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Zarqa River Conveyance Study

Part 3: Selection of Preferred Alternative

Harza Engineering Consolidated Conslt.

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USAID

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ZARQA RIVER CONVEYANCE STUDY

PHASE A - CONCEPTUAL STUDY

PART 3 - SELECTION OF PREFERRED ALTERNATIVE

B

EXECUTIVE SUMMARY

The Zarqa River Conveyance Study, a component of the Jordan Valley Quality Improvement Project, is being performed by Harza Engineering Company and Consolidated Consultants in two phases

Phase A Conceptual Study
- Part 1 Data Collection
- Part 2 Data Evaluation
- Part 3 Selection of Preferred Alternative

Phase B Feasibility and Environmental Assessment

This Conceptual Study Draft Report discusses the studies completed under Phase A, Part 3 - Selection of Preferred Alternative The studies were directed at the reevaluation of channel efficiency based on additional field measurements, and geological and hydrogeological investigations, identification and conceptualization of alternatives, and selection of a preferred alternative

Channel Efficiency

A discharge and water quality measurement program was undertaken to develop a consensus on the conclusions arrived in the Phase A - Part 2 report A set of flow and water quality measurements was made from September 11 to September 14, 1995 The following conclusions were reached

1. The river reach between King Talal Dam (KTD) and Thahab Weir is most likely a minor fresh water gaining reach

2. The river reach between Thahab Weir and Hwaret Weir could be a gaining or losing reach without any adverse effect on water quality

3. The river reach from Hwaiet Weir to Abu Zeighan Weir has saline seepage and springs which reduce the water quality There could be losses in this reach

4. Any future monitoring of spring flows should be done with a portable flume under the condition that all KTD release is diverted at Thahab Weir and the downstream river channel is allowed to dry up for 2 to 3 days

Geological Investigations

Regional geology of the area between the KTD and the Abu Zeighan Weir was studied Field investigations were made to determine any geological factors that affect the flow regime in the Zarqa Rivei It was determined that the river reach between the KTD and the Abu Zeighan Weir is most likely to be a gaining reach

Ground Water Regime

The hydrodynamic pattern of the ground water regime was studied Two aquifer systems, the Upper Aquifer Complex (including the Kurnub Aquifer) and the Lower Aquifer Complex (including the Zarqa Aquifer), were identified

According to the hydrogeological conditions prevailing in the area between KTD and the Abu Zeighan Weir, the river reach between KTD and the Thahab Weir should be continuously recharged from the Kurnub Aquifer with good quality water The river reach between the Thahab Weir and the Abu Zeighan Weir should be continuously recharged with poor quality saline water from the Zarqa Aquifer However, there is a possibility that the reach between Thahab and Hwaret weirs may have contribution from the Kurnub Aquifer as well

Identification and Conceptualization of Alternatives

Several solutions and concepts listed in the TOR, plus configurations that were identified after site visits and discussions with the JVA officials, were consolidated into five alternatives four irrigation supply schemes (**IRR1**, **IRR2**, **IRR3a**, and **IRR3b**), and one multi-purpose (irrigation / power) development (**POW**) In defining the alternatives, a significant value was placed on the opinions of the people from the Irrigation Department and the JVA who are most familiar with the studies and the river, including the existing structures, consumers, and operation

The schemes considered intake locations at two existing weirs along the Zarqa River (Thahab and Hwaret), as well as various types of conveyance (ductile iron pipe, canal, and steel pipe) Some alternatives, depending on the configuration and intended use, integrated pumping stations, powerhouses, and re-regulating ponds The conceptualization of the alternatives was primarily based on hydraulic design criteria and on preliminary structural and stability considerations Main criteria that were observed in the alternative definition process include

All schemes incorporated existing structures in the Zarqa River watershed, including dams (KTD), weirs, powerplants and waterways

- Alternatives were mainly conceived to provide good quality water to existing irrigation consumers As such, the Zarqa Carriers and the King Abdullah Canal (KAC) were integrated at the current requirement level However, expansions of current requirements were also considered in the project feature sizing, as was the case with the consumers along KAC

- Basic studies of water availability and requirements were conducted based on current inflows into the King Talal Reservoir (KTR) However, the effect of potential future inflows into the reservoir from M&I returns was also assessed, especially for the power addition alternative

- Velocities into the conveyances were maintained, as much as possible, below or at the admissible level, particularly in the concrete-lined canals and in the cement-lined ductile iron pipes

- Whenever head losses along the closed conduits exceeded the current situation, threatening to affect the current consumers, booster pumps were incorporated into the configurations

- Closed conduits were generally preferred to canals, especially in reaches where the extent of losses was still to be determined

Reservoir Operation Studies

Reservoir operation studies were performed for the current operating regime in the Zarqa River watershed, in order to estimate the amount of water presently available Additional operating regimes consistent with the alternatives identified were also investigated They included various scenarios of increased inflow into the KTR in the future (from M&I returns), future irrigation demand growth along the KAC, as well as the possibility of implementing a new powerplant immediately upstream of the Abu Zeighan Weir Flows still available after supplying these demands were determined as inflows into the Karamah Reservoir

Reservoir operation studies were simulated using the Army Corps of Engineers' **HEC-5** computer model developed by U S Army Corps of Engineers Input into the simulation included reservoir inflow, intervening flows, irrigation requirements, power generation regimes, net evaporation amounts, and the KTR area-capacity curve The application of the model resulted in the following findings for the irrigation alternatives

- In the current situation of inflow into the reservoir and irrigation demand downstream of the dam, assuming that the Zarqa Carriers demand is fully satisfied, periods without shortage for the KAC (on a monthly basis) amount to 68 percent

- An additional future inflow of 1 cms (on a monthly basis) into the reservoir would increase the period without shortage to 94 percent

- An irrigation demand growth of 20 percent along the KAC would result in a period without shortage to these consumers of about 63 percent with no increase in the reservoir inflow, and of 91 percent if an additional inflow of 1 cms enters the reservoir in the future, a future inflow increase of 2 cms would satisfy full-time demand growths along the canal in the range of 20 to 40 percent

The implementation of a 7 MW new powerplant at Abu Zeighan, harnessing the 121 m gross head between Thahab and Abu Zeighan and sized for a 7 5 cms design discharge, was considered within the multi-purpose alternative Simulation results for this configuration show that for an additional future monthly inflow into the reservoir of 3 5 cms, an amount that was considered high enough to ensure a design discharge of 7 5 cms (this flow includes the maximum irrigation requirement for the consumers along the canal), the percent of time with no shortage is about 85 percent to both power and irrigation along the canal The percentage represents a proper range of reliability for the power generation

The Preferred Alternative

As mentioned, four irrigation water supply schemes and one multi-purpose development (irrigation / power) were configured, assessed and compared at the conceptual level in order to select a preferred alternative The alternatives were compared on the basis of capital and operation cost, implementation period, volume of water saved, quality of water delivered to the KAC, an initial environmental assessment, and where applicable, energy generation Based on the comparison, the preferred arrangement consists of the rehabilitation of the Hwaret Weir, a 3 5 km ductile iron pipeline, and an outlet at the Abu Zeighan Weir This alternative meets the objectives of the JVA in that it eliminates losses in the reach of Zarqa River that was identified as potentially losing water and it carries the releases from the KTD around the area of saline springs and seeps It is a low cost alternative (although not the lowest) that can be implemented quickly and has only minor adverse impacts

A second alternative was retained that consisted of a diversion form the Thahab Weir and a conveyance by pipeline to the Abu Zeighan Weir Although more costly, it is acceptable on the basis of the other comparison parameters and might be implemented if there is difficulty in rehabilitating the Hwaret weir

The lowest capital cost alternative was not selected because it includes a reach of open channel that could result in water contamination from the saline springs and would require an intensive maintenance program over the reach of canal, and because a simpler more practical alternative exists The remaining alternatives were rejected on the basis of cost and/or environmental problems

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1 INTRODUCTION

The United States Agency for International Development (USAID) is supporting investments to assist the Government of Jordan in improving the management and conservation of water resources As a part of this assistance, the Jordan Water Quality Improvement and Conservation Project (WQIC) was initiated under Contract No 278-0288-C-00-4026-00, between Development Alternatives, Inc (DAI) and USAID

The Zarqa River Conveyance Study was included as a part of the WQIC program to evaluate the potential for improving the conveyance efficiency of water released from King Talal Dam (KTD) and the quality of water diverted from the Zarqa River at the Abu Zeighan Weir The objective of this study is to assess the technical, environmental, economic and financial feasibility of conveying water efficiently and improving quality in the 23-kilometer reach of the Zarqa River between KTD and the Abu Zeighan Weir

The study is being performed in two phases Phase A consists of a conceptual study to identify feasible alternatives and priorities Phase A is divided into three parts, 1) data collection and evaluation, 2) analysis of data, and 3) identification and evaluation of alternatives to mitigate channel efficiency or quality impacts leading to the selection of a preferred alternative Phase B includes an environmental assessment of the preferred alternative, an economic and financial analysis and a preliminary design for the elements of the preferred alternative

Pertinent data and information relevant to the study were collected in Phase A, Part 1 and presented in an inception report in April, 1995 Phase A, Part 2 report entitled, "Data Evaluation," was presented in May 1995 This Phase A, Part 3 draft report includes a conceptual study of various alternatives and a selection of a preferred alternative

1 1 Authorization

This study is being performed as a part of the Jordan Water Quality Improvement and Conservation Project by Harza Engineering Company (Harza) in association with Consolidated Consultants (CC) under a subcontract with DAI

1 2 Mobilized Staff

Part 3 of phase A, selection of preferred alternative was performed as a cooperative effort by Harza and CC staff The personnel mobilized to perform this effort included the following individuals

Individual	Company	Position
Michael Saunders	Harza	Project Manager
Khalid Jawed	Harza	Lead Engineer
Alex Vircol	Harza	Senior Planning Engineer
Monica Cheng	Harza	Senior Hydrologist

Khaled Murad	CC	Deputy Manager
O Rimawi	CC	Hydrogeologist
I Abu Taha	CC	Geologist
L Kandah	CC	Water Engineer
S Smadi	CC	Senior Hydraulic Engineer
S Dweiri	CC	Hydrologist
N Nafash	CC	Senior Civil Engineer
M Habash	CC	Senior Civil Engineer

1 3 Background

In the later part of the 1970's, the Jordan Valley Authority (JVA) began to suspect that all of the water released from the King Talal Reservoir (KTR) was not reaching the King Abdullah Canal (KAC) In 1980, the JVA performed a two-day study that appeared to confirm this suspicion Over the next ten years a total of six studies were performed in an attempt to confirm that losses do occur, to quantify the losses, and to identify the river reaches within which the losses were occurring In 1994, two additional studies were performed, one by the University of Jordan which consisted of a water balance study of the river using estimated data and the actual data provided by JVA, and one by ISPAN which consisted of a review of the other studies The ISPAN review was done to support funding by USAID of additional study of the Zarqa River channel efficiency

In addition to the issue of conveyance efficiency, the poor quality of the Zarqa River is an issue of increasing concern Greater diversions from the KAC to Amman for municipal and industrial (M&I) use has resulted in a greater use of the poorer quality Zarqa River water for irrigation on lands in the Jordan Valley south of the Zarqa River During the summer months of 1994, all of the water diverted into the KAC from the Yarmouk River was used in Amman or on the lands north of the Zarqa River The application of Zarqa River water to the lands south of the river has evidently resulted in decreased yields and damage to citrus trees The deterioration of the quality of the Zarqa River water is caused primarily by a series of salt springs and seeps located in the lower reach of the river

The overall objectives of this Conveyance Study, therefore, are to

1 Develop a defensible argument with respect to channel losses,
2 If warranted, recommend a plan to improve channel efficiency, and
3 Identify the means to improve the Zarqa River water quality

In addition, the potential for developing hydroelectric power was included as an overall objective in the study plan

2 SUMMARY OF PREVIOUS INVESTIGATIONS

This section of the report summarizes the results of the previous investigations on two major issues, Conveyance Efficiency and Water Quality of the Zarqa River

2 1 Conveyance Efficiency

Since 1980, seven studies were performed which attempted to determine the magnitude of water losses or gains and to identify where they might occur These studies or the results of these studies were obtained as a part of data collection and reviewed In addition, previous studies by ISPAN were also reviewed A high value was placed on the opinions of the personnel of the Irrigation Department and the JVA who are most familiar with the studies and the river

Six of the seven studies of channel efficiency were based on discharge measurements The baseline water balance report by University of Jordan was based on water records for the period of 1990-1993 All except one included the reach between KTD and Thahab Weir The number of days with discharge measurements ranged from one to twelve days All studies except the study made by the University of Jordan were performed in one day or on sequential days In most studies, estimates of pumping, spring flow, evaporation, diversions, and the effect of variable inflow were not made or were of questionable quality

Based on the above review, it may be concluded that little or no loss occurs in the reach of Zarqa River between KTD and Thahab Weir When flows in the Zarqa River are greater than about 1,000 l/s, the losses mav occur in the reach between Thahab Weir and the Abu Zeighan Weir varying between 10 and 15 percent However, this is also the reach where practically all springs and seeps have been identified

2 2 Water Quality

The JVA has a comprehensive and extensive water quality monitoring program which includes the Zarqa River and the KAC Selected reports and water quality data were collected and evaluated to determine if a quality problem exists and to identify the magnitude and location of the problem

The collected water quality data at various locations on the Zarqa River and the KAC were plotted and compared The following observations were made from the evaluation of these data

- The water in the KAC north of the Zarqa River, which primarily originates in the Yarmouk River, has been and continues to be of good quality for irrigation

- The quality of water released from KTD is of marginal quality and may be deteriorating

- The water from the saline springs and seeps would be toxic to crops, if undiluted
- The mixing of water from KTD and the seeps and springs results in an irrigation supply that must be diluted to avoid significant reductions in the yields of vegetable and citrus crops

The above observations indicate that the deterioration of the KTD releases occurs in the reach between the Hwaret Weir and the Abu Zeighan Weir and that the elimination of these sources of pollution will improve the quality of the irrigation supply

3 FLOW AND WATER QUALITY MEASUREMENTS

In the Phase A-Part 2 Report on "Data Evaluation," Harza/CC concluded that

1 Practically there is no loss/gain or water quality deterioration within the river reach between the KTD and the Thahab Weir Eliminating minor loss, if any, could not be accomplished economically

2 The river reach from downstream of the Thahab Weir to upstream of the Hwaret Weir does not have a water quality problem but minor losses can be expected

3 River reach from downstream of the Hwaret Weir to upstream of the Abu Zeighan Weir has a severe water quality deterioration and losses in the range of 10 to 15 percent could occur depending upon the magnitude of flow in the river

The above conclusions were based on the previous studies, opinions of the JVA personnel associated with the conveyance efficiency of the Zarqa River, and the preliminary geological and hydrogeologic assessments To develop a consensus on these conclusions, a discharge and water quality measurement program was designed by Harza/CC to be implemented after the geological and hydrogeologic investigations The results of these investigations are reported under Sections 5 and 6 of this report The discharge and water quality measurements made under the program are discussed below

3 1 Field Measurements

The initial program of making two sets of measurements could not be accomplished because of KTD release constraints The JVA had to meet irrigation demands and was required to set a constant release for the period from September 10 through September 15, 1995 A deviation from this release was not possible Therefore, one set of measurements was made from September 12 to September 14 A temporary staff gage was installed downstream from the KTD near an old weir The gage was maintained up to September 14 The river stage remained constant throughout the period of measurements Temporary gages were also used during the flow measurements

Necessary precautions were observed during the measurements to avoid all potential measuring errors A new current meter was used A sufficient number of sections was observed across the river to properly account for the spatial variation of velocity and depth At each section, 60 seconds were used for counting the current meter revolutions (normal range is 40 to 70 seconds)

The river bed mostly consists of gravel, cobbles and boulders and it was difficult to locate a uniform cross section for flow measurement The cross sections upstream from the Thahab and Abu Zeighan weirs were good and the flow measurements at these locations are rated excellent The cross sections at other locations were somewhat nonuniform The measurements at these locations are rated good At the Thahab Weir, all water was diverted to the desanding basins (three sections) The flow in one of the sections was released to the

river The river at this location is narrow and flow was quite turbulent Therefore, the flow measurement was made about 500 meters downstream from the weir

Generally in a river, stage fluctuations can cause bank storage release which can affect the difference between measurements made upstream and downstream of such a reach Because the KTD release was constant for at least 48 hours prior to the flow measurements, any potential error due to bank storage effect was eliminated

Table 3 1 shows the flow and water quality parameters measured during the measurement program

Table 3 1

Discharge and Water Quality Measurements

Date	Location	Disch (cms)	Diff (cms)	Diff (per)	EC mmhos/cm	pH	Temp (°C)
1995							
Sep 12	Downstream KTD	3 362			1 15	7 40	23
			+0 134	+4 0			
Sep 12	Upstream Thahab	3 496			1 30	7 75	25
Sep 12	Downstream Thahab	1 603			1 10	7 93	26
			+0 008	+0 5			
Sep 12	Upstream Hwaret	1 611			1 20	7 59	27
			+0 011	+0 7			
Sep 13	Downstream Hwaret	1 622			1 25	8 05	28
			+0 143	+8 8			
Sep 13	Downstream Women Spring	1 765			2 00	7 83	22
			+0 025	+1 4			
Sep 13	Upstream Abu Zeighan	1 790			3 10	6 80	23
Sep 14	Spring No 15				12 00	6 15	26
Sep 14	Spring No 21				13 50	-	27
Sep 14	River Upstream Spring 21				2 40	-	21
Sep 14	River Downstream Spring 21				2 95	-	21

3 2 Analysis

Table 3 1 shows an increase of about 134 litres between KTD downstream and Thahab upstream The accuracy of flow measurements at the two locations is judged to be plus or minus five and two percent, respectively The indicated increase is within the accuracy of the measurements However, as per geological and hydrogeological investigations (see Sections 5 and 6 of this report), this reach could be a fresh water gaining reach There in no water quality deterioration

From Thahab downstream to Hwaret upstream, there is a minor gain but within the accuracy of measurement Water quality is unaffected

A short reach, Hwaret upstream to Hwaret downstream, indicates a minor gain in flow though within the measuring accuracy However, this reach has a few saline springs The locations of the springs are shown on Exhibit 3 1

From Hwaret downstream to Abu Zeighan upstream, the data on Table 3 1 shows gains During the measurements, a few places were observed where minor irrigation returns were entering the river Also, most of the saline water from the springs enter in this reach As per hydrogeologic investigations, this reach could be a gaining reach at times However, the gains are of highly saline water This is clearly indicated by the water quality measurements on and near Spring No 21 (Table 3 1, see Exhibit 3 1 for location)

3 3 Conclusions

From the above analysis, the following conclusions are made which are consistent with the conclusions made in Harza/CC report, Phase A- Part 2

1 The river reach between KTD and the Thahab Weir is most likely a minor fresh water gaining reach

2 The river reach between the Thahab Weir and the Hwaret Weir could be a gaining/losing reach at times are there is no deterioration in the water quality

3 The river reach from the Hwaret Weir to the Abu Zeighan Weir has severe water quality deterioration due to saline springs

Spring contributions to the river cannot be estimated by flow measurements using conventional current meter procedures The best way to measure these contributions would be to completely divert the KTD release at Thahab Weir, let the river dry up for two to three days and then measure spring flows by a portable flume or a pygmy type current meter The JVA probably has used this procedure, however, better equipment is required Most desirable would be a portable flume

4 HYDROLOGY OF PROJECT AREA

4 1 Hydrologic Setting

4 1 1 Zarqa River Basin

The Zarqa River is a major tributary of the Jordan River and originates in the central part of Jordan at an elevation of about 1,600 meters (above mean sea level) near Salkhad and joins the Jordan River at an elevation of -300 meters (below mean sea level) The river drains the eastern escarpment which begins at the edge of the Jordan River Valley (the Valley) and merges gradually with the elevated plains and deserts of the Arabian and Syrian plateaus The elevation of the escarpment varies around 700 meters while the valley ranges from -200 to -400 meters

The area of the Zarqa River basin of interest for this study is the basin below KTD located about 40 kilometers upstream from the confluence of the Zarqa River with the Jordan River and about 23 km upstream from the KAC The drainage areas of the river at the KTD, KAC and its confluence with the Jordan River are about 3300, 3440, and 3540 square kilometers (sq km), respectively

KTD was constructed in the 1960's and raised in the 1980's The dam is about 110 meters high and impounds a reservoir of about 86 million cubic meters (MCM) at the normal pool level (El 179 m)

Over the 23-km river reach between KTD and KAC, the Zarqa River flows through a winding, steep-sided valley In this reach, there are three weirs, Thahab, Hwaret and Abu Zeighan

The Thahab Weir is located approximately 11 5 km downstream from KTD This is a concrete diversion weir used for diverting water from the weir into Carrier Pipes I and II for irrigation The capacities of these pipes are about 1,000 and 1,770 litres per second, respectively

The Hwaret Weir is located about 5 km downstream from the Thahab Weir The weir served a canal with a capacity of 800 l/s for irrigation in the Valley which also could be supplied from a turnout in Carrier Pipe I The weir and canal are in poor condition and have been abandoned by the JVA

The Abu Zeighan Weir is located at the eastern edge of the Valley and diverts Zarqa River water into the KAC through the Abu Zeighan Canal The capacity of this canal is about 7,500 l/s

4 1 2 General Climate

The general climate of the Zarqa River basin is a transition between Mediterranean and arid climate Altitude and latitude are effective factors which control prevailing weather Average daily maximum and minimum temperatures are 45°C and 5°C, respectively There is a rapid decrease in relative humidity and precipitation moving east of the Jordanian Highlands

In winter, northeast winds bring continental polar air from the interior of Asia and make the Valley cool for its latitude The mean temperature of the plateau of Amman during January is about 8°C compared to about 14°C in the Valley Ground frosts are frequent on the plateau during winter nights

During spring Kamsinic frontal depressions traveling from the north African coast occasionally cause abnormally increased surface winds and temperatures Associated unstable air at higher altitude often develops into thunderstorms with occasional hail

A seasonal low pressure trough in summer, over the Arabian Gulf, Iraq, Syria and Cyprus causes westerly winds to enter Jordan from the Mediterranean Sea Fall is associated with a change in the pressure system as the seasonal trough extending over Cyprus to Iraq begins to migrate southeast Mediterranean depressions start developing with continental air from the Asiatic Steppes and warmer moist air from the Mediterranean Sea, causing a decrease in temperature and the onset of seasonal frontal rains

Annual precipitation is highest over the elevated edge of the Valley and decreases gradually toward the eastern deserts Mean annual precipitation over the entire Zarqa River basin is about 235 mm Over the basin, downstream from KTD, the annual precipitation decreases significantly

4 1 3 Precipitation and Temperature

Mean monthly precipitation and temperatures for Amman, located in the Highlands, are given in **Table 4 1**

Table 4 1
MEAN MONTHLY PRECIPITATION AND TEMPERATURES IN AMMAN

Month	Precipitation[1] (mm)	Temperature[2] (°C)
January	66 4	8 1
February	57 0	9 0
March	53 5	11 8
April	11 0	16 0
May	5 1	20 7
June	0	23 7
July	0	25 1
August	0	25 6
September	0	23 5
October	5 9	20 6
November	29 7	15 3
December	51 9	10 0
Total	280 5	
Mean		17 4

[1] 34-year average, water years (October through September) 1937 through 1970 from Jordan Natural Resources Authority Rainfall in Jordan

[2] 45-year average, from unpublished records, Jordan Natural Resources Authority

4 2 Water Yield

4 2 1 Available Streamflow Data

The inflow to the KTR includes three components, 1) natural streamflow, 2) diversion from the Qa'Khanna Basin and 3) municipal and industrial return waste water from the Amman/ Zarqa area Monthly flow data for these components were collected by Harza from various agencies in Jordan including the JVA and the Water Department during earlier hydrological investigations The pertinent reports are listed below

1 Harza Overseas Engineering Company," The Raising of King Talal Dam, Feasibility Study," prepared for the Jordan Valley Authority, April 1982 (Harza 1982)

2 Harza Engineering Company International," The Raising of King Talal Dam, Final Design Report," prepared for the Jordan Valley Authority, August 1983 (Harza, 1983)

3 Harza Engineering Company in association with Arabtech Consulting Engineers," Storage Facilities in Jordan Valley, Final Report on Technical, Economic and Financial Feasibility and Preliminary Design," Three Volumes, prepared for the IVA, April 1989 (Harza, 1989)

The inflow data from October 1953 through September 1985 were obtained from the previous reports Additional data up to September 1994 were collected as part of this study

4 2 2 Long-term Streamflow Data

As indicated above, the streamflow data were collected from various agencies in Jordan Procedures were used to generate a consistent monthly long-term inflow series for KTD The estimated long-term data are given in Table 4 2

Intervening flows between the KTD and the Thahab Weir (drainage area = 96 km) were required for the reservoir operation study These were generated in two steps First, the intervening flow between the KTD and the Abu Zeighan Weir (drainage area = 140 km) were obtained from Harza's previous reports for the period from October 1953 to September 1985 and updated for the period from October 1985 to September 1994 as a part of this study (Table 4 3) In the second step, the flows estimated in the first step were multiplied by a factor of 0 69 (drainage area ratio 96/140) to represent flows from the area between the KTD and the Thahab Weir (**Table 4 4**)

4 2 3 Net Reservoir Evaporation

Computations of net reservoir evaporation in the Zarqa River basin are discussed in Harza's reports (Harza, April 1982 and Harza, April 1989) The net reservoir evaporation was computed using the following relationship

TABLE 4 2

HISTORICAL MONTHLY STREAMFLOW (CMS)
ZARQA RIVER AT KTD
PERIOD WY 1954-1994

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1954	1 90	2 16	1 94	2 43	4 88	2 69	1 77	1 94	1 89	1 57	1 57	1 77	2 21
1955	1 83	1 89	2 61	2 17	1 57	1 49	1 31	1 23	0 96	0 78	0 75	0 96	1 46
1956	1 27	3 67	2 91	2 20	1 52	2 13	2 04	1 57	1 35	1 27	1 19	1 12	1 85
1957	1 23	1 16	2 43	2 28	8 89	6 72	1 97	2 09	1 77	1 46	1 38	1 35	2 73
1958	1 49	1 85	2 17	2 69	8 27	1 61	1 62	1 49	1 27	1 08	1 08	1 23	2 15
1959	1 27	1 23	1 27	4 93	3 22	3 25	1 12	1 12	0 96	1 01	0 93	1 04	1 78
1960	1 08	1 12	1 42	1 72	1 28	1 27	1 04	0 56	0 50	0 41	0 78	0 81	1 00
1961	0 78	1 12	1 49	3 62	5 00	1 57	1 81	1 38	0 39	0 67	0 71	0 69	1 60
1962	1 05	1 81	6 35	4 41	6 16	1 90	0 93	0 90	0 96	1 08	1 31	1 43	2 36
1963	1 27	1 31	1 75	1 72	8 23	1 64	1 43	4 52	1 12	1 05	1 08	1 08	2 18
1964	2 10	2 52	7 55	3 83	6 69	4 34	1 86	1 11	1 09	0 74	0 73	0 81	2 78
1965	1 85	1 22	6 05	9 41	6 27	3 30	5 15	2 83	2 36	1 56	1 62	2 19	3 65
1966	1 16	0 54	0 71	0 72	0 75	9 38	1 40	1 06	1 00	0 83	0 80	0 87	1 60
1967	1 01	1 43	2 69	5 49	3 89	3 10	1 81	1 12	1 04	0 93	0 93	1 08	2 04
1968	1 01	0 93	3 92	7 54	4 83	3 17	2 16	1 46	1 23	0 93	0 93	0 81	2 41
1969	1 16	2 32	1 91	3 10	3 30	13 3	3 14	2 23	1 58	1 25	0 99	1 28	2 96
1970	1 50	1 60	1 61	2 82	2 05	3 70	1 79	1 52	1 44	1 23	1 94	2 12	1 94
1971	1 25	1 37	1 64	2 57	1 46	1 73	11 8	0 55	0 37	0 32	0 28	0 42	1 98
1972	0 82	1 08	3 60	1 90	2 59	2 25	2 15	0 51	0 31	0 37	0 53	0 53	1 39
1973	0 52	1 20	0 75	2 00	1 17	1 56	0 63	0 64	0 69	0 62	0 54	0 46	0 90
1974	0 48	1 50	1 09	21 3	12 1	5 78	3 69	1 99	1 23	0 95	0 77	0 78	4 30
1975	0 58	1 22	1 69	1 46	4 73	2 23	3 44	0 53	0 35	0 30	0 32	0 34	1 43
1976	0 34	0 86	1 28	1 61	1 80	5 92	0 75	0 68	0 55	0 52	0 47	0 42	1 27
1977	0 53	0 74	0 87	1 55	1 55	1 29	0 98	0 47	0 27	0 22	0 30	0 31	0 76
1978	1 36	0 66	2 03	2 00	1 05	1 90	0 73	0 37	0 10	0 12	0 16	0 18	0 89
1979	0 28	0 41	1 16	1 01	0 66	0 90	0 49	0 11	0 07	0 10	0 38	0 33	0 49
1980	1 97	18 0	9 68	5 11	4 59	13 1	3 43	1 90	1 19	0 82	0 71	0 77	5 10
1981	0 80	1 04	11 5	2 77	4 08	3 23	1 86	1 15	0 81	0 74	0 93	0 93	2 49
1982	0 90	1 15	1 09	1 55	4 42	2 12	5 74	3 97	0 94	0 92	1 09	0 74	2 05
1983	1 26	1 85	1 46	4 04	7 18	11 2	3 36	2 72	1 59	1 54	0 92	1 06	3 18
1984	1 24	3 28	1 57	2 83	2 41	3 75	2 03	1 59	1 27	1 09	1 03	0 93	1 92
1985	1 54	3 51	3 34	1 19	10 4	3 52	1 92	1 10	0 50	0 41	0 40	0 68	2 37
1986	0 81	0 98	1 32	1 83	2 99	1 36	1 74	1 02	0 84	0 89	0 79	0 96	1 29
1987	1 10	8 71	1 84	2 79	1 71	1 40	0 71	0 76	0 76	0 77	0 71	0 77	1 84
1988	6 96	1 32	2 21	4 36	15 5	7 89	2 04	1 65	1 25	1 12	1 23	1 55	3 92
1989	1 44	1 51	6 47	2 59	2 11	2 53	1 62	1 42	1 28	1 17	1 26	1 36	2 06
1990	1 31	2 17	2 87	3 07	3 35	3 06	2 23	1 52	1 28	1 40	1 39	1 28	2 08
1991	1 37	1 52	1 65	3 24	3 05	3 89	1 68	1 58	1 36	1 16	1 18	1 20	1 91
1992	1 30	1 65	13 7	9 85	30 3	11 7	6 28	4 12	3 60	2 77	2 64	2 56	7 54
1993	2 62	3 47	5 93	5 90	5 40	4 32	3 68	3 55	3 63	2 10	2 16	2 12	3 74
1994	2 23	3 26	2 93	4 13	3 88	3 44	2 25	1 90	1 73	1 39	1 59	1 46	2 52
AVG	1 37	2 20	3 18	3 70	5 00	4 01	2 38	1 56	1 14	0 97	0 99	1 04	2 30

TABLE 4 3

HISTORICAL MONTHLY INTERVENING FLOW (CMS)
KTD TO ABU ZEIGHAN WEIR
PERIOD WY 1954-1994

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1954	0 11	0 12	0 11	0 11	0 25	0 15	0 08	0 07	0 08	0 07	0 07	0 08	0 11
1955	0 11	0 12	0 15	0 11	0 08	0 07	0 08	0 07	0 04	0 04	0 04	0 04	0 08
1956	0 07	0 19	0 15	0 11	0 08	0 11	0 12	0 07	0 08	0 07	0 07	0 08	0 10
1957	0 07	0 08	0 11	0 11	0 45	0 37	0 12	0 11	0 08	0 07	0 07	0 08	0 14
1958	0 07	0 08	0 11	0 15	0 45	0 07	0 08	0 07	0 08	0 07	0 07	0 08	0 12
1959	0 07	0 08	0 07	0 26	0 17	0 19	0 08	0 07	0 04	0 04	0 04	0 04	0 10
1960	0 07	0 08	0 07	0 07	0 08	0 07	0 04	0 04	0 04	0 04	0 04	0 04	0 06
1961	0 04	0 08	0 07	0 19	0 25	0 07	0 08	0 07	0 04	0 04	0 04	0 04	0 08
1962	0 04	0 08	0 34	0 22	0 33	0 11	0 04	0 04	0 04	0 07	0 07	0 08	0 12
1963	0 07	0 08	0 07	0 07	0 45	0 07	0 08	0 22	0 08	0 04	0 04	0 04	0 11
1964	0 12	0 14	0 43	0 22	0 38	0 25	0 10	0 06	0 06	0 04	0 04	0 05	0 16
1965	0 10	0 07	0 34	0 53	0 36	0 19	0 29	0 16	0 13	0 09	0 09	0 12	0 21
1966	0 07	0 03	0 04	0 04	0 04	0 53	0 08	0 06	0 06	0 05	0 04	0 05	0 09
1967	0 04	0 08	0 15	0 30	0 21	0 15	0 08	0 07	0 04	0 04	0 04	0 04	0 10
1968	0 04	0 04	0 22	0 41	0 24	0 15	0 12	0 07	0 08	0 04	0 04	0 04	0 12
1969	0 07	0 13	0 11	0 18	0 19	0 76	0 18	0 13	0 09	0 07	0 06	0 07	0 17
1970	0 09	0 09	0 09	0 16	0 12	0 21	0 10	0 09	0 08	0 07	0 11	0 12	0 11
1971	0 07	0 08	0 09	0 15	0 08	0 10	0 67	0 03	0 02	0 02	0 01	0 02	0 11
1972	0 05	0 06	0 21	0 11	0 15	0 13	0 12	0 03	0 02	0 02	0 03	0 03	0 08
1973	0 03	0 07	0 04	0 12	0 07	0 09	0 03	0 04	0 04	0 03	0 03	0 03	0 05
1974	0 03	0 08	0 06	1 21	0 69	0 33	0 21	0 11	0 07	0 05	0 04	0 05	0 24
1975	0 03	0 07	0 10	0 08	0 27	0 13	0 20	0 03	0 02	0 02	0 02	0 02	0 08
1976	0 02	0 05	0 07	0 09	0 10	0 34	0 04	0 04	0 03	0 03	0 03	0 02	0 07
1977	0 03	0 04	0 05	0 09	0 09	0 09	0 05	0 03	0 01	0 01	0 01	0 02	0 04
1978	0 08	0 03	0 15	0 15	0 07	0 18	0 05	0 02	0 00	0 01	0 01	0 01	0 06
1979	0 02	0 03	0 10	0 10	0 04	0 05	0 02	0 01	0 01	0 01	0 01	0 01	0 03
1980	0 39	1 13	1 03	0 40	0 24	0 77	0 10	0 07	0 07	0 06	0 06	0 05	0 36
1981	0 04	0 05	0 79	0 14	0 23	0 16	0 10	0 06	0 05	0 05	0 06	0 05	0 15
1982	0 06	0 07	0 07	0 08	0 24	0 15	0 51	0 33	0 05	0 04	0 04	0 04	0 14
1983	0 06	0 09	0 09	0 29	0 48	0 64	0 16	0 14	0 14	0 11	0 13	0 13	0 21
1984	0 09	0 10	0 09	0 14	0 11	0 18	0 10	0 09	0 07	0 05	0 06	0 07	0 10
1985	0 11	0 25	0 24	0 09	0 74	0 25	0 14	0 08	0 03	0 03	0 03	0 05	0 17
1986	0 05	0 07	0 11	0 12	0 15	0 14	0 08	0 05	0 03	0 03	0 03	0 03	0 07
1987	0 06	0 10	0 16	0 18	0 21	0 19	0 12	0 07	0 05	0 04	0 04	0 05	0 11
1988	0 14	0 22	0 34	0 38	0 44	0 41	0 25	0 15	0 10	0 09	0 09	0 10	0 22
1989	0 07	0 12	0 18	0 20	0 24	0 22	0 13	0 08	0 05	0 05	0 05	0 05	0 12
1990	0 07	0 12	0 18	0 20	0 24	0 22	0 13	0 08	0 05	0 05	0 05	0 05	0 12
1991	0 07	0 11	0 17	0 18	0 22	0 20	0 12	0 07	0 05	0 04	0 04	0 05	0 11
1992	0 26	0 42	0 64	0 72	0 83	0 79	0 47	0 29	0 19	0 17	0 17	0 18	0 43
1993	0 13	0 21	0 32	0 36	0 43	0 40	0 23	0 15	0 10	0 08	0 09	0 09	0 22
1994	0 09	0 14	0 22	0 24	0 29	0 27	0 16	0 10	0 07	0 06	0 06	0 06	0 15
AVG	0 08	0 13	0 20	0 22	0 26	0 24	0 14	0 09	0 06	0 05	0 05	0 06	0 13

TABLE 4 4

HISTORICAL MONTHLY INTERVENING FLOW (CMS)
KTD TO THAHAB WEIR
PERIOD WY 1954-1994

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1954	0 08	0 08	0 08	0 08	0 17	0 10	0 05	0 05	0 05	0 05	0 05	0 05	0 08
1955	0 08	0 08	0 10	0 08	0 06	0 05	0 05	0 05	0 03	0 03	0 03	0 03	0 06
1956	0 05	0 14	0 10	0 08	0 06	0 08	0 08	0 05	0 05	0 05	0 05	0 05	0 07
1957	0 05	0 05	0 08	0 08	0 32	0 26	0 08	0 08	0 05	0 05	0 05	0 05	0 10
1958	0 05	0 05	0 08	0 10	0 32	0 05	0 05	0 05	0 05	0 05	0 05	0 05	0 08
1959	0 05	0 05	0 05	0 18	0 12	0 13	0 05	0 05	0 03	0 03	0 03	0 03	0 07
1960	0 05	0 05	0 05	0 05	0 06	0 05	0 03	0 03	0 03	0 03	0 03	0 03	0 04
1961	0 03	0 05	0 05	0 13	0 17	0 05	0 05	0 05	0 03	0 03	0 03	0 03	0 06
1962	0 03	0 05	0 24	0 16	0 23	0 08	0 03	0 03	0 03	0 05	0 05	0 05	0 09
1963	0 05	0 05	0 05	0 05	0 32	0 05	0 05	0 16	0 05	0 03	0 03	0 03	0 08
1964	0 08	0 10	0 30	0 15	0 27	0 17	0 07	0 04	0 04	0 03	0 03	0 03	0 11
1965	0 07	0 05	0 24	0 37	0 25	0 13	0 21	0 11	0 09	0 06	0 07	0 09	0 14
1966	0 05	0 02	0 03	0 03	0 03	0 37	0 06	0 04	0 04	0 03	0 03	0 04	0 06
1967	0 03	0 05	0 10	0 21	0 14	0 10	0 05	0 05	0 03	0 03	0 03	0 03	0 07
1968	0 03	0 03	0 16	0 29	0 17	0 10	0 08	0 05	0 05	0 03	0 03	0 03	0 09
1969	0 05	0 09	0 08	0 12	0 13	0 53	0 12	0 09	0 06	0 05	0 04	0 05	0 12
1970	0 06	0 06	0 06	0 11	0 08	0 15	0 07	0 06	0 06	0 05	0 08	0 08	0 08
1971	0 05	0 05	0 07	0 10	0 06	0 07	0 47	0 02	0 02	0 01	0 01	0 02	0 08
1972	0 03	0 04	0 14	0 08	0 10	0 09	0 09	0 02	0 01	0 02	0 02	0 02	0 06
1973	0 02	0 05	0 03	0 08	0 05	0 06	0 02	0 03	0 03	0 02	0 02	0 02	0 04
1974	0 02	0 06	0 04	0 85	0 48	0 23	0 15	0 08	0 05	0 04	0 03	0 03	0 17
1975	0 02	0 05	0 07	0 06	0 19	0 09	0 14	0 02	0 01	0 01	0 01	0 01	0 06
1976	0 01	0 04	0 05	0 06	0 07	0 24	0 03	0 03	0 02	0 02	0 02	0 02	0 05
1977	0 02	0 03	0 03	0 06	0 06	0 06	0 04	0 02	0 01	0 01	0 01	0 01	0 03
1978	0 05	0 02	0 10	0 11	0 05	0 13	0 03	0 02	0 00	0 01	0 01	0 01	0 04
1979	0 01	0 02	0 07	0 07	0 03	0 03	0 01	0 01	0 01	0 01	0 01	0 01	0 02
1980	0 27	0 79	0 72	0 28	0 17	0 54	0 07	0 05	0 05	0 04	0 04	0 04	0 25
1981	0 03	0 04	0 55	0 10	0 16	0 11	0 07	0 04	0 03	0 04	0 04	0 04	0 10
1982	0 04	0 05	0 05	0 06	0 17	0 10	0 35	0 23	0 04	0 03	0 03	0 03	0 10
1983	0 04	0 06	0 06	0 20	0 34	0 45	0 11	0 10	0 10	0 08	0 09	0 09	0 14
1984	0 06	0 07	0 07	0 10	0 08	0 12	0 07	0 07	0 05	0 04	0 04	0 05	0 07
1985	0 08	0 18	0 17	0 06	0 52	0 18	0 10	0 05	0 02	0 02	0 02	0 04	0 12
1986	0 03	0 05	0 08	0 09	0 10	0 10	0 06	0 04	0 02	0 02	0 02	0 02	0 05
1987	0 05	0 07	0 11	0 12	0 15	0 14	0 08	0 05	0 03	0 03	0 03	0 03	0 07
1988	0 10	0 15	0 24	0 26	0 31	0 29	0 17	0 11	0 07	0 06	0 06	0 07	0 16
1989	0 05	0 08	0 13	0 14	0 17	0 15	0 09	0 06	0 04	0 03	0 03	0 04	0 08
1990	0 05	0 08	0 13	0 14	0 17	0 15	0 09	0 06	0 04	0 03	0 03	0 04	0 08
1991	0 05	0 07	0 12	0 13	0 15	0 14	0 08	0 05	0 03	0 03	0 03	0 03	0 08
1992	0 18	0 29	0 45	0 50	0 58	0 55	0 33	0 20	0 13	0 12	0 12	0 13	0 30
1993	0 09	0 15	0 23	0 25	0 30	0 28	0 16	0 10	0 07	0 06	0 06	0 07	0 15
1994	0 06	0 10	0 15	0 17	0 20	0 19	0 11	0 07	0 05	0 04	0 04	0 04	0 10
AVG	0 06	0 09	0 14	0 15	0 18	0 17	0 10	0 06	0 04	0 04	0 04	0 04	0 09

$$NRE = F \times E - (P + Q)$$

in which

NRE = net reservoir evaporation, mm
F = pan coefficient
E = class A pan evaporation, mm
P = precipitation on the lake surface, mm
Q = runoff from the reservoir area before the construction of lake, mm

Table 4 5 shows the net reservoir evaporation estimated for the KTR and a potential Zarqa reregulation dam

Table 4 5

NET RESERVOIR EVAPORATION (MM)

Month	Reservoirs	
	KTR	Zarqa Reregulating
Oct	149	153
Nov	109	73
Dec	-5	12
Jan	-23	-1
Feb	10	29
Mar	48	66
Apr	156	139
May	235	210
Jun	258	258
Jul	281	274
Aug	261	253
Sep	197	203
Total	1676	1669

4 3 Watershed Characteristics

The drainage areas of interest at the KTD and the downstream weirs are listed in **Table 4 6**

Table 4 6

DRAINAGE AREAS

Basin	Drainage Area (sq km)
Upstream from KTD	3300
Between KTD and Thahab Weir	96
Between Thahab Weir and Hwaret Weir	35
Between Hwaret Weir and Abu Zeighan Weir	9
Total	3440

The watershed characteristics of the drainage basin upstream from the KTD are not of interest for this report The characteristics of the basin between KTD and the Abu Zeighan Weir are discussed below

4 3 1 Between KTD and Thahab Weir

This reach is about 11 5 km long, with a drainage area of about 96 sq km The river Valley is narrow with steep, high hills on both banks A number of small tributaries draining the steep hilly slopes and relatively flat slopes near the top of the hills join the Zarqa River Small villages or a few scattered homes are located on the flat slopes Significant tributaries are Wadi en Naim, Wadi el Azab, Wadi el Huna, Wadi Abu er Ruweis and Wadi el Bam The length and overall slopes of these wadis are given in **Table 4 7**

Table 4 7

LENGTHS AND OVERALL SLOPES OF WADIS JOINING ZARQA RIVER D/S KTD

Wadı	Length (km)	SLOPE (Percent)
En Naım	6 2	13 9
El Azab	10 0	7 2
El Nuna	5 3	15 8
Er Ruweıs	5 1	16 5
El Bam	5 0	14 4
Sadd En Nımı	9 2	8 9
Hajjaj	5 2	13 8
El Tahıma	4 7	18 3
Raud El Mokhamal	2 1	23 8
Hanıfa	3 1	17 4

The steep-sıded valley of the Zarqa Rıver ın thıs reach has many ındıcatıons of ınstabılıty and there ıs a potentıal for land-slıdıng The channel has been downcut through sandstone and lımestone formatıons The channel bed consısts of large cobbles, gravel, shıngle and coarse sand wıth an underlyıng strata of fine sand and gravel Soıls are domınantly clayey sılt and fine sand wıth relatıvely low permeabılıty Agrıculture ıs practıced on both banks There ıs a well developed farm on the left bank near the mınıng area Two ırrıgatıon water lıft pumps were seen durıng the field vısıt on April 18, 1995

4 3 2 Between Thahab Weır and Hwaret Weıı

Thıs reach ıs about 4 8 km long, wıth a draınage area of about 35 sq km The rıver valley ıs somewhat wıder, compared to the upper reach The rıver bed consısts of cobbles, gravel and sand The underlyıng strata ıs fine to coarse alluvıum

Three maın wadıs enter the rıver ın thıs reach, ın addıtıon to small water courses These ınclude Wadı Sadd en Nım, Wadı Hajjaj, and Wadı el Tahıma The lengths and overall slopes of these wadıs are gıven ın Table 4 7

Agrıculture ıs practıced on both banks where feasıble Soıls are domınantly clayey sılt and fine sand wıth relatıvely low peımeabılıty

4 3 3 Between Hwaret Weıı and Abu Zeıghan Weır

The reach ıs about 4 7 km long, wıth a draınage area of about 9 sq km Downstream from Hwaret Weır, the valley wıdens and permıts cultıvatıon especıally on the rıght bank The ırrıgated area ıs served by the pıpe lıne orıgınatıng at the Thahab Weır Sıgnıfıcant ırrıgatıon return flow oı overflow from the water courses can enter the Zarqa rıver ın thıs reach

A few small wadis enter the river The two named wadis are Raud El Mokhamah and Hanifa The lengths and overall slopes of these two wadis are given in Table 4 7 A number of springs exist in this reach

4 4 Flood Analysis

4 4 1 Methodology

Flood frequency data were estimated for the intervening areas between KTD and the Thahab Weir, between KTD and the Hwaret Weir, and between KTD and the Abu Zeighan Weir, based on the flood frequency data for the Zarqa River at New Jerash Bridge The flood frequency curve at the bridge site was developed using the annual maximum observed flood peaks The flood peak data and procedure to develop the frequency curve are discussed in Harza 1983 and 1989 reports

4 4 2 Flood Frequency Data

A number of procedures are available to transpose the flood data from a gaged site to an ungaged site In previous hydrological investigations in Jordan, Harza's hydrologists determined that better flood peak data at an ungaged site were obtained when the transposition of flood peaks from a gaged site was made using the same value of Creager's C for a given return period Creager's formula is given below **Table 4 8** shows the flood data at various locations

$$Q = 1\ 303\ C\ (386A)^{0\ 936\ A^{0\ 048}}$$

in which

Q = peak discharge, cms
A = drainage area, sq km

Table 4 8

FLOOD PEAKS (CMS)

Zarqa New Jerash	Return Period (years)	C Value	Thahab Weir	Hwaret Weir	Abu Zeighan Weir
200	5	2	39 4	47 6	49 6
330	10	3	59 1	71 5	74 4
572	25	5	98 5	119	124
820	50	7	138	167	174
1140	100	10	197	238	248

Transposition of flood peaks from New Jerash Bridge to the weir sites was accomplished using "C" values given in **Table 4 8** The flood peaks at the weir sites are also given in the table

The flood peaks given in **Table 4 8** for the weir sites are for the intervening drainage areas only The outflow from KTR is not added because of the assumption that the floods up to 100-year return period will be regulated by KTR and the releases would be only for downstream irrigation requirements

4 5 Sediment Transport

The JVA has conducted periodic reservoir sedimentation surveys of KTR since 1980 For the period from 1980 to 1994, ten surveys were conducted The total sediment deposition is estimated to be about 11 million cubic meters (MCM) This is equivalent to about 1 1 MCM per year

The trap efficiency of the reservoir was estimated to be about 99 percent in a previous report (Harza, April 1982) Using this value, the unit sediment yield for the basin above KTD is about 337 $m^3/km^2/yr$ (1 1 X 10^6 / 0 99 / 3300) or 0 34 mm/yr

The physical conditions and rainfall pattern of the basin above KTD and below KTD are judged to be not significantly different Therefore, the unit yield was transposed to intervening areas using a drainage area ratio raised to the power -0 125 (ASCE, Sedimentation Engineering) The estimated sediment yields are given in **Table 4 9**

Table 4 9

SEDIMENT YIELD

Location	Drainage Area (sq km)	Unit Yield (m^3 or m3/sq km/yr)	Annual Yield (m^3 or m3)
Thahab Weir	96	524	50,300
Hwaret Weir	131	504	66,000
Abu Zeighan Weir	140	500	70,000

5 GEOLOGY OF PROJECT AREA

5 1 Regional Geology

The study area investigated extends from the KTD downstream to the Abu Zeighan Weir, along the river course, and up to the highlands on both sides of the Zarqa River A geological map of the Zarqa River is given as Exhibit 6 1

The study area consists of four distinct geomorphic - topographic zones extending from the north to the wadi course, from the south to wadi course and in the east-west direction from KTD to the Abu Zeighan Weir in the Ghor area The formation of the Zarqa River is within these geomorphic - topographic zones and is associated with the development of the Dead Sea - Wadi Araba Rift Zone

The geomorphic - topographic zones, in accordance with Ministry of Agriculture and Natural Resources Authority (NRA) classifications are as follows

"Highlands" where the elevation exceeds 800 m above mean sea level,
"Escarpment" with elevation ranges between 800 m and sea level,
"Foothills" with elevations in the range of sea level to -200 m, and
"Rift Zone", which is between -200 m and the Dead Sea level

The highlands are actually away from the Zarqa River course near the Khashaba village of the Jerash District in the northern side of the river The second zone, known as the escarpment, covers the area between KTD and about 5 km downstream from the dam

The area located between 5 km downstream from KTD and the Hwaret Weir falls under the foothill classification while the area below the Hwaret Weir and up to the Abu Zeighan Weir belongs to the Rift Valley Zone

These geomorphic - topographic zones are characterized by the presence of various geological formations These formations are discussed below

The highlands are characterized by upper cretaceous sediments of the lower part of the Ajlun Group Because of this formation occasional high slope cuts dominate in the areas of the highlands From the Subeihi area to the Zarqa River and from the Khashaba village to the Zarqa River, lower cretaceous rocks (Kurnub Sandstones) are exposed with the occasional appearance of Jurassic rocks

Because of the lithological nature of the Kurnub formation, which mainly consists of friable sandstone with some intercalations of calareous sandstone, the slopes of the Zarqa River flanks are steep varying between 15 to 8 percent Because of the lithological nature of Jurassic rocks, which are of limestone and dolomitic limestone, wadi flank slopes are relatively less steep in the range of 8 to 5 percent In the foothill area, the lithological nature of the exposed Triassic rocks, which consist of limestone, shales marls, and marly limestones, has resulted in gentle slopes in the range of 3 to 6 percent Downstream from the foothills

towards the Ghor area, where the Rift Valley Zone predominates and quaternary rocks of the Lisan formation, alluvium, colluvium and soil(s) are present, the Zarqa River channel slope is relatively flat The rocks exposed in this zone are Kurnub, Triassic, Jurassic and Quaternary Due to the different types of rocks exposed in this zone, the slopes of the adjacent flanks are variable and range between 3 and 15 percent

5 2 Stratigraphy

The rock units exposed in the area between KTD and the Abu Zeighan Weir range in age from Triassic to recent The spatial distribution of these rock units is in the order of their existence and is discussed below

Kurnub sandstone of early Cretaceous age is exposed at KTD and extends downstream until Jurassic rocks appear These rocks are older in age and extend downstream till rocks of the Triassic age (the oldest rocks) become exposed at the surface of the wadi course and in the adjacent area as a core of a geological window Further downstream from the Triassic rocks, the Jurassic reappears again Lastly Quaternary deposits (lisan, alluvial, and colluvial deposits) are unconformably overlying the Jurassic rocks

Detailed descriptions of the different exposed rocks are discussed as follows

Triassic - Jurassic Rocks Zarqa Group
The Triassic - Jurassic rocks exposed in the area and encountered in deep wells drilled in the Jordan Valley and other parts of Jordan are known as the Zarqa Group, which is further subdivided into two formations the Main Formation (Z1) of Triassic age and Azab Formation (Z2)

Main Formation (Z1)
The rocks of this formation crop out in a region of about 3 5 km, the starting exposure appears at a distance of 5 km downstream of the KTD along the Zarqa River This formation consist of shales, clays, marly limestone, marls, calcareous sandstones, limestones and massive gypsum beds, where the gypsum bands are mined for use as cement The thickness of this formation reaches about 100 m, as exposed in Wadi Huna

Azab Formation (Z2)
This formation consists of limestone, hard, massive, yellowish-gray in color, dolomite, sandstone and shale This formation is exposed at two regions along the course of the Zarqa River The first exposure appears at KTD along a stretch of 5 km where it overlies the Main Formation The second exposure appears once again as an overlying material of the Main Formation 8 5 km downstream of KTD

Early Cretaceous Rocks Kurnub Group
The Early Cretaceous rocks, which are known locally as the Kurnub Group (K), over lies conformably the Azab Formation of the Zarqa Group The Kurnub Group is not exposed along the river course between KTD and the Abu Zeighan Weir but it is exposed on both flanks of the river course It consists of arenaceous deposits at its base, generally composed

of white sandstone with thin beds of dolomite and shales, while its upper part consists of varicolored sandstones with intercalations of shale, limestone, dolomite, and marl

Quaternary Deposits

The Quaternary deposits consist of Lisan Formation and recent superficial deposits The Lisan Formation consists of marl, clay, gypsum and occasionally gravels of brackish - lacustrine deposits It is exposed on both flanks of the Zarqa River downstream of the Abu Zeighan bridge, where, as its exposure on the left flank is directly near the river, the right flank exposure is more than 100 m away from the river course Recent superficial deposits occasionally cover the Lisan deposits Generally, these deposits consist of alluvial fluorite, colluvium, fan deposits, talus deposits and soils These deposits consist of unsorted coarse to fine clastics The Alluvial deposits along the Zarqa River course have variable thickness ranging from few centimeters to more than 40 m, as indicated in the recently drilled well downstream of Hwaret weir (Abu Zeighan well No 1)

5 3 Geology of Old Channel

The rocks above which an irrigation channel was previously constructed (starting at about 5 km from the Thahab Weir) belong to the Azab Formation of Jurassic Age The first stretch of the channel is completely destroyed due to construction of an emergency road in 1992 The exposed rocks consist of alternating layers of marl, shale, limestone and dolomitic limestone The other parts of the channel are constructed on occasional Jurassic rocks and mostly above recent deposits

5 4 Gaining or Losing Sub-Reaches

During geological field investigations in the area of interest, the river course was divided into two subreaches The first subreach was considered upstream from the Thahab Weir and the second subreach was considered downstream to the Abu Zeighan Weir

From our preliminary investigations, the first stretch is believed to gain some fresh water from seepages and springs, the water originates from infiltrated rainfall Discharges of the springs and seepages are relatively low and disappear totally in the summer season Generally, this stretch may be considered to be a stretch of no losses and very small gaining of water The second stretch downstream from the Thahab Weir has both fresh water gaining and saline water gaining zones The fresh water gaining zones are very limited while the zones contributing saline water appear on both banks of the river

5 5 Additional Study

The engineering geology of the entire reach for a potential alternative would be identified in the light of the proposed structure location

6 GROUND WATER REGIME

6 1 Regional Ground Water

The aquifer systems in North-Central Jordan are classified into two main systems, the Lower Aquifer System and the Upper Aquifer System The Lower System consists primarily the Kurnub Group of Early Cretaceous Age and the Zarqa Group of Triassic - Jurassic Age These two groups are hydraulically connected on a regional scale forming one aquifer complex However, the Upper Aquifer System, which consists of alternating aquicludes and aquifers of Late Cretaceous-Early Tertiary Age of the Ajlun and Balqa Group (A1-7 and B1-4), covers most parts of North and Central Jordan

Two separate water levels and different water qualities in the Kurnub Group and Zarqa Group are observed in some places in the highlands, like the Subeihi and Baqqa' area However, these form one static water level in the Rift Valley

The hydrodynamic patterns of Central and Northern Jordan at the Eastern flank of the Jordan Valley are discussed by many others (Salameh and Udluft, 1985, and El-Naser 1990) (Exhibits 6 1 and 6 2)

A general description of the hydrodynamic pattern is as follows

Infiltration occurs over the highlands through the Upper Aquifer Complex Because of the topography, there is a ground water divide in the recharge area (Highlands) Some of the ground water in the Upper Aquifer Complex moves towards the Jordan Valley in the West and appears on the escarpment as base flow, seepages and springs (good water quality) while most of the water moves towards the east away from the divide As water flows eastward in the Upper Aquifer Complex, it infiltrates downwards through the different aquifers, aquitards and aquicludes through fractures, and major and minor faults until it finally recharges the Lower Aquifer Complex In the Lower Aquifer Complex the water changes its direction to westward and finally emerges as springs or encountered in wells (flowing or nonflowing) with thermal brackish water in the Jordan Valley

In the study area and its surroundings (northern and southern adjacent areas), the Kurnub and Zarqa Groups are exposed The Kurnub Group exposures are much larger than the Zarqa Group, which is restricted to the Zarqa River Course and its flanks downstream from KTD The Kurnub Group (Upper Aquifer Complex) is recharged annually in the highlands by rainfall This annual recharge explains the presence of fresh water springs and wells in the Kurnub Group, as in the Subeihi and Baqqa' area Contrary to this, saline water is encountered in deep wells penetrating the Zarqa Group in the Baqqa's area In the highlands, the Kurnub and Zarqa Groups are separated from each other, but as water flows towards the west the two groups form one static water level This was recently proved by JICA (1995) in their study on Brackish Groundwater Desalination in Jordan, where five tests wells were drilled in the Jordan Valley The nearest wells to the Zarqa River are Test Well No 1 and Abu Zeighan Well No 1, which was drilled two years ago by JVA in the Zarqa Course downstream of Hwaret Weir (A Z 1) The groundwater equipotential map of the area and hydrogeological cross sections are shown in Exhibits 6 3 to 6 5 (JICA, 1995)

The hydraulic characteristics of the Kurnub and Zarqa Groups encountered as separate aquifers are given in **Table 6 1** (JICA, 1995)

Table 6 1

GROUND WATER CHARACTERISTICS

Aquifer	Transmissibility m^2/day	Permeability m/d	Storage Coefficient
Zarqa	157	0 7	0 01-0 09
Kurnub	110-120	1 0-1 1	0 002

The piezometric surface of the Zarqa Aquifer (Exhibit 6 3) is almost parallel with the escarpment and the groundwater flows from the highlands in the east towards the Jordan Valley in the west The concavity in the piezometric surface along the Zarqa River is caused by the springs and seepage The average piezometric surface gradient of the Zarqa Aquifer is about 3 percent

6 2 Springs and Seepage

Seepage and springs of brackish and thermal nature are present along most of the entire reach downstream from the Hwaret Weir to the Abu Zeighan Weir, and continuously recharge the surface water flow in the Zarqa River During the field investigation along the Zarqa River course from the Thahab Weir to the Abu Zeighan Weir, electrical conductivity measurements were carried out The results of these measurements are given in **Table 6 2** The numbers assigned to the locations are the same as shown on Exhibit 3 1

Table 6 2

ELECTRICAL CONDUCTIVITY MEASUREMENTS

No	Location	EC ms/cm (mmhos/cm)
1	Thahab Weir	1 280
2	Seepages	1 780
3		1 330
4		1 330
5		1 330
6		1 370
7		1 370
8	Abu Zeighan Well No 1	>11 50
11	Seepages (left side)	5 00,5 50,5 25 and 5 01
12	River Water	1 51
15	Seepages (right side)	3 95,3 85
16	River	1 540
18	Thermal Springs	6 25,6 16
24	Abu Zeighan bridge (River)	2 40,2 82 And 2 00 (across the river)
25		2 49
26	Abu Zeighan Weir	2 55

Complete chemical analyses of water from drilled wells (JICA 1995 Test wells No 1 and 2, and Abu Zeighan well No 1), penetrating the Zarqa Aquifer and water from Men and Women thermal springs located on the Zarqa River downstream of Abu Zeighan well No 1 are presented in Table 6 3 Most of the test wells drilled by JICA in the Jordan Valley found water present under high piezometric pressure, water flows naturally to the earth surface and is then put under control Contrary to this, Abu Zeighan Well No 1, when drilled, found water under very high pressure, which made flow control very difficult Special processes had to evolved to bring the water under control (Discussions with Eng Hamed Abu Obeid, Eng Abu Obeid believes that blocking of the well has had no influence on the seepage and springs discharges, contrary to JVA Engineers who believe that after the water flow from the Abu Zeighan well was brought under control, seepage and springs discharges downstream of the well increased from 20 l/s or less to more than 150 l/s) About 60 m of the well is believed to have caved in

It is not important whether the control of the well is the major cause of seepage discharge or not, since seepage and springs are present and severely impact the water quality of Zarqa River

6 3 Potential Channel Loss or Gain

From the ground water regime, it appears that there is a gain in the amount of water flowing in the Zarqa River downstream from the Hwaret Weir to the Abu Zeighan Weir Also, most probably, there is a gain in water between KTD and the Hwaret Weir but in much smaller amount

Table 6 3

CHEMICAL ANALYSES OF ZARQA AQUIFER IN JORDAN VALLEY

	Test Well 1 7-1-1995	Test Well 2 3-1-1995	Abu Zeighan I Summer 1994	Man Spring Summer 1994	Woman Spring Summer 1994
Temp °C	36 3	31 9	35	34 9	35
pH-Value	6 38	6 47	6 28	6 31	6 39
EC, ms/cm	8 55	14 76	11 85	6 88	8 08
TDS mg/L	7262	9724	7622	4422	5002
Ca mg/L	37 15	46 69	42 2	25 29	33 43
Mg mg/L	10 4	16 6	11 5	10 8	6 5
Na mg/L	51 4	108	79 8	37 5	45 2
K mg/L	4 2	6 5	4 6	2 9	3 4
CL mg/L	50	116 7	76 92	35 95	42 40
SO_4 mg/L	34 3	36 34	36 76	23 64	26 46
HCO_3	17 16	26 62	23 63	17 17	19 24
NO_3	8 27	3 94	1 99	0 57	2 61
Fe mg/L	10 7	10 8	100 5	0 06	0 06
Mn mg/L	0 32	0 11	3 5	0 09	0 11
NH_4+ mg/L	0 26	1 02	25 6	1 28	1 02
H_2S mg/L	0 49	0 49	0 25	0 25	< 0 1

6 4 Conclusions

According to hydrogeological conditions prevailing in the area, the Zarqa River course between KTD and the Abu Zeighan Weir should be continuously recharged from the exposed Zarqa Group at the base and the Kurnub Group at higher elevations through springs and seepages

The Kurnub water seepages are of good quality because it is infiltrated rainfall water at the highlands Contrary to this, the Zarqa Group water, which is considered to present under artesian conditions, is of poor quality This deteriorates the quality of the Zarqa River water released from KTD

7 IDENTIFICATION OF ALTERNATIVES

The process of identifying alternatives for conceptual design consisted of a review and initial screening of the conceptual alternatives described in the Scope of Work, and the formulation of new alternatives that were identified as a result of the initial screening and the results of studies performed to date

Nine concepts were identified in the Scope of Work as appropriate for consideration in this Conceptual Studies Report These nine concepts included total-solution alternatives, and the idea that some of the alternatives and features of alternatives could be combined It must be remembered that these concepts were identified before the evaluation of current water losses was performed

As a result of our evaluation of the prior studies of water loss, a flow measurement program performed for this study, and the geological and hydrogeological investigations performed as a part of this study, it was concluded that

1 Practically, there is no gain or loss or water quality deterioration in the reach between the KTD and the Thahab Weir and, most likely, it is a minor fresh water gaining reach

2 The river reach between the Thahab Weir and the Hwaret weir could be a gaining or losing reach at times and there is no deterioration in water quality

3 In the river reach between the Hwaret Weir and the Abu Zeighan Weir, losses in the range of 10% to 15% could occur and there is a severe deterioration in water quality

Therefore, the initial evaluation was to reconsider the identified conceptual alternatives in light of the results of the water loss evaluation and to change the emphasis of this study to improvement of water quality

7 1 Initial Screening of the Six Total-Solution Alternatives

The initial screening was performed for the six total-solution Conceptual Alternatives described in the Scope of Work

Conceptual Alternative No 1 - Using a pipeline over the entire 23-kilometer reach This concept was originally identified as a solution to water losses or quality deterioration over the entire reach of the Zarqa River between KTD and the Abu Zeighan Weir Based on the conclusions stated above that there are no losses or water quality deterioration over most of the reach of river, the river itself is an acceptable conveyance between KTD and the Hwaret Weir Therefore, this alternative is no longer valid as a solution to the stated objectives of the work effort

Conceptual Alternative No 2 - Limiting the pipeline to certain reaches of the channel. This alternative is valid and is carried into the conceptual design stage

Conceptual Alternative No 3 - Improving the river bed rather than using a pipeline This alternative was originally identified as an alternative to eliminate seepage in the river channel through the construction of a channel or by applying an impervious membrane to the existing channel While such an alternative might be effective in reducing losses from seepage, it is not a practical solution for improving the quality of the water delivered to the KAC

The water quality deterioration results from a series of springs and seeps that discharge into the river all along the lower reach The application of an impervious membrane on the river bed or the construction of a lined channel in the river bed might provide an acceptable solution, however, it probably would not eliminate either losses or the deterioration of quality In the case of a concrete lined canal (trapezoidal or rectangular cross section), the expansion joints will provide ready access to the flowing saline flows An impervious membrane is subject to cracking or ripping or, at a minimum, high maintenance In addition, an impervious barrier to the seeps and springs might only force them to discharge up-bank or in another location that would eventually allow them to return to the river

Finally, such an open conveyance might cost as much as a closed conduit under some circumstances Indeed, building (or rehabilitating) a canal all the way from Hwaret to Abu Zeighan under a maximum acceptable slope of 0 5 percent (for instance), would imply solving the problem of a 38 m drop along a 3 5 to 4 km-long alignment, or about 10 m per km Up to four drop structures may be required for each 1000 m, which will result in a rather expensive solution Therefore Conceptual Alternative No 3 is rejected In its place, we have identified an alternative with a combined conveyance (part canal, part pipe - Alternative IRR3b), and one completely enclosed in a ductile iron pipe (Alternative IRR3a) between Hwaret and Abu Zeighan Both alternatives are retained for cost comparison

Conceptual Alternative No 4 - Use of a deep cutoff wall within the Zarqa River channel to recover seepage losses This alternative was originally conceived to intercept river flow that was traveling down-river in the alluvium and gravel of the riverbed By intercepting this flow and forcing it to the surface, it could be diverted and used beneficially The only reach that is now considered to have the potential for losses is the lower reach between the Hwaret Weir and the Abu Zeighan Weir It is in this reach that the saline springs and seeps contaminate the water released from the KTD Interception of any losses would also intercept the saline water and no purpose would be served

A cutoff wall could be added to the alternatives with intake at Hwaret (Alternatives IRR3a and 3b) to recover any losses that might occur in the reach between Thahab and Hwaret Weirs This will make the schemes more expensive without guaranteeing performance For instance, trying to recover losses during low flow season by constructing a cutoff wall could very well be counterproductive, inducing saline contamination upstream of the Hwaret Weir (currently this river portion does not have saline contamination), by putting the saline springs under pressure and forcing their flow back into the river

Therefore, it was decided to eliminate a cutoff wall as an option for reducing losses or improving the quality of the Zarqa River water

Conceptual Alternative No 5 - Constructing a canal rather than a pipeline In comparison to Alternative 3, this alternative suggests a canal outside of the river channel It is a valid alternative although mutually exclusive to a pipeline It is carried forward for further study

Conceptual Alternative No 6 - Preventing saline spring and seep water from entering the river This alternative was conceived when the nature and extent of the springs and seeps was not clearly understood It is now understood that most of the existing contamination sources are flowing and this complicates significantly the implementation of a viable solution Any structural confinement attempt might simply lead to a shift of the contamination sources to other locations as a result of pressure build-up Intercept and conveyance of sources and springs would represent an expensive scheme given the seasonal variation of discharges, let alone that during the rainy season such a conveyance might not be necessary as flow concentrations are much lower Past experiences show that a more convenient solution in such situations is passing the better-quality water around the contaminated reaches Therefore, Conceptual alternative No 6 is rejected in favor of alternatives that convey the KTD discharge around the reach between the Hwaret Weir and the Abu Zeighan Weir

Feature No 1 - Including power generation in the project can be an addition to any of the pipeline projects A part of the conveyance cost that represents the difference between the cost of a penstock and the cost of the ductile iron pipe that would be suitable for the irrigation supply scheme and the cost of the equipment and equipment housing will be allocated to the power addition

The addition of power to the rejected 23 km-long pipe also was considered for this initial screening For this alternative, the total conveyance cost upstream of the Thahab Weir would be allocated to the power purpose of the development, in addition to an increment similar to the one described above for the reach between the Hwaret and Abu Zeighan Weirs Based on preliminary unit prices, the cost of the 23 km-long pipe (installed) would reach between $31 1 and $61 5 million, depending if the pipe is ductile iron 1 5 m ID, or structural (pressure vessels) steel 2 0 m ID (thickness varying between 10 and 25 mm), respectively, and the conveyance component incremental cost of adding power to the configuration with the 23 km-long pipe configuration could reach as high as $30 4 million (the difference of the above costs), or about $1320/kw for a 23 MW powerplant at Abu Zeighan This unit cost is computed without taking into consideration other expenses such as the powerhouse civil and equipment costs, as well as the expenses associated with building an intake at KTD (to intake both the turbined discharge and the irrigation by-pass) When all costs are considered, it suggests a prohibitive total development cost, consequently, the power option added to a 23-km long pipe was discarded

Feature No 2 - Provision of a reregulation reservoir near the Abu Zeighan Weir can serve to permit on-peak generation with any power addition Historically, on-peak power is worth up to two times as much as off-peak power Therefore, the potential for this benefit is carried forward

As a result of the initial screening the following alternatives and features are retained for the development of conceptual designs

Limiting the Pipeline to a certain reach of the channel
Constructing a canal rather than a pipeline
Including power generation with the pipeline
Provision of a reregulation reservoir

For the purpose of the conceptual design, these retained conceptual alternatives and features were developed into specific alternatives

7 2 Alternatives for Conceptual Design

The alternatives for conceptual design were formed as combinations of the retained conceptual alternatives that take into consideration the results of the prior studies performed as a part of this investigation The alternatives allow for the existing power facilities at KTD that currently generate secondary energy and release a maximum of 6 4 cms (plant design discharge) for existing irrigation users, whenever water is available The intakes for these alternatives will be either at the Thahab Weir or at the Hwaret Weir For reasons related to channel loss and contamination potential, closed conveyance in pipe is preferred to canal solutions Attempts were made to take advantage of existing works One alternative incorporated the existing carrier ZC II, despite high peak velocities expected in the pipe within the new scheme In another alternative, an existing but heavily damaged canal, which takes off from the Hwaret Weir, was partially integrated in an alternative in which the conveyance is part in canal and part in pipe Based on these criteria, the four alternatives briefly described below are recommended to be developed at a conceptual level **Table 7 1** presents main characteristics of these schemes

7 2 1 Alternative IRR1

A 7 2 km long closed conveyance (ductile iron pipe with 1 4 m ID) would be incorporated in the reach from the Thahab Weir to the Abu Zeighan canal The intake at Thahab Weir would be expanded to accommodate this new pipeline The preliminary pipe alignment is shown on **Exhibit 7 1** on 1/10,000 topographic maps, together with the location of the existing structures and with the new project feature locations

7 2 2 Alternative IRR2

This alternative is based on the use of the existing ZC II pipe to convey a discharge up to a maximum of 6 3 cms (including the 1 8 cms maximum flow currently sent to ZC II consumers), down to a bifurcation where a new pipe would convey the water normally released down the Zarqa River past the Thahab Weir to Abu Zeighan **Exhibit 7 2** presents this alternative arrangement on 1/10,000 topographic maps, together with the location of the existing structures and with the new scheme component locations

7 2 3 Alternative IRR3a

This alternative considers the possibility of constructing a conveyance in pipe (ductile iron pipe with 1 4 m ID) to by-pass the Hwaret - Abu Zeighan critical reach **Exhibit 7 3** presents this alternative scheme on 1/10,000 topographic maps, together with the location of the existing structures and with the new scheme component locations

7 2 4 Alternative IRR3b

This alternative considers the possibility of constructing a combination canal / pipe conveyance (ductile iron pipe with 1 4 m ID) to by-pass the Hwaret - Abu Zeighan critical reach **Exhibit 7 4** presents this alternative scheme on 1/10,000 topographic maps, together with the location of the existing structures and with the new scheme component locations

7 3 Power Alternative (POW)

The addition of power could be considered for alternatives that incorporate closed conduits, provided that head is high enough to justify an installation In order to take advantage of the full 121-m gross head between the settling basin take-off at the Thahab and the Abu Zeighan location, the addition of power was considered only for the alternative with the intake at Thahab Weir (IRR1) A power installation harnessing the 56-m gross head between Hwaret and Abu Zeighan would only develop a maximum of 3 MW, an installed capacity of little interest to the Jordan Electric Authority especially since it most probably would be too small to justify the investment **Exhibit 7 5** presents the features of the selected alternative **Table 7 1** also presents the main characteristics of this alternative

Table 7 1

ALTERNATIVES FOR THE ZARQA RIVER CONVEYANCE STUDY

Alternative	Purpose	CONVEYANCE					Settling Basins		Power		Special Features
		Pipe/Penstock			Canal						
		Type	Length (KM)	Capacity (CMS)	Length (KM)	Capacity (CMS)	Expansion (CMS)	New (CMS)	Secondary (MW)	Firm (MW)	
IRR1	Irrigation	Ductile Iron 1 4 m ID	7 2	4 5	-	-	-	-	6 0[2/]	-	* Dissipation Equipment (valve) at Pipe Downstream End
IRR2	Irrigation	Ductile Iron 1 4 m ID	2 0	4 5	-	-	4 5[1/]	-	6 0[2/]	-	* Bifurcation from ZC II * Increase of ZC II discharge (6 3 cms) over First 5 km * Pumping Station * Dissipation Equipment at Pipe Downstream End
IRR3a	Irrigation	Ductile Iron 1 4 m ID	3 5	4 5	-	-	-	-	6 0[2/]	-	* Rehabilitation of Hwaret Weir and Intake * Dissipation Equipment at Pipe Downstream End
IRR3b	Irrigation	Ductile Iron 1 4 m ID	2 0[4/]	4 5	1 5	4 5	-	-	6 0[2/]	-	* Rehabilitation of Hwaret Weir and Intake * Construction of 1 5 km Canal * Dissipation Equipment at Pipe Downstream End
POW	Irrigation and Power	Pressure Vessel Steel 2 0 m ID	7 0	7 5	-	-	-	7 5[1/]	-	13 0[3/]	* Re-regulating dam and fresh water pond at the Abu-Zeighan site * 7 MW Plant at Abu Zeighan site * Diversion of low and average flows of Zarqa R Upstream of Abu-Zeighan Weir

Notes 1/ At Tal Al Thahab Weir
2/ Existing Plant at King Talal Dam
3/ Includes new 7 MW Plant at the Abu Zeighan Site
4/ Includes Aqueduct Length (300 m)

7 4 Staged Development

The alternatives IRR1 and POW could represent stages of the same development, with the power development installed at a later stage, when and if required In this case, the irrigation development should be the one with a totally new by-pass pipe along the reach Thahab Weir - Abu Zeighan Canal, with the comment that this conveyance should be installed as a penstock from the very beginning (that is, manufactured of malleable, structural pressure vessels steel) Of course, this would represent a higher initial investment with a temporarily non-performing component This staged development is only conceptually presented at this time and was not detailed at the cost estimate level

8 RESERVOIR OPERATION STUDIES

Reservoir operation studies were performed for the current operating regime using inflow and release data for the KTR The studies were used to estimate the amount of water available for regulation in the reservoir and for diversion below the dam Additional operating regimes representing ranges of flow requirements consistent with the development alternatives identified above were also investigated They included various scenarios of increased inflow into the KTR in the future (from M&I returns), future irrigation demand growth along KAC, as well as the possibility of implementing a new power plant immediately upstream of the Abu Zeighan Weir Flows still available after supplying these irrigation developments were determined as inflows into the Karamah Reservoir

8 1 Simulation Model

The monthly reservoir operation for all scenarios was simulated using the Army Corps of Engineers' **HEC-5** computer model for the period from 1954 to 1994 (water years) The **HEC-5** program is commonly used in planning studies for evaluating the performance of existing and proposed reservoirs within a watershed system, and to assist in sizing the flood control and conservation storage requirements for each dam incorporated into the system at various stages of development The model can be used in simulating the sequential operation of a system of reservoirs of different configuration In the case of this project, the **HEC-5** simulation represented various scenarios of operation of the KTR for irrigation requirements by the Zarqa Carriers (ZC) I & II and by the KAC, as well as for power generation

8 2 Simulation of Alternatives

Both the irrigation alternatives and the multi-purpose alternative (irrigation and power) were simulated in this study The irrigation alternatives model the operation of the KTR to meet the several levels of downstream irrigation requirements for ZC I & ZC II and the KAC All alternatives consider the existing powerplant at the KTD that currently generates energy at a maximum plant capacity of 6 MW (design discharge of 6 36 cms) The water is released primarily for irrigation use and secondarily for power generation Alternatives modeled included, in addition to the historical inflow of Zarqa River into the KTR (these values already include some return flow, especially during the most recent years), additional constant monthly inflows estimated at 1 and 2 cms and representing future levels of M&I return flows Under all scenarios of monthly inflows (including the current estimated inflow) into the KTR, the effects of increasing existing irrigation requirements along the KAC by 20 and 40 percent were investigated

The multi-purpose alternative models the operation of the KTR to meet the current downstream irrigation requirements of ZC I & II and along the KAC, while generating energy at a new powerplant located immediately upstream of the Abu Zeighan Weir

In order to allow a power installation at the Abu Zeighan Weir in the order of magnitude of the existing plant at KTD (a smaller installation will not be, most probably, economically attractive), this alternative was only modeled under the assumption of a maximum potential future M&I return flow of 3 5 cms added to the historical inflow of the Zarqa River into the KTR This potential future additional inflow into the reservoir will allow the delivery of a design discharge to the new plant that will be close to the one turbined at the existing plant (6 35 cms), despite upstream diversions to the Zarqa Carriers Scenarios with maximum monthly average flow requirements for power generation at the new plant of 2 5 and 3 0 cms, in addition to the monthly KAC irrigation requirements that are also available for turbining (maximum monthly requirement for KAC is about 1 5 cms), were simulated Zarqa Carriers requirements were maintained constant at the current level

8 3 Simulation Input

Input into the simulation includes reservoir inflow, intervening flow, irrigation requirements, evaporation data, and the reservoir capacity curve

8 3 1 Reservoir Inflow

The estimated historical monthly streamflow data (see Section 4 2 2) in the Zarqa River at KTD for the period of water years 1954 to 1994 are listed in **Table 4 2**

8 3 2 Intervening Flow

For reservoir operation study, intervening flows between KTD and the Thahab Weir are required These are listed in **Table 4 4**

8 3 3 Irrigation Requirements

Irrigation requirements were computed from available measured flows diverted through the ZC I & ZC II pipes and through the KAC Measured flows were available from August 1993 to January 1995 The flows conveyed through ZC I & ZC II pipes were combined When more than one monthly requirement was available, maximum monthly values were used as irrigation requirement in this study The monthly irrigation requirement used for ZC I & II (combined), and the KAC are

Irrigation Requirements (cms)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
ZC I & ZC II												
	2 00	2 01	1 03	0 48	1 06	2 41	2 28	1 94	1 94	2 00	2 35	1 83
KAC												
	1 24	0 75	0 16	0 30	0 59	1 48	1 28	1 16	0 99	1 11	1 50	1 01

8 3 4 Evaporation

The mean monthly net reservoir evaporation (total evaporation minus rainfall) used in the simulation is shown below

Net Evaporation (mm)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
149	109	-5	-23	10	48	156	235	259	281	261	197

8 3 5 Reservoir Capacity Curve

The reservoir volume-area-elevation relationship used in the simulation is shown below

Reservoir Capacity Curve

Elevation (m)	74	120	123	130	135	140	145	150	155	160	164	170	173 5	175	180
Volume ($10^6 m^3$)	0	6 6	8	12	15	19	24	30	37	45	52	64	72	75 6	88
Area ($10^3 m^2$)	0	410	500	590	725	875	1025	1225	1525	1675	1875	2125	2340	2450	2800

8 4 Simulation Results

8 4 1 Irrigation Alternatives

Table 8 1 presents summaries of average flows available for ZC I & II combined, and KAC, for the scenarios modeled for the irrigation alternative requirements The average spills from KTD and the percent of time that irrigation requirement was met without shortage are also tabulated in **Table 8 1** The spill can be considered as flow available for the proposed Karamah Reservoir downstream of the Abu Zeighan Weir The results indicated that by adding a M&I return flow of 1 cms to the historical streamflow, the percent of time with no shortage would increase from 68% to 94% if observing current KAC requirements Under this same scenario of the additional 1 cms return flow into the KTR, even a 140 percent increase in the irrigation requirements along KAC would correspond to a very satisfactory delivery for irrigation to ZC I & II and KAC (87 percent of the time) If the additional M&I return flow is increased to 2 cms, the combined ZC I & ZC II requirement and the existing (100 percent) and increased (120 and 140 percent) KAC requirements can be met without shortage (99 percent of the time under the highest demand)

TABLE 8 1

SUMMARY OF AVAILABLE FLOW
PERIOD WY 1954-1994

KAC	AVERAGE AVAIL FLOW (CMS)					
	ZC I & ZC II			KA CANAL		
	ADDITIONAL INFLOW TO KTD			ADDITIONAL INFLOW TO KTD		
USE	+ 0 CMS	+ 1 CMS	+ 2 CMS	+ 0 CMS	+ 1 CMS	+ 2 CMS
100 %	1 50	1 80	1 83	0 63	0 95	1 01
120 %	1 46	1 79	1 83	0 70	1 10	1 21
140 %	1 42	1 78	1 83	0 76	1 22	1 40

KAC	KARAMAH RESERVOIR (CMS)			TIME WITHOUT SHORTAGE		
	ADDITIONAL INFLOW TO KTD			ADDITIONAL INFLOW TO KTD		
USE	+ 0 CMS	+ 1 CMS	+ 2 CMS	+ 0 CMS	+ 1 CMS	+ 2 CMS
100 %	0 19	0 53	1 41	68 %	94 %	100 %
120 %	0 17	0 39	1 21	63 %	91 %	100 %
140 %	0 16	0 30	1 03	59 %	87 %	99 %

TABLE 8 2

SUMMARY OF SHORTAGES
PERIOD WY 1954-1994

KA CANAL USE	AVERAGE SHORTAGE FLOW (CMS)					
	ZC I & ZC II			KAC		
	ADDITIONAL INFLOW TO KTD			ADDITIONAL INFLOW TO KTD		
	+ 0 CMS	+ 1 CMS	+ 2 CMS	+ 0 CMS	+ 1 CMS	+ 2 CMS
100 %	0 33	0 03	0 00	0 38	0 06	0 00
120 %	0 37	0 04	0 00	0 52	0 11	0 00
140 %	0 41	0 05	0 00	0 66	0 20	0 01

KA CANAL USE	AVERAGE SHORTAGE FLOW (%)					
	ZC I & ZC II			KAC		
	ADDITIONAL INFLOW TO KTD			ADDITIONAL INFLOW TO KTD		
	+ 0 CMS	+ 1 CMS	+ 2 CMS	+ 0 CMS	+ 1 CMS	+ 2 CMS
100 %	15	2	0	31	5	0
120 %	17	2	0	35	8	0
140 %	19	2	0	38	11	1

The corresponding shortages (mostly for the existing situation and for the 1 cms additional inflow into the KTR), are summarized in **Table 8 2** for the combined ZC I & II and KAC The corresponding detailed monthly shortages are listed in **Table 8 3** through **Table 8 8** for three relevant scenarios no additional inflow into KTR with 100% and 120% of KAC irrigation requirement, and 1 cms additional M&I return inflow into KTR with 120% KAC requirement These tables show the shortage distribution over the total simulation period of water years from 1954 to 1994

Table 8 3

MONTHLY SHORTAGE FOR ZC I AND ZC II (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 43	0 12
1956	1 19	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 64	0 72	0 85	1 25	0 39
1957	1 23	0 83	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 17
1958	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 48	1 14	0 13
1959	1 19	0 76	0 69	0 00	0 00	0 00	0 00	0 00	0 00	0 45	1 13	1 35	0 46
1960	1 38	0 87	0 54	0 00	0 00	0 00	0 62	1 78	1 51	1 60	1 28	1 58	0 93
1961	1 70	0 87	0 47	0 00	0 00	0 00	0 00	0 00	0 00	1 34	1 35	1 70	0 62
1962	1 43	0 18	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 04	0 14
1963	1 19	0 68	0 21	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 23	0 28
1964	0 33	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03
1965	0 00	0 77	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 06
1966	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1967	1 47	0 56	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 89	1 31	0 35
1968	1 47	1 08	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 21
1969	1 07	0 00	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 09
1970	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 47	0 07	0 22	0 06
1971	1 21	0 62	0 30	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 13	1 98	0 35
1972	1 66	0 92	0 00	0 00	0 00	0 00	0 00	0 00	1 72	1 65	1 54	1 87	0 78
1973	1 97	0 79	1 23	0 00	0 00	0 00	0 54	1 70	1 32	1 40	1 53	1 94	1 03
1974	2 01	0 48	0 88	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 28
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 49	2 07	0 21
1976	2 16	1 14	0 68	0 00	0 00	0 00	0 00	0 00	1 47	1 50	1 60	1 98	0 88
1977	1 96	1 27	1 11	0 00	0 00	0 00	0 57	1 88	1 76	1 81	1 78	2 10	1 19
1978	1 10	1 36	0 00	0 00	0 00	0 00	0 09	1 98	1 94	1 91	1 92	2 23	1 04
1979	2 22	1 61	0 78	0 00	0 00	0 15	1 97	2 25	1 91	1 91	1 78	2 08	1 39
1980	0 27	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 68	0 06
1983	1 21	0 13	0 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 15
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 20	0 02
1985	0 89	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 70	0 22
1986	1 67	1 01	0 61	0 00	0 00	0 00	0 00	0 78	1 18	1 13	1 28	1 44	0 76
1987	1 36	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 09	1 24	1 35	1 62	0 47
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1990	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 67	1 10	0 15
1991	1 09	0 45	0 24	0 00	0 00	0 00	0 00	0 00	0 00	0 09	0 88	1 19	0 33
1992	1 03	0 10	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 09
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	0 86	0 40	0 20	0 00	0 00	0 00	0 09	0 25	0 33	0 42	0 51	0 86	0 33

NOTE NO ADDITIONAL RETURN FLOW 100 PERCENT OF CANAL USE

Table 8 4

MONTHLY SHORTAGE FOR KAC (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 49	1 50	0 17
1956	1 58	0 00	0 00	0 00	0 00	0 00	0 00	0 67	1 16	0 99	1 11	1 50	0 58
1957	1 58	1 24	0 25	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 26
1958	0 00	0 60	0 51	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 11	1 50	0 31
1959	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 99	1 11	1 50	0 60
1960	1 58	1 24	0 75	0 00	0 00	0 00	1 48	1 28	1 16	0 99	1 11	1 50	0 92
1961	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 54	0 99	1 11	1 50	0 64
1962	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 50	0 36
1963	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 50	0 42
1964	1 58	0 66	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 19
1965	0 22	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 12
1966	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 01	0 08
1967	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 11	1 50	0 45
1968	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 24
1969	1 58	0 87	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 27
1970	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 99	1 11	1 50	0 30
1971	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 11	1 50	0 52
1972	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 57	1 16	0 99	1 11	1 50	0 68
1973	1 58	1 24	0 75	0 00	0 00	0 00	1 48	1 28	1 16	0 99	1 11	1 50	0 92
1974	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 30
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 11	1 50	0 22
1976	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 05	1 16	0 99	1 11	1 50	0 70
1977	1 58	1 24	0 75	0 00	0 00	0 00	1 48	1 28	1 16	0 99	1 11	1 50	0 92
1978	1 58	1 24	0 63	0 00	0 00	0 00	1 48	1 28	1 16	0 99	1 11	1 50	0 91
1979	1 58	1 24	0 75	0 10	0 09	0 59	1 48	1 28	1 16	0 99	1 11	1 50	0 99
1980	1 58	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 13
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 50	0 12
1983	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 30
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 50	0 12
1985	1 58	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 22	1 50	0 28
1986	1 58	1 24	0 75	0 00	0 00	0 00	0 00	1 28	1 16	0 99	1 11	1 50	0 80
1987	1 58	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 16	0 99	1 11	1 50	0 53
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1990	0 18	1 03	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 86	1 11	1 50	0 39
1991	1 58	1 24	0 75	0 00	0 00	0 00	0 00	0 00	0 00	0 99	1 11	1 50	0 60
1992	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 24
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	1 01	0 71	0 29	0 00	0 00	0 01	0 18	0 22	0 30	0 36	0 53	0 94	0 38

NOTE NO ADDITIONAL RETURN FLOW 100 PERCENT OF CANAL USE

Table 8 5

MONTHLY SHORTAGE FOR ZC I & ZC II (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 12	1 31	1 43	0 24
1956	1 19	0 00	0 00	0 00	0 00	0 00	0 00	0 27	0 64	0 72	0 85	1 25	0 41
1957	1 23	0 83	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 17
1958	0 00	0 14	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 96	1 14	0 19
1959	1 19	0 76	0 69	0 00	0 00	0 00	0 00	0 00	0 00	1 00	1 13	1 35	0 51
1960	1 38	0 87	0 54	0 00	0 00	0 00	0 83	1 78	1 51	1 60	1 28	1 58	0 95
1961	1 70	0 87	0 47	0 00	0 00	0 00	0 00	0 00	0 14	1 34	1 35	1 70	0 63
1962	1 43	0 18	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 94	0 21
1963	1 19	0 68	0 21	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 31	0 28
1964	0 33	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03
1965	0 43	0 77	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 10
1966	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 51	1 51	0 17
1967	1 47	0 56	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 13	1 31	0 37
1968	1 47	1 08	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 21
1969	1 30	0 00	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 11
1970	0 00	0 00	0 34	0 00	0 00	0 00	0 00	0 00	0 26	0 76	0 07	0 22	0 14
1971	1 21	0 62	0 30	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 28	1 98	0 45
1972	1 66	0 92	0 00	0 00	0 00	0 00	0 00	0 00	1 72	1 65	1 54	1 87	0 78
1973	1 97	0 79	1 23	0 00	0 00	0 00	0 75	1 70	1 32	1 40	1 53	1 94	1 05
1974	2 01	0 48	0 88	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 28
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 79	1 76	2 07	0 38
1976	2 16	1 14	0 68	0 00	0 00	0 00	0 00	0 00	1 47	1 50	1 60	1 98	0 88
1977	1 96	1 27	1 11	0 00	0 00	0 00	0 78	1 88	1 76	1 81	1 78	2 10	1 20
1978	1 10	1 36	0 00	0 00	0 00	0 00	0 30	1 98	1 94	1 91	1 92	2 23	1 06
1979	2 22	1 61	0 78	0 00	0 00	0 15	1 97	2 25	1 91	1 91	1 78	2 08	1 39
1980	0 27	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	0 81	0 87	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 65	0 28
1983	1 21	0 13	0 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 15
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 02	1 44	0 20
1985	0 89	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 64	1 70	0 27
1986	1 67	1 01	0 61	0 00	0 00	0 00	0 00	1 28	1 18	1 13	1 28	1 44	0 80
1987	1 36	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 25	1 24	1 35	1 62	0 57
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1990	1 15	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 61	0 67	1 10	0 29
1991	1 09	0 45	0 24	0 00	0 00	0 00	0 00	0 00	0 00	0 85	0 88	1 19	0 39
1992	1 03	0 10	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 09
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	0 91	0 43	0 23	0 00	0 00	0 00	0 11	0 27	0 37	0 50	0 67	0 98	0 37

NOTE NO ADDITIONAL FLOW 120 PERCENT OF CANAL USE

Table 8 6

MONTHLY SHORTAGE FOR KAC (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 19	1 33	1 80	0 36
1956	1 90	0 00	0 00	0 00	0 00	0 00	0 00	1 54	1 39	1 19	1 33	1 80	0 76
1957	1 90	1 49	0 40	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 31
1958	1 21	1 49	0 66	0 00	0 00	0 00	0 00	0 00	0 00	0 67	1 33	1 80	0 60
1959	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 42	1 19	1 33	1 80	0 75
1960	1 90	1 49	0 90	0 00	0 00	0 00	1 78	1 54	1 39	1 19	1 33	1 80	1 11
1961	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	1 39	1 19	1 33	1 80	0 83
1962	1 90	1 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 64	1 80	0 48
1963	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 29	1 80	0 61
1964	1 90	0 91	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 23
1965	1 90	1 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 28
1966	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 33	1 80	0 26
1967	1 90	1 49	0 12	0 00	0 00	0 00	0 00	0 00	0 00	0 94	1 33	1 80	0 63
1968	1 90	1 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 61	0 42
1969	1 90	1 12	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 33
1970	0 00	0 18	0 90	0 00	0 00	0 00	0 00	0 00	1 39	1 19	1 33	1 80	0 56
1971	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 33	1 80	0 62
1972	1 90	1 49	0 00	0 00	0 00	0 00	0 00	1 47	1 39	1 19	1 33	1 80	0 88
1973	1 90	1 49	0 90	0 00	0 00	0 00	1 78	1 54	1 39	1 19	1 33	1 80	1 11
1974	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 36
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 19	1 33	1 80	0 36
1976	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 80	1 39	1 19	1 33	1 80	0 90
1977	1 90	1 49	0 90	0 00	0 00	0 00	1 78	1 54	1 39	1 19	1 33	1 80	1 11
1978	1 90	1 49	0 78	0 00	0 00	0 00	1 78	1 54	1 39	1 19	1 33	1 80	1 10
1979	1 90	1 49	0 90	0 13	0 15	0 71	1 78	1 54	1 39	1 19	1 33	1 80	1 19
1980	1 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 16
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 83	1 80	0 42
1983	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 36
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 08	1 33	1 80	0 27
1985	1 90	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 33	1 80	0 42
1986	1 90	1 49	0 90	0 00	0 00	0 00	0 00	1 54	1 39	1 19	1 33	1 80	0 96
1987	1 90	0 00	0 00	0 00	0 00	0 00	0 00	0 01	1 39	1 19	1 33	1 80	0 63
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	1 20	0 10
1990	1 90	1 28	0 00	0 00	0 00	0 00	0 00	0 00	0 38	1 19	1 33	1 80	0 66
1991	1 90	1 49	0 90	0 00	0 00	0 00	0 00	0 00	0 20	1 19	1 33	1 80	0 73
1992	1 90	1 49	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 28
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	1 32	0 92	0 40	0 01	0 00	0 02	0 21	0 31	0 43	0 53	0 82	1 21	0 52

NOTE NO ADDITIONAL FLOW 120 PERCENT OF CANAL USE

Table 8 7

MONTHLY SHORTAGE FOR ZC I & ZC II (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1956	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1957	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1958	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1959	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1960	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1961	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1962	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1963	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1964	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1965	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1966	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1967	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1968	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1969	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1970	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1971	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1972	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1973	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 53	0 94	0 12
1974	1 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 08
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1976	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1977	0 00	0 00	0 11	0 00	0 00	0 00	0 00	0 00	0 76	0 81	0 78	1 10	0 30
1978	0 10	0 36	0 00	0 00	0 00	0 00	0 00	0 00	0 48	0 91	0 92	1 23	0 33
1979	1 22	0 61	0 00	0 00	0 00	0 00	0 00	1 25	0 96	0 93	0 70	1 08	0 56
1980	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1983	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1985	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1986	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1987	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1990	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1991	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1992	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	0 06	0 02	0 00	0 00	0 00	0 00	0 00	0 03	0 05	0 06	0 07	0 11	0 03

NOTE 1 CMS ADDITIONAL RETURN FLOW 100 PERCENT OF CANAL USE

Table 8 8

MONTHLY SHORTAGE FOR KAC (CMS)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1954	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1955	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1956	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1957	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1958	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1959	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1960	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1961	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1962	1 26	0 42	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 14
1963	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1964	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1965	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1966	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1967	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1968	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1969	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1970	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1971	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1972	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1973	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 15	1 11	1 50	0 23
1974	1 58	0 72	0 63	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 24
1975	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1976	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1977	0 00	0 06	0 75	0 00	0 00	0 00	0 00	0 29	1 16	0 99	1 11	1 50	0 49
1978	1 58	1 24	0 00	0 00	0 00	0 00	0 00	0 00	1 16	0 99	1 11	1 50	0 63
1979	1 58	1 24	0 53	0 00	0 00	0 00	0 41	1 28	1 16	0 99	1 11	1 50	0 82
1980	0 85	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 07
1981	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1982	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1983	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1984	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1985	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1986	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1987	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1988	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1989	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1990	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1991	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1992	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1993	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
1994	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
AVE	0 17	0 09	0 05	0 00	0 00	0 00	0 01	0 04	0 08	0 08	0 11	0 15	0 06

NOTE 1 CMS ADDITIONAL RETURN FLOW 100 PERCENT OF CANAL USE

8 4 2 The Multi-Purpose Alternative

Simulation results show that for an additional monthly inflow into the KTR of 3 5 cms and a monthly power flow requirement of 3 0 cms (not including KAC irrigation requirements that are also available for turbining), the available monthly flow KAC/Power amounts to 3 71 cms during 85 percent of the simulation period (percentage computed on a monthly basis) Based on this figure, a maximum daily available power flow of 7 5 cms was accepted as design discharge for the new powerplant (this would include the maximum KAC requirement of 1 5 cms, or even more on a daily basis) To obtain the required flow for irrigation along the KAC (downstream of the turbines) on a constant basis for several hours each day, a re-regulating fresh water pond will be built at the Abu Zeighan Weir in order to intercept the tailrace of the powerplant Flows that will be additional to the KAC requirements will be released by this pond in a mixed regime, perhaps all day long, to become future inflow into the Karamah Reservoir

Table 8 9 summarizes the results of the simulation in the multi-purpose (irrigation and power) alternative With an additional M&I return inflow into the KTR of 3 5 cms, the percent of time with no shortage is about 94% and 85% for a monthly power flow of 2 5 and 3 0 cms, respectively (not including KAC irrigation requirements) Available flows for KAC/Power are 3 41 cms and 3 71 cms, respectively Most of the shortage occurred in the late 1970's when the reservoir inflow to KTR is low The corresponding average monthly shortage is about 0 10 and 0 30 cms

Table 8 9

SUMMARY OF AVAILABLE FLOW AND SHORTAGE
MULTI-PURPOSE ALTERNATIVE
(PERIOD WY 1954-1994)

DESCRIPTION	U/M	LOCATION	CASE I	CASE II
ADDITIONAL INFLOW	CMS	KTR	3 5	3 5
AVE POWER REQ s	CMS	ABU-ZEIGHAN PLANT	2 5	3 0
AVE AVAILABLE FLOW	CMS	ZC I & ZC II	1 83	1 83
AVE AVAILABLE FLOW	CMS	KAC / POWER	3 41	3 71
AVE AVAILABLE FLOW	CMS	KARAMAH RESERVOIR	0 53	0 25
AVERAGE SHORTAGE	CMS	ZC I & ZC II	0 00	0 00
AVERAGE SHORTAGE	CMS	KAC / POWER	0 10	0 30
AVERAGE SHORTAGE	(%)	ZC I & ZC II	0	0
AVERAGE SHORTAGE	(%)	KAC / POWER	3	7
PERIOD OF TIME WITHOUT SHORTAGE	(%)	KAC / POWER	94	85

9 CONCEPTUAL DESIGN FOR THE IDENTIFIED ALTERNATIVES

Details of the various alternatives identified in the Scope of Work and their evaluation for inclusion in the conceptual design phase is presented in Chapter 7 As a result of this evaluation, which consisted of a qualitative screening, two total-solution alternatives and two features that could be combined with the total-solution alternatives were accepted and developed into five feasible alternatives for a conceptual design comparison These five feasible alternatives are

Alternative IRR1 - A 7 2 km-long closed conveyance from the Thahab intake to the Abu Zeighan canal

Alternative IRR2 - Use of the existing ZC II pipe to convey water to a bifurcation where a new pipe will convey it to the Abu Zeighan Weir

Alternative IRR3a - A pipe conveyance to by-pass the Hwaret - Abu Zeighan critical reach

Alternative IRR3b - A combination canal / pipe conveyance to by-pass the Hwaret - Abu Zeighan critical reach

The power Alternative (POW) - A power addition for alternative IRR1

The conveyance design was estimated to be 4 5 cms Maximum monthly values of 2 46 cms and 1 58 cms were determined for the current irrigation requirements of the Zarqa Carriers and KAC, respectively Part of the new M&I returns into the KTR were considered to allow a 40 percent growth for consumers along the KAC This addition brings the total maximum monthly requirement to some 4 7 cms downstream the KTD A 50 percent addition to this value, for a total of 7 0 cms, would normally represent a maximum daily requirement and is in the range of the design discharge of the existing powerplant at KTD (6 38 cms) As mentioned above in the reservoir operation study findings, for additional inflows into KTR carrying between 1 and 2 cms at the average monthly level, these requirements will experience only limited shortages (never higher than 11 percent in volume), for between 13 and 1 percent of time

After subtracting 2 5 cms that will be diverted through the Zarqa Carriers from the daily requirement, the remaining discharge of 4 5 cms was adopted

9 1 Alternative IRR1

The purpose of Alternative IRR1 is to expand the intake for Carrier Pipes I and II to accommodate a third pipe which will be used to convey water released from the KTD around the area of saline springs and seeps This alternative will eliminate the potential for loss in the entire reach between Thahab Weir and Abu Zeighan Weir and improve the quality of water diverted to the KAC

9 1 1 Alternative Description

A new ductile iron pipe with an internal diameter (ID) of 1 4 m would extend from the Thahab Weir intake 7 2 kilometers to the Abu Zeighan Weir, by-passing the existing desanders at Thahab

Limiting reinforced-concrete demolishing and rebuilding work behind a stone and sand cofferdam will be required to extend the intake front Additional trashracks and a control structure will be installed at the new opening At this time, it was assumed that there is no need for additional desanding facilities at the intake, based on the information that current consumers along the KAC have operational settling basins at the corresponding pumping stations It is recommended that the capacity and physical condition of these facilities be checked at the next study phase If there will be a need to incorporate a large settling basin at the intake, in parallel to the existing facilities, preliminary computations based on the control of a minimum size sand particle of 0 2 mm show that a new separate basin (connected to the existing forebay and having its own upstream and downstream controls), would have to have a cross section of about 4 0 to 5 0 m width and 3 5 m depth (the length of 48 m of the existing desanders is more than adequate) Site inspection indicated that there is enough space to add this new basin on the left side (looking downstream) of the existing ones

A new pipe with 1 4 m ID will connect the Thahab intake to the settling basins existing (extended) forebay The two existing 900 mm pipes will continue to supply the Valley for the needs of ZC I and ZC II (a maximum of about 2 5 cms) The conveyance capacity from the weir to the desander (intake and connecting pipes between intake and desanders) will have to be checked, including verification of the vortex submergence for the pipe that connects to the new desander (maximum flow of about 4 5 cms, maximum velocity of about 2 9 mps) The 7-km long ductile iron pipe will have a thickness of 7 mm

The pipe will require energy dissipation valves before releasing into the Abu Zeighan Canal In the current configuration, two Bailey Polyjet valves were incorporated in a parallel installation just upstream of the canal As with the ZC II pipe, the new pipe will be mostly buried and might have viaduct and/or syphon alignments, depending on the selected route **Drawing 1** presents plan views and sections of this alternative

9 1 2 Hydraulic Consideration

As mentioned previously, the design discharge is estimated to be 4 5 cms The gross head of this installation between the Thahab Weir and the Abu Zeighan Canal amounts to about 121 5 m Total losses (friction losses plus a 10 percent addition for local losses) reach 30 1 m and the valves will have to dissipate 91 4 m of head at the Abu Zeighan outlet **Exhibit 9 1** presents the hydraulic parameters of this configuration

9 1 3 Other Considerations

At this time, even if additional return flows higher than 2 cms are expected to be discharged in the future, recent information from the Ministry of Water and Irrigation revealed that these volumes are intended to be used for irrigation in the highlands and will not reach KTR However, should the availability of flows entering KTR increase in the future, the selected 1 4 m ID ductile iron conveyance has the capability of transporting up to 5 5 cms (velocity of about 3 5 mps) and the dissipation equipment will only have to be adjusted downwards, which is perfectly feasible with the Bailey valves and is actually common practice

9 2 Alternative IRR2

This alternative makes use of the existing Carrier Pipe II facilities over a major reach of the bypass in an attempt to reduce costs and limit Environmental impact As for Alternative IRR1, it will eliminate the potential for loss in the entire reach between Thahab and the Abu Zeighan Weir and improve the quality of water diverted to the KAC

9 2 1 Alternative Description

This alternative incorporates the existing ZC II pipe (1 5 m ID) into the conveyance works along the first five kilometers In this reach ZC II will convey the KAC irrigation requirements in addition to the existing flow currently delivered to the carrier consumers

The intake at Thahab Weir will be expanded with the addition of a new opening, trashrack, and control (slide gate) Because current ZC II consumers do not have settling basins, this alternative also implies the expansion of the desander facility existing downstream of the weir An additional pipe will connect the intake new opening to the expanded forebay at the desanders and the additional settling bay will be connected to the river by enlarging the existing canal that serves currently for flushing purposes

The bifurcation of the ZC II pipeline to the reach of new pipe will be located about 50 m downstream from the junction with an existing small pumping station At this point, a new 2 km-long ductile iron pipe 1 4 m ID will branch towards the Abu Zeighan Canal where, after dissipation, will discharge a maximum of 4 5 cms From the same junction point, the ZC II pipe would continue as is today, to serve the existing consumers Additional booster pumps will have to be installed in a new pumping station along the ZC II pipe to make up for the head loss increment generated by the larger flow conveyed from Thahab to the bifurcation point This alternative also implies a certain interruption of irrigation water delivery to consumers currently served by the ZC II conveyance

For head dissipation purposes, two parallel Bailey Polyjet valves are incorporated in the configuration in a parallel arrangement just upstream of the canal **Drawing 2** presents plan views and sections of this alternative

9 2 2 Hydraulic Considerations

A discharge of 4 5 cms was adopted as design discharge for the new branching pipe The existing carrier ZC II will transport a total of 6 3 cms (7 0 cms maximum release from KTD, minus 0 7 cms that will flow through the ZC I pipe), at a maximum velocity of 3 7 m/s that is still acceptable, albeit close to the upper limit for cement lining In the current situation, the head loss along the ZC II pipe down to the existing pumping station (about the location of the planned bifurcation) amounts to 0 61 m/km, resulting in a net head of about 78 7 m For the new flow forced into the carrier, the head loss increases to some 7 46 m/km, down to the bifurcation point, resulting in a reduced net head of 44 5 m To make up for the reduction that might harm existing ZC II consumers, a 1,200 HP booster pumping station was incorporated into the scheme just downstream of the bifurcation point

The 2-km long, 1 4 m ID branch pipe will operate with a moderate velocity of 2 92 mps under a net head of 73 6 m that will have to be dissipated by the Bailey valves at the Abu Zeighan landing **Exhibit 9 2** presents the hydraulic parameters of this configuration

9 2 3 Other Considerations

Unlike Alternative IRR1, increased requirements downstream of the KTD (along the KAC) that could be theoretically covered by additional return flows into the reservoir higher than 2 cms, cannot be accommodated by the ZC II pipe (the branch will still be able to convey additional flows), not to mention the additional installation required in the new pumping station However, as mentioned before, recent information from the Ministry of Water and Irrigation revealed that any such additional volumes will be used for irrigation in the highlands and will not reach KTR

9 3 Alternative IRR3a

This alternative conveys water from the Hwaret Weir to the Abu Zeighan canal It accommodates the conclusions that the quality of the river water, does not deteriorate nor is there much gain or loss of water in the reach between the Thahab Weir and the Hwaret Weir

9 3 1 Alternative Description

This alternative includes an intake at the existing Hwaret Weir and, to supply the 4 5 cms flow from Hwaret Weir to Abu Zeighan Canal, a 3 5-km long, 1 4 m ID ductile iron pipe as the conveyance Implementation of this alternative would require the rehabilitation of the Hwaret Weir and its intake and corresponding controls, as well as demolishing, clearing and grubbing works at the weir and along the river close to the intake (weir forebay and river downstream of the weir) Parts of the existing disaffected canal that will block the pipe alignment will also have to be demolished The pipe will cross the river in aqueduct

As in the case of Alternative IRR1, a settling facility was not incorporated at the Hwaret intake based on the information that current consumers along KAC have operating settling basins at the local pumping stations This assumption will have to be verified at the next design phase If the installations at the current consumers prove to have insufficient capacities or if their physical condition is not satisfactory, a settling basin could be implemented at the Hwaret intake If required, this basin will have to have dimensions of 40 m-long, 5 m-wide, 3 5 m-deep and will have to include a flushing path back to the river

At the Abu Zeighan outlet, the pipe will require energy dissipation valves before releasing into the canal For this purpose, two Bailey Polyjet valves were incorporated in a parallel arrangement just upstream of the canal As with the ZC II pipe, the new pipe will be mostly buried and might have viaduct and/or syphon reaches, depending on the selected route **Drawing 3** presents plan views and sections of this alternative For future design activity of this alternative and of corresponding rehabilitation works, a complete survey of the in-situ structures in their current state will be required Such survey will still be necessary even if the as-built drawings of the Hwaret weir and of the conveyance canal are located (at the time of this report, they were not available)

9 3 2 Hydraulic Considerations

A discharge of 4 5 cms was adopted as the design discharge for the conveyance The gross head of this installation between Hwaret Weir and Abu Zeighan Canal amounts to about 56 m Total head losses (friction losses plus a 10 percent addition for local losses) reach some 14 6 m and the valves will have to dissipate 41 4 m of head at the Abu Zeighan landing **Exhibit 9 3** presents the hydraulic parameters of this configuration

9 3 3 Other Considerations

This scheme will not eliminate any losses that might occur in the Zarqa channel between the Thahab and Hwaret Weirs, however, as the reach is considered to show either or both gains and losses, the net result is neutral At the present time, contamination does not seem to represent a problem along this reach

It is also noted that even if additional return flows higher than 2 cms are expected to be discharged in the future upstream of KTD, recent information from the Ministry of Water and Irrigation revealed that this volume will be used exclusively for irrigation in the highlands and will not enter KTR Should however the availability of flows entering KTR increase in the future allowing for requirements growth downstream of the dam along KAC, the selected 1 4 m ID ductile iron conveyance has the capability of transporting up to 5 5 cms (velocity of about 3 5 mps) and the dissipation equipment will only have to be adjusted downwards, which is perfectly feasible with the Bailey valves The intake at Hwaret would have to be sized slightly larger to allow for discharge increases in the future

9 4 Alternative IRR3b

This alternative considers the possibility of constructing a combined conveyance, part canal and part pipe, from the Hwaret Weir to the Abu Zeighan Canal It will provide for the same advantages as IRR3a

9 4 1 Alternative Description

The initial reach of the conveyance is a 1 5 km-long canal that might incorporate rehabilitated portions of the existing canal Visits at the site and examination of the disaffected canal reaches suggested that most of the open conveyance will be a new canal whose construction will also imply the demolishing of the existing structure To supply the 4 5 cms flow to Abu Zeighan Canal, a 2 0-km long, 1 4 m ID ductile iron pipe will connect with the open conveyance in a small forebay serving as the pipe intake and providing vortex protection (a 3-m deep forebay should provide sufficient submergence for the 1 4 m ID pipe) To consider building a canal in this second stretch instead of a closed conduit is a difficult proposition, as it would require the incorporation of at least 10 to 12 drop structures along a 2-km alignment, raising significantly the cost of the alternative The scheme implementation implies the rehabilitation of Hwaret Weir and the intake with the corresponding controls, as well as demolishing, clearing and grubbing works at the weir and along the river close to the intake (weir forebay and river downstream of the weir) The pipe will cross the river in aqueduct, will be mostly buried, and might have additional viaduct and/or syphon reaches, depending on the selected route

Settling facilities were not included at the Hwaret intake as it was assumed that current operating desanders along the KAC have sufficient capacities During final design, this assumption will have to be verified If a desanding basin is required at Hwaret, its configuration will have to include a flushing path back to the river

The pipe flow will require energy dissipation before being released into the Abu Zeighan Canal For this purpose, two Bailey Polyjet valves were incorporated in a parallel arrangement at the canal landing **Drawing 3** presents plan views and sections of this alternative

For future design activity of this alternative and of the corresponding rehabilitation works, a survey of the in-situ structures in their current state will be required Such survey will still be necessary even if the as-built drawings of the Hwaret weir and of the conveyance canal are located (at the time of this report, they were not available)

9 4 2 Hydraulic Considerations

A discharge of 4 5 cms was adopted as design discharge for the combined conveyance

A rectangular section 2 0 m wide by 1 6 m deep was selected for the reinforced concrete-lined canal reach At a slope of 0 12 percent, this canal conveys slightly

more than 4 5 cms with a freeboard of 20 cm At 1 7 mps, the resulting velocity is well below the admissible value for average workmanship concrete The canal drop between the Hwaret Weir and the pipe intakes amounts to about two meters

The gross head for the pipe between intake forebay and the Abu Zeighan Canal amounts to about 54 m, taking into account the canal drop Total head losses (friction losses plus a 10 percent addition for local losses) reach some 8 4 m along the closed conveyance and the Bailey valves will have to dissipate 45 6 m of head at the Abu Zeighan landing **Exhibit 9 4** presents the hydraulic parameters of this configuration

9 4 3 Other Considerations

The implementation of IRR3b could only be promoted after a careful consideration of the potential for contamination of the diverted water in the canal reach from the flowing saline springs and seeps

As for the other alternatives, if additional return flows higher than 2 cms are expected to be discharged in the future upstream of the existing dam, recent information from the Ministry of Water and Irrigation revealed that these volumes will be used exclusively for irrigation in the highlands and will not reach KTR Should, however, the availability of flows entering KTR increase in the future allowing for requirement growth downstream of the dam along KAC, the rectangular canal and the 1 4 m ID ductile iron conveyance have the capability of transporting up to 5 5 cms (under these conditions, in the canal, the velocity would be about 1 8 mps and the freeboard would be reduced to 10 cm, and in the pipe, the velocity would be about 3 6 mps) The dissipation equipment will only have to be adjusted downwards, which can be done with the Bailey valves The intake at Hwaret will have to be sized slightly larger to allow for future discharge increases

9 5 Alternative POW

Power addition could be considered for configurations that incorporate closed conduits, provided that head is high enough to justify an installation In order to take advantage of the full 120 m gross head between the settling basin take-off at the Thahab Weir and the Abu Zeighan location, power addition was considered for IRR1 A reregulating pond also is incorporated into this alternative

9 5 1 Alternative Description

The conveyance alignment for the power addition alternative is similar to that of the pipe in Alternative IRR1 The conveyance for this alternative has to be a penstock built out of pressure vessel malleable steel The penstock will convey water to the powerhouse which will be located near the Abu Zeighan Weir From the powerhouse, water will be discharged into a reregulating pond and diverted into the Abu Zeighan Canal

The size of the penstock (2 0 m ID) is dictated by conveyance efficiency requirements within the power scheme Iron ductile pipes with internal diameters larger than 60" (1 52 m ID) are only available as a special order from major manufacturers contacted in Amman and, consequently, are intuitively more expensive

The power addition plant will be equipped with two vertical-shaft Francis turbines direct connected to generators each with a total installed capacity of 3 5 MW, slightly larger than the ones currently operated at the King Talal Plant (those are horizontal shaft, but for the new plant, powerhouse pit excavation requirements will probably be much more significant in order to reach rock, and a vertical shaft unit will fit better)

The new plant is located immediately before the Abu Zeighan Weir (some 150 m upstream of the weir), on the bank of the re-regulating pond The tailrace will have to be properly submerged against the minimum operating level of the pond The re-regulating pond at the Abu Zeighan site will be provided with a spillway large enough to release the Zarqa River design floods that constituted the design criteria for the Abu Zeighan Weir The pond will retain only fresh water discharged through the tailrace and shift the flows for the irrigation purpose to a daily cycle To control water quality for irrigation, low and average Zarqa River flows will be diverted around the pond Only Zarqa River floods will discharge into the pond, with the understanding that irrigation requirements will be minimal during the floods period and that river flows will be less contaminated then Annual maintenance and cleaning will be required in order to preserve the pondage at the new powerplant tailrace **Drawing 5** presents plan views and sections of this alternative

9 5 2 Hydraulic Considerations

As noted previously, the objective of the power addition was to implement a new power installation at Abu Zeighan in the order of magnitude of the existing plant at KTD for a cascade operation Taking into account a flow travel time between KTD and the new plant of some 5 to 6 hours, cascade operation will cover more time during the day at higher capacity and improve the attractiveness of the whole power installation For this reason, the availability of a design discharge of 7 5 cms was contemplated (higher that the 6 4 cms design discharge at KTD, to account for head losses along the 7 km headrace pipe) To satisfy the 2 5 cms to be diverted through the carriers, a maximum instantaneous release of about 10 cms from KTD will be required It was assumed that such releases could be available with enough reliability to suit power generation only under the assumption of a maximum future M&I return flow of 3 5 cms on a monthly basis, added to the historical inflow of Zarqa River into KTR With the intake at Thahab, the new plant will operate under a gross head of 121 5 m For a 2 0 m ID, 7 km-long steel conveyance, head losses amount to 11 1 m for a good waterway efficiency of 90 percent (a 1 6 m ID structural steel pipe would operate with an unacceptable waterway efficiency of maximum 70 percent, without offering significant cost advantages) The resultant plant capacity is about 7 MW It could be provided in two 3 5-MW units or three 2 33-MW units A two-unit configuration was estimated at this time **Exhibit 9 5** presents the hydraulic parameters of this configuration

9 5 3 Other Considerations

This alternative is attractive only if it operates in cascade with the existing King Talal power facility for a total generating time of 10 to 12 hours per day at close to the installed capacities At a monthly average of 3 5 cms additional inflow into KTR, reservoir operation studies have shown that the period of time without shortage in design discharge at the new plant can be as high as 85 percent This type of operation could make the power addition attractive, especially when compared to the savings in fuel cost

Alternative power arrangements were considered but always at lower installations and with unacceptable headrace pipe efficiencies They included

(a) using a 7 km-long conveyance pipe made of structural steel with 1 6 m ID for the 7 5 cms design discharge This installation would result in a power development of 5 6 MW at Abu Zeighan, for a waterway efficiency of 70 percent and a total plant efficiency at a low value of 63 percent The savings in pipe costs will not improve the unit cost of the plant due to the reduction in the installed capacity,

(b) installing a 7 km-long ductile iron pipe with 1 52 m ID (60" pipe is readily available) resulting in a 7 5 cms design discharge This installation would result in a power development of 3 5 MW at Abu Zeighan, with an unacceptable waterway efficiency of 44 percent and total plant efficiency of 40 percent The scale of this development is unlikely to make the project attractive,

(c) installing a 7 km-long ductile iron pipe with 1 52 m ID (60"), for a 4 5 cms design discharge that also represents the irrigation requirements This installation results in a power development of 4 3 MW at Abu Zeighan, for a total plant efficiency of 71 percent (80 percent waterway efficiency)

The alternative described under (c) could be developed as an addition to the irrigation scheme, operated according to the irrigation requirements schedule In this case, the tailrace could discharge directly into the Abu Zeighan Canal and the re-regulating pond, river by-pass canal and spillway, as well as the Bailey valves arrangement at the landing, will become unnecessary Also, no conveyance costs will affect the power component cost However, the scale of this development would still imply high unit costs for power (due to the costs of the equipment in the powerhouse and switchyard, and of the irrigation by-pass facilities), especially when the installation is a secondary user generating in the irrigation regime

At this conceptual stage, all three above alternatives were discarded in favor of the larger 7 MW development that will have the ability to operate in cascade with the existing plant at KTD and take full advantage of potential growth in the return flows inflowing into KTR

10 SELECTION OF PROPOSED DEVELOPMENT

This chapter provides a comparison of the alternatives selected for conceptual design The comparison is based on the overall costs and the operation and maintenance costs cost of the alternatives plus a consideration of the implementation time, volume of water saved, quality of water delivered, power generated, and an initial assessment of environmental impacts

10 1 Estimated Overall Cost of Alternatives

The overall cost of the alternatives was estimated using materials quantities and unit prices Quantity measurements were done for all alternatives on major civil works Following principal items were measured

- Clearing and grubbing
- Unclassified excavations
- Backfill with selected materials
- Mass concrete
- Reinforced concrete (Class A, Class B, according to the Jordanian classification for all civil works, except the powerhouse in the power alternative)
- Structural concrete (substructure and superstructure, for the powerhouse)
- Reinforcing steel
- Structural steel (powerhouse superstructure frame)
- Steel plate (rolled and welded, for penstock construction)
- Gates, trashracks

Unit prices for civil works items were determined based on values used in recent projects (mid - 1995) at final design stage or built in Jordan There was no attempt at this stage to perform cost analyses based on material, labor, and equipment cost components, or to consider any contractor's related markups Quotations from manufacturers were used for pipeline and for the electro-mechanical equipment, as follows

- Ductile iron pipe, cement lined, various ID's
- Pipe accessories
- Turbines and governors
- Inlet valves, cranes
- Powerhouse mechanical systems
- Generators and transformers
- Controls and switchyard equipment
- Miscellaneous electrical equipment
- Plant by-pass equipment
- Dissipation valves and accessories
- Pumping station equipment

Some civil works, including demolishing, rehabilitation, cofferdamming, controls, and headwork in general (at both Thahab and Hwaret intakes), were reflected as lump sums These global price representations were checked by evaluating major quantities that were involved in the corresponding works

The quantities of works and of equipment were multiplied by the unit prices to obtain item construction costs A 12 percent contingency was added to the sum of item costs to yield the total construction costs

Total construction costs for the alternatives estimated, together with the major component costs, are summarized in the **Table 10 1**

TABLE 10 1

SUMMARY OF CONSTRUCTION COSTS
(Jordan Dinars)

Works	ALT IRR1	ALT IRR2	ALT IRR3a	ALT IRR3b	ALT POW
Headwork	0 033	0 204	0 136	0 136	0 277
Conveyance (Pipeline)	5 522	1 708	2 786	1 626	—
Conveyance (Canal)	—	—	—	0 365	—
Conveyance (Penstock)	—	—	—	—	7 365
Pumping Station	—	1 624	—	—	—
Powerhouse	—	—	—	—	4 564
Outlet and Reg Pond	0 818	0 818	0 818	0 818	1 548
Construction Cost (J D)	7 20	4 90	4 20	3 30	15 4
Construction Cost ($US)	10 75	7 31	6 27	4 93	23 0

Exhibits 10 1 to 10 5 present the detailed bills of quantities and cost schedules for the five alternatives

10 2 Operation and Maintenance Costs

The operation and maintenance cost was estimated on the basis of experience percentages applied to the construction cost Although IRR3b has a lower capital cost, its arrangement is more complicated and it extends over the same distance as IRR3a Therefore, it was estimated to have a slightly greater O&M cost than IRR3a Pumping costs were estimated at JD 0 015/kWh Estimates of O&M by alternative are presented below

Alternative	Annual O&M Cost (JD)
IRR1	100,000
IRR2	134,000
IRR3a	56,000
IRR3b	41,000
POW	191,000

10 3 Implementation Plan

Implementation of any of the alternatives will require time for the following activities funding, design and preparation of bid documents, award of contract, and construction

The funding requirements are relatively minor and the MWI has already indicated that the funds could be made available from internal sources if no other source is readily available It is estimated that this activity will take from one to two months after completion of a feasibility report

The design and contract document preparation for the four irrigation alternatives will take about four months for alternatives IRR1, IRR3a, and IRR3b The pumping station for IRR2 will lengthen the design stage to about six months Design of the Power alternatives will require about nine months Prequalification of bidders will be relatively easy as it is expected that the facilities will be constructed by a local contractor This prequalification can be performed during the design stage and will require no extra time

Bid preparation, evaluation, and award will require about two months for all alternatives

The construction for the four non-power alternatives will require 10 to 14 months depending on the delivery time for the pipe IRR2, because of the pumping station will take a little longer The power alternative will take from two to three years again depending on the delivery schedule for the generation equipment

Alternative	Implementation Period (Months)
IRR1	18
IRR2	24
IRR3a	18
IRR3b	18
POW	44

10 4 Total Annual Volume of Water Saved

In the reach of river between Thahab Weir and the Hwaret Weir, it is concluded that either gains or losses could occur but that the quantity of water gained or lost is insignificant The gains and losses measured for this reach are not significant in a statistical sense because they are within the limits of accuracy of the measurement devices It is thought, based on the field programs and the results of the geologic and hydrogeologic studies, that there probably are both gains and losses that occur at different times in the year If this is the case then, it can be postulated that neither the gains or the losses impact on the pipeline that begins at the Thahab Weir, that the losses in the reach will not be collected by a pipeline starting at the Hwaret Weir, and

that the gains in the reach will be collected by a pipe at the Hwaret Weir Therefore, there is no advantage to starting the pipe at the Thahab Weir from the standpoint of water savings and, in fact, there might be a small disadvantage

In the reach of river between the Hwaret Weir and the Abu Zeighan Weir, it is concluded that losses might reach about 10% or 15% of the flow in the river These losses are more likely to occur in the low flow summer months Under the condition of 1 0 cms of return flow to the historical streamflow, the flow in the Zarqa River below Thahab Weir averages about 1 5 cms or about 47 MCM/yr The volume of water saved, therefore amounts to between five and seven million cubic meters per year The lower value is selected as more representative of the actual loss

10 5 Quality of Water Delivered

There is no deterioration of quality in the reach between the Thahab Weir and the Hwaret Weir Therefore, all alternatives will provide the same quality of water delivered to the Abu Zeighan Canal

10 6 Total Annual Generated Power

The addition of power is technically feasible for alternatives which are comprised of new facilities (IRR1, IRR3a, and IRR3b) IRR2 makes use of a portion of the Zarqa Carrier II which is not constructed of a material suitable for use as a penstock For Alternative IRR1, and installation of 7 0 MW would result in the generation of about 20 Gwh of electricity If power were added to IRR3a and IRR3b, the installed capacity would be about 3 0 MW and the average annual power generation would be about 9 Gwh

10 7 Initial Assessment of Environmental Impacts

The environmental benefits of all the feasible conveyance alternatives will be equivalent These benefits will be considerable and will accrue to irrigated agriculture along the KAC downstream of the junction with the Abu Zeighan Canal as a result of the improvement in the quality of water in the canal

The potential negative environmental impacts of all the feasible conveyance alternatives are largely dependent on the point of the flow diversion (Thahab or Hwaret Weir) and the amount of construction required for each alternative These negative impacts will occur in four areas 1) the Zarqa River channel from Thahab or Hwaret Weirs downstream to Abu Zeighan Weir, 2) in and adjacent to the pipeline (or canal) corridor in the Zarqa River valley in the area from Thahab or Hwaret Weirs to Abu Zeighan Weir, and 3) in and adjacent to the Zarqa River channel downstream from Abu Zeighan Weir The major impacts to natural resources will be from loss of flow and changes in water quality in the segment of the Zarqa River between Thahab Weir and Abu Zeighan Weir Social and cultural resources will be affected primarily in the area of the pipeline corridor and, in addition, there may be effects on water use along the Zarqa both upstream and downstream from Abu Zeighan Weir

Major economic impacts will be in the irrigated area and should be largely positive, however, there may be adverse economic effects due to changes in water quality downstream from Abu Zeighan Weir and on water users along the left (south) bank of the Zarqa along the segment affected by the diversion

10 7 1 Present Situation (No-action Alternative)

Presently (under the no-action alternative), flows of up to 2 8 cms (maximum combined flow for ZC I & II) are diverted from the Zarqa at Thahab Weir Flow in excess of the irrigation requirement for ZC I & II is passed at Thahab Weir and continues downstream approximately 9 5 km to the Abu Zeighan Weir where it is diverted, via the Abu Zeighan Canal, to the KAC The present diversion affects the Zarqa River between Thahab Weir and the Jordan River (a distance of approximately 27 km) Because water is released from King Talal Dam (KTD) to support irrigation, flows in the Zarqa River rarely exceed the quantity required for the irrigation diversions at Thahab and Abu Zeighan Weirs Thus, the present situation involves diversion of virtually all flows released at KTD from the 17 km river segment below Abu Zeighan Weir

The river segment from Hwaret Weir to Abu Zeighan Weir is affected by year-round spring inflows, some of geothermal origin The inflow from springs in this segment has a high salinity (approximately 5,000-10,000 mg/L) Appreciable inflows begin to occur approximately 1 3 km below Hwaret Weir Total flow accumulation at Abu Zeighan Weir is 150-300 l/s from springs in the segment below Hwaret Weir Due to their highly saline nature, the springs adversely affect water quality in the KAC during periods when flow below the Thahab Weir is relatively low and when water in the KAC upstream from the Zarqa River is diverted to Amman for municipal and industrial use

To limit the effect of the saline springs on the water diverted into the KAC, the JVA has channelized the streambed, dividing it into two separate channels, for a distance of approximately 2 1 km above Abu Zeighan Weir This measure partially separates saline spring inflows from the fresh water flowing downstream from KTD Upstream from the channelized area, the sources of saline inflow are too widely dispersed over the width and length of the channel to separate them from the freshwater flow Thus, the main channel carries a mixed saline and freshwater flow to the entrance of the Abu Zeighan Canal The secondary channel diverts approximately 25-40% of the saline inflow (about 80 l/s) over the Abu Zeighan Weir to continue downstream

Channelization of the river above Abu Zeighan Weir was done in response to problems with salinity in KAC that occurred during 1993 and 1994 Prior to channelization all flow was diverted to KAC at Abu Zeighan Weir Adoption of the no-action alternatives would thus result either in a release of approximately 80 l/s of saline water immediately below Abu Zeighan or in no release, depending on whether channelization is continued in the future

Due to its partial origin as municipal and industrial return flows from the Khribet As-Samra wastewater treatment plant, water flowing downstream from KTD is somewhat enriched with nutrients and has a relatively high Biological Oxygen Demand Water quality data collected during the summer of 1994[1] allow a comparison between the quality of water in the KAC near Sawalha, which is representative of water quality in the relatively unpolluted Yarmouk River, and the quality of water from the Zarqa River at Thahab Weir The concentration of ammonia nitrogen (NH_4) averaged 7 0 mg/l at Thahab Weir vs 0 1 mg/l in the KAC, nitrate nitrogen (NO_3) averaged 32 mg/l in the Zarqa and 12 5 mg/l in the KAC, and BOD_5 averaged 23 mg/l in the Zarqa and 6 mg/l in the KAC Total coliform bacteria counts, however were similar in the Zarqa at Thahab Weir and in the KAC near Sawalha[2,3]

Enriched water released at KTD is subjected to aeration in the 13-km segment between KTD and Thahab Weir Additional aeration of water intended for KAC occurs in the 9 5-km reach between Thahab Weir and Abu Zeighan Weir The water quality benefit of additional aeration between Thahab and Abu Zeighan Weirs is relatively small The reduction in average BOD_5 was 3 mg/l (13%) between Thahab and Abu Zeighan Weirs during summer 1994 Biological activity and with spring inflows (dilution) may further affect nutrient levels Ammonia was reduced by 4 8 mg/l (68%), however, nitrate increased by 6 mg/l (19%) Fecal coliform bacteria levels typically increased between Thahab and Abu Zeighan Weirs, possibly due to use of the stream channel for grazing, while total coliform bacteria levels typically decreased slightly

10 7 2 Construction Effects

The likely pipeline alignments pass through largely agricultural areas and will be located in or adjacent to previously disturbed areas (such as roads and existing pipeline corridors) thereby minimizing disruption of natural and agricultural areas during construction Because the corridor for all alternatives will be adjacent to existing roads, no construction of access roads is required The corridor width will be approximately 10 m (12 m for alternative POW) Construction of river crossings is likely to create the greatest disturbance of natural areas by disrupting the riverbed and creating the potential for erosion and siltation in the channel Known cultural

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1 Water and Environment Research and Study Center - University of Jordan 1995 Irrigation management & water quality in the Central Jordan Valley (Baseline Survey) Water Quality Improvement and Conservation Project Report 3114-95-3b-05

2 Water and Environment Research and Study Center 1995 Ibid

3 Irrigation Support Project for Asia and the Near East and Water and Environment Research and Study Centre University of Jordan 1994 Irrigation management and water quality in the Central Jordan Valley winter cropping season

resources (antiquities - ruins) are located well away from the corridor alignments Proposed alignments do not affect any buildings Dust, noise and traffic will affect nearby areas at a level commensurate with the length of the conveyance (pipeline or canal) corridor An additional potential construction impact on socio-economic conditions is the possible disruption of service to users of water from ZC II during construction of a pipeline bifurcation and pumping station

Alternative IRR1 will have the longest corridor of the irrigation alternatives, approximately 7 km, and will require up to five river crossings Intake modifications will be required

Alternative IRR2 will have a corridor approximately 2 0 km long and will require one river crossing Additional desanding capacity will have to be added at the upstream end of the pipeline Users of ZC II will likely experience a one-season period of disruption of service during construction of the pipeline bifurcation and interconnection to the booster pumping station downstream from the bifurcation

Alternatives IRR3a and IRR3b will have corridors approximately 3 5 km long and will follow the same alignment These alternatives will require two river crossings Rehabilitation of Hwaret Weir will be required for both alternatives, thus requiring disruption of the streambed and use of land for construction lay-down areas in the vicinity of the present weir No desanding facilities are contemplated, thus occupation of additional land area for operation of these alternatives will not be required

Alternative POW, which is a power addition to IRR1, has the same corridor length of seven kilometers and a more extensive modification to the existing intake potentially increasing any period of disrupted service on ZC I & II POW will require expansion of the desanders and construction of a re-regulating reservoir at its downstream end POW will thus require the greatest land area for construction and will occupy much more land area during operation than will IRR1

Table 10 2 presents potential effects of construction and operation of the project on land use in the affected area Most agricultural areas affected during construction will lost to production for the growing season Cultivation on land over the pipeline can be conducted following construction

Table 10 2

Effects of Construction of Feasible Alternatives

Effects of Construction of Feasible Alternatives on Land Use					
Feasible Alt	Loss of Cultivated Land (maximum dunums)		Non-Cultivated Land Required (dunums)	New River Crossings	One-Season Irrigation Interruption (max dunums)
	Temporary (One Season)	Permanent (Project Lifetime)			
IRR1	70	0	0 2 (desander)	5	None
IRR2	20	0 3 (Booster Pump Station)	0 2 (desander)	1	ZC II Command Area
IRR3a	35	0	0	2	None
IRR3b	35	0	0	2	None
POW	84	0	0 3 (desander) ~50 (reservoir)	5	None
no-action	0	0	0	0	None

10 7 3 Operation Effects

All alternatives will have a major beneficial impact on irrigated agriculture served by the KAC In terms of impacts relative to the no-action alternative, all options will produce equivalent positive benefits to irrigated agriculture along the KAC

Negative impacts will largely result from changes in water quantity and water quality in the stream channel between Thahab Weir and Abu Zeighan Weir These will primarily affect the natural aquatic and riparian communities of the Zarqa A potential loss of irrigation water for farms on the left (south) bank of the river must also be considered (at least three irrigation withdrawals occur between Thahab and Abu Zeighan Weirs) Effects on water quantity and water quality in the Zarqa River downstream from Abu Zeighan Weir will be equivalent for all alternatives and will result in somewhat higher flows than presently occur in that river segment Effects on salinity of water in the river segment below Abu Zeighan have not been determined at this time

<u>Impact on Aquatic and Riparian Habitat</u> The major impact of operation will be potential dessication of the streambed for some distance downstream from the intake structure for each conveyance alternative Presently, the natural riparian and streambed vegetation includes plant species adapted to wet, or frequently wet conditions These are dominated by oleander, tamarix, sedge (Juncus), and common reed Some plant species, such as oleander, are highly tolerant of brackish conditions Aquatic communities present in the river are well-developed and include amphibians (frogs), freshwater crab, fish (probably), aquatic insects and microcrustaceans, and

algae It should be noted that enriched water present in the river probably affects the density and types of vegetation and the aquatic community - reducing diversity somewhat and increasing densities of species adapted to eutrophic conditions

In the area affected by saline inflows, the diversity of the riparian vegetation and aquatic community are reduced to species tolerant of brackish conditions In this area, channelization of the streambed has occurred further disrupting the natural communities The area of saline inflows is also subject to increased human pressure from livestock grazing on vegetation in and adjacent to the stream channel

Birds use the riparian vegetation for cover, foraging and, for some species, nesting habitat Kingfishers and herons feed directly on fish, crabs and amphibians Mammals in the area may use the river as a water source Diversity and density of plant species and the associated bird community will likely be reduced by loss or reduction of streamflow The aquatic community will be altered significantly or extirpated from segments affected by continuous flow diversion The length of streambed affected by the various options is a useful indicator of the relative magnitude of impacts associated with each alternative

Alternatives IRR1, IRR2 and POW will affect approximately 9 5 km of river channel between Thahab and Abu Zeighan Weirs There are at least three irrigation withdrawals along the left bank of the river in this segment Approximately 6 2 km can be described as brackish habitat The freshwater habitat will be affected significantly by dessication and appreciable reduction of habitat is expected Effects on the brackish habitat will be less pronounced as inflow from saline springs will be maintained, however, transitional freshwater-brackish habitat will be lost and salinity will increase in remaining habitat Compared to present conditions, channelization of 2 0 km of the streambed will no longer be necessary and more natural riparian and aquatic community, adapted to brackish conditions, may develop Alternative POW will involve use of hydro-electric peaking releases from KTD This will subject an additional 13 km of stream channel above Thahab weir to the effects of more frequent, higher magnitude fluctuations in flow This will subject the riparian and aquatic community upstream to scouring and dessication on a short term basis

Alternatives IRR3a and IRR3b will affect approximately 4 7 km of river channel between Hwaret and Abu Zeighan Weirs There are at least two irrigation withdrawals along the left bank of the river in this segment Approximately 1 3 km can be described as freshwater habitat and the remainder as brackish The freshwater habitat will be affected significantly by dessication, and appreciable loss of habitat is expected Effects on the brackish habitat will be less pronounced as inflow from saline springs will be maintained, however, transitional freshwater-brackish habitat will be lost and salinity will increase in remaining habitat Compared to present conditions, channelization of 2 0 km of the streambed will no longer be necessary and a more natural riparian and aquatic community, adapted to brackish conditions, may develop

Impacts on water use and water quality in the area below Abu Zeighan Weir will be similar for all alternatives Negative impacts of alternative POW on natural riparian and aquatic communities of the Zarqa River will be greatest (approximately 6 5 km of freshwater habitats will be lost and 13 km will be affected by increased flow fluctuations) IRR1 and IRR2 will have somewhat less impact (approximately 6 5 km of freshwater habitats will be lost) IRR3a and IRR3b will have the least negative impact (approximately 1 7 km of freshwater habitats will be lost)

Effects on Water Quantity All the feasible alternative involve provisions for diversion of up to an additional 4 5 cms (7 5 cms for POW) from the Zarqa River Alternative IRR1, IRR2 and POW will divert all water at Thahab Weir, thus diverting flows up to 7 3 cms (2 8 cms for ZC I & II plus 4 5 cms for new pipeline) from the Zarqa River Alternatives IRR3a and IRR3b involve diversions at both Thahab Weir and Hwaret Weir Under these related alternatives, flows up to 7 3 cms will be diverted from a segment approximately 4 7 km in length (Hwaret to Abu Zeighan) and flows up to 2 8 cms will be diverted by ZC I & II from a segment 4 8 km in length (Thahab to Hwaret) Inflow from springs in the reach between Thahab and Hwaret may occur but is not believed to be appreciable The effect of the alternatives on flow below the Thahab Weir are summarized in **Table 10 3**

Table 10 3

Effects of Feasible Conveyance Alternatives on Zarqa River flow below Thahab Weir			
Feasible Alternative	**Thahab to Hwaret (4 8 km)**	**Hwaret to Abu Zeighan (4 7 km)**	**Downstream from Abu Zeighan (17 km)**
IRR1	No Flow[1]	No Flow upstream 1 3 km - Spring Inflows downstream	100% of Spring Inflows (200-300 l/s)
IRR2	No Flow	No Flow upstream 1 3 km - Spring Inflows downstream	100% of Spring Inflows (200-300 l/s)
IRR3a	KAC Irrigation[2]	No Flow upstream 1 3 km - Spring Inflows downstream	100% of Spring Inflows (200-300 l/s)
IRR3b	KAC Irrigation	No Flow upstream 1 3 km - Spring Inflows downstream	100% of Spring Inflows (200-300 l/s)
POW	KAC Flow	No Flow upstream 1 3 km - Spring Inflows downstream	100% of Spring Inflows (200-300 l/s)
no-action	KAC Irrigation	KAC Irrigation	0% or 25-40% of Spring Inflows (0 or ~80 l/s)

Notes 1 Flow reaching Thahab is not expected to exceed total irrigation requirement for ZC I + ZC II + KAC unless significant runoff from rainfall is occurring
2 Flow passed at Thahab after requirement for ZC I + ZC II (≤2 8 cms) is satisfied

When compared to the no-action alternative, all conveyance alternatives are expected to result in a slight reduction of the quantity of flow reaching the KAC This quantity would be equivalent to the saline inflow that mixes with water from KTD in the reach between Hwaret and Abu Zeighan

Effect on Water Quality Water quality in the river segment(s) affected by flow diversions will be less subject to the influence of dilution by water from upstream, and thus, will be controlled by inflows from springs in the river channel Any inflows from springs in the segment between Thahab Weir and Hwaret Weir are probably of low salinity, however, the volume of is likely negligible Therefore, water quality is probably of little consequence in the absence of appreciable inflow

Springs in the reach between Hwaret and Abu Zeighan Weirs vary in salinity, however, the combined springflow is brackish with a potential salinity range of 5,000-10,000 mg/l This reach will see increasing inflows of saline water beginning about 1 3 km below Hwaret Weir and reaching about 100-300 l/s immediately upstream from Abu Zeighan Weir Although brackish, the water contributed by the springs is not affected by nutrient enrichment

Mixing with spring inflows and additional opportunity for aeration and biological processing of water in the reach between Thahab and Abu Zeighan will not occur The conveyance alternatives may thus cause slight increases (to levels similar to those at Thahab Weir) in nutrient levels and BOD of water delivered to KAC for irrigation Energy dissipation of water leaving the pipeline at Abu Zeighan canal will probably result in vigorous aeration, thus reducing BOD The expected difference in water quality in the KAC between present (no-action) conditions and any of the conveyance alternatives should not be appreciable The effect of the alternatives on water quality is presented in **Table 10 4**

Table 10 4

Effects of Feasible Alternatives on Zarqa River Water Quality below Thahab Weir				
Feasible Alternative	**Thahab to Hwaret (4 8 km)**	**Hwaret to Abu Zeighan (4 7 km)**	**Downstream from Abu Zeighan (17 km)**	**Irrigated Area (KAC below Abu Zeighan Canal)**
IRR1	Not Applicable[1]	Increased salinity, reduced nutrients	Potential salinity change (+ / -)	Decreased salinity, Increased? nutrients
IRR2	Not Applicable	Increased salinity, reduced nutrients	Potential salinity change (+ / -)	Decreased salinity, Increased? nutrients
IRR3a	No Change[2]	Increased salinity, reduced nutrients	Potential salinity change (+ / -)	Decreased salinity, Increased? nutrients
IRR3b	No Change	Increased salinity, reduced nutrients	Potential salinity change (+ / -)	Decreased salinity, Increased? nutrients
POW	Not Applicable	Increased salinity, reduced nutrients	Potential salinity change (+ / -)	Decreased salinity, Increased? nutrients
no-action	No Change	No Change	No Change	No Change

1 Due to lack of flow, water quality effects are not considered
2 Water quality is expected to be unchanged from pre-project conditions See text for description of those conditions in each stream segment

10 7 4 Order of Preference for Feasible Alternatives

With respect to their potential environmental effects, Alternatives IRR3a and IRR3b are preferred as having lower potential for adverse impacts during construction and operation of the project than other feasible alternatives Alternative IRR1 will have less impact due to construction than IRR2 and similar impacts during operation, thus it is considered second in preference, followed by IRR2 Alternative POW is the least preferred due to hydro-peaking effects on the Zarqa River above Thahab Weir To assist in the comparison among alternatives, they have been qualitatively ranked according to the initial assessment IRR3a and IRR3b have been ranked evenly and relatively the best IRR1 has been ranked next, followed by IRR2 and POW

10 8 Evaluation of Alternatives

Selection of the alternative(s) for subsequent study at the feasibility phase was based on a consideration of the selection parameters discussed in the previous sections These parameters are summarized in Table 10 5

All of the alternatives are equal with respect to meeting the objectives of the study, i e they all save an equal amount of water and they all result in the same quality of water delivered to the King Abdullah Canal On the basis of all other parameters considered, IRR3a and IRR3b appear to the most attractive followed by IRR1, IRR2, and POW

IRR3b, which includes a 1 5 km reach of open, lined canal is slightly less costly than IRR3a, from a capital standpoint, however, it has some disadvantages Alternative IRR3b incorporates a stretch of open conveyance is expected to require constant maintenance to keep the canal in proper operating condition (the current physical condition of the existing canal that begins from the Hwaret Weir is a clear example of what can happen to an open conveyance when maintenance activities are neglected or minimized) This maintenance is reflected in the O&M cost for the alternative Also, losses and contamination effects that have been previously detected in the river reach from Hwaret to Abu Zeighan, might affect the lined canal through the expansion joints Both IRR3a and IRR3b are retained, however, it is noted that both alternatives are contingent upon the successful rehabilitation of the Hwaret Weir

IRR2 is the more cost effective of the two options that begin at the Thahab Weir on the basis of a cost analysis which compared the next present values of the capital and annual costs However, from the standpoint of the implementation period and the environmental ranking, IRR1 is superior IRR2 has the further disadvantage that the ZC II pipeline would be out of service for a period during construction (or a bypass arrangement would have to be constructed at a significant cost) The ZC II pipe could also be out of service during any protracted maintenance of the pumping station It is concluded that IRR1 is a more practical solution to the problem and even though it is more costly, IRR1 is retained and IRR2 is rejected

IRR1 is less attractive than either of the IRR3 options on the bases of all parameters, however its implementation can be accomplished within the present framework of information Because the IRR3 options are contingent upon the successful rehabilitation of the Hwaret Weir, which cannot be assumed until further study is performed, IRR1 also is retained

Alternative POW is rejected on the basis of preliminary economic analysis, the duration of the implementation period, and its environmental ranking The economic analysis consisted of a life-cycle analysis using a 10 percent interest rate, a 30-year period of analysis, and a value of energy and capacity of 27 fils/kWh and JD 630/kW respectively

Table 10 5

Comparison of Alternative

Parameter	IRR1	IRR2	IRR3a	IRR3b	IRR1 w/ power
Overall Cost (JD thousand)	7,200	4,900	4,200	3,300	15,400
O&M Cost (JD thousand)	91	131	51	60	167
Implementation Period (Years)	1 5	2	1 5	1 5	3 7
Annual Volume of Water saved (MCM/yr)	5-7	5-7	5-7	5-7	5-7
Quality of Water Delivered to KAC	fair	fair	fair	fair	fair
Average Annual Energy - GWh	N/A	N/A	N/A	N/A	20
Environmental Ranking	2	3	1	1	4

The preferred alternative is IRR3a It is a low cost, low maintenance option that is relatively easy to construct and which will provide a dependable solution to the problems of water loss and water quality deterioration Alternative IRR1 also is an acceptable alternative to be considered if problems arise with the concept of diverting at the Hwaret Weir

11 CONCLUSIONS AND RECOMMENDATIONS

As a result of the studies described in the preceding sections, it is concluded that

1 All alternatives provide for the same quantity of water saved and result in the delivery of the same quality of water to the King Abdullah Canal

2 The IRR3 options are the least costly, require the shortest period to implement, and have the least adverse environmental impact

3 IRR3a, which is a buried pipeline, is the preferred option because, although slightly more costly, it will be a more secure option, will require less maintenance activity than IRR3b which includes an open canal reach, and has the least chance of permitting contamination of the diverted flows by saline inflow

4 IRR1 should be retained for further study because, although more expensive than either of the IRR3 options, the IRR3 options require a confirmation that the Hwaret Weir can be economically rehabilitated

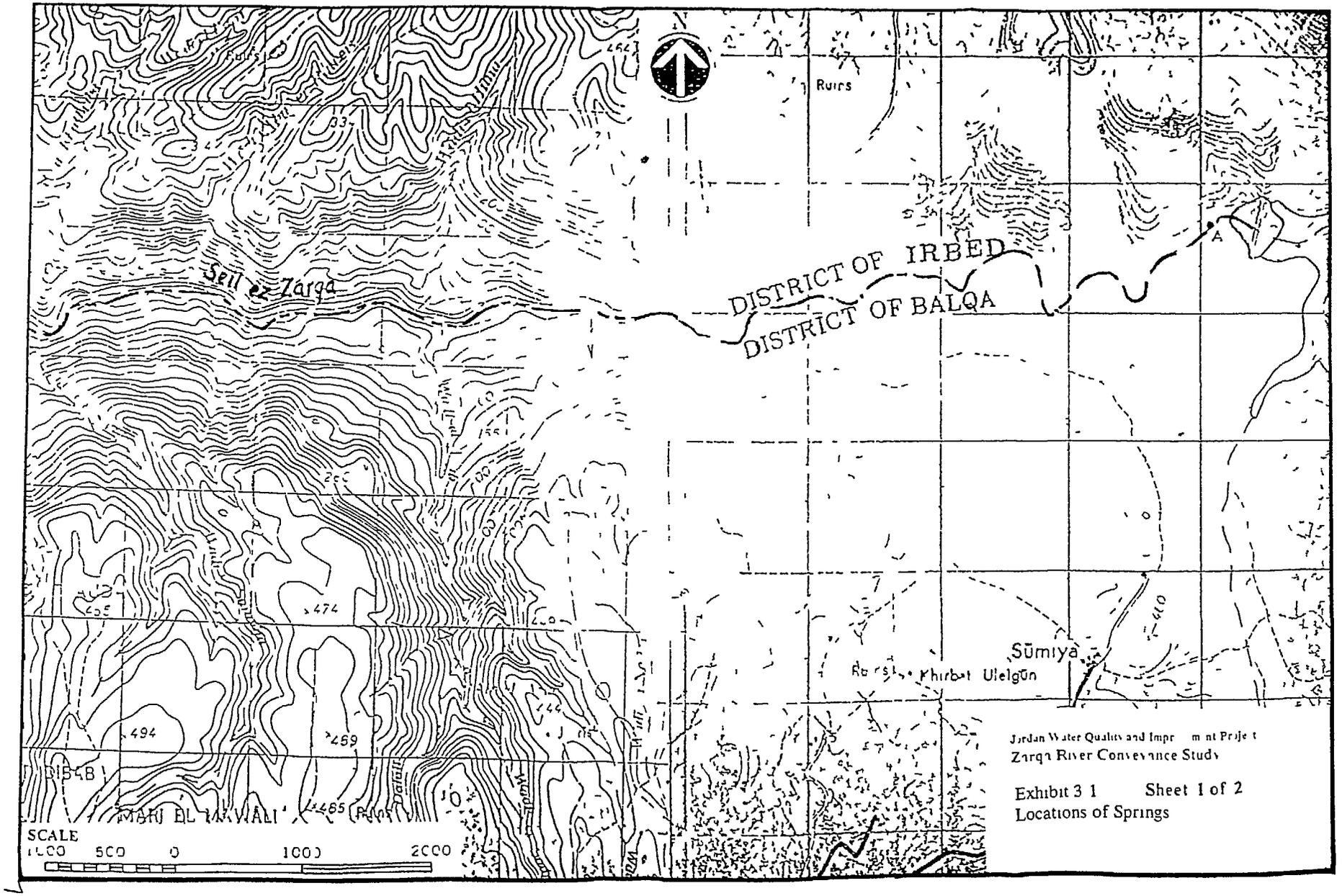
5 IRR2 should be rejected in favor of IRR1 because it is a less practical solution and will cause disruption of service to the ZC II service area

6 Alternative POW should be rejected on the basis of cost, adverse environmental impact, and a lengthy implementation period

Based on these conclusions, it is recommended that

1 IRR3a, IRR3b, and IRR1 be retained for further study in the feasibility study
2 The decision not to include desanding facilities as a part of the IRR3a and IRR3b Project Concepts be confirmed

EXHIBITS



Jordan Water Quality and Impr m nt Proje t
Zarqa River Conveyance Study

Exhibit 3 1 Sheet 1 of 2
Locations of Springs

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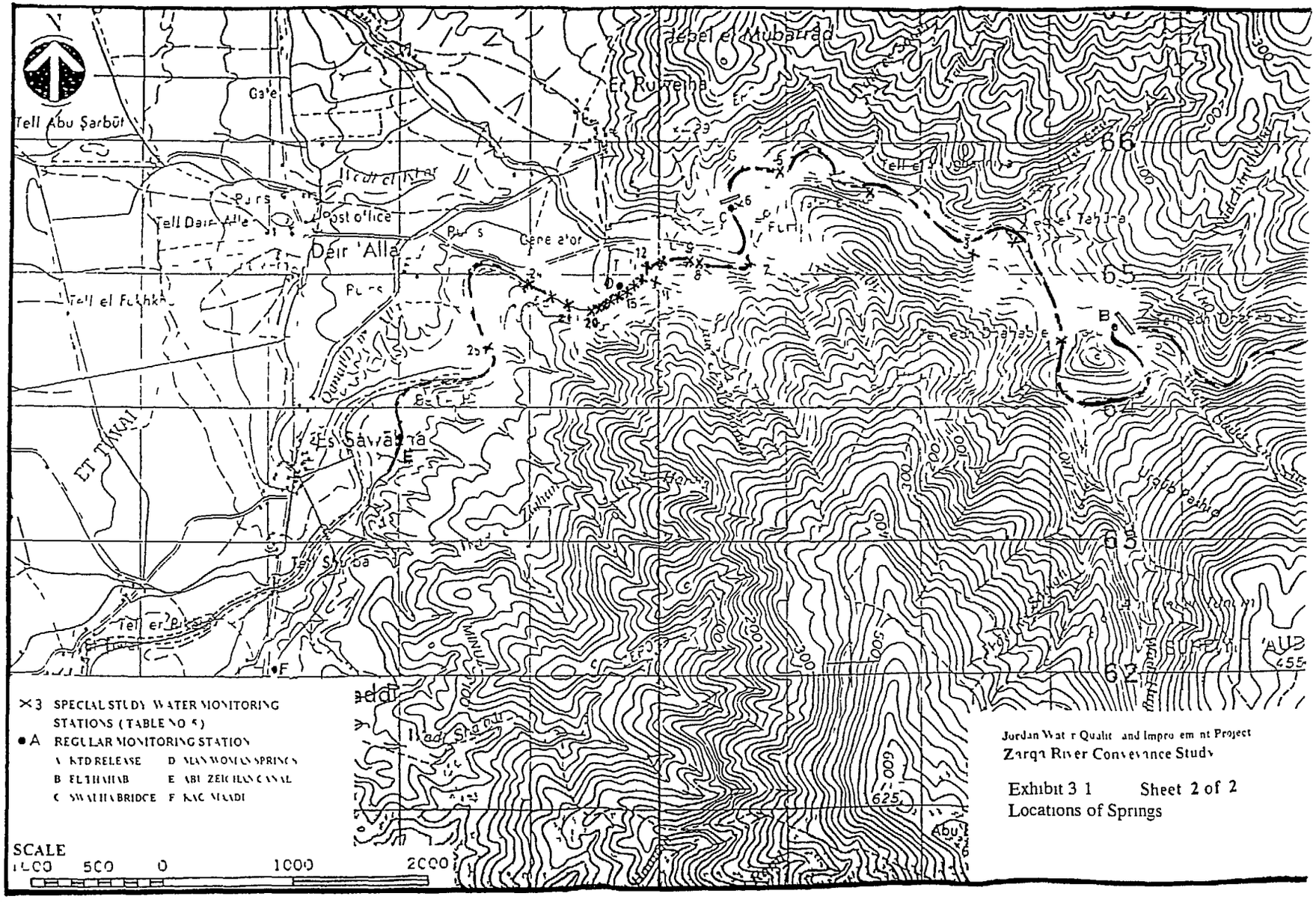

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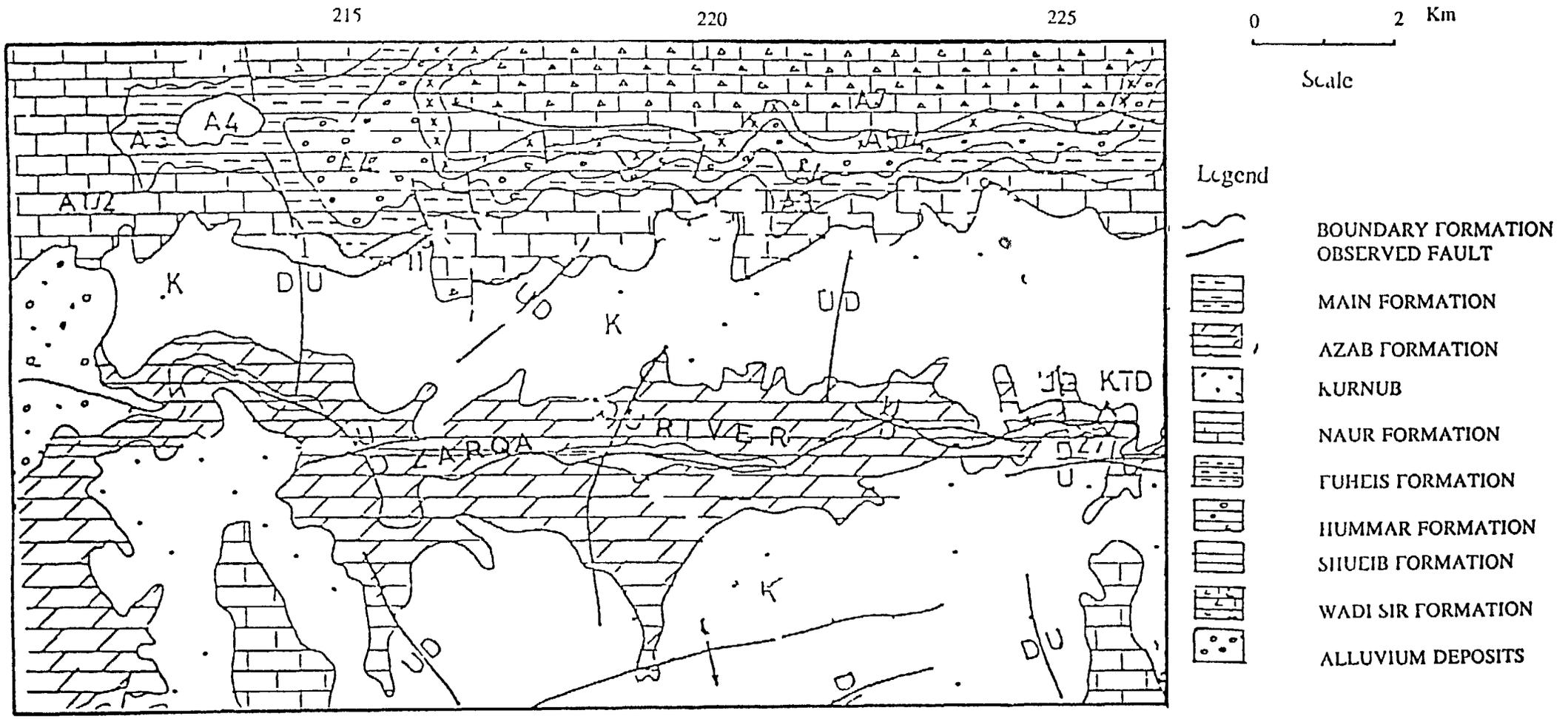

Exhibit 5 1 Geological Map of Zarqa River

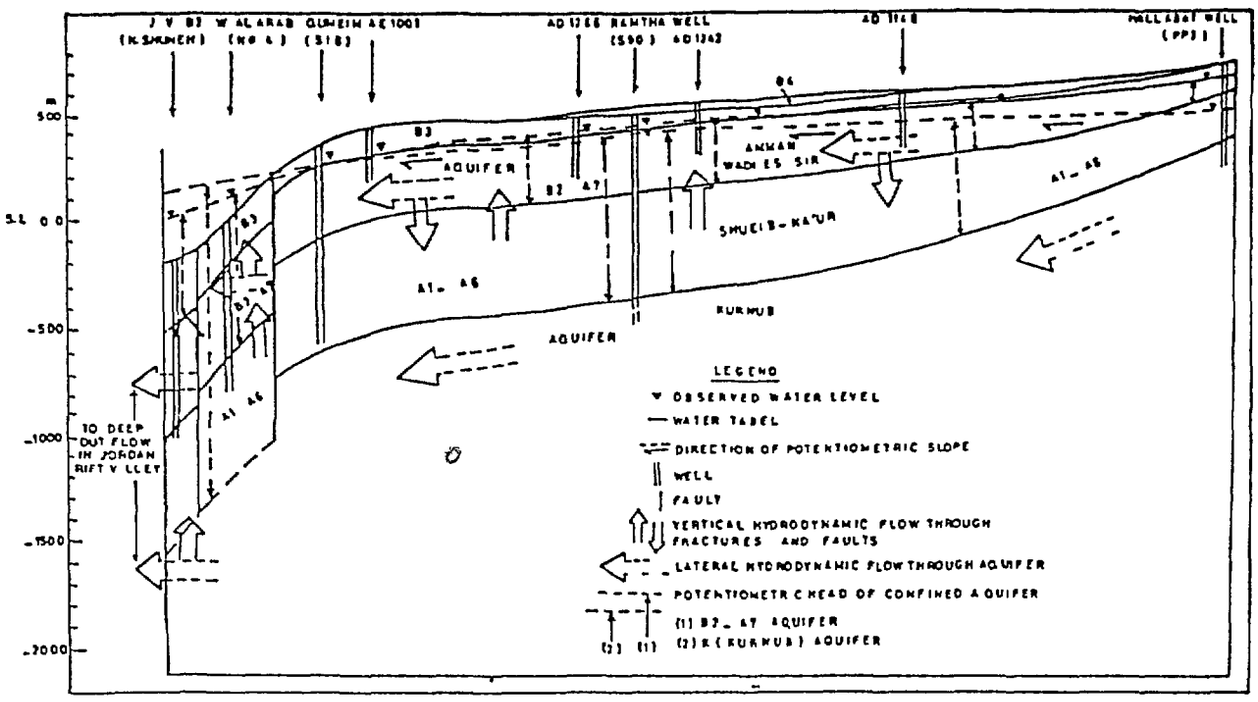

Exhibit 6 1 Hydrodynamic Pattern in Northern Jordan

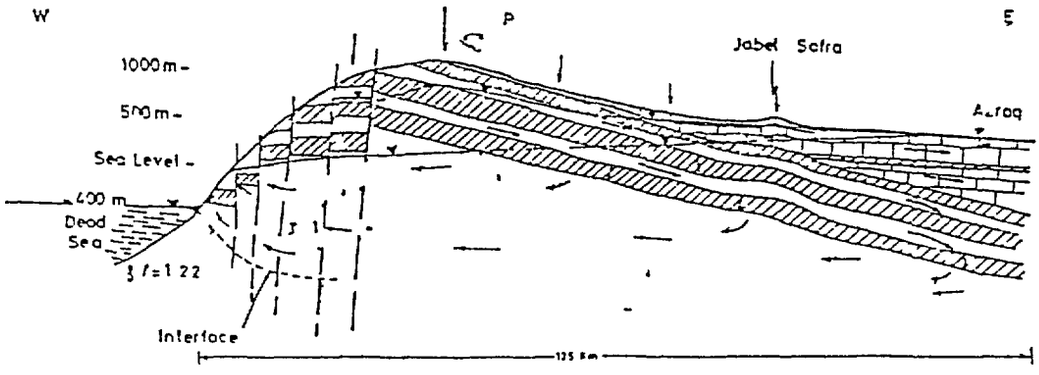

Exhibit 6 2 Hydrodynamic Pattern in Central Jordan

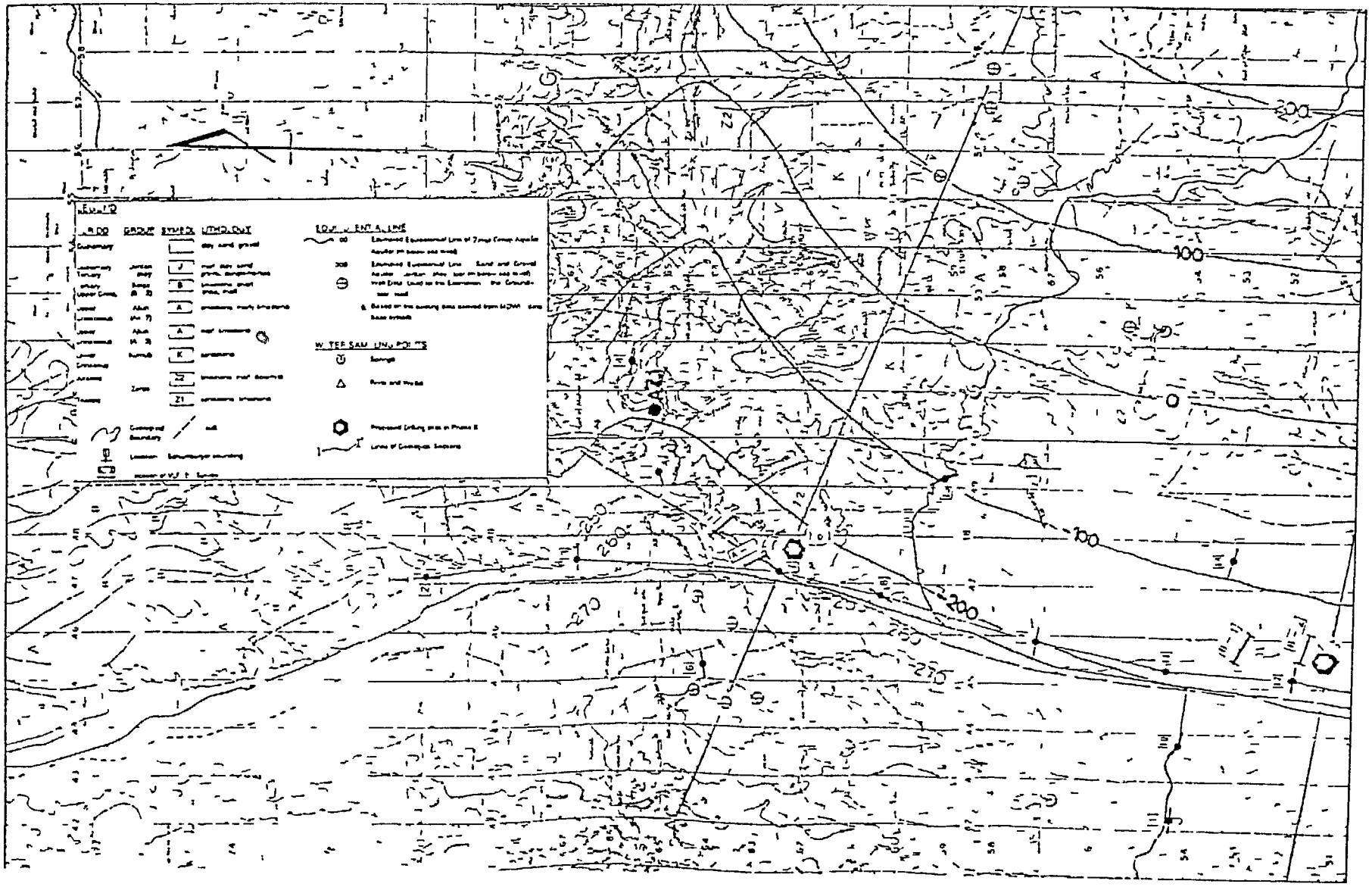

Exhibit 6 3 Groundwater Equipotential Lines of the Zarqa Group Aquifer Systems

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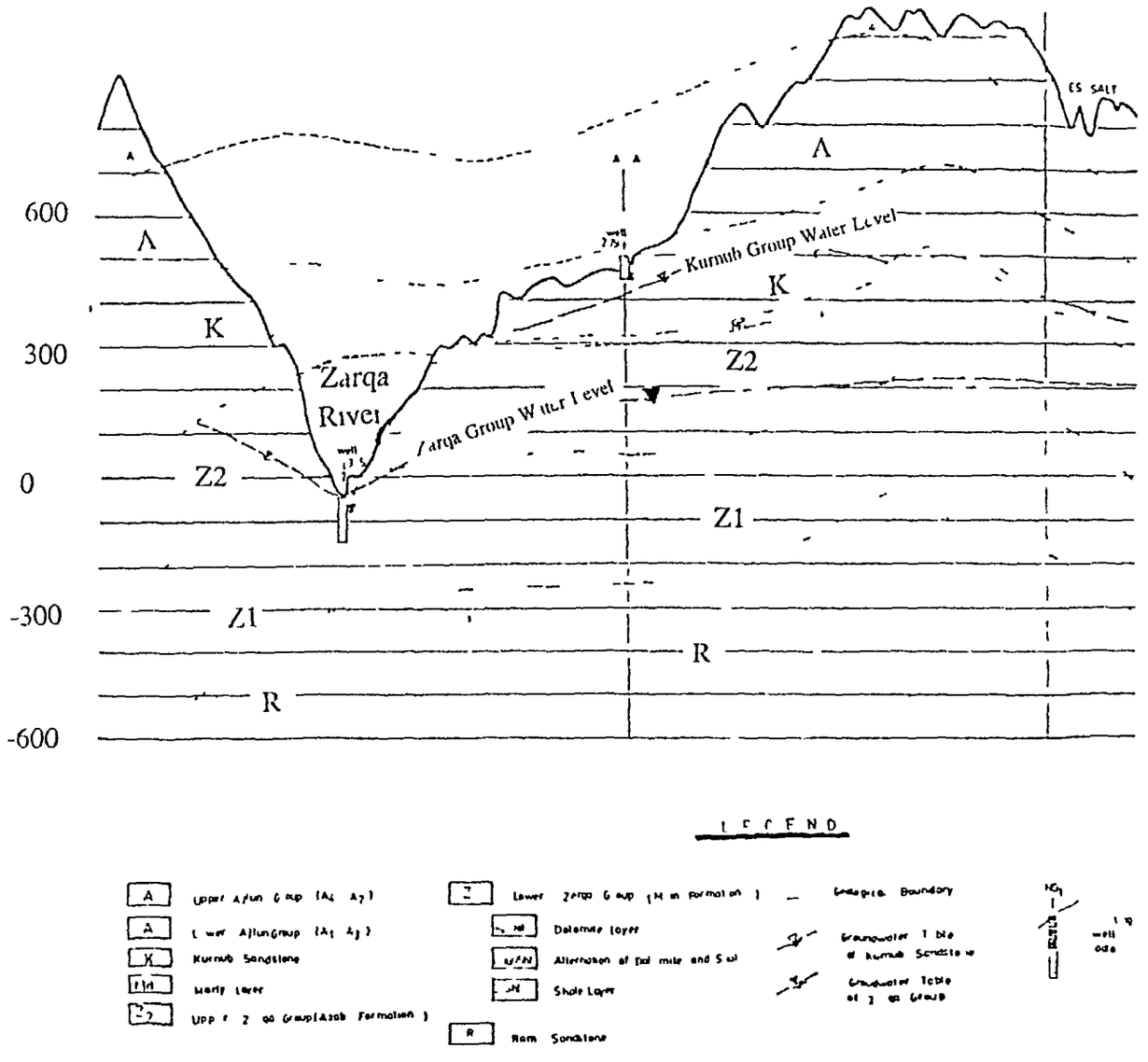

Exhibit 6 4 Hydrogeological Cross Section

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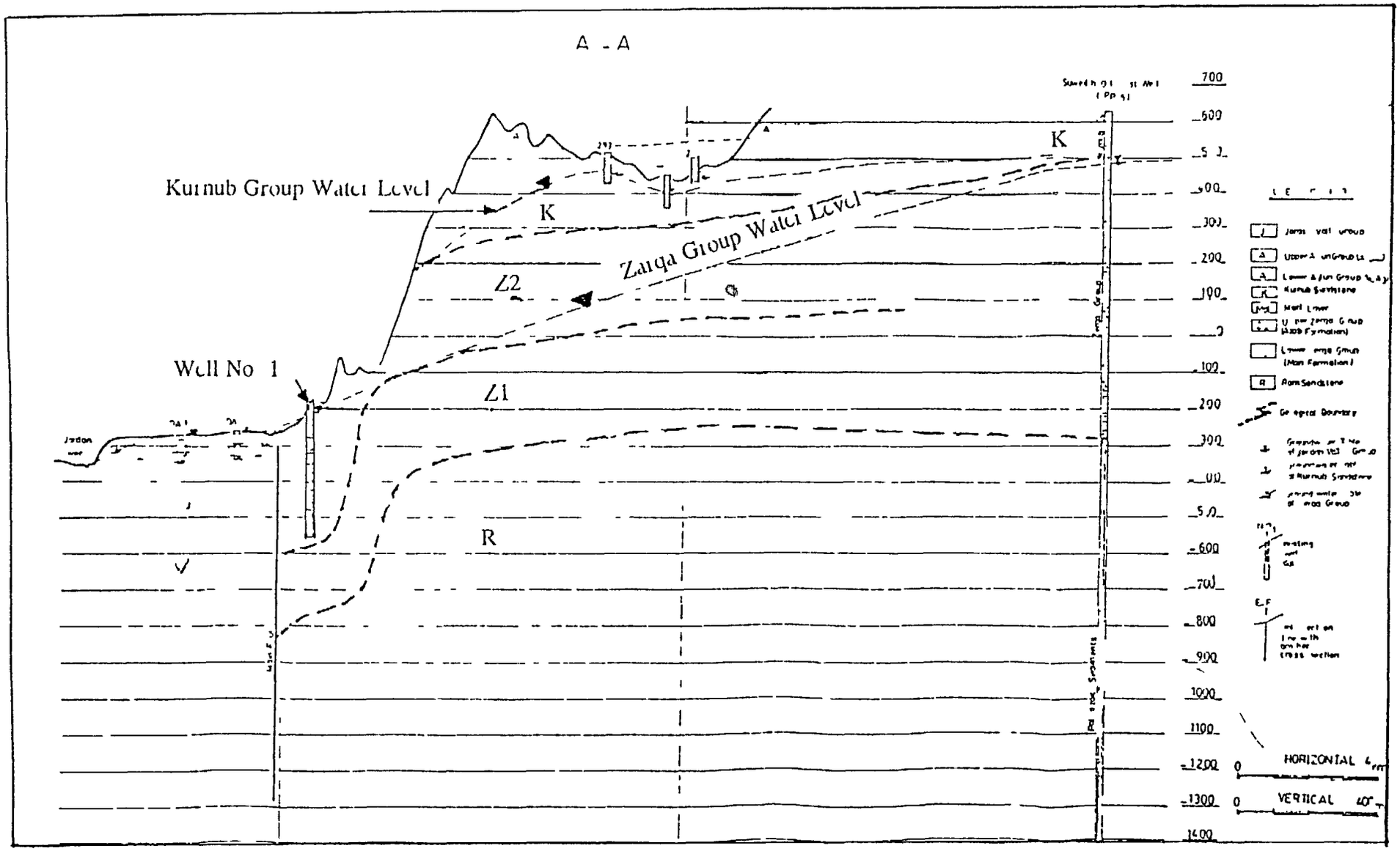

Exhibit 6 5 Hydrogeological Cross Section

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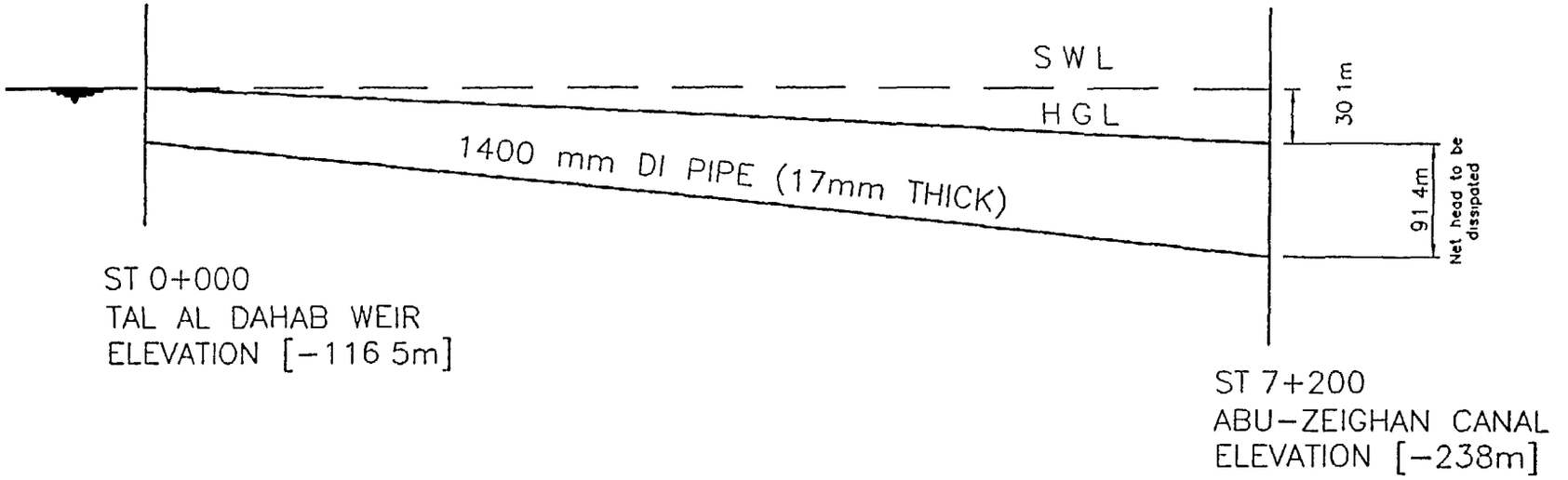
HYDRAULIC PARAMETERS

EXHIBIT 9 1



Alternative IRR1
Q=4 5CMS , Diameter=1400mm
Velocity=2 92MPS , Friction in m/km=3 8
Length of pipe = 7200m , Total headloss (friction+minor) = 30 1m
Net head at outlet to be dissipated = 91 4m

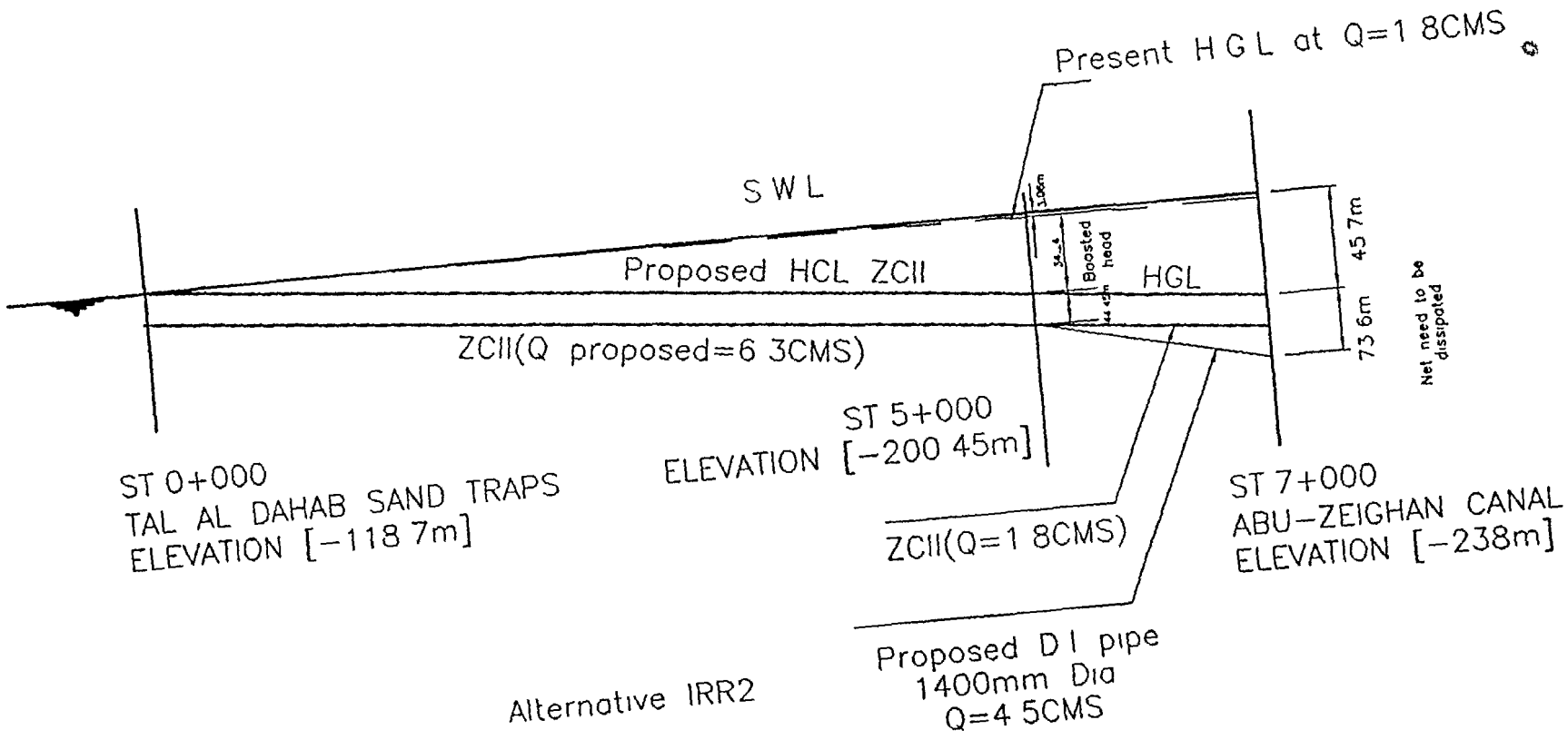
REQUIRED

- Pressure dissipator at Abu-Zeighan Canal (Two pressure reducing valves are needed)
- Vortex inhibitor at Tal-Al Dahab new pipe intake from the existing weir
- New pipe intake at Tal-Al Dahab weir to accomodate 1400MM pipe

N B Sand traps are not needed at intake They exist in projects on KAC

EXHIBIT 9 2
(PAGE 1 OF 2)

HYDRAULIC PARAMETERS



Alternative IRR2

HYDRAULIC PARAMETERS

EXHIBIT 9 2
(PAGE 2 OF 2)

Alternative IRR2
Qmax =6 3CMS up to station 5+000 , Diameter=1500mm
Velocity=3 51MPS , Friction in m/km=6 78m
Length of pipe to station 5+000 = 5000m , Total headloss (friction+minor) =37 3m
Qmax from station 5+000 to station 7+000 = 4 5CMS , Diameter=1400mm
Velocity=2 92MPS , Headloss in m/km=4 2m
Length of pipe from station 5+000 to station 7+000 = 2000m , Total headloss=8 4m
Net head at boosting pumping station=44 45m[(−118 7)−(−200 45)−37 3]
Net head at Abu−Zeighan weir (to be dissipated)= 73 6m[−(−200 45)−(−238)+44 45−8 4]
Existing head loss at the Junction =3 06m
Head to be boosted= 34 24m[−(118 7)−(−200 45)−44 45−3 06]
H P required assuming 70% overall efficiency

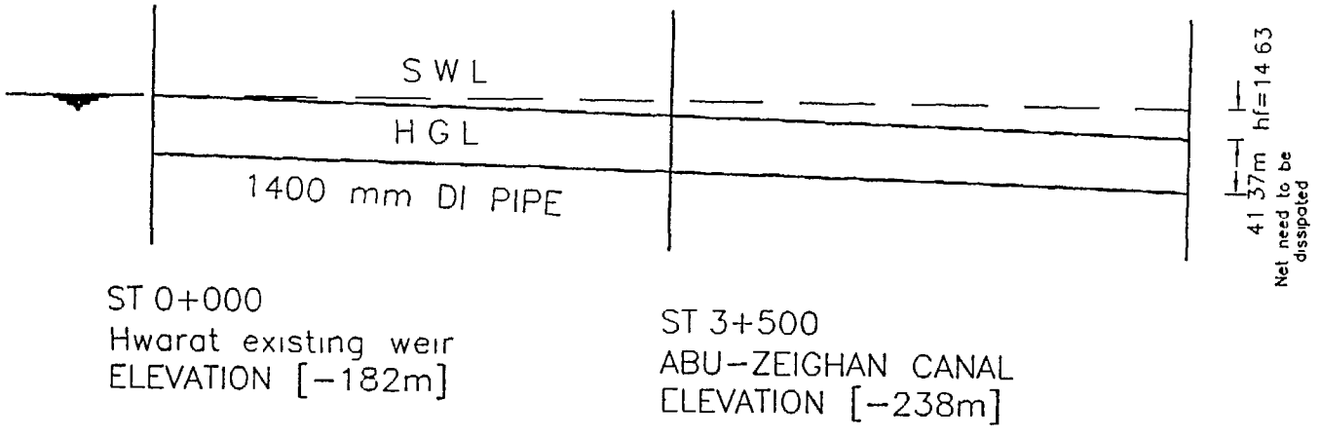
$$HPmax = \frac{1\ 8*9810*34\ 81}{0\ 7*746} = 1160$$

REQUIRED

- One additional sand trap at Tal−Al Dahab
- Pressure dissipator at Abu−Zeighan Canal (Two pressure reducing valves are needed)
- Vortex inhibitor at Tal−Al Dahab weir
- Boosting pumping station at station 5+000 to bring the head back to the existing value at the junction to satisfy irrigation head requirements of ZCII

HYDRAULIC PARAMETERS

EXHIBIT 9 3



Alternative IRR3 (a)

Q=4 5CMS , Diameter=1400mm

- Velocity=2 92MPS , Frictionloss in m/km=3 8

Length of pipe = 3500m , Total headloss (friction+minor) = 14 63m

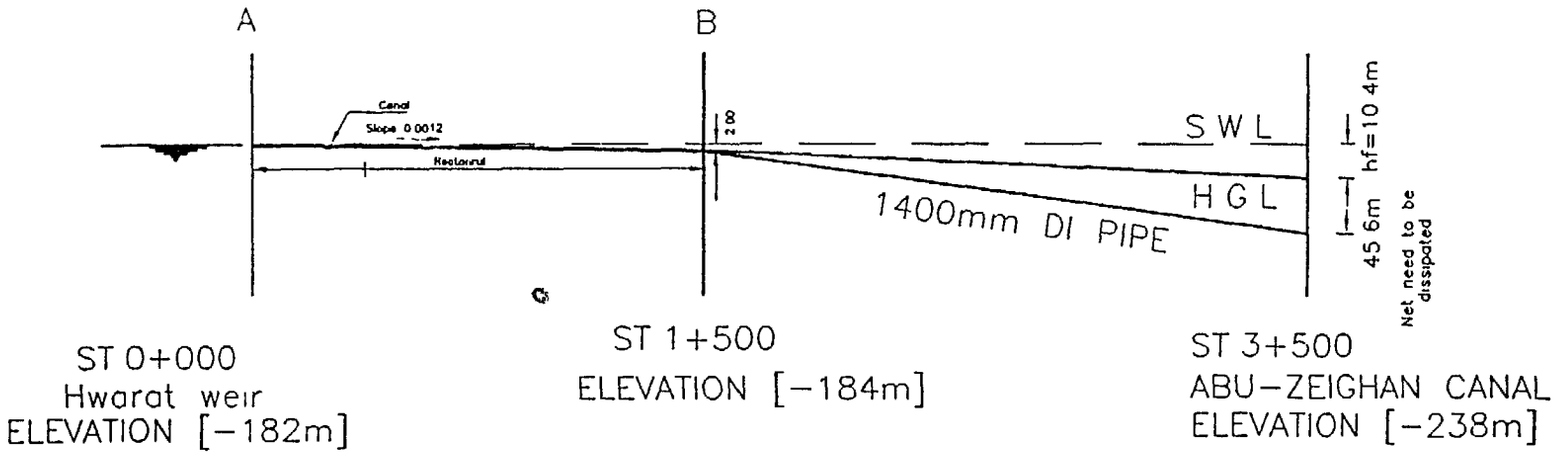
- Net head at outlet to be dissipated = 41 37m[(-182)-(-238)-14 63]

REQUIRED

- Rehabilitation of the existing Hwarat weir and intake
- Pressure dissipator at Abu-Zeighan Canal (Two pressure reducing valves are needed)

HYDRAULIC PARAMETERS

EXHIBIT 9 4



- Alternative IRR3 (b)

Q=4 5CMS 1500m rectangular channel

Head at B(Junction to pipe)= −182−2 00=−184

Length of pipe =2000m , Total headloss = 8 4m

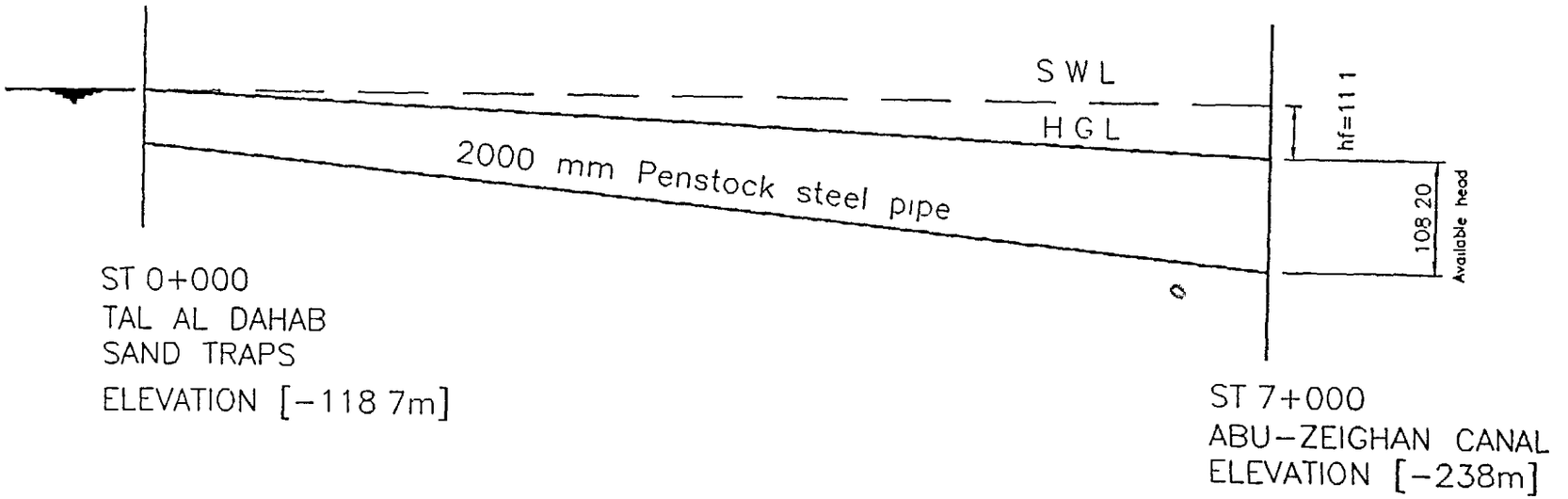
Net head at outlet to be dissipated = 45 6m[(−184)−(−238)−8 4]

REQUIRED

- Rehabilitation of the existing Hwarat weir and intake
- Pressure dissipator at Abu−Zeighan Canal (Two pressure reducing valves are needed)

HYDRAULIC PARAMETERS

EXHIBIT 9 5



Alternative POW

Q=7 5CMS , Pipe Diameter=2000mm

Velocity=2 39MPS , Friction in m/km=1 44

Length of pipe = 7000m , Total headloss (friction+minor) = 11 1m

Available head for power generation = 108 20

Power Generated = 7MW (2*3 5 units)

REQUIRED

- One additional sand trap at Tal Al - Dahab area
- Vortex inhibitor at Tal-Al Dahab weir
- Two power generation units
- By pass to the Canal with pressure dissipator valve

COST ESTIMATE OF IRR1

No	Item	Unit	Quantity	Unit Price	Total
1-	**Headworks**				
1 1	Cofferdam	L S	1	5,000	5,000
1 2	Demolishing R C Wall (about 15 cu m)	L S	1	5,000	5 000
1 3	Building the R C Wall of item 1 2 (after being shifted with the gate)	L S	1	10,000	10,000
1 4	Fixing Pipe 1 4 m I D in the wall of the weir	L S	1	3 000	3,000
1 5	Intake Gate Trashrack Vortex Inhibitor (Supply and Installation)	L S	1	10 000	10 000
	Total Headworks (J D)				33 000

COST ESTIMATE OF IRR1 / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
2-	Conveyance				
2 1	Unclassified Excavation	Cu m	60,000	3	180 000
2 2	Backfill (selected material)	Cu m	50,000	4	200 000
2 3	R Concrete Class A (encasement)	Cu m	600	90	54 000
2 4	R Concrete Class A (viaduct construction)	Cu m	200	120	24 000
2 5	R Concrete Class B (thrust blocks)	Cu m	200	80	16 000
2 6	Reinforcing steel	Ton	80	450	36 000
2 7	Ductile Iron Pipe 1 4 m I D with Cement Lining (Supply and Installation)	m	6 700	660	4 422 000
2 8	Steel Pipe 1 4 m I D for Viaduct Crossing (Supply and Installation)	Ton	100	2 000	200 000
2 9	Conveyance Pipe Accessories				
	* Air Valves (with chambers)	ea	8	10 000	80 000
	* Blow-off Valves (with chambers)	ea	8	8 000	64 000
	* Bends	ea	30	8 200	246 000
	Total Conveyance (J D)				5 522 000

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COST ESTIMATE OF IRR1 / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
3-	Outlet Works				
3 1	Dissipating valves and accessories	ea	2	290 000	580,000
3 2	R Concrete Class A (pipe landing structure)	Cu m	40	100	4 000
3 3	Reinforcing steel	Ton	3 2	450	1 440
3 4	Valve house (10x6 m)	Sq m	60	300	18,000
3 5	Crane	L S	1	15 000	15 000
3 6	Electrical equipment	L S	1	200 000	200 000
	Total Outlet Works (J D)				818 440

Summary of Costs (J D)

1 Headworks	33 000
2 Conveyance	5 522,000
3 Outlet works	818 440
Sub-Total	6 373 440
12% Contingencies	764 813
	7 138,253
Total Construction Cost (Rounded)	7 200,000

COST ESTIMATE OF IRR2

No	Item	Unit	Quantity	Unit Price	Total
1-	Headworks				
1 1	Cofferdam	L S	1	5 000	5 000
1 2	Demolishing R C Wall (about 15 cu m)	L S	1	5 000	5 000
1 3	Building the R C Wall of item 1 2 (after being shifted with the gate)	L S	1	10 000	10 000
1 4	Fixing Pipe 1 4 m I D in the wall of the weir	L S	1	3 000	3 000
1 5	R Concrete Class A (additional desander)	Cu m	150	90	13 500
1 6	Reinforcing steel	Ton	20	450	9 000
1 7	Intake and Desander Gates Trashracks Vortex Inhibitor (Supply and Installation)	L S	2	13,000	26 000
1 8	Ductile Iron Pipe 1 4 m I D with Cement Lining - from Intake to Desanders	m	200	660	132 000
	Total Headworks (J D)				203 500

COST ESTIMATE OF IRR2 / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
2-	**Conveyance**				
2.1	Unclassified Excavation	Cu.m	18,000	3	54,000
2.2	Backfill (selected material)	Cu.m	14,500	4	58,000
2.3	R. Concrete Class A (encasement)	Cu.m	100	90	9,000
2.4	R. Concrete Class A (viaduct construction)	Cu.m	60	120	7,200
2.5	R. Concrete Class B (thrust blocks)	Cu.m	60	80	4,800
2.6	Reinforcing steel	Ton	20	450	9,000
2.7	Ductile Iron Pipe 1.4 m I.D. with Cement Lining (Supply and Installation)	m	2,000	660	1,320,000
2.8	Steel Pipe 1.4 m I.D. for Viaduct Crossing (Supply and Installation)	Ton	50	2,000	100,000
2.9	Conveyance Pipe Accessories				
	* Air Valves (with chambers)	ea	3	10,000	30,000
	* Blow-off Valves (with chambers)	ea	3	8,000	24,000
	* Bends	ea	9	7,500	67,500
	* Bifurcation	L.S.	1	24,000	24,000
	Total Conveyance (J.D.)				1,707,500

COST ESTIMATE OF IRR2 / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
3-	Pumping Station				
3.1	Mechanical Equipment (including Crane)	L.S.	1	1,130,000	1,130,000
3.2	Electrical Equipment	L.S.	1	400,000	400,000
3.3	Pump House (26x12 m)	Sq.m.	312	300	93,600
	Total Pumping Station (J.D.)				1,623,600

COST ESTIMATE OF IRR2 / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
4-	Outlet Works				
4.1	Dissipation valves and accessories	ea	2	290 000	580 000
4.2	R. Concrete Class A (pipe landing structure)	Cu m	40	100	4 000
4.3	Reinforcing steel	Ton	3.2	450	1 440
4.4	Valve house (10x6 m)	Sq m	60	300	18 000
4.5	Crane	L.S.	1	15 000	15 000
4.6	Electrical equipment	L.S.	1	200 000	200 000
	Total Outlet Works (J.D.)				818 440

Summary of Costs (J.D.)

1	Headworks	203 500
2	Conveyance	1 707 500
3	Pumping Station	1 623 600
4	Outlet works	818 440
Sub-Total		4 353,040
12% Contingencies		522 365
		4,875 405
Total Construction Cost (Rounded)		4,900,000

COST ESTIMATE OF IRR3 (a)

No	Item	Unit	Quantity	Unit Price	Total
1-	Headworks				
1 1	Clearing and Grubbing (at Hqwaret)	Sq m	25,000	1	25 000
1 2	Cofferdams	L S	2	5 000	10 000
1 3	Unclassified Excavation Dredging (at Hwaret)	Cu m	6 600	4	26 400
1 4	Repairs at Hwaret Weir (overflow stilling basin sill, right abutment training wall)	L S	1	40 000	40,000
1 5	Demolishing Existing Intake	L S	1	10,000	10,000
1 6	R Concrete Class A (at new intake)	Cu m	30	100	3 000
1 7	Reinforcing steel	Ton	3	450	1 350
1 8	Intake Gates, Trashracks and Vortex Inhibitor (Supply and Installation)	L S	1	20 000	20 000
	Total Headworks (J D)				135,750

COST ESTIMATE OF IRR3 (a) / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
2-	Conveyance				
2.1	Demolishing existing canal (over a length of 50 m)	L.S	1	10,000	10 000
2.2	Unclassified Excavation	Cu m	33 000	3	99 000
2.3	Backfill (selected material)	Cu m	23,000	4	92,000
2.4	R. Concrete Class A (encasement)	Cu m	200	90	18,000
2.5	R. Concrete Class B (thrust blocks)	Cu m	100	80	8 000
2.6	Reinforcing steel	Ton	27	450	12,150
2.7	Ductile Iron Pipe 1.4 m I.D. with Cement Lining (Supply and Installation)	m	3,400	660	2 244,000
2.8	Steel Pipe 1.4 m I.D. for Viaduct Crossing (Supply and Installation)	Ton	50	2 000	100,000
2.9	Conveyance Pipe Accessories				
	* Air Valves (with chambers)	ea	4	10,000	40,000
	* Blow-off Valves (with chambers)	ea	4	8 000	32 000
	* Bends	ea	16	8 200	131 200
	Total Conveyance (J.D.)				2 786 350

COST ESTIMATE OF IRR3 (a) / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
3-	Outlet Works				
3 1	Energy Dissipation valves and accessories	ea	2	290,000	580,000
3 2	R Concrete Class A (pipe landing)	Cu m	40	100	4,000
3 3	Reinforcing steel	Ton	3 2	450	1 440
3 4	Valve House (10x6 m)	Sq m	60	300	18,000
3 5	Crane	L S	1	15 000	15,000
3 6	Electrical equipment	L S	1	200,000	200,000
	Total Outlet Works (J D)				818,440

Summary of Costs (J D)

1 Headworks	135 750
2 Conveyance	2,786,350
3 Outlet works	818 440
Sub-Total	3,740 540
12% Contingencies	448,865
	4 189,405
Total Construction Cost (Rounded)	4,200,000

COST ESTIMATE OF IRR3 (b)

No	Item	Unit	Quantity	Unit Price	Total
1-	**Headworks**				
1 1	Clearing and Grubbing (at Hwaret)	Sq m	25 000	1	25 000
1 2	Cofferdams	L S	2	5,000	10,000
1 3	Unclassified Excavation Dredging (at Hwaret)	Cu m	6,600	4	26 400
1 4	Repairs at Hwaret Weir (overflow stilling basin, sill, right abutment training wall)	L S	1	40 000	40 000
1 5	Demolishing Existing Intake	L S	1	10 000	10 000
1 6	R Concrete Class A (at new intake)	Cu m	30	100	3 000
1 7	Reinforcing Steel	Ton	3	450	1 350
1 8	Intake Gates, Trashracks and Vortex Inhibitor (Supply and Installation)	L S	1	20,000	20 000
	Total Headworks (J D)				135 750
2-	**Rectangular Canal**				
2 1	Demolishing Existing Canal (1 5 km reach)	L S	1	20 000	20,000
2 2	Unclassified Excavation (1500 m reach)	Cu m	9 500	3	28 500
2 3	R Concrete Class A (700 m of canal)	Cu m	2 200	100	220 000
2 4	R Concrete Class A (viaduct construction)	Cu m	50	120	6 000
2 5	Reinforcing steel	Ton	200	450	90 000
	Total Rectangular Canal (J D)				364 500

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COST ESTIMATE OF IRR3 (b) / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
3-	Pipeline				
3 1	Unclassified Excavation	Cu m	18,500	3	55,500
3 2	Backfill (selected material)	Cu m	14,500	4	58,000
3 3	R Concrete Class A (encasement)	Cu m	120	90	10,800
3 4	R Concrete Class B (thrust blocks)	Cu m	60	80	4,800
3 5	Reinforcing steel	Ton	16	450	7,200
3 6	Ductile Iron Pipe 1 4 m I D with Cement Lining (Supply and Installation)	m	1,900	660	1,254 000
3 7	Steel Pipe 1 4 m I D for Viaduct Crossing (Supply and Installation)	Ton	50	2 000	100,000
3 8	Pipe Accessories				
	* Air Valves (with chambers)	ea	3	10 000	30,000
	* Blow-off Valves (with chambers)	ea	3	8 000	24 000
	* Bends	ea	10	8 200	82,000
	Total Pipeline (J D)				1,626 300

COST ESTIMATE OF IRR3 (b) / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
4-	Outlet Works				
4 1	Energy dissipation valves and accessories	ea	2	290,000	580 000
4 2	R Concrete Class A (pipe landing)	Cu m	40	100	4 000
4 3	Reinforcing steel	Ton	3 2	450	1 440
4 4	Valve House (10x6 m)	Sq m	60	300	18,000
4 5	Crane	L S	1	15 000	15,000
4 6	Electrical equipment	L S	1	200,000	200 000
	Total Outlet Works (J D)				818 440

Summary of Costs (J D)

1	Headworks	135 750
2	Rectangular Canal	364 500
3	Pipeline	1 626 300
4	Outlet Works	818 440
Sub-Total		2,944,990
12% Contingencies		353 399
		3,298,389
Total Construction Cost (Rounded)		3,300,000

COST ESTIMATE FOR POW

No	Item	Unit	Quantity	Unit Price	Total
1-	**Headworks**				
1 1	Cofferdam	L S	1	5 000	5,000
1 2	Demolishing R C Wall (about 15 cu m)	L S	1	5,000	5 000
1 3	Building the wall of item 1 2 (after being shifted)	L S	1	10,000	10,000
1 4	Unclassified Excavation	Cu m	1 300	3	3,900
1 5	Backfill (selected material)	Cu m	1 000	4	4,000
1 6	R Concrete Class A (additional desander)	Cu m	150	90	13 500
1 7	Reinforcing steel	Ton	13 5	450	6,075
1 8	Intake Gate Trashrack, Vortex Inhibitor (Supply and Installation)	L S	1	10,000	10,000
1 9	Steel Pipe 2 0 m I D from Weir to Desander (Supply and Installation)	Ton	100	2 000	200,000
1 10	Desander Gates and Vortex Inhibitor (Supply and Installation)	L S	1	20 000	20,000
	Total Headworks (J D)				277,475

COST ESTIMATE FOR POW / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
2-	Penstock				
2 1	Unclassified Excavation	Cu m	84 000	3	252 000
2 2	Backfill (selected material)	Cu m	61 000	4	244 000
2 3	R Concrete Class A (viaduct crossing)	Cu m	250	100	25 000
2 4	R Concrete Class B (thrust blocks)	Cu m	300	80	24,000
2 5	Reinforcing steel	Ton	44	450	19,800
2 6	Steel Penstock 2 0 m I D 7 0 km 1 0 cm average thickness (supply and installation including accessories)	Ton	3 400	2 000	6 800 000
	Total Penstock (J D)				7,364,800

COST ESTIMATE FOR POW / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
3-	**Powerhouse**				
3 1	Unclassified Excavation	Cu m	10,000	3	30,000
3 2	Backfill (selected material)	Cu m	4 000	4	16,000
3 3	Structural Concrete Powerhouse Substructure	Cu m	1 500	150	225,000
3 4	Structural Concrete, Powerhouse Superstructure	Cu m	250	200	50,000
3 5	Reinforcing steel	Ton	160	450	72 000
3 6	Structural Steel	Ton	30	600	18 000
3 7	Mechanical Equipment				
	* Turbines (Output 3 63 MW)	ea	2	345,000	690,000
	* Inlet Valves	ea	2	40,000	80,000
	* Crane (10 tm)	ea	1	25,000	25,000
	* D Tube Gate	L S	1	7,700	7 700
	* Station Systems	L S	1	262 500	262,500
	* By-pass System (including Dissipation)	L S	1	358 200	358 200
3 8	Electrical Equipment				
	* Generator (Output 3 9 MVA)	ea	2	435,000	870 000
	* Transformer (3 85 MVA)	ea	1	150,000	150,000
	* Switchyard Equipment	L S	1	360 000	360,000
	* Miscellaneous Equipment	L S	1	1,350,000	1 350 000
	Total Powerhouse (J D)				4,564,400

COST ESTIMATE FOR POW / Cont'd

No	Item	Unit	Quantity	Unit Price	Total
4-	**Outlet Works for Irrigation By-Pass and Re-regulating Pond Works**				
4 1	Unclassified Excavation and Backfill	Cu m	28 000	3	84,000
4 2	R Concrete Class A (pipe landing)	Cu m	40	100	4,000
4 3	R Concrete Class A (diversion canal)	Cu m	10,000	100	1,000,000
4 4	R Concrete Class A (side spillway at diversion weir)	Cu m	1 000	100	100,000
4 5	Reinforcing steel	Ton	800	450	360,000
	Total Outlet Works and Pond (J D)				1 548,000

Summary of Costs (J D)

1 Headworks	277,475
2 Penstock	7,364,800
3 Powerhouse	4 564,400
4 Outlet & Pond	1,548,000
Sub-Total	13,754,675
12% Contingencies	1 650,561
	15,405,236
Total Construction Cost (Rounded)	15,400,000