazardous Discharges to Sewers and Wadis

As continuing urbanization and industrialization of the upper catchment of the AZB are taking place, the reuse potential of reclaimed water in the AZB and JV are at considerable risk. Industrial water discharges or sewer connections that could harm the reuse potential of reclaimed water have been investigated (MWI/ARD, 2001i)[32]. Existing relevant regulations were also investigated, and approaches for improving the regulations are proposed.

Available data indicate that the reuse potential of reclaimed water is probably not at present being negatively impacted by industrial or commercial discharges. Specifically, the following points can be made:

- Heavy metals and other monitored constituents discharged by the industries or passing through the current As Samra system do not appear to have significant impact on reuse approaches under consideration.

- The available monitoring data are not fully adequate for assessing and preventing problems that could be caused by compounds such as toxic organics. Facilities using or manufacturing toxic chemicals that are discharged, or could be spilled or otherwise reach the wastewater collection system, are of potential concern. Resulting problems include possible poisoning or inhibition of biological treatment systems, pass-through of harmful constituents, or interference with beneficial reuse of sludges.

- Dissolved solids and sodium levels are on the verge of affecting agricultural reuse options. Chloride levels and possible presence of unknown compounds of concern could be potentially inhibitory to nitrification facilities. Available field data on TDS do not indicate problems for the wastewater treatment system. However, some discharges used for irrigation may be of concern in terms of groundwater and surface water impacts. The chief sources of dissolved solids in wastewater are the potable water supplies. Many well sources have very high TDS levels. TDS levels could go down when a new 45 MCM/year reverse osmosis system serving Amman starts operating because reject from this system will be sent to the Dead Sea. Reverse osmosis reject and ion exchange brines can add to TDS and sodium levels particularly when excess regenerant solutions are discharged. Blow-down from cooling towers, used usually on site for irrigation, is also high in TDS and can reach groundwater and surface water by infiltration and washout.

Despite the fact that present heavy metals levels are not high, these contaminants could build up in the soil with time (Grattan, 2000). Reject from reverse osmosis, ion exchange resins regeneration water, cooling tower blow-down, and saline wastewater from a number of industries are contributing to salinity of the water. Where possible, these discharges should not reach Wadi Zarqa.

In addition, as Jordan is expected to develop more industries in the future, increases in industrial the mass discharge is expected to be substantial. Therefore, more stringent regulations and enforcement are necessary to protect the reclaimed water from contaminants that could prevent it from being used for its intended reuse application. Specific actions that should be taken include:

32. Water Reuse Component Working Paper - “Controlling Harmful Discharges to Wadi Zarqa.”

- Developing water quality standards for receiving bodies (such as Wadi Zarqa and the KTR) can have a number of benefits. In addition to water quality criteria, other useful information for setting water quality standards includes baseline data, lists of priority pollutants, and information on known discharges. These standards could initially be set up as nonbinding guidelines outside of legal frameworks.

- Industries should be prevented from discharging to the wadis, unless they have written approval for discharging. It is suggested that this approval be in the form of a permit written for each facility. Discharge limits and monitoring requirements would be set by considering water quality standards in the receiving stream(s), the specific industrial processes in use, wastewater characteristics, and pollution control technologies appropriate for those processes. Permit applications would also include submitting for approval plans and specifications for pollution control facilities, along with providing a full chemical inventory, mass flow diagrams, and spill control procedures.

- The existing industrial standards should include, in addition to the existing parameters, some relevant toxic organics. The list should only include those organics that are expected to be present in the effluent of those industries present in the AZB. To reduce cost, the regulatory body could make the industries responsible for testing and reporting from certified water quality laboratories, and the regulatory body role would then play a verifying role.

- Industries should be prevented from discharging to the sewer system without having a pretreatment plant at the industry site. The type of pretreatment plant and its size should be approved by the regulatory authority. A guideline document could be prepared for each type of industry explaining the type of treatment suitable (most applicable or best available technology) for such an industry.

- Industries with access to the sewer system should be required to connect to the sewer system. This will prevent the illegal dumping of their wastewater through tanks in the wadis or sewer systems without treatment. In case the industry is far away from the sewer system, the industry should propose plans for the complete treatment of their wastewater. The plans should also be approved by the regulatory authority.

- Industries that can show that their wastewater is of no potential threat to the environment or to the potential reuse of wastewater, and after being approved by the regulatory authority, can be exempted from having a pretreatment plant.

- Existing industries could be exempted from the previous points for a period of time, and can be phased in to comply with the new regulations. New industries should comply from the start.

- Cooling water blow-down, reverse osmosis reject, and ion exchange regenerants may have to be prohibited from discharging to wastewater collection systems. It may be necessary to restrict some discharges of high TDS wastes, requiring evaporation ponds, for example. The present use of brine water in irrigation at the plant site will cause TDS either to infiltrate into the groundwater or to be washed out to surface waters during rainy periods, and therefore should not be considered a solution to the problem.

- Other suggestions for strengthening the municipal discharge regulation include setting up a pretreatment program with a small staff. These staff would coordinate sampling, testing, permit-writing, and enforcement. One goal of a pretreatment program is to work with industrial dischargers to help them come into compliance. Enforcement should be exercised where there are real problems and where there is no cooperation on the part of an industry.

- Pretreatment regulation will benefit from requiring, at the regulators' discretion, the owner to install both a sampling point outside the property and a discharge flow meter. Sampling point and flow-meter construction details can be specified in the municipal code. Portable, battery-operated sampling equipment that can be installed in manholes and take 24-hour composite samples will be helpful for monitoring industrial dischargers.

VI. CONCLUSIONS

By the year 2005, the expected volume of reclaimed water will satisfy the additional water needs in the Middle Directorate of the JV and allow for intensification of irrigated agriculture along Wadi Zarqa, if it should happen. The development of the option to provide reclaimed water for industrial use in the Hashemite–Zarqa area, which will provide a significant portion of the present and future water needs for the major industrial users and result in conservation of groundwater, can receive its full allocation by the year 2006.

Following the above, and assuming reclaimed water from the AZB is not required in the Northern Directorate, the next most attractive option is to use the reclaimed water in Stage Office 9 (kilometer 14.5 extension) of the Karameh Directorate. The projected increase in volume of reclaimed water can satisfy this demand by the year 2014.

The full development of the Dhuleil–Hallabat irrigation network, which exchanges reclaimed water for groundwater, can be achieved by 2015. Because of the opportunity to conserve groundwater, this option is economically more attractive. However, the technical complexity, the potential threat of contamination of an important aquifer, and the burden of the system operational costs threaten the sustainability of such a development.

Finally, the development of smaller-scale irrigated agriculture adjacent to the minor WWTPs can be fully satisfied by the year 2016. This is economically the least attractive of the options examined because of the required pumping and conveyance. However, realizing that by the year 2016 all identified options for using reclaimed water will be satisfied and the relatively small volumes of reclaimed water involved, initiatives to develop commercial irrigation adjacent to the plants should not be discouraged. The Government should not undertake these developments, as it is economically advantageous to allow the reclaimed water to be used in the higher priority options first. Reuse practices at these minor WWTPs should be in full compliance with the relevant standards.

Should a decision be made in the near future to use reclaimed water to replace freshwater in the Northern Directorate, this becomes a much more attractive option than the Karameh Directorate. The full allocation required to satisfy this option will, however, require all future volumes of reclaimed water through the year 2017. The Karameh Directorate cannot then be satisfied until the year 2030.

Using the reclaimed water from the AZB for productive irrigated agriculture is possible. However, the management challenges are much greater than irrigating with freshwater. To sustain irrigated agriculture in the JV with reclaimed water requires a number of supporting actions. These include a major farmer-focused effort to support the farmers in improving there understanding and relevant skills; enhancement of the information management system to allow farmers to make more informed decisions and reduce the misinformation; remove the health risk of irrigating raw-eaten vegetables in Wadi Zarqa; control secondary fecal contamination; enhance the standards; and strengthen the control of hazardous discharges into the sewers and wadis.

Microbiological contamination from secondary sources in the AZB will continue to make Wadi Zarqa water unsafe for irrigating raw-eaten vegetables. Downstream of the KTR, the risk of pathogens in the water supply is greatly reduced, but remain a concern due to local secondary contamination and flood flows passing through the reservoir. Interestingly, neither of these two phenomena is directly related to reclaimed water.

The risk of heavy metals and trace elements are of considerable concern to the farmers in the JV. The existing data do not support this concern. The existing information is confusing and, in some cases, misleading. However, the threat needs to be taken seriously. Mn, Mo, Li, and V are near levels that could cause problems for some crops. Regular monitoring of the water, soils, and crops is required.

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VIII. GLOSSARY OF TERMS

Cropped area: The cumulative area of crops planted over a year.

Cropping intensity: Cropped area/irrigated area

Direct Water Reuse: The beneficial use of reclaimed water that has been transported from the treatment plant to the point of use directly through pipes or in lined channels, without an intervening discharge to a natural water body, such as a stream of pond.

Domestic Wastewater: Wastewater generated in residential and commercial activities, possibly also including minor amounts of industrial wastewater subjected to pretreatment meeting the requirements of connection to the sewer network issued by the Department of Meteorology and Standards.

Effluent: Flow discharged at the end of a treatment process or a treatment train, which may be suitable for some uses, depending on the level of remaining pollutants.

Food Crops: Any crops intended for human consumption.

Guidelines: Semi-official rules and limits for long-term sustainability of water activities in agricultural, industrial, or urban sectors.

Indirect Water Reuse: The use of effluent from a WWTP after it has been discharged to a natural water body, such as a stream, pond, or reservoir.

Irrigable Area: The area of land that can sustainably be used for irrigation.

Irrigated Area: The area of land that is under irrigation.

Recycled Water: Water created as a result of treatment and disinfection of wastewater, and deemed safe for specific, intended uses (defined above). Recycled water is a water resource, with tremendous beneficial usefulness, the only limitations being dependent on level of treatment, salt content, and other characteristics that might restrict it to certain uses.

Reclaimed Water: Synonymous with “recycled water,” and usually used interchangeably. Strictly speaking, “reclaimed” water originates at a central water reclamation facility, whereas “recycled” water originates on site. This is especially true at an industrial site recycling its own water over and over again, for example, in a cooling tower.

Regulations: Legally adopted, enforceable rules and limits for water reclamation activities, with measured penalties provided for violations.

Standards: Limits on specific parameters, set for the purpose of protecting the public health or the environment. Standards are usually incorporated in regulations. Sometimes “standards” are used synonymously with “regulations.”

Unplanned Reuse: Withdrawal by gravity or pumping from wadis where a major portion of the flow is effluent from an upstream WWTP. This is an unauthorized use of wastewater, even if at the point of discharge, effluent quality meets the standards in effect.

Unrestricted Use: Use of pathogen-free water for all nonpotable uses, including irrigation of food crops consumed without further processing. The restriction on potable use still applies, unless treatment includes membrane filtration and fail-safe provisions against survival of microorganisms and trace organic compounds.

Use Area: Any area where reclaimed water is used, with defined boundaries.

Wastewater: Polluted and contaminated sewage, resulting from residential and industrial uses of water and carrying waste products, including organic materials, inorganic compounds, and various microorganisms. Wastewater per se is not a water resource for any beneficial uses, unless treated appropriately and converted to "recycled water."

Wastewater Reuse: Unregulated (illicit) use of wastewater or inadequately treated wastewater effluent for irrigation of crops or for any other uses.

Water: All usable water, including surface runoff, groundwater, brackish, and recycled water, but excluding contaminated, saline, and raw wastewaters, which are unsuitable for beneficial use.

Water Reclamation: The process of salvaging usable water from wastewater by mechanical treatment (physical, chemical, and biological) and disinfection, salt removal, or natural processes.

Water Recycling: Synonymous with "water reuse." This term is used in some regions exclusively in reference to all water reclamation and reuse activities, because of the positive public image of "recycling" as an environmentally good deed.

Water Reuse: The intentional, planned reclamation of water from wastewater and its conveyance and distribution to agricultural, industrial, and other sites, where it can be put to beneficial use. The term "wastewater reuse" is avoided in this document to prevent confusion with the unplanned, unauthorized uses of inadequately treated waste and its unwholesome consequences.