MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

Groundwater Management Component

Assessment of Potential Use of Brackish Water for M&I Supply in Amman Zarqa basin

May 2001

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Executive Summary

Using the existing information from the MWI database Water Information System (WIS) and review of pertinent reports, the brackish waters of both groundwater and springs were accessed to determine their availability and exploitation potential in the Amman-Zarqa Basin (AZB).

Within the AZB, the brackish water resource consists of the lower sandstone hydraulic complex made up of the regional aquifers of the Ram Group overladen by the Zarqa Group and the Kurnub Group. There are springs that discharge from the contacts within this sandstone complex. The lower sandstone hydraulic complex is overladen in the north eastern highlands by the fresh water aquifers of the B2-A7 and Basalt. Deterioration of the fresh water aquifers as well as severe shortages of potable water especially in the summer months has led WAJ to look at developing brackish water resources. Reverse Osmosis (RO) desalination technology can be used for treatment of brackish water from existing sources to potable standards to either augment existing distribution networks or to supply remote areas. The long term implication is that brackish water can be an additional valuable resource for Jordan.

Brackish springs provide an immediate available resource for potable supply when this is coupled with treatment using RO technology. Some of these springs may be polluted since they are in proximity to the urban environment. Full hydrochemical analysis will be required to determine the pre-treatment criteria of the spring discharges before this water can be desalinated.

Recent historical average values of six relevant brackish springs discharging in or within proximity to AZB (Figure 1) are about 10 MCM per year. However, discharge averages from the last 5, 10 and 15 years of 2.0, 2.6, and 2.8 MCM/a, respectively, reflect the recent dry periods encountered in Jordan. Therefore a conservative estimate of available resources should look at the 5 year average of 2.0 MCM/a. Due to the recent dry period the discharge from two of the six relevant brackish springs (Seil Zarqa and Sukhneh) have decreased substantially. Nimra Spring is being used by Sabeel Water bottling company and farmers. Ras El Mai Spring is exploited by farmers. Only the Abu Zigan springs with a total discharge of 1.2 MCM/a are not being used and could be developed for M&I supply. However, the allocation of spring discharges in respect to water rights should be clarified prior to any activities. The six relevant springs are shown in the location map.

Table 1. Brackish Spring Average Discharges and Water Quality (TDS)

SPRING ID	SPRING NAME	* Historical Average Discharge		Average In Last			Disharge		TDS Readings (mg/l)		REMARKS
		MCM/a	Date	5 yr	10yr	15yr.	Min	Max	Last Reading	Date	
				MCM/a							
AL0517	Seil Zarqa	3.2	1937-2000	.070	0.13	0.11	0	28.4	1574	2000	Not used for any purpose, proximity to residential areas probably contaminated by bacteria and chemical from human activity
AL0522	Sukhneh	4.0	1937-1999	0.051	0.30	0.30	0	11.4	1562	2000	Presently has very low discharge. Collected in ponds and used by nearby bricks factories
AL0528	Nimra	1.2	1962-2000	0.44	0.68	0.85	0	4.5	2157	2000	Spring water used by Sabeel Water Bottling factory and the nearby farmers
AL0822	Ras El Mai	0.36	1962-2000	0.23	0.29	0.31	0.07	2.4	1014	1998	Used by the farmers in the area
ABZ1	Abu Zigan (Upper)	(1.1)	2001	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	1280	2001	Visited Apr01, discussion with local people indicated discharge is not used.
ABZ2	Abu Zigan (Lower)	(.09)	2001	(.09)	(.09)	(.09)	(.09)	(.09)	1280	2001	
TOTAL (MCM)/a (Rounded)		**10.0**		**2.0**	**2.6**	**2.8**	**1.3**	**47.9**			

( ) limited historical data

Availability of the quantities of the resources is dependent upon the exploitable quantities versus the effects on the downstream water bodies such as wadi base flow, drainage to the Dead Sea and other brackish water development plans. For example the flowlines of the sandstone complex (JICA 2000) indicate that the outflow from the AZB is outside the recommended brackish groundwater development plans of the Hisban-Kafrein area. Available yield estimation should look initially at 10-20% of the total inflow calculated to be about 15-30 MCM/a, until the results of the findings from an exploration programme are available. Preliminary locations of exploration boreholes to access the potential aquifers should not only target the Kurnub and Zarqa but also the deeper Ram Aquifer.

Preliminary estimates of drilling costs assume that sites are at the Kurnub outcrop, that the thickness of the lower sandstone aquifers are 100-200 m (Kurnub) and 1100-1300 m (Zarqa), and that - to minimise penetration effects from the pumping tests - the Ram aquifer should be penetrated about 200 m. This will minimise the overall drilling costs but still give a reliable estimate of resource potential. Borehole exploration costs include drilling, construction, development and testing. Boreholes into the Kurnub / Zarqa aquifers with depths of 600-800m will cost about 230,000 to 260,000 JD, and boreholes penetrating into the Ram aquifer to depths of about 1500m will cost about 350,000 JD. Average yields from boreholes penetrating into the Kurnub aquifer are about 56 m^3/hr according to data from the WIS database information. Therefore the cost of 230,000 JD for the drilling and construction of a 600m borehole is expected to produce a supply volume of water of 0.5 MCM/a.

As the exploratory sites described in this report are only estimated and drilling costs are high, it is highly recommended that a detailed hydrogeological investigation be conducted prior to finalizing the locations of exploration boreholes. In addition, as these boreholes may be treated by RO desalination, siting should take into account suitable means of brine disposal.

Acknowledgment

This report was prepared by Howard Wong with input from Ahmed Abu Hijleh and Mohamed Chebaane. The support and input of Eng. Edward Qunqar, Director of Water Resources Management at MWI, are highly appreciated

Table of Contents

Figures

Tables

Appendices

List of Abbreviations

AZB	Amman-Zarqa Basin
m asl	metres above sea level (mediterrean0
m bgl	metre below ground level
MCM/a	Million Cubic Metres per Annum
mg/l	milligrams per litre
M&I	Municipal and Industrial
MWI	Ministry of Water and Irrigation
RO	Reverse Osmosis
TDS	Total Dissolved Solids
WAJ	Water Authority of Jordan

1. Introduction

Classification of water as defined by Charalombus (1991) is used in this study, as shown in Table 2.

Table 2. Water Classification

Class		total dissolved solids TDS (mg/l)
Fresh		0 - 1000
Brackish	Mildly	1000 - 3000
	Moderately	3000 - 6000
	Very	6000 - 10000
Saline		10000 - 100000
Brine		> 100000

Note: adapted after HSI 1991
EC to TDS values calculated using formula: TDS (mg/l) = 0.64 x EC (µs/cm) @ 25°C

Due to the increasing problem with water shortages experienced over the past few years in Jordan the utilisation of brackish water which was once not an attractive option has gained in prominence. This is especially true for the option to desalinate brackish water for potable supply. The cost per unit of desalinated water has been dropping as advances have been made in desalination technology.

Preliminary estimates of exploitable brackish groundwater within proximity of Amman is in the order of 70-90 MCM/a (HSI, 1991). These values refer to the brackish water resources available from natural outflow to the southern Jordan Valley and Zarqa Main. JICA (Draft Sept 2000) indicates that in the whole of Jordan potential brackish groundwater resources are estimated to be about 250 MCM/a.

Within the AZB the brackish water sources originate from the lower sandstone hydraulic complex. The general flow direction of the sandstone complex is towards the eastern escarpment and Jordan Valley.

In the AZB the upper cretaceous fresh water aquifers are becoming increasingly brackish due in large part to over-exploitation and irrigation return flows. Domestic water supply boreholes have been closed in the past as a result of deteriorating water quality due to aquifer over abstraction and pollution. These boreholes are now earmarked for treatment and desalination, and this is considered to be a ready solution. Although this is not in the true sense considered brackish water, it fits the simple definition of brackish water shown in Table 2. Utilising this resource would generally be the most cost effective as the infrastructure has already been set-up except for treatment faculties such as RO desalination to allow this water back into the main distribution system. One of the main objectives of this report is to estimate the natural brackish water resources available within the AZB and adjacent areas.

2. Sources of Brackish Water

2.1 Main aquifers

Various desk studies (HSI 1991, El Naser & Al-Hadidi 2000 and JICA/Yachiyo Eng. 2000) have been completed describing and evaluating the water resources in the Hashemite Kingdom of Jordan. Within the AZB the significant aquifers are the fresh water aquifers of the upper cretaceous hydraulic complex with carbonates of the (B2-A7) and Basalts (BA) with relatively minor contributions from the A4 and B5-B6 aquifers. Underlying these aquifers are the lower sandstone hydraulic complex composed of the Kurnub, Zarqa and Ram Groups which consist mainly of groundwater 10,000 to 35,000 years old. In the AZB the lower aquifers are regarded as brackish except in areas of outcrop where the groundwater quality is good due to the recharge from rainfall. This is true within the Kurnub and Zarqa Groups where these aquifers outcrop in Baqa and Jerash. The Ram Group is a regional aquifer originating in the outcrop areas in southern Saudi Arabia. The water is fresh at outcrop and flows in a north-east direction gradually increasing in salinity and is brackish within the Jafr Basin. Depending upon the flowlines and hydraulic interconnections with adjacent aquifers the salinity of the discharge areas from south of the Dead Sea near Karak to the northern areas of the Jordan Valley grades from TDS values of 500 to more than 7000 mg/l. These values represent mixed waters showing the interconnection of the fresher waters of Kurnub-Ram in the south and more saline water of the Kurnub-Zarqa-Ram. Within the AZB, outcrops of Ram Group are absent and recharge only occurs from flows from adjacent aquifers. The outflow of the lower sandstone hydraulic complex in the AZB is to the side wadis and floor of the Jordan Valley but ultimately drains to the Dead Sea. A more detailed summary of aquifer characteristics are given in Appendix 1.

Table 3. is a summary of water resources in AZB and adjacent areas of the principal regional aquifers of the lower sandstone hydraulic complex. For these types of regional aquifers with large amounts of storage, the effects of abstraction in areas distant from each other is minimal. For example the boreholes currently providing groundwater from the Rum aquifer in the Disi-Mudawwara Area will have very little or no effect on abstraction boreholes along the areas of outflow such as along the Rift Side Wadis of the Jordan Valley.

2.2 Springs

Natural Brackish water springs in AZB may be considered as additional water resources potential. Depending on their water quality these springs have limited use for irrigation schemes. In remote areas these springs may be utilised for domestic water demands in the many small communities scattered within the basin by applying the appropriate desalination and treatment techniques to bring the water to potable standards. In some cases the springs may be polluted due to their proximity to the urban environment; therefore pre-treatment measures must be instituted prior to desalination.

Table 3. Aquifers in the AZB

Aquifer	Type	Recharge/ Abstraction (MCM/a)	Comments
Basalt (BA)	Fresh Renewable	28** / (53.3)*	Originally fresh but water salinity is increasing due to over exploitation.
B2 – A7	Fresh Renewable	42**/ (73.9)*	Originally fresh but water salinity is increasing due to over exploitation.
A1-A6	Fresh renewable	10** / (14)*	Relatively minor aquifer. Exceeding safe yield by 4 MCM/a.
Kurnub/ Zarqa	Fresh – brackish Renewable Limited	8.0** / (8.8)*	Kurnub Group: Variable water salinity due in part to hydraulic connection to the underlying Zarqa and limited recharge at outcrops in Baqa, Jerash and Zarqa River.
			Zarqa Group: Water Salinity is result of hydraulic contact with Ram and limited recharge at outcrop.
Ram	Fresh – brackish Renewable Limited	0-78*** / (75)*** S. Desert	Fresh in the S. Deserts and becomes increasingly saline along the flowline line discharging to Dead Sea area. Abstraction occurring in the S. Deserts but extensively utilised in Saudi Arabia (600-900 MCM/a). Mining of this fossil water is already occurring.

( ) refers to actual abstraction from MWI 1998 data
* ARD internal report - calculated from renewable aquifers within AZB, data (1998) from WIS, MWI
** Safe Yield, ARD 2000 “Hydrogeology of the Amman-Zarqa Basin”
*** SW 1995 “ Qa Disi Aquifer Study, Jordan

2.3 Availability of Brackish Water in AZB

2.3.1 Springs

Data for all the springs in the basin were collected from the MWI Water Information System (WIS). This includes the following parameters:

- Discharge rate
- Total Dissolved Solid (TDS)
- Water Use

Field visits were conducted for the selected springs in order to update the available data. A total of 13 brackish springs were identified (Table4 and figure1). Long term average discharge values for these springs range between .007 MCM/a and 4 MCM/a graphical representation of flows over time is shown in Appendix 3. The most recent TDS measurements shown in Table 4. range between 1014 and 2157 mg/l.

Six out of the 13 brackish water springs have relatively significant discharges. These springs are Seil Zarqa, Sukhneh, Nimra, Ras El Mai, Abu Zighan (upper) and Abu Zighan (lower). Sukhneh spring is located north of Zarqa, both Seil Zarqa and Nimara springs are located south Samra/Balama area, and Ras El Mai spring located south of Jerash area. Abu Zigan (Upper) and Abu Zigan (lower) were recently identified west of the AZB at Abu Zigan within Deir Alla area in the Jordan valley (Figure 1). The discharge rates of these two springs were found to be about 1.1 MCM/a and 0.09 MCM/a respectively, while their TDS is about 1280 mg/l. Long term monitoring of these springs will be required to establish long term trends for the discharge and water quality.

The remaining seven brackish water springs have an annual average discharge less than 0.03 MCM/a and range between 0.002 MCM/a for Tallet Ruz spring to 0.03 MCM/a for Mursi spring (Table 4).

The total average historical discharge of the six main springs is around 10.0 MCM per year (Tables 1 and 4). However, averages from the last 5, 10 and 15 years of 2.0, 2.6, and 2.8 MCM/a, respectively, reflect the recent dry periods encountered in Jordan. Therefore, a conservative estimate of available resources should look at the 5 year average of 2.0 MCM/a.

Due to the recent dry period, the discharge from two of the six relevant brackish springs (Seil Zarqa and Sukhneh) has decreased substantially (Tables 1 and 4). Nimra Spring is being used by Sabeel Water bottling company and farmers. Farmers exploit Ras El Mai Spring. Only the Abu Zigan springs with a total discharge of around 1.2 MCM/a are not being used and could be developed for M&I supply. However, the allocation of spring discharges in respect to water rights should be clarified prior to any activities.

2.3.2 Groundwater

The brackish water resources located in AZB are mainly of fossil origin. Availability and estimate of exploitable yield is dependent upon its effect on adjacent aquifers, other water bodies such as the Dead Sea, effects on proposed development plans of brackish water such as the Hisban-Kafrein area.

Table 4. Discharge Rates and TDS (mg/l) For The Major Brackish Water Springs In AZB.

Spring ID	Spring Name	Historical Average Discharge		Last Discharge Reading		Average in Last			Discharge		Last TDS Readings (mg/l)		Remarks & Recommendations
						5 yr	10 yr	15 yr.	Min.	Max			
		MCM/a	Date	MCM/a	Date	MCM/a					Reading	Date	
ABZ1	Abu Zigan Upper)	(1.1)	2001	(1.1)	2001	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	1280	2001	Site visit April 01 & discussions with local people indicated spring water not used. Suggestion to desalinate these spring flows for local demand in Deir Alla and surrounding areas.
ABZ2	Abuzigan (Lower)	(0.09)	2001	(0.09)	2001	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	1280	2001	
AL0528	Nimra	1.2	1962-2000	0.21	11/00	0.44	0.68	0.85	0	4.5	2157	2000	Spring water used by Al Sabeel Water Bottling factory and the nearby farmers
AL0822	Ras El Mai	0.36	1962-2000	0.21	11/00	0.23	0.29	0.31	0.07	2.4	1014	1998	Spring water used by farmers in the area
AL0517	Seil Zarqa	3.2	1937-2000	0.036	11/00	.070	0.13	0.11	0	28.4	1574	2000	Discharge into Zarqa river. It may be contaminated by bacteria due to proximity to residential areas.
AL0522	Sukhneh	4.0	1937-1999	NA	2000	0.051	0.30	0.30	0	11.4	1562	2000	Currently has very low discharge. Collected in ponds and used by nearby bricks factories
AL0815	Mursi (Mirsa)	0.027	1973-2000	0.010	9/00	0.017	0.018	0.029	0.0054	0.11	1760	2000	Used by farmers in the area
AL0912	Abuhamid	0.022	1962-2000	0.017	11/00	0.018	0.027	0.023	0.0051	0.14	2080	2000	
AL0942	El Balad (Sumuya)	0.012	1976-1998	0.067	3/98	0.023	0.017	0.015	0.0004	0.067	1140	1995	
AL0952	Dafali (Sumuya)	0.017	1973-1997	0.027	8/97	0.032	0.022	0.019	0.0019	0.054	1542	1997	
AL0960	El Azab	0.019	1974-1998	0.023	8/98	0.040	0.027	0.023	0.0015	0.054	1120	1994	
AL0962	Ed Dafali(Subeihi)	0.0067	1974-1998	0.004	8/98	NA	NA	0.0056	0	0.023	1080	1995	
AL0990	Jamma'in	0.017	1973-1997	0.027	8/97	0.019	0.013	0.014	0	0.090	1053	1997	
TOTAL (MCM)/a (Rounded)		**10.2**		**1.8**		**2.1**	**2.7**	**2.9**	**1.3**	**48.4**			

Note: This data was compiled from WIS and field visits conducted by ARD staff in April 01 for usage of these springs. ( ) limited historical data

The main brackish groundwater aquifers are those found in the lower sandstone hydraulic complex. Estimates of brackish groundwater resources utilise the existing information of aquifer characteristics averaged from regional data sets. The values used to calculate the inflow rate of the lower sandstone hydraulic complex shown in Appendix 5 is taken from values listed in Appendix 1. The combined direct recharge of the lower sandstone complex is about 8 MCM/a in AZB (Table 3). As current abstraction already exceeds this value the exploitability of these aquifers will essentially be mining of fossil water. The degree in which the brackish water can be exploited will be a trade off on how it affects the adjacent aquifer systems, and the downstream effects on base flow of the wadis and springs as well as drainage to the Dead Sea. Using the schematic diagram from the JICA 2000 main report shown in Appendix 2, the flow lines indicate that the outflow from the AZB is outside the main proposed development areas for brackish groundwater such as the Hisban-Kafrein area.

The area, which produces the largest amounts of brackish water without affecting other water bodies, is located along the slopes overlooking the Dead Sea. In this area and the adjacent South Jordan Valley total outflows are in the order of 444 MCM/a (JICA 2000). A component of the outflow of 151 MCM/a shown in Table 5 is from the lower sandstone complex underlying the AZB towards the Jordan Valley and the side wadis of the eastern escarpment. Available yield estimation should look initially at 10-20% of the total inflow calculated to be about 15-30 MCM/a until the results of the findings from the exploration programme are available.

The most promising areas to tap the brackish water resources in the AZB both in terms of minimising drilling depths and availability to major urban centres are those located at the outcrops of the Kurnub and Zarqa Aquifers.

Table 5. Calculated Volume of Brackish Water

Aquifer	Brackish Water Resource Estimates in AZB (MCM/a) — Within AZB		Comments
	Inflow	Exploitable	
Combined Kurnub/Zarqa	55	33-38	Largely confined aquifer
Ram	96	57-67	Unconfined at outcrop in S. Desert but highly confined in N. Jordan /Dead Sea area.
Total	151	90-105	

Note: Inflow rates calculation in Appendix 5
Using JICA 2000 calculations of exploitable resources using 60-70% of aquifer inflow

2.4 Brackish Water as a result of deterioration in quality

In the Amman-Zarqa area production boreholes abstract from the B2- A7 and to a lesser extent the A4. The water quality as TDS values were originally in the region of 300 to 500 mg/l. With the increased over-abstraction, the B2-A7 aquifer has deteriorated to a point where a significant number of the production boreholes with water quality records obtained from the WIS database are now abstracting groundwater with a TDS value greater than 1000 mg/l. JICA (2000) tabulated 56 boreholes with water quality records in the AZB and indicated that the average TDS value from 1985 – 1989 was about 900 mg/l. Averages of TDS values for the period 1995 – 1999 were calculated to be about 1100 mg/l showing an increase in the salinity of the aquifer of over 20%. The percentage of brackish water being abstracted is slowly increasing in the basalt aquifer to the north-east of Amman as well. A survey conducted by ARD staff indicates up to 20% of the boreholes visited have shown water salinity deterioration.

Typical trends are shown below for boreholes abstractions in the B2-A7 aquifer within proximity of industry, urban areas and agricultural land.

Table 6. Typical Trends in Groundwater Deterioration of Boreholes Near the Urban Environment

Year	1977	1979	1981	1985	1989	1993	2000 *
TDS (mg/l)	360	640	770	1060	1300	1470	1740 2180**

From the Al-Husssein Thermal Power Station (1995, Industrial Audit, Water Quality Improvement Project, DAI)
* average results obtained from WIS Database, MWI for Thermal Power Station wells
** average results obtained from WIS Database, MWI Jordan Petroleum Refinery wells

3. Treatment of Brackish Water

3.1 Cost of Treatment Using Desalination Technology

Using the study conducted by JICA (1995) the estimates of costs are listed below for a 10000-50000 m^3/day Capacity Desalination Plant.

Table 7. Costs for 10,000 to 50,000 m3/day RO Desalination Plant

Process	Raw Water Quality	Water Salinity mg/l	Capital Cost JD/m^3/ Day	Water Cost JD/m^3	Energy Consumption Kwh/m^3
Electrodialysis	Brackish Water	1600	420 - 840	0.2 - 0.5	1.2
Electrodialysis	Brackish Water	5000	1000 - 1400	0.6 – 0.8	2.5
Multi-stage flash	Sea Water	35000	1100 - 2100	0.8 – 1.8	25
Reverse Osmosis	Sea Water	35000	900 - 1700	0.8 - 1.1	7
Reverse Osmosis	Brackish Water	1600	400 - 8400	0.2 - 0.4	1.1
Reverse Osmosis	Brackish Water	5000	630 - 1000	0.3 – 0.7	1.6
Reverse Osmosis	Brackish Water	2000	630 - 1000	0.3 – 0.7	1.6

Notes: Source : IDA & JICA study team ,1995 — Fixed Charge (7% 20 years)
Desalination for Domestic Water Supply — Membrane Replacement : 3-6 years

JICA describes the cost effectiveness of using RO desalination technology for brackish water and the added benefit with advances in membrane technology which have lowered the overall cost of RO desalination production. WAJ is now utilising RO technology on various small desalination schemes described in section 3.4.

Certain industries require higher quality water such as power generating plants and refineries. The reverse osmosis technique is being used by these industries since the mid-80's for various applications. A visit was made on 10 April 2001 to the Hussein Thermal Power Station. The staff very kindly provided answers to the question shown in Appendix 4. The estimated cost of the RO unit at the power station is tabulated in Table 7. The groundwater abstracted from the surrounding boreholes has been deteriorating in quality and pre-treatment costs are slowly increasing as shown in Table 8.

Table 8. Costs for 1000- 3600 m3/day Capacity RO Desalination Plants

Description	Raw Water Quality	Intake Water Salinity mg/l	Capital Cost Plant Construction (JD)	Water Cost JD/m^3
Al Hussein Thermal Power Station	Brackish groundwater from company drilled boreholes in the vicinity	1900 - 2000	250,000	0.45

Notes: Desalination costs do not include WAJ water supply charge of 0.25JD/m^3

3.2 Construction of Facilities

To get an indicative cost for construction of a RO desalination plant, one can use 0.35 – 0.7 JD per cubic metre output water. For a 100 m^3/hr or 2400 m^3/day plant, one would require between 310,000 – 600,000 JD depending upon the pre-treatment needed for the intake water.

The typical construction costs of seawater desalination plants in the mid to late 1990s range between 700 – 2100 JD /m^3/d of installed capacity depending on plant size, location and design requirements. The cost variation is high in the case of brackish water desalination plants because they are very sensitive to feed water quality. However, brackish water desalination equipment is usually less than 50% of seawater equipment cost. The major elements of cost and their expected range as percentage of unit cost are as follows:

- Construction (30-40%)
- O&M (40-70%)
- Energy (20-70%)
- Labour, chemicals, spares (10-30%)
- Membrane replacement (10-20%)

The cost of brine disposal may be significant, especially if it cannot be disposed of on-site. Typical TDS values of brine range from 8000 to 15000 mg/l.

3.3 Brine Disposal

This may be a considerable problem as the brine produced from the desalination process should not be available to remix back into the groundwater system. Up to 15-25% of the original inflow to the desalination plant must be disposed of as brine.

Various methods of disposal of brine are available in Jordan. In areas within proximity to the Dead Sea, the brine may be discharged into the sea. Inland where this is not possible then evaporation ponds may used. Brine may be discharged to an engineered design pond and using natural evaporation this will precipitate the brine to a salt that can be transported off-site for disposal or further processing. The rate of evaporation will determine the size of the evaporation ponds needed. This may be a problem in areas where there is limited available land. To seal the base of the pond from leakage of this brine either the pond is lined with a geomembrane or, using chemicals, obtain a precipitate onto the top soil to produce an impermeable layer.

Other alternatives are listed below:

- Deep well injection of brine into non-use formations containing formation water with similar characteristics as the brine to minimise clogging.
- Remove the brine by Tankers (high volumes will not make this option cost effective)
- Discharge the brine to a treatment plant. This will be dependent on the quantity and quality of the brine compared to that of the intake at the treatment plant.

3.4 Current Projects

WAJ of the Ministry of Water and Irrigation is tendering contracts to treat brackish groundwater from existing production boreholes by either conventional means or using desalination. Part of the water to be treated may come from boreholes that have been closed due to high coliform and/or nitrate levels.

WAJ stated that RO was the preferred option in the tender documents. The contractors were allowed to bid according to construction on a BOT or as a conventional service/supply contract basis.

- **WITHIN AZB**

Rusiefa/Ghazal Area

It is expected that boreholes nos. 2, 5, 10 and 17 with a combined yield of up to 800 m^3/hr will be dispatched to a conventional treatment plant for filtration and aeration.

Borehole No. 2	(AL2363)	Borehole No. 10	(AL1856)
Borehole No. 5	(AL1283)	Borehole No. 17	(AL1860)

Mashtal Faysal – Jerash

Tender documents were issued by WAJ for construction of a RO desalination facility for the brackish groundwater from the capped Mashtal Faisal borehole. The feed water supply was in the range of 150 m^3/hr. Identification of a suitable way to dispose of the brine has delayed the award of tender.

- **ADJACENT AREAS**

Mafraq – Ruweished Area

A RO desalination plant currently nearing the end of construction with feed water (100 m^3/hr) from existing brackish water boreholes from the shallow aquifer. Water quality data of boreholes in the area indicate pre-treatment for H_2S, Iron and manganese is needed.

Deir Alla Area

A RO desalination plant currently at the end of construction with feed water (50 m^3/hr) from existing brackish water borehole AL 2806. The desalinated water will be used to supplement the existing supply to the villages in the area. The reject brine will be discharged to an adjacent wadi.

Zarqa Area

A RO desalination plant currently at the end of construction with feed water in the region of 800 m^3/hr from existing brackish water boreholes.

Zarqa 14 (AL 1898)
Zarqa 14a
Zarqa 16 (AL 1899)

The brine will be discharged to the municipal sewerage system.

4. Further Work

4.1 Locations of Exploration Boreholes

The areas most suitable for exploitation of brackish water within the AZB will be at the outcrop of the lower sandstone hydraulic complex. Initial estimates of depth to aquifer using the isopach maps from USAID/DAI (1998) and existing information from the WIS database is tabulated in Table 9.

Table 9. Aquifer Characteristics at Kurnub Outcrop in AZB

Aquifer	Metres below ground level				TDS mg/l
	Top	Bottom	Thickness	Water Level	
Kurnub	0	100-200	100-200	0-200	< 1000 at outcrop
Zarqa	100-200	1200-1400	1100-1300	100-275	1000-3000
Ram	1200-1400	2200-2900	1000-1500	150-350*	5000-5200**

* these are only first approximation of water levels and confirmation must await exploration of the Rum in AZB
** these values obtained from boreholes penetrating into Zarqa & Ram in Hisban Area, JICA 1995

The two primary areas are Jerash/Mashtal area and Baqa shown in the location map. Of secondary importance is the Sukhneh area as the lower sandstone complex does not outcrop but is considered an area of relatively low elevation with AZB.

Jerash – Mashtal Faisal area
Recent boreholes drilled by the WAJ drilling department indicates good potential resource in the Kurnub outcrop near Jerash. The high yielding borehole near Jerash bridge crossing over the Wadi Zarqa penetrated 70m with TDS values of 3000 mg/l and yield of up to 200 m^3/hr. From discussions with the toolpusher that drilled the borehole the groundwater was fresh until penetration to 70m whereby the water level rose and the salinity of the borehole water increased to become brackish. Initial estimate of the elevation of the Mashtal Faisal borehole from topographical maps is about 480m asl. Drilling of further boreholes are recommended to be in the vicinity to the north of wadi Zarqa and at topographical lows.

The general location in Palestine Grid (PG) coordinates would be (East: 220-228 North: 1172-1178). The area contains outcrops of the Lower Kurnub and Zarqa formation.

Baqa Area.
About 15 km north-west of Amman is the Baqa area where the Kurnub aquifer outcrops. The area is highly structured and it appears that water quality in the Kurnub is better south of the Baqa strike slip fault in Ein Al Basha. The water quality is related to recharge from rainfall. The altitude in this area is about 400-700masl. Suggested general location would be in (PG East: 225-228 North: 1160-1168) at topographical lows.

Sukhneh area
Of lesser importance is the Sukhneh area as the top of the Kurnub aquifer is about 200 m depth. Exploration drilling should consider the Kurnub/Zarqa aquifers as the depth to Rum may be prohibitive.

4.2 Cost of Exploration Program

Preliminary estimates of drilling costs assumes that sites are at the Kurnub outcrop and thicknesses of the lower sandstone aquifers are 100-200m (Kurnub), 1100-1300m (Zarqa) and - to minimise penetration effects from the pumping tests - the Ram aquifer should be penetrated about 200m. This will minimize the overall drilling costs but still give a reliable estimate of resource potential. Borehole exploration costs include drilling, construction, development and testing. Boreholes into the Kurnub / Zarqa aquifers with depths of 600-800m are about 230,000 to 260,000 JD in cost, and boreholes penetrating into the Ram aquifer to depths of about 1500m will cost about 350,000 JD.

As the exploratory sites described in section 4.1 are only estimated and drilling costs are high, it is highly recommended that a detailed hydrogeological investigation be conducted prior to finalising the locations for drilling of these exploration boreholes. In addition, these boreholes may be utilized for water supply after treatment of brackish water using RO desalination, in which case siting of these boreholes should consider suitable means of brine disposal.

5. Conclusion

The brackish water resources of the AZB consists of the lower sandstone hydraulic complex made up of the regional aquifers of the Ram Group overladen by the Zarqa Group and the Kurnub Group. The sandstone hydraulic complex is overladen by the fresh water aquifers of the B2-A7 and Basalt. Tapping of the brackish water resources is the most feasible at the Kurnub outcrop located in the areas of Jerash, Baqa and Sukhneh. Availability of the quantities of the resources is dependent upon the exploitation quantities versus the effects on the downstream water bodies such as wadi base flow. Initial estimation of available yield should consider only 10-20% of the inflows calculated to be 15-30 MCM/a

There are brackish springs discharging from the contacts near the Kurnub/Zarqa outcrops. Recent historical average values (shown in Table 1) of six relevant brackish springs discharging in or within proximity to AZB are about 10.2 MCM per year. However, averages from the last 5, 10 and 15 years of 2.0, 2.6, and 2.8 MCM/a, respectively, reflect the recent dry periods encountered in Jordan. Therefore a conservative estimate of available resource should look at the 5 year average of 2.0 MCM/a. Due to the recent dry period the discharge from two of the six relevant brackish springs (Seil Zarqa and Sukhneh) have decreased substantially. Nimra Spring is being used by Sabeel Water bottling company and farmers. Ras El Mai Spring is exploited by farmers. Only the Abu Zigan springs are not being used and are available to be developed for M&I supply. However, the allocation of spring discharges in respect to water rights should be clarified prior to any activities.
From JICA 1995 the most suitable and cost effective means to treat this brackish water to potable standard is using RO desalination technology. This has been confirmed by the implementation of small desalination projects utilising RO technology described in section 3.4. Therefore small RO desalination plants may be set up near these springs to treat the water to potable levels for distribution to local community supplies or, if near a piped distribution system, to augment this water for municipal supply.

The borehole exploration program should be targeted to define the resources of the lower sandstone hydraulic complex separated according to the resources of each of the aquifers. As these boreholes may be utilized for water supply after treatment using RO desalination, siting of these boreholes should consider suitable means of brine disposal.

The resource exploitability must be qualified since the outflow of the lower sandstone complex is towards the Jordan Valley and escarpment side wadis. Therefore abstraction of the brackish groundwater may affect the base flow of these wadis.

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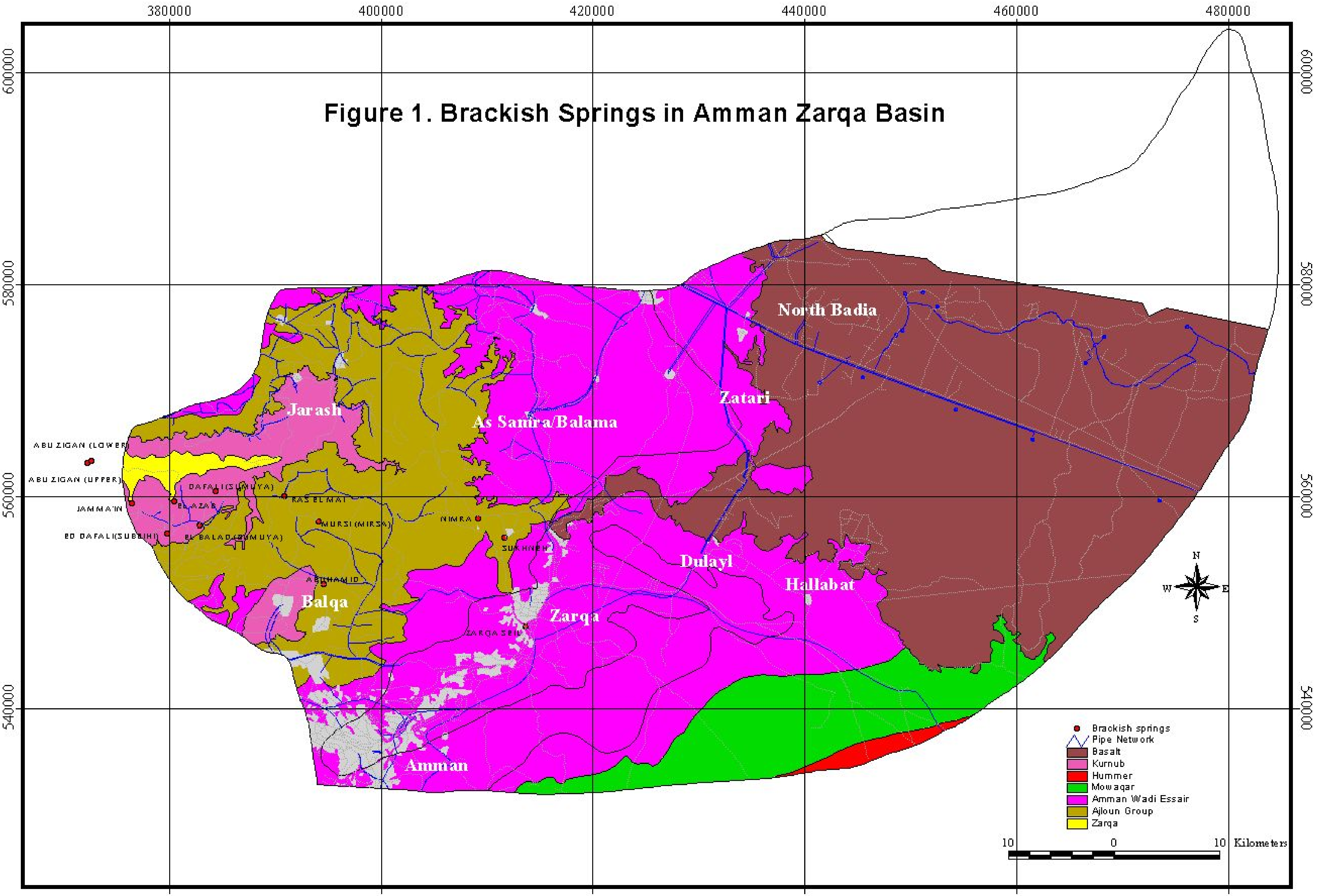


Figure 1. Brackish Springs in Amman Zarqa Basin

Appendices

Appendix 1

Summary of Aquifer Characteristics in AZB

Within AZB

Ram Group

This aquifer system underlies most of Jordan except along the basement outcrops in the western boundary of Jordan. The Ram Group is considered to be the most important sandstone aquifer for strategic long term supply. Where the Ram aquifer outcrops in the southern deserts of Jordan the water quality is very good with TDS values in the range of 200-450 mg/l. The outflow of the Ram aquifer trending north and north-east is considered the lowest point in Jordan, the Dead Sea. Along the flow line the groundwater increases in TDS (1000-6000 mg/l) The depth to aquifer increases along the Jafr and Sirhan/Hammad basins from 2000-4000 m and decreases in the Jordan River and Dead Sea Basins to 1000-1500m. In the AZB average thickness of the Ram aquifer varies from 1000-2300m. Preliminary estimates to depths to the top of the aquifer in AZB at the Kurnub outcrop is estimated to be about 800-1000 metres below ground level (m bgl) with water levels in the region of up to 250 300 m bgl estimated for areas with the Kurnub outcropping.

Zarqa Group

The Zarqa Group is generally regarded as an aquitard although local variability in formation characteristics from, marls, dolomite, to sandstone bands allows higher permeability zones. The Zarqa Group confines the overlying Ram Group. Boreholes penetrating these formations such as in the Baqa Valley are regarded as good local aquifers within AZB. In the adjacent basins near Kafrein/Hisban boreholes penetrating into the Zarqa Group shows significant brackish groundwater potential with rates of discharge up to 150 to 200 m^3/hr under artesian conditions with TDS values ranging from 2,400 to greater than 10,000 mg/l.

Kurnub Group

Except at outcrop the Kurnub Group is overladen and confined by the Naur limestones and marls. In the outcrop areas in Jerash, Baqa and Sukhneh water quality of the Kurnub is generally considered good ranging from TDS values of 300 to 700 mg/l. Away from the recharge areas the salinity increases up to 3000 mg/l due to the confined nature of the aquifer and upward flow of groundwater from the more brackish Zarqa Group.

Adjacent Areas

The adjacent areas the Jordan Valley and eastern escarpments may be used to guide the understanding of the resources of the lower sandstone aquifer complex in the AZB.

Hisban/ Kafrein Area

JICA 1995 conducted a study of the brackish groundwater potential in the area. The groundwater is brackish with TDS ranging between 5000 and 7000mg/l. Yields of project boreholes indicates good potential with brackish water under artisan conditions discharging 150-200 m^3/hr. The flow model concluded a potential of 121 MCM/a in the Zarqa Aquifer recommending 75 MCM/a to be desalinated water using Reverse Osmosis technology. Further recommendations considers a resource potential of the Ram aquifer at least equal to or greater than the Zarqa/Kurnub aquifer system.

The elevation in the area is about –200m asl. Drilling depths to the Zarqa aquifer range from 200 to 400 metres, water levels about 40m bgl and TDS values around 5000 and 7000mg/1. First estimates of the depth to penetration of the Ram aquifer is in the region of 600 and 800m bgl and water levels above the Zarqa aquifer.

Karamah-Deir Alla Area

Boreholes penetrating into the Kurnub-Zarqa aquifers indicates TDS values between 3000 and 5000 mg/l. Presently no use have been made of these aquifers except for a small desalination plant currently been built under contract by WAJ abstracting brackish water of about 40 m^3/hr from an existing borehole.

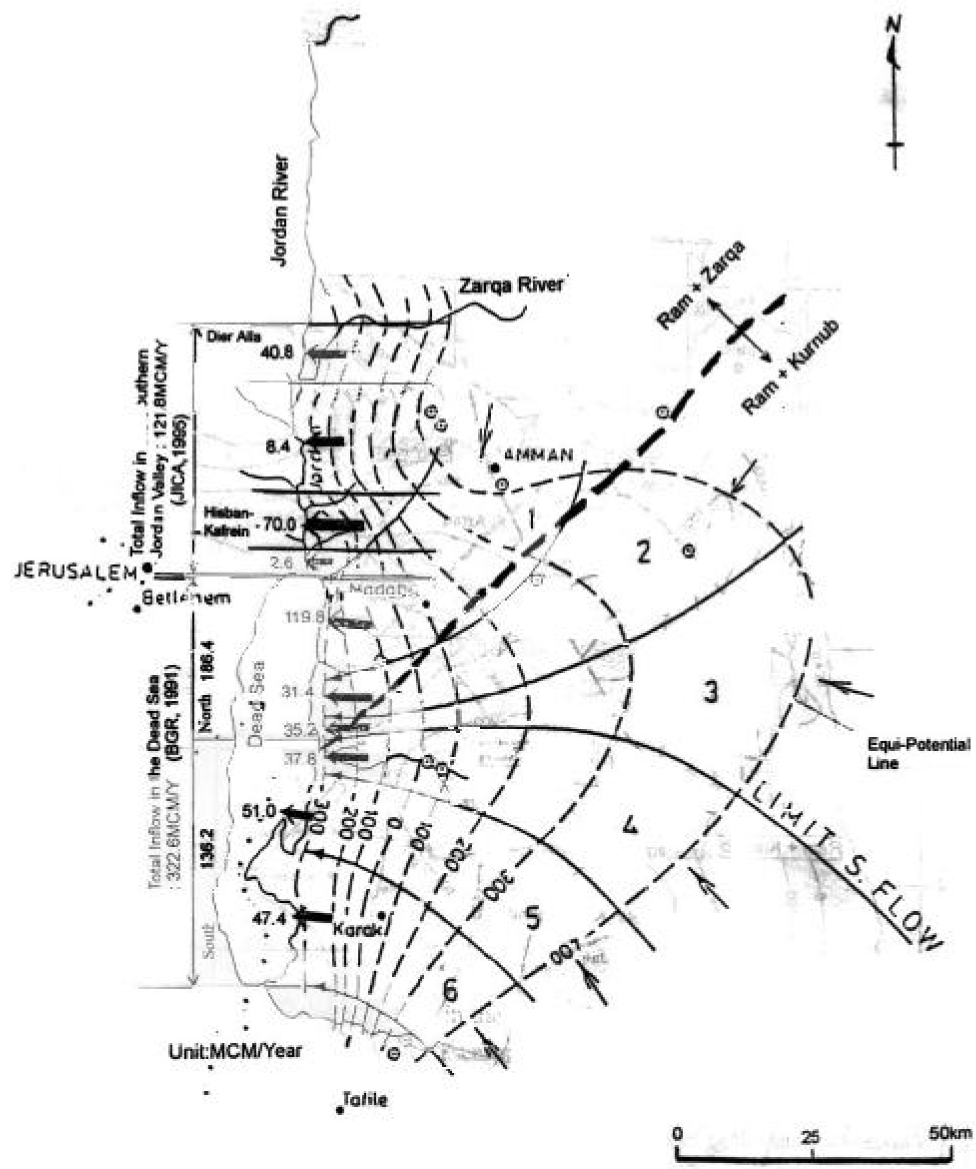
Table 10 summarises the aquifer characteristics, flows and water quality aspects of the lower sandstone hydraulic complex from studies completed in various areas of Jordan.

Table 1 Hydraulic Parameters of the Lower Sandstone Hydraulic Complex

Hydraulic Parameters	*Jordan Valley*	*Other Areas in Jordan*	*Amman-Zarqa*	*Comments*	*References*
Permeability (m/d)		Rum Group = 0.4 - 1.0		Disi Mudawwara Area	SWK, 1995
		Kurnub & Disi fm = 6		Wadi Mujeb well No 1	WAJ Reports 1996
		Kurnub & Disi fm = 1		Hasa (Tanour 1)	
		Kurnub & Disi fm = 4		Central Jordan	
	Kurnub= 1.0 - 1.1			North of Jordan Valley	JICA, 1995
	Zerqa= 0.3 - 0.8			North of Jordan Valley	JICA, 1995
	Rum= 4.2 - 16			North of Jordan Valley	JICA, 1995
			Kurnub= 2 - 5 Zerqa= 1.2 - 9		USAID/ARD 2000
Transmissivity (m^2/d)		Rum Group = 120 - 2000		Disi Mudawwara Area	SWK, 1995
			Kurnub= 23 - 84		USAID/ARD 2000
			Zerqa= 27 - 290		USAID/ARD 2000
	Kurnub= 110 - 120			North Jordan Valley	JICA, 1995
	Zerqa = 100			North Jordan Valley	JICA, 1995
	Rum= 120 - 320			North Jordan Valley	JICA, 1995
Specific Yield Sy		Rum Group = 0.03 - 0.12		Disi Mudawwara Area	SWK, 1995
(unitless)			Kurnub= 10^{-4}		USAID/ARD 2000
Confined Storage Sc (unitless)	Kurnub = 0.0019 - 0.0025			North Jordan Valley	JICA, 1995
	Zerqa= 0.0004 - 0.001			North Jordan Valley	
	Rum=0.0000006 - 0.003			North Jordan Valley	
		Rum Group = 0.0008 - 0.01		Disi Mudawwara Area	SWK, 1995
Hydraulic Gradient		Rum Group = 0.0007		Disi Mudawwara Area	SWK, 1995
			Kurnub- 0.014	Corridor Model	MWI 2000
unitless	Kurnub = 0.0396 Zerqa= 0.0264				JICA 1995
Out Flow MCM/a		Rum Group = 140		Dead Sea Area	SWK, 1995
Abstraction MCM/a		Rum Group = 75		1993, in Disi-Mudawwara Area	SWK, 1995
		Rum Group = 68		1998, in Disi-Mudawwara Area	WAJ files
			Kurnub= 8 Zerqa= 0.06		JICA 2000
TDS mg/l			Kurnub/Zerqa = 300-700	near outcrop	USAID/ARD 2000
			Kurnub up to 3000	confined	
			Zarqa =4000	confined	
	Kurnub= 400-2000			outcrop - confined	JICA 2000
	Ram= 5000-5200 Zerqa= 5000-10000 Kurnub = 5200 Kurnub up to 6000			Obtained bhs screened both in Zerqa and Ram Karame area	JICA 1995
		Kurnub and Disi = 900		Wadi Mujeb well No 1	WAJ Reports 1996
		Kurnub and Disi = 370		, Hasa (Tanour 1)	
		Disi = 300 - 500		Disi Mudawarra area	SWK, 1995

Appendix 2

Schematic Diagram: Outflow of Groundwater from Lower Sandstone Aquifer Complex to Dead Sea and Surrounding Areas



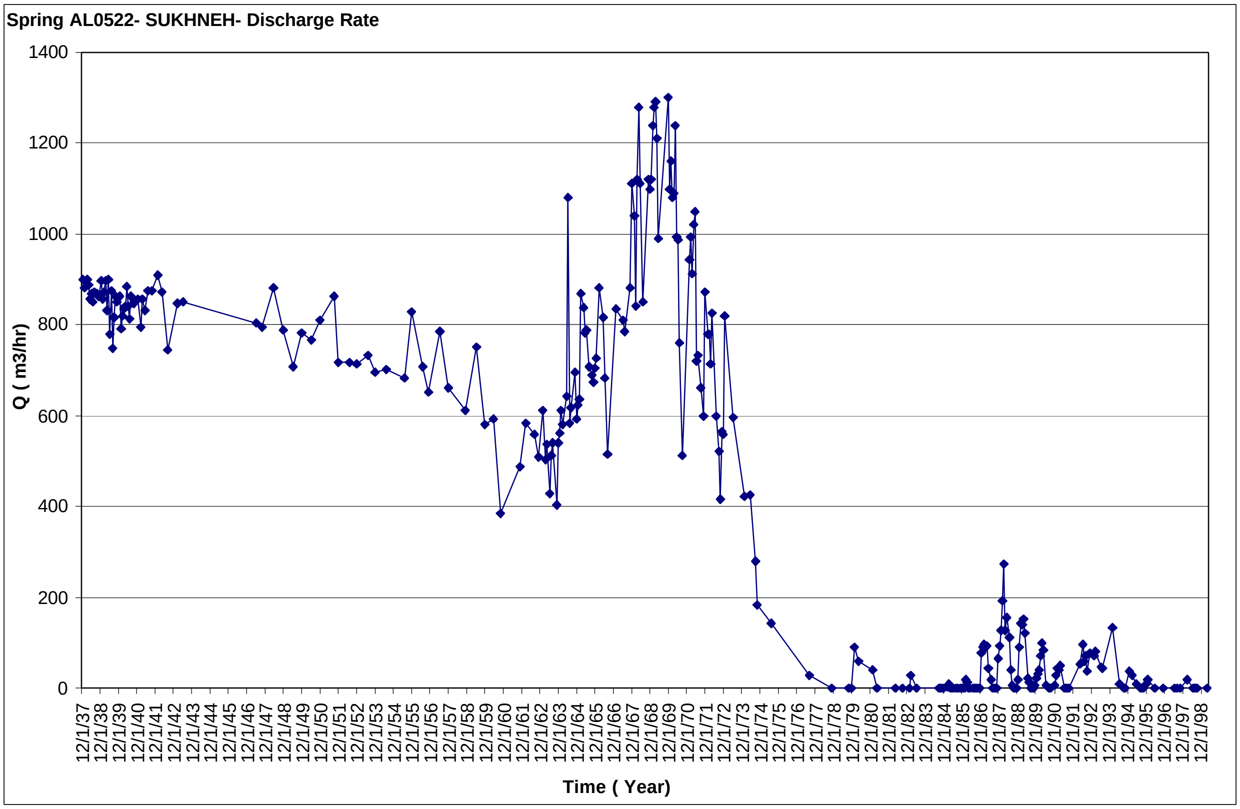
Total Inflow to the Dead Sea and the Southern Jordan Valley : 444.4MCM/Year

Fig.2.2.4-2 Inflow Amount from the Lower Aquifer System to the Dead Sea and Southern Jordan Valley (BGR, 1991 and JICA, 1995)

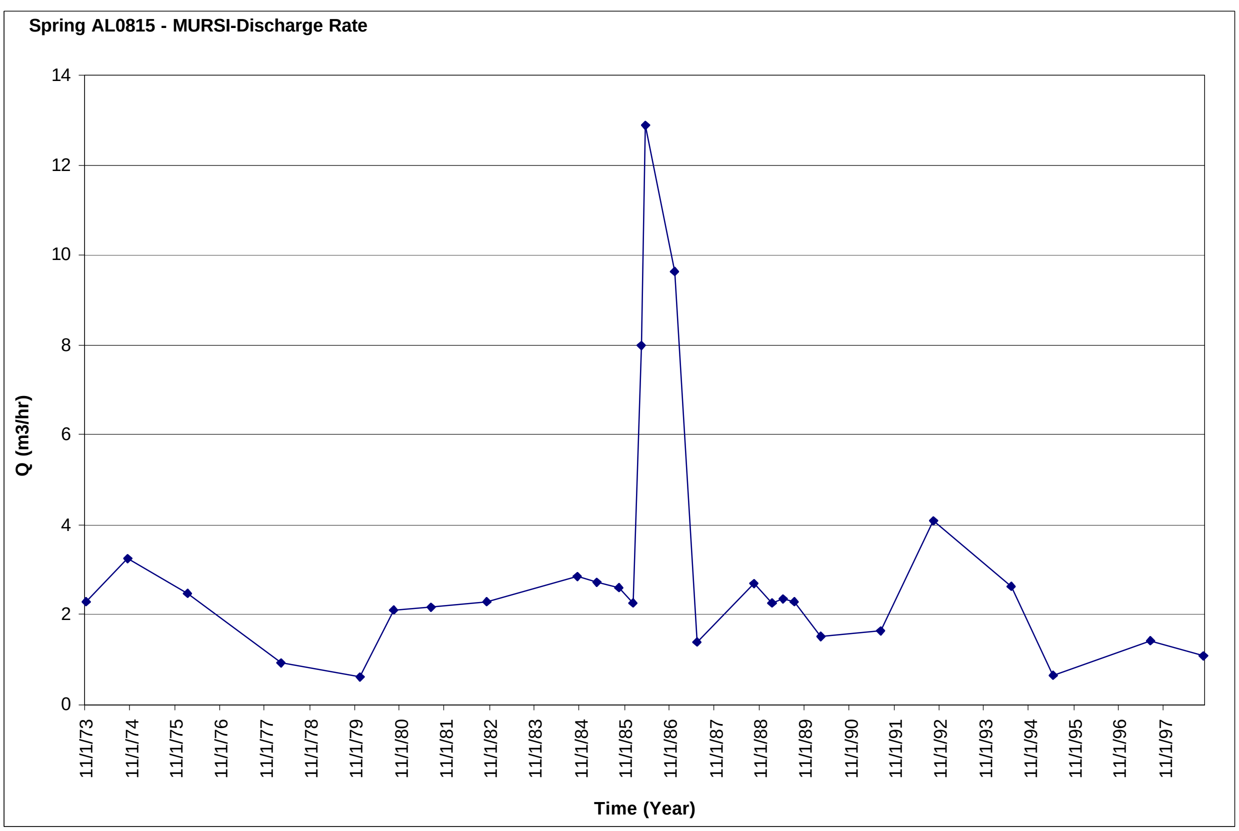
From JICA (Draft October 2000)

Appendix 3

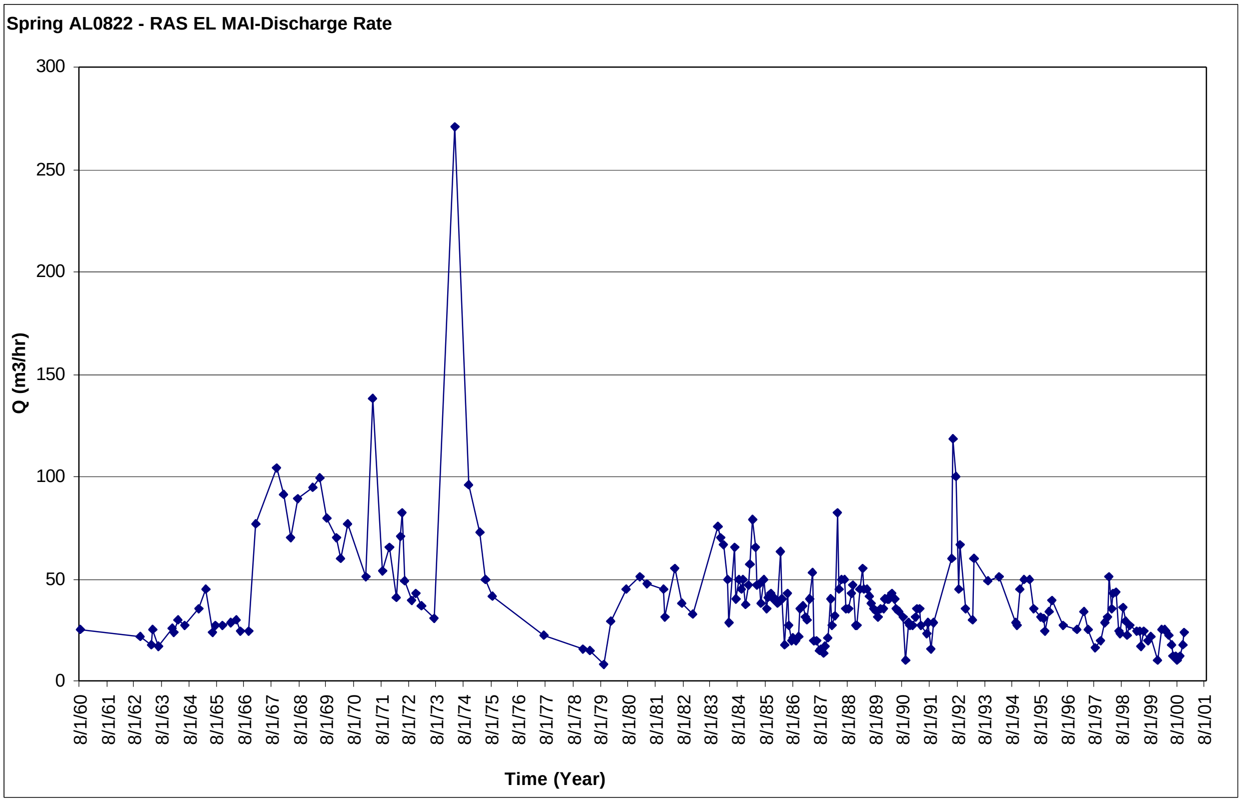
Charts on Brackish Spring Flow

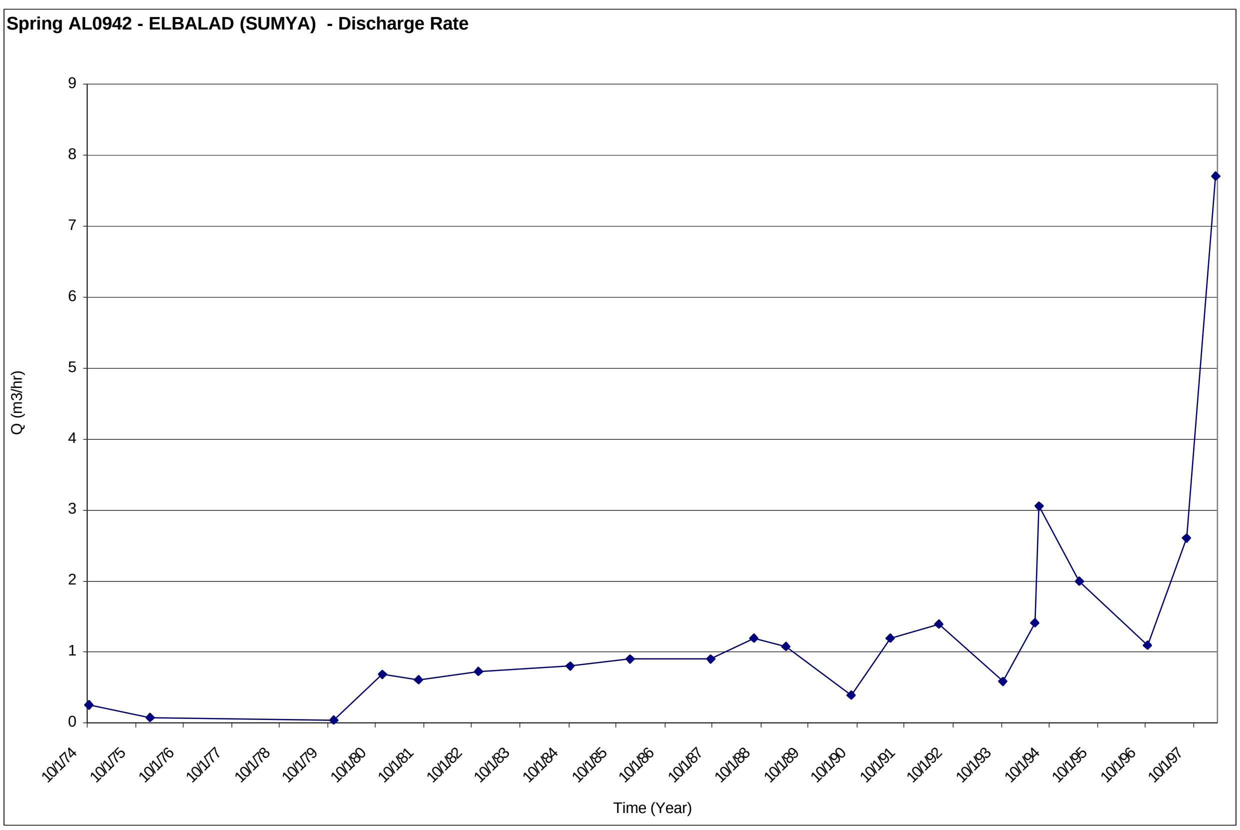


Spring AL0522- SUKHNEH- Discharge Rate
Q (m3/hr)
0
200
400
600
800
1000
1200
1400
Time (Year)



Spring AL0815 - MURSI-Discharge Rate
Q (m3/hr)
0
2
4
6
8
10
12
14
Time (Year)


Spring AL0822 - RAS EL MAI-Discharge Rate
Q (m3/hr)
300
250
200
150
100
50
0
8/1/60
8/1/61
8/1/62
8/1/63
8/1/64
8/1/65
8/1/66
8/1/67
8/1/68
8/1/69
8/1/70
8/1/71
8/1/72
8/1/73
8/1/74
8/1/75
8/1/76
8/1/77
8/1/78
8/1/79
8/1/80
8/1/81
8/1/82
8/1/83
8/1/84
8/1/85
8/1/86
8/1/87
8/1/88
8/1/89
8/1/90
8/1/91
8/1/92
8/1/93
8/1/94
8/1/95
8/1/96
8/1/97
8/1/98
8/1/99
8/1/00
8/1/01
Time (Year)


Spring AL0942 - ELBALAD (SUMYA) - Discharge Rate
Q (m3/hr)
9
8
7
6
5
4
3
2
1
0
10/1/74
10/1/75
10/1/76
10/1/77
10/1/78
10/1/79
10/1/80
10/1/81
10/1/82
10/1/83
10/1/84
10/1/85
10/1/86
10/1/87
10/1/88
10/1/89
10/1/90
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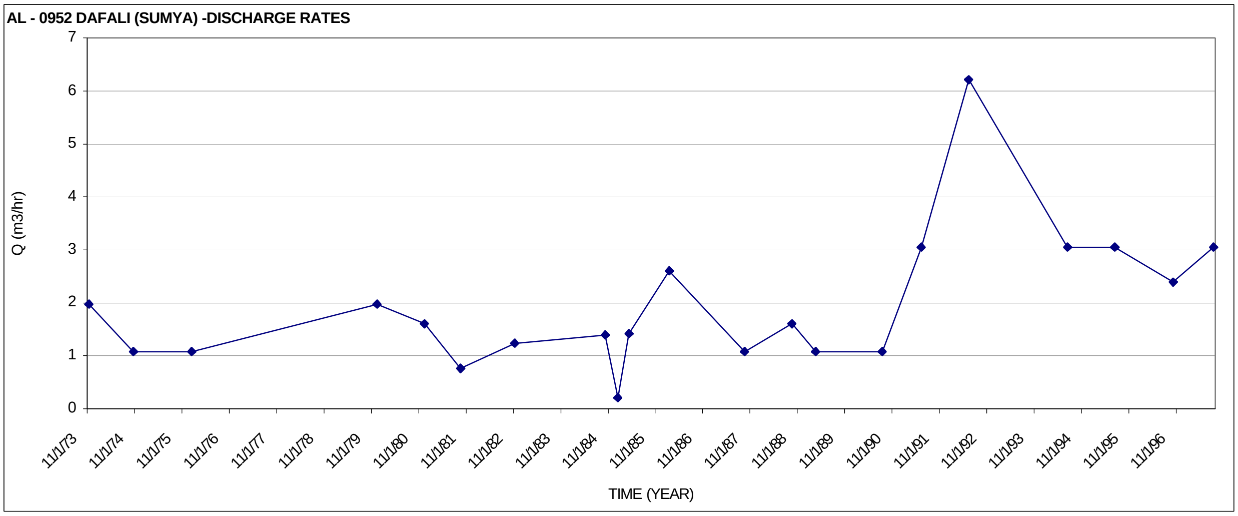
10/1/96
10/1/97
Time (Year)


AL - 0952 DAFALI (SUMYA) -DISCHARGE RATES
Q (m3/hr)
0
1
2
3
4
5
6
7
11/1/73
11/1/74
11/1/75
11/1/76
11/1/77
11/1/78
11/1/79
11/1/80
11/1/81
11/1/82
11/1/83
11/1/84
11/1/85
11/1/86
11/1/87
11/1/88
11/1/89
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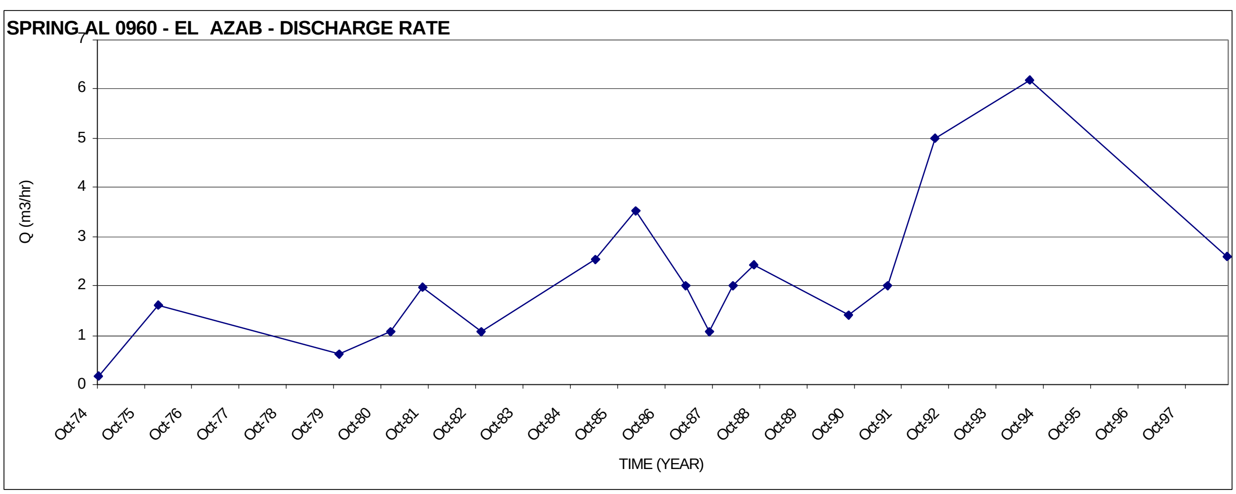
11/1/95
11/1/96
TIME (YEAR)


SPRING AL 0960 - EL AZAB - DISCHARGE RATE
Q (m3/hr)
0
1
2
3
4
5
6
7
Oct-74
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
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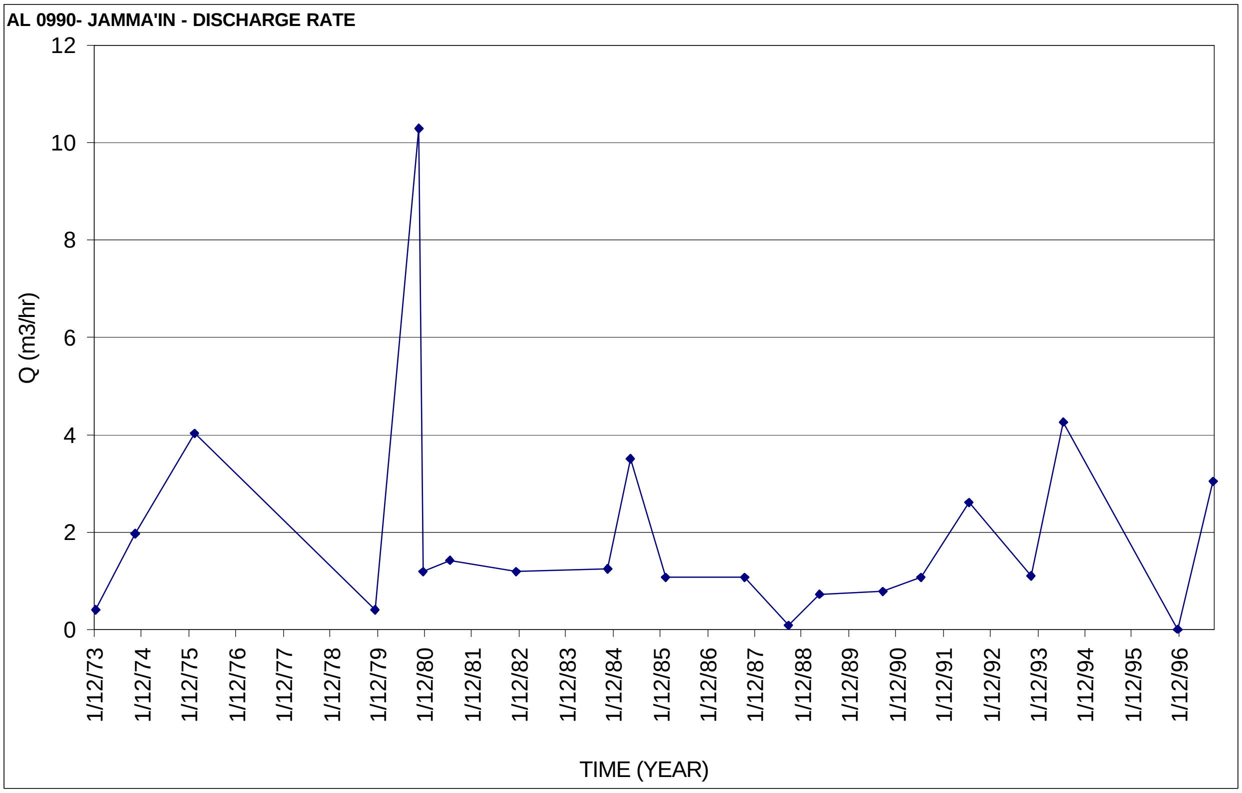
Oct-95
Oct-96
Oct-97
TIME (YEAR)


AL 0990- JAMMA'IN - DISCHARGE RATE
Q (m3/hr)
0
2
4
6
8
10
12
1/12/73
1/12/74
1/12/75
1/12/76
1/12/77
1/12/78
1/12/79
1/12/80
1/12/81
1/12/82
1/12/83
1/12/84
1/12/85
1/12/86
1/12/87
1/12/88
1/12/89
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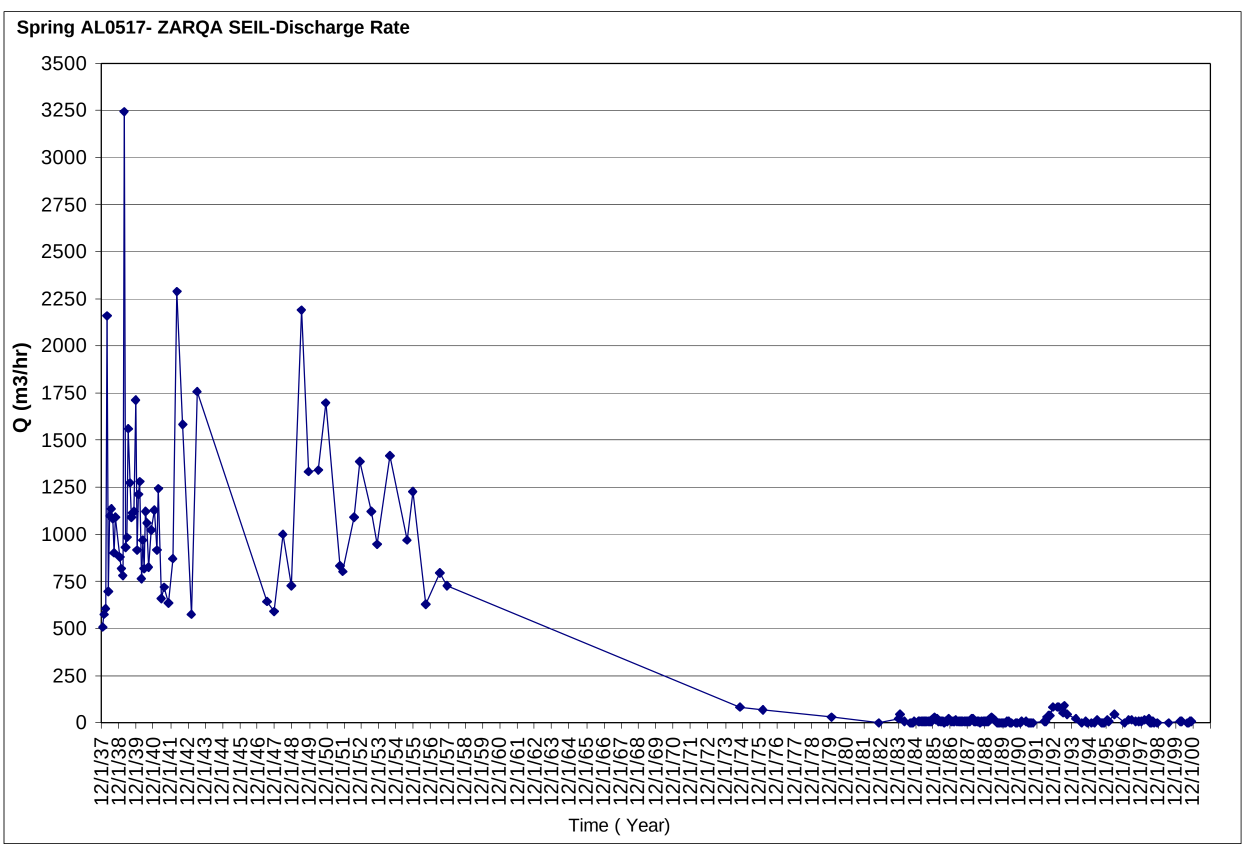
1/12/95
1/12/96
TIME (YEAR)


Spring AL0517- ZARQA SEIL-Discharge Rate
Q (m3/hr)
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
12/1/37
12/1/38
12/1/39
12/1/40
12/1/41
12/1/42
12/1/43
12/1/44
12/1/45
12/1/46
12/1/47
12/1/48
12/1/49
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12/1/53
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12/1/92
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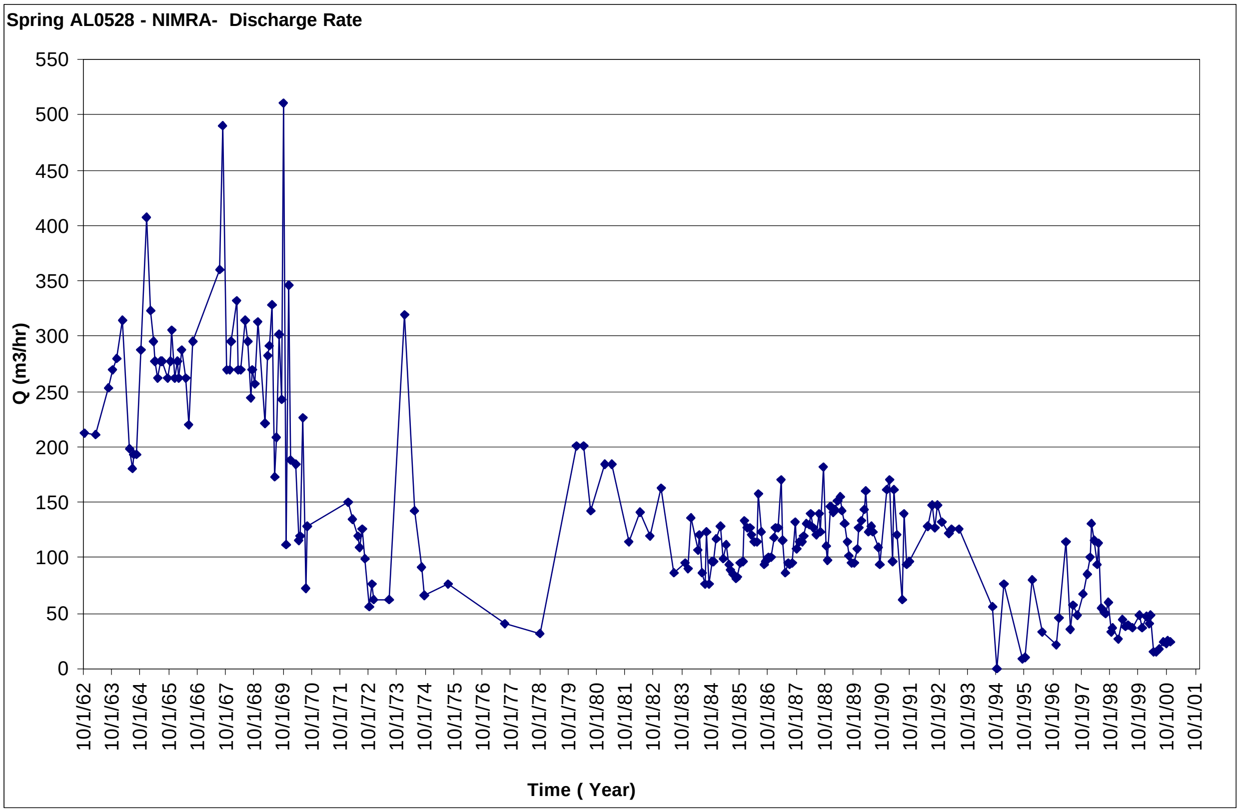
12/1/00
Time (Year)


Spring AL0528 - NIMRA- Discharge Rate
Q (m3/hr)
Time (Year)
550
500
450
400
350
300
250
200
150
100
50
0
10/1/62
10/1/63
10/1/64
10/1/65
10/1/66
10/1/67
10/1/68
10/1/69
10/1/70
10/1/71
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10/1/92
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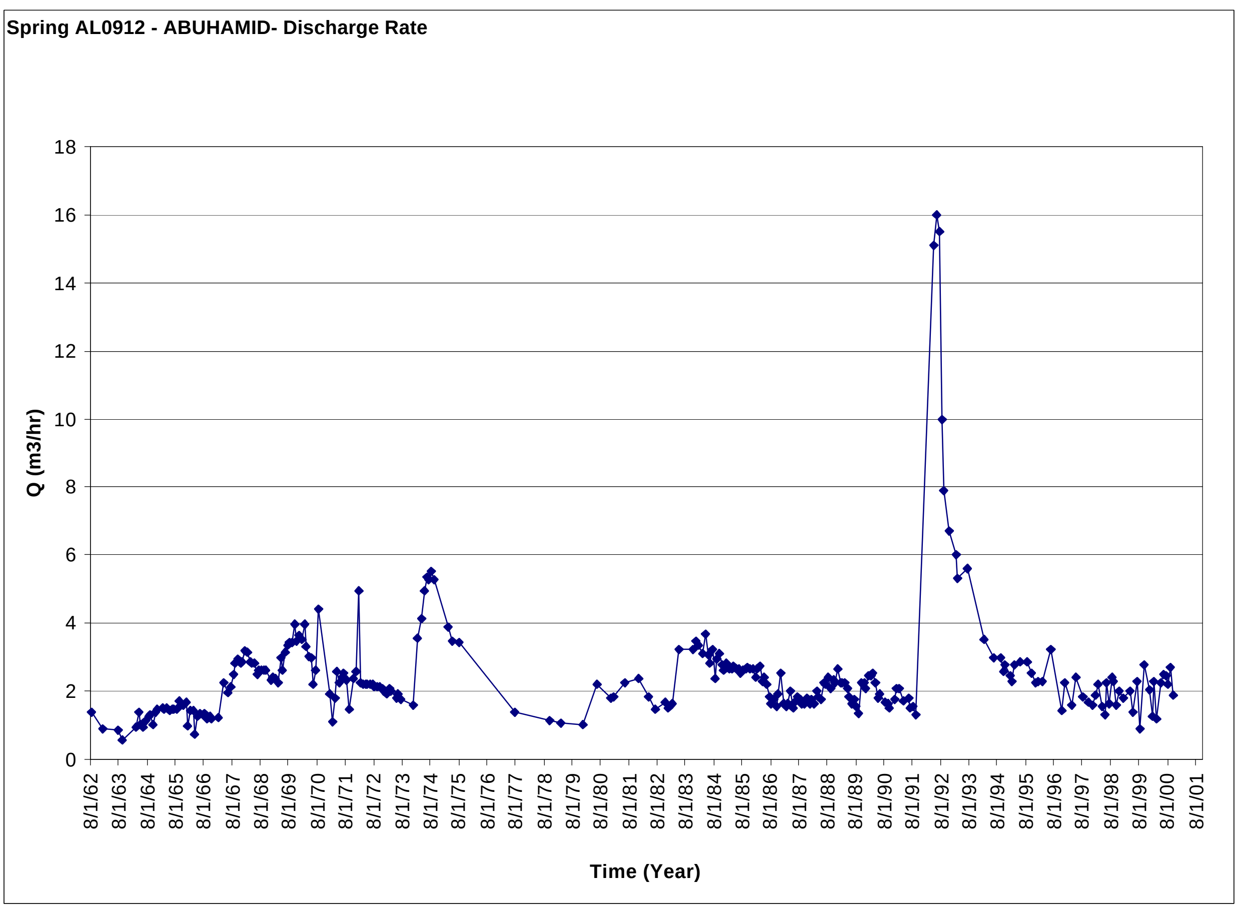
10/1/00
10/1/01


Spring AL0912 - ABUHAMID- Discharge Rate
Q (m3/hr)
Time (Year)
18
16
14
12
10
8
6
4
2
0
8/1/62
8/1/63
8/1/64
8/1/65
8/1/66
8/1/67
8/1/68
8/1/69
8/1/70
8/1/71
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8/1/73
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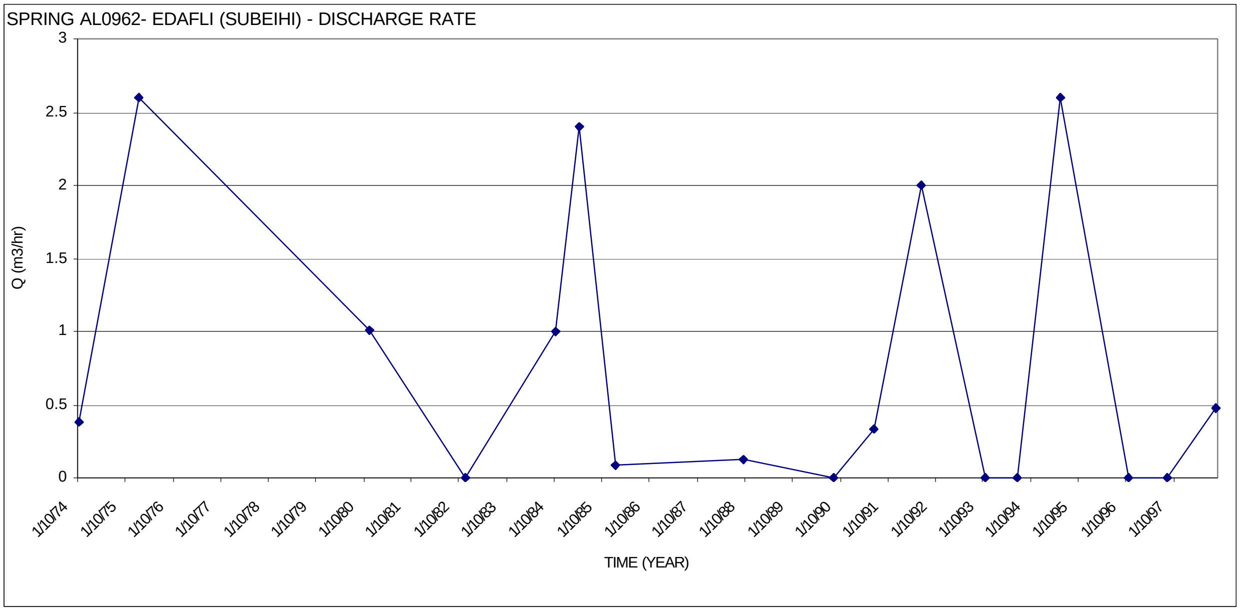
8/1/00
8/1/01



SPRING AL0962- EDAFLI (SUBEIHI) - DISCHARGE RATE
Q (m3/hr)
3
2.5
2
1.5
1
0.5
0
1/10/74
1/10/75
1/10/76
1/10/77
1/10/78
1/10/79
1/10/80
1/10/81
1/10/82
1/10/83
1/10/84
1/10/85
1/10/86
1/10/87
1/10/88
1/10/89
1/10/90
1/10/91
1/10/92
1/10/93
1/10/94
1/10/95
1/10/96
1/10/97
TIME (YEAR)

Appendix 4

Questionnaire Sheet - Visit to RO Plant at Thermal Power Station

Water supply from boreholes	Currently 6 boreholes are allocated for water supply. Water quality has gradually been decreasing since late 1980's. A borehole drilled in 2000 produced discharge water at about 4000 us/cm.
Existing water demand for desalinated water	About 1000 m^3/day. Average feed intake about 45 m^3/hr.
Water quality data from water supply boreholes	Currently (April 01) the average electrical conductivity value is about 3000 us/cm
Pre-treatment: Problems with scaling and biofouling	Some problems in winter time with turbidity. Use HCl as anti-scaler and hypochlorite (<1pp) for biofouling
Cost of water supplied to the plant From the boreholes Pre-treatment Desalination	 WAJ charges 0.25 JD per m^3 for water supplied from Power station boreholes The average cost of desalination of the groundwater is about 0.45JD and includes pre-treatment
Desalination Plant process type and design; plant size, Capacity Construction Cost intake type Pre-treatment RO intake water quality RO discharge water quality O&M requirements Energy labour, chemicals, spares membrane replacement	 The first plant was build in 1986 using a cellulose membrane then another unit built in 1995 that uses polyamide membrane. The estimated cost per unit was about 200,000JD each. Filter intake Using anti-scaling and biofouling agents such as citric acid, HCl and activated carbon. 3000us/cm (apr01) 350-400 us/cm then change membrane about 15-20% of the cost of desalination (0.45JD) is for O&M, labour, chemicals, membrances, etc. Membrance cost about 400JD each and require about no. 42 for each plant
environmental factors/concerns	The brine is mixed other treated water and used for irrigation of trees around the plant complex.
Discharge water	About 1000-1200 m3/day of effluent is discharged from the plant 25% for irrigation and 27% to municipal sewerage.

Quality	The water quality is monitored by the plant in all phases of process line. WAJ labs and RSS monitors the intake and discharge waters
Disposal Evaporation Residue for evaporation ponds Holding ponds Solid waste	Described above Not used
Disposal of brine	25% Diluted to 2000us/cm and used for irrigation and 75% discharged to municipal sewerage.

Appendix 5

Calculation of Aquifer Inflow to AZB

Calculation of Groundwater inflow to the AZB of the Lower Sandstone Hydraulic Complex

Inflow from the north-eastern and south-western boundaries can be estimated using universal Darcy flow equation Q = T i W. Values used in the equation are mean values obtained from the piezometric surface of the Ram Aquifer from SWK 1995 and those used in the Karak Flow Model produced by the MWI. The Corridor Model indicates Kurnub gradient at 0.014. JICA 1995 shows the gradients from the model to be 0.0396 for Kurnub and 0.0264 for Zarqa. These values are probably high to be used in the AZB as the flow is down the escarpment. The values are listed in Appendix 1. As the Kurnub and Zarqa are interconnected hydraulically and the thickness of the combined Kurnub/Zarqa aquifer is about 1200-1400m the calculated transmissivity for both the Kurnub and Zarqa was set as an average value of 200 m^2/d.

Layer 1 (Kurnub/Zarqa Aquifer)

T	=	Transmissivity	= 180 m^2/d
i	=	Hydraulic gradient	= 0.014
W	=	Width of boundary	= 60,000 m
Q	=	Throughflow	= 151,000 m^3/d or 55 MCM/a

Layer 2 (Ram Aquifer)

T	=	Transmissivity	= 220 m^2/d
i	=	Hydraulic gradient	= 0.020
W	=	Width of boundary	= 60,000 m
Q	=	Inflow	= 264,000 m^3/d or 96 MCM/a

The rate of inflow calculated from the formula for the combined layers is about 151 MCM/a for the AZB.