5. Hydrogeology

(1) Hydrogeological Structure

1) Aquifers

The hydrogeology of the Study Area consists of four (4) aquifers and one (1) aquitard as shown next:

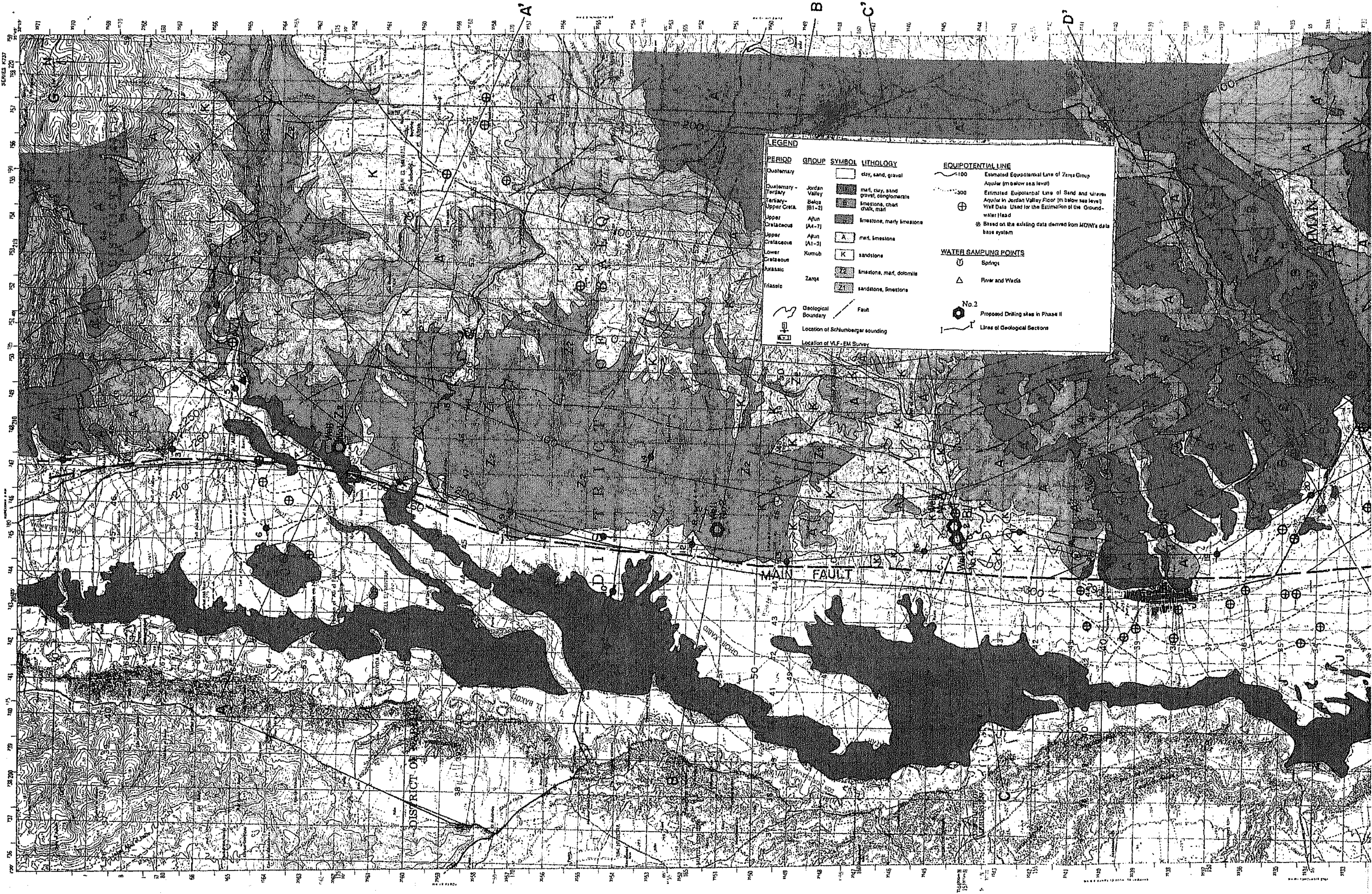
Period	Stratigraphy	Hydrogeological Classification
Quaternary	Jordan Valley Group	Aquifer
Cretaceous	Kurnub Sandstone (Kurnub Group)	Aquifer
Cretaceous/Jurassic	Marl/Shale Layer	Aquitard
Jurassic	Zerqa Group	Aquifer
Jurassic	Shale Layer	Impervious Layer
Cambrian	Ram Sandstone	Aquifer

As shown in Fig. I-5.1, Jordan Valley Group distributes in the Jordan Valley and Zerqa Group, Kurnub Sandstone and Tertiary layers distribute in the east escarpment of the Jordan Valley.

As the Zerqa aquifer, the target aquifer of the Study, contacts with the overlying Kurnub sandstone aquifer and the Jordan Valley Group aquifer at the fault boundary in the West, the discussion that follows will cover all three of these aquifers.

For the Ram Sandstone aquifer, it is difficult to discuss in detail because only two wells partially penetrated the Ram Sandstone. Only the data obtained through the drilling works are shown in this chapter.

Two wells penetrated the Ram Sandstone aquifer in the southern part of the Study area (Well No. 5 and No. 6) and huge amount of flow started from this aquifer.


A'
B'
C'
D'
LEGEND
PERIOD
GROUP
SYMBOL
LITHOLOGY
Quaternary
clay, sand, gravel
Quaternary - Tertiary
Jordan Valley
marl, clay, sand gravel, conglomerate
Tertiary-Upper Creta.
Belqa (B1-2)
B
limestone, chert chalk, marl
Upper Cretaceous
Ajlun (A4-7)
limestone, marly limestone
Upper Cretaceous
Ajlun (A1-3)
A
marl, limestone
Lower Cretaceous
Kurnub
K
sandstone
Jurassic
Z2
limestone, marl, dolomite
Zarqa
Triassic
Z1
sandstone, limestone
Geological Boundary
Fault
Location of Schlumberger sounding
Location of VLF-EM Survey
EQUIPOTENTIAL LINE
-100
Estimated Equipotential Line of Zarqa Group Aquifer (m below sea level)
-300
Estimated Euipotential Line of Sand and Gravel Aquifer in Jordan Valley Floor (m below sea level)
Well Data Used for the Estimation of the Ground-water Head
※ Based on the existing data derived from MOWI's data base system
WATER SAMPLING POINTS
Springs
River and Wadis
No.2
Proposed Drilling sites in Phase II
I
I'
Lines of Geological Sections
MAIN FAULT
DISTRICT
DISTRICT OF
AMMAN
200
100
300
250
260
270
B
C

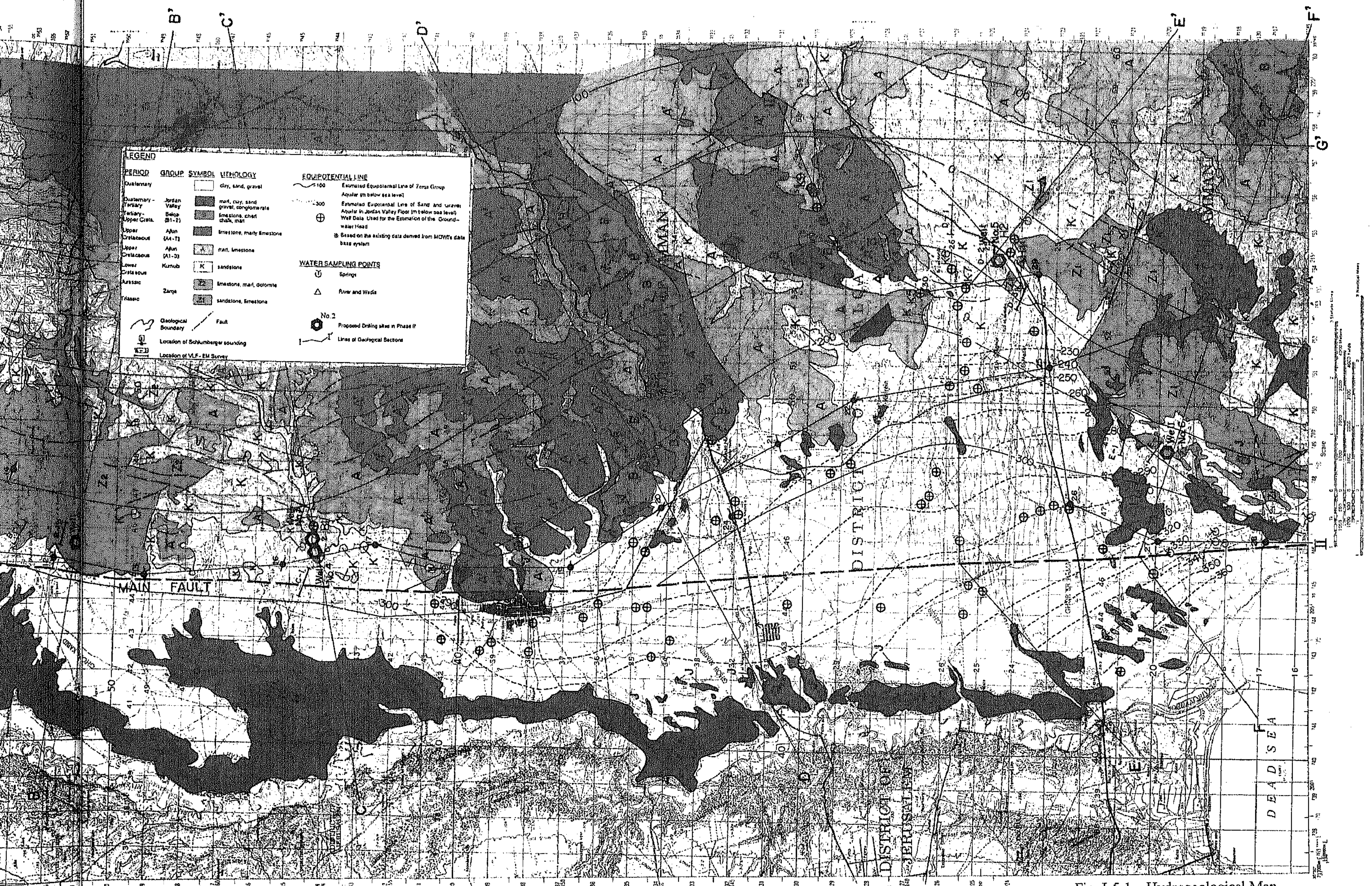


Fig. I-5.1 Hydrogeological Map

Ram Sandstone Aquifer

The Ram Sandstone consists of very friable (weekly cemented) medium to coarse grained white and arkosic porous sandstone and some black shale (see Supporting Report).

According to the drilling records of Well No. 5 and No. 6, it is suggested that the Ram Sandstone aquifer has higher piezometric pressure and higher permeability than the Zerqa Group aquifer.

The hydraulic properties of the Ram Sandstone aquifer are summarized as follows:

Table I-5.1 Hydraulic Properties of the Ram Sandstone Aquifer

Well	Stratigraphy	Transmissibility (m^2/day)	Permeability Coefficient (m/day)	Storage Coefficient
No. 5	R	205~262	4.1~5.2	$4 \times 10^{-3} \sim 6 \times 10^{-4}$
No. 6	R	120~369	5.2~16.0	1×10^{-6}

Zerqa Group Aquifer

The lower Zerqa Group aquifer (Z1) consists of sandstone, shale and dolomite. The upper Zerqa Group aquifer (Z2) consists of dolomitic limestone with intercalation of shale and marl, sandstone and sandstone with intercalation of shale and marl. Both aquifers are hydraulically connected and can be regarded as one aquifer.

The total thickness of the Zerqa Group aquifer is estimated to be around 600 m in the Northern part and around 300 m in the Southern part.

The hydraulic properties of the Zerqa Group aquifer are summarized as follows:

Table I-5.2 Hydraulic Properties of the Zerqa Aquifer

Well	Stratigraphy	Transmissibility (m^2/day)	Permeability Coefficient (m/day)	Storage Coefficient
No. 1	Z_2	63~157	0.3~0.7	1×10^{-2}
No. 2	Z_2	91~143	0.5~0.6	$1 \times 10^{-2} \sim 4 \times 10^{-3}$
No. 4	Z_2	100	0.8	1×10^{-3}
Hisban No. 1	Z_1	2,157	21.6	1×10^{-3}

Marly Layers (Mrl)

The marly layer is intercalated between the Zerqa Group aquifer and the Kurnub sandstone aquifer. Its thickness is 25 m to 55 m and plays the role of "Aquitard" between them.

This layer does not completely separate the two aquifers hydraulically, and leakage mutually takes place among both aquifers.

The leakance factor of this layer obtained by the combination pumping test is 0.7×10^{-4}/day.

Kurnub Sandstone Aquifer

The Kurnub Sandstone aquifer underlain by marly Layer is mainly arenaceous and consists of reddish to purplish, fine - medium grained sandstone. The thickness of the Kurnub Sandstone is 200 m to 250 m in the Study area and it was eroded out in the Southern and Northern parts of the Study area.

Following hydraulic properties of the Kurnub Sandstone aquifer were obtained in the Study.

Table I-5.3 Hydraulic Properties of the Kurnub Sandstone Aquifer

Well	Transmissibility (m^2/day)	Permeability Coefficient (m/day)	Storage Coefficient
No. 3	110~120	1.0~1.1	0.002

Jordan Valley Group Aquifer (Sand /Gravel aquifer)

The Jordan Valley Group is Quaternary deposits which fills the rift valley and forms a wide valley floor, and contact with the Zerqa Group and the Kurnub Sandstone in the Eastern escarpment by the main Fault.

It is reported that the thickness of the Jordan Valley Group is more than 3,000 m in the Lisan area situated in the South of Dead Sea. The specific capacity of wells tapped into the Jordan Valley Group aquifer is estimated around 100 to 300 m^2/day according to the existing data.

2) Structure

According to the geological survey and aerial photo interpretation, it is clear that there is no large scale fault, breaking the continuity of the strata in the Study area except the Main Fault bounding the escarpment and the valley plain. The maximum dislocation of the minor faults is around 20 m in the escarpment. Therefore, it has been assumed that the aquifer extends without any large hydraulic breaks due to faults in the escarpment area.

The strata including the Zerqa Group and Kurnub Sandstone incline toward the Jordan Valley almost in the eastern escarpment. The inclination of the strata is around 3 to 10 degrees. In the highlands above the escarpment, the strata's inclination becomes nearly horizontal or very gentle.

Along Wadi Kafrein which flows toward West, a large scale syncline runs in a NE-SW direction.

3) Piezometric Potential

As shown in hydrogeological map, it is assumed that the piezometric surface of the Zerqa Group aquifer inclines from highlands in the East toward the Jordan Valley in the West. The average inclination of the piezometric surface of the Zerqa Group aquifer in the Study area is estimated to be around 3%.

Concavities in the piezometric surface can be found along the Zarqa River and in the Wadi Hisban and Wadi Kafrein area. The concavity along the Zarqa River is formed by the groundwater discharging from the Zerqa Group aquifer into the Zarqa River. It has been verified by the flow measurements conducted as part of the Study that the Zarqa River gains a recharge of 0.1 m^3/sec per kilometer from the Zerqa Group aquifer. For the concavity in the Wadi Hisban and Wadi Kafrein area, it is inferred that a high permeable zone such as faults or fractured zones might be formed along the syncline running in parallel with Wadi Kafrein. The Zerqa Group aquifer is normally under the artesian condition on the foot of the escarpment.

On the other hand, the Zerqa Group aquifer is under the water table condition in the escarpment. The artesian area with high pressure were found in the downstream of Wadi Hisban which located in the Southern part of the Study area. The maximum piezometric pressure is assumed around 70 m above the ground surface in this area.

(2) Hydrogeochemistry

1) Brackish Groundwater Salinity Distribution

As shown in assumed iso-salinity contour map, the Zerqa Group aquifer groundwater shows high salinity in the middle of the Study area and low salinity in the Southern part of the

Study area. TDS in the high salinity zone almost reaches 10,000 mg/L and around 5,000 mg/L in the low salinity zone.

The high salinity zone is coincident with low permeability zone and low zone is coincident with high permeability zone vice versa. From this finding, it is inferred that high salinity groundwater distributes in low seepage velocity and stagnant areas and low salinity groundwater distributes high seepage velocity area.

On the other hand, clear difference of major ion composition can be found between Northern high salinity zone and Southern low salinity zone from the view point of hydrogeochemistry (see Fig. I-5.2). This finding suggests that the groundwater flow system and recharge system may differ from the Northern ~ Central part of the Southern part.

The analysis results show that the age of Kurnub water ranges BP 6,200 years to BP 7,200 years and the age of Zerqa and Ram water ranges BP 15,000 years to BP 22,000 years.

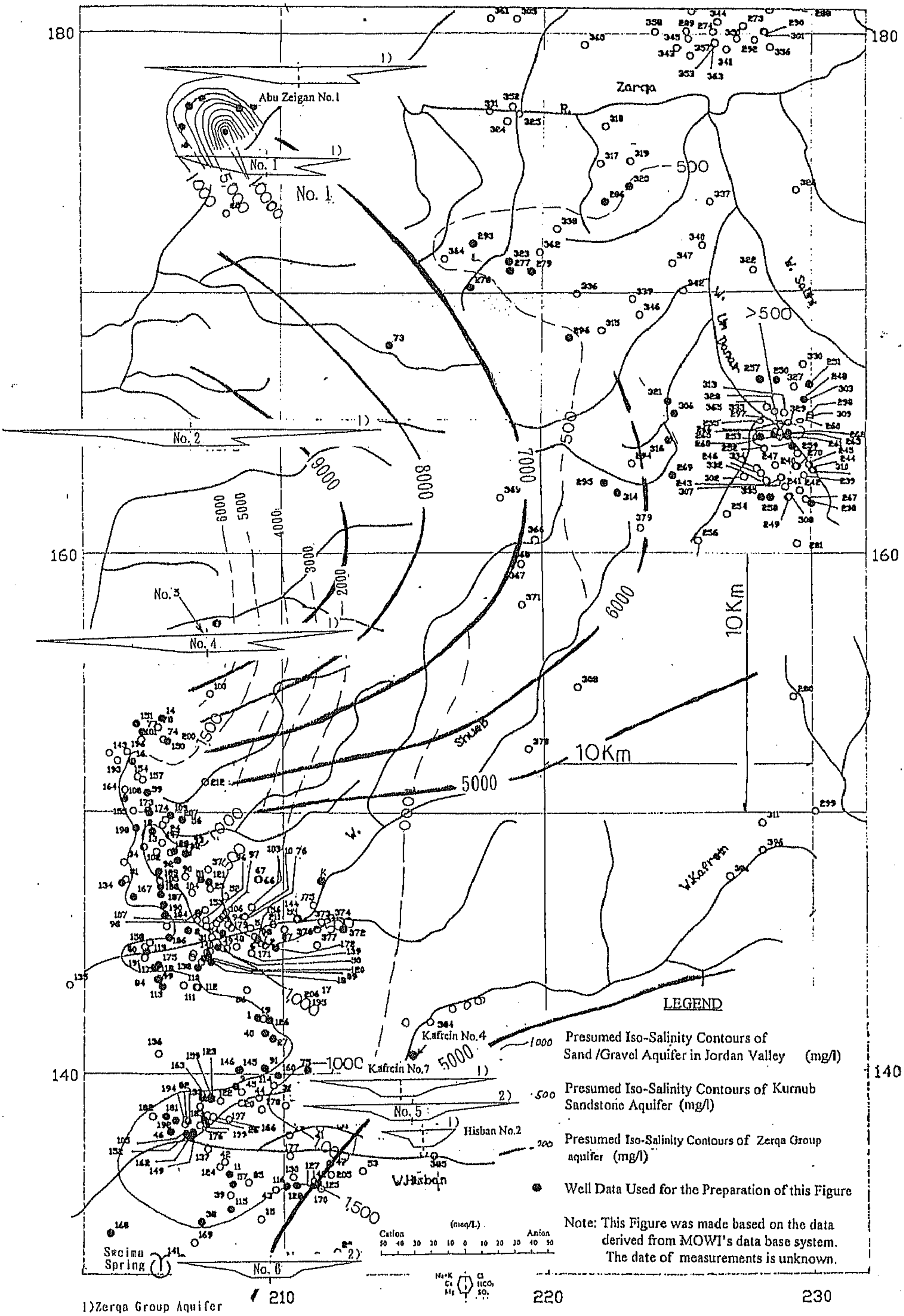
As mentioned above, the distinctive difference of age is shown between the Kurnub water and the Zerqa water and it is concluded that the Zerqa water is very old water. Accordingly, it can be concluded that the groundwater of Zerqa Group aquifer receives very few recharge from replenishable water if any. It should be also noted that the age of Zerqa water and Ram water is almost same. This finding suggests that the groundwater origin of both aquifers might be same.

2) Age of Brackish Groundwater

Carbon-13 and Carbon-14 analysis were carried out in the Study in order to determine the age of the groundwater.

Stable isotope analysis of Oxygen-18 and Deuterium was also carried out in order to see the origin of the Zerqa Group aquifer and Ram Sandstone aquifer groundwater.

The analysis results show that the groundwater of the Zerqa Group aquifer and Ram Sandstone aquifer can be plotted on the Global Water Line. It is reported that old groundwater which was recharged around 20,000 years ago is plotted on the Global Water Line on many cases in Jordan. This finding also strongly reinforce the assumption that the Zerqa and Ram water is very old and originated from same source.



Note: This Figure was made based on the data derived from MOWI's data base system. The date of measurements is unknown.

1)Zerqa Group Aquifer
2)Ram Sandstone Aquifer

Fig. I-5.2 Assumed Iso-Salinity Contour Map

(3) Hydrogeological Model

1) Hydrogeological Model

Based on the hydrogeological analysis results, inclined two layer model (Kurnub Sandstone aquifer and Zerqa Group aquifer) plugged with the low permeability layer at the end can be adapted for the hydrogeological model as shown in Fig. I-5.3. In this model two layers connected each other through the Marly Layer (aquitard). All the groundwater which seeped to the plug layer (Jordan Valley Group) finally discharged to the Jordan River.

2) Recharge System

As discussed in Section I-5.2, the Zerqa Group aquifer groundwater is very old and very few water recharges the aquifer if any. Therefore, the recharge to the Zerqa Group aquifer from surface is negligible in the hydrogeological model.

Although the Zerqa Group aquifer cannot be regarded as replenishable, it is believed that the present flow amount in the Zerqa Group aquifer toward the Study area will not change within hundreds years taking the geological time scale into consideration.

The data concerning the Ram Sandstone aquifer is too limited to evaluate the actual groundwater movement to the Zerqa Group aquifer. Therefore, the recharge or discharge between Ram and Zerqa was not taken into consideration in the hydrogeological model.

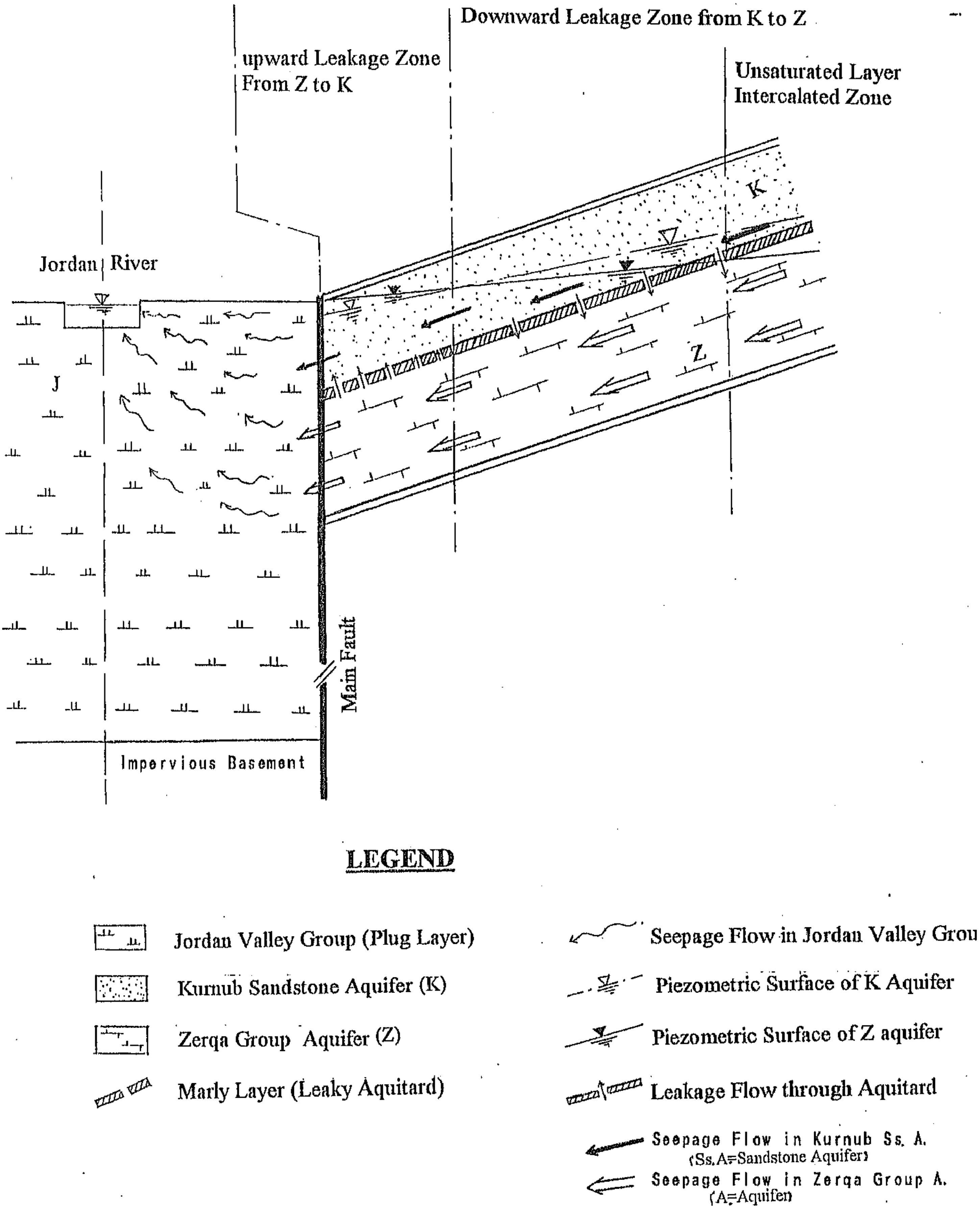


Fig. I-5.3 Schematic Hydrogeological Model of the Study Area

(6) Groundwater Simulation

(1) Procedure of Groundwater Simulation

A series of groundwater simulation was carried out in order to evaluate the potential of the brackish groundwater in the Study area. Quasi-three-dimensional program was employed for the groundwater simulation because the wide-area groundwater seepage flow will have to be examined. The MODFLOW program was selected among the quasi-three dimensional program because the influence on the other aquifers must be taken into consideration.

The procedure of the groundwater simulation is shown below:

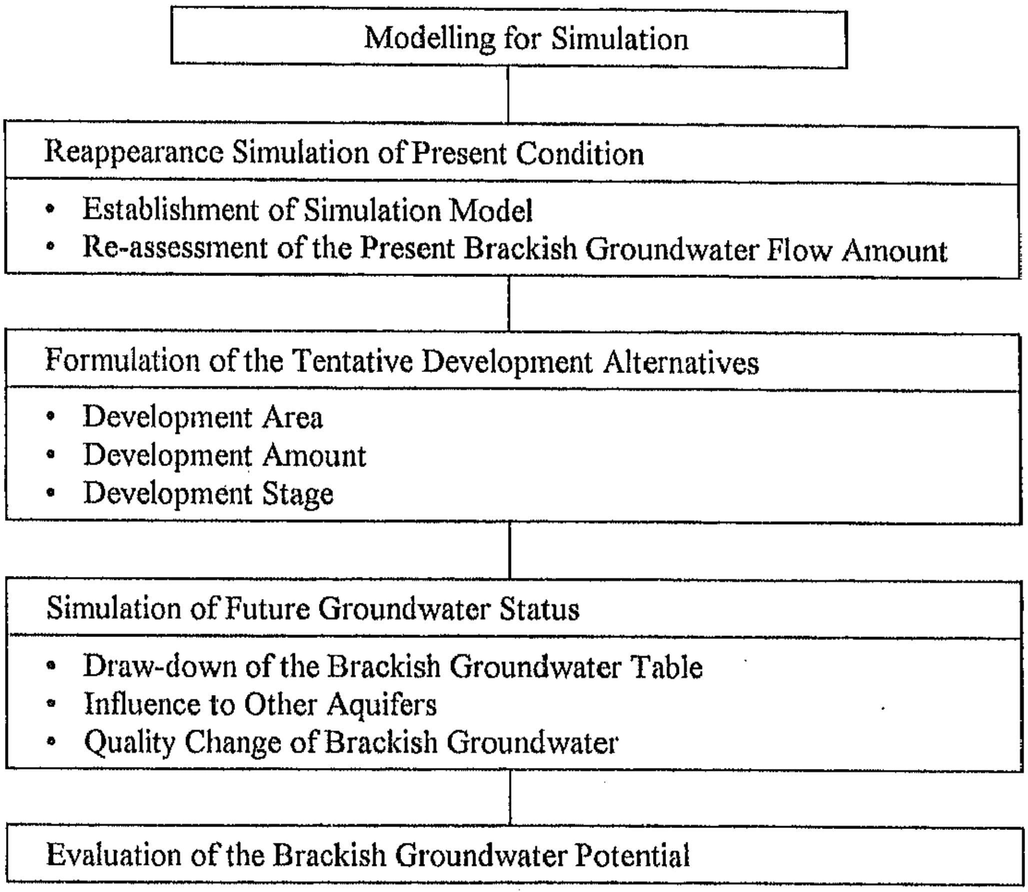


Fig. I-6.1 Flow of Groundwater Simulation

(2) Modelling for Simulation

The area of 50 km in E-W direction and 60 km in N-S direction including the Study area was set for the groundwater simulation in order to see the regional draw-down influence.

Along the Jordan river and Zarqa river, the head constant condition was set as Western and Northern boundaries condition respectively. For the Eastern and Southern condition, the head constant boundaries were set apart far from the Study area.

As shown in Fig. I-6.2, the simulation model consists of three (3) layers which are two layers at aquifer (Zerqa and Kurnub) with intercalation of an aquitard (Marly Layer) in the escarpment area. The Jordan Valley Group aquifer distributes in the Jordan Valley floor and they are bounded by Main Fault which is running along the foot of the escarpment.

The hydraulic properties described in Section I-5.1 were employed as the initial values for the reappearance simulation.

(3) Reappearance Simulation of Present Piezometric Surface

The trials of the simulation were conducted until satisfactory reappearance of the present piezometric surface configuration of the Zerqa Group aquifer was gotten by changing the hydraulic properties distributions (transmissibility, storage coefficient, leakance factor) taking the hydrogeological condition into consideration. The trials were done for about three hundred (300) cases.

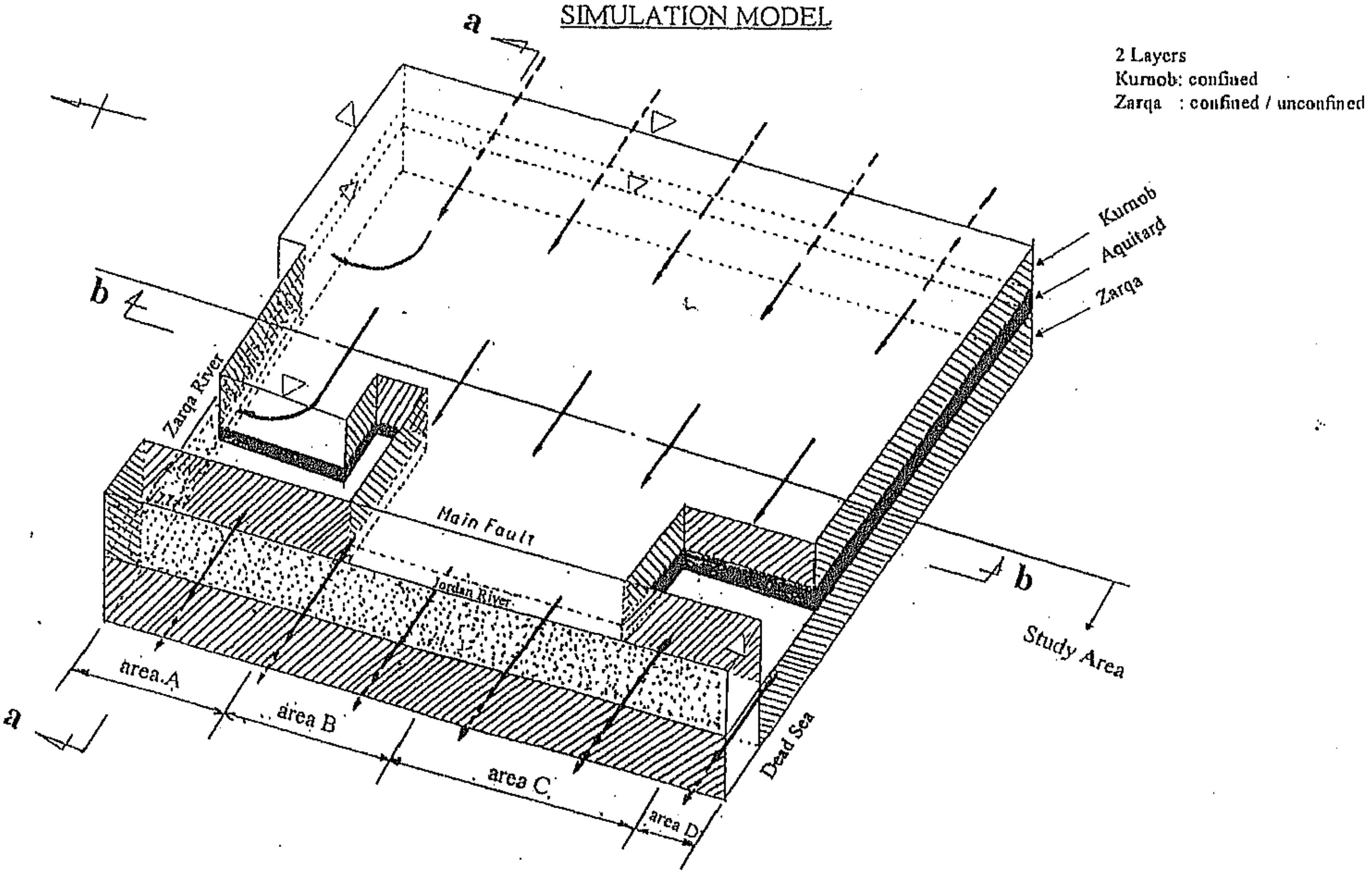
Through these trials, the final simulation model, which was best combination of hydrogeological conditions (hydrogeological structure, transmissibility, storage coefficient, leakance factor, flow amount), was obtained. This simulation model was used for the simulation of future operation.

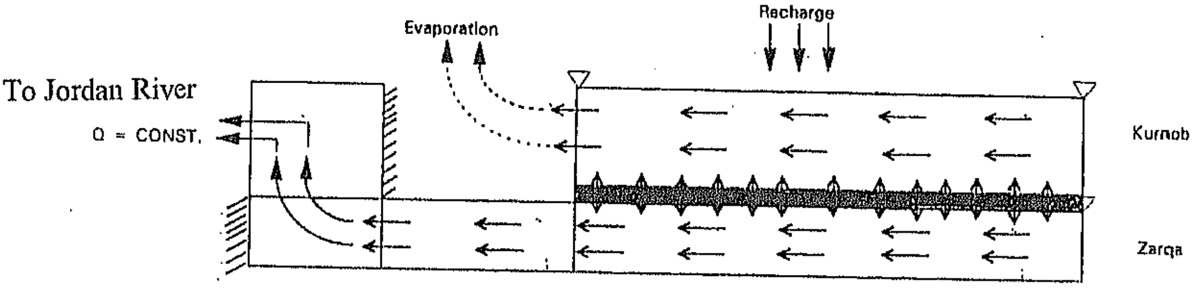
The re-assessment results of the flow amount of the Zerqa Group aquifer are shown in Fig. I-6.3 with the reappearing piezometric surface. According to the results of the re-assessment, the total flow amount of the Zerqa Group aquifer in the Study Area is estimated at around 120 MCM/year as shown in Table I-6.1.

Table I-6.1 Flow Amount of the Zerqa Group Aquifer in the Study Area

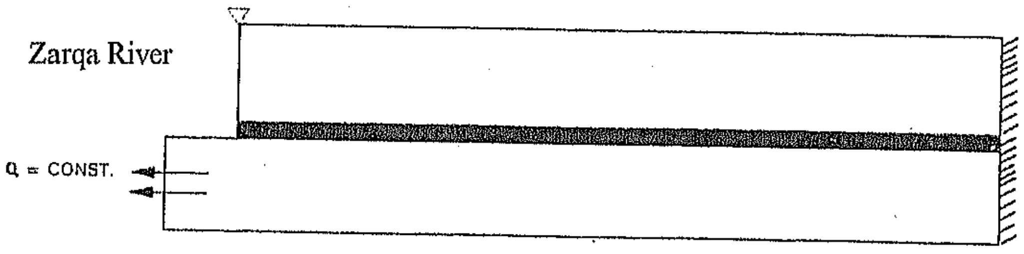
	Area A	Area B	Area C	Area D	Total
Brackish Groundwater Flow Amount of the Zerqa Group Aquifer (MCM/year)	40.8	8.4	70	2.6	121.8

SIMULATION MODEL





Section "a"

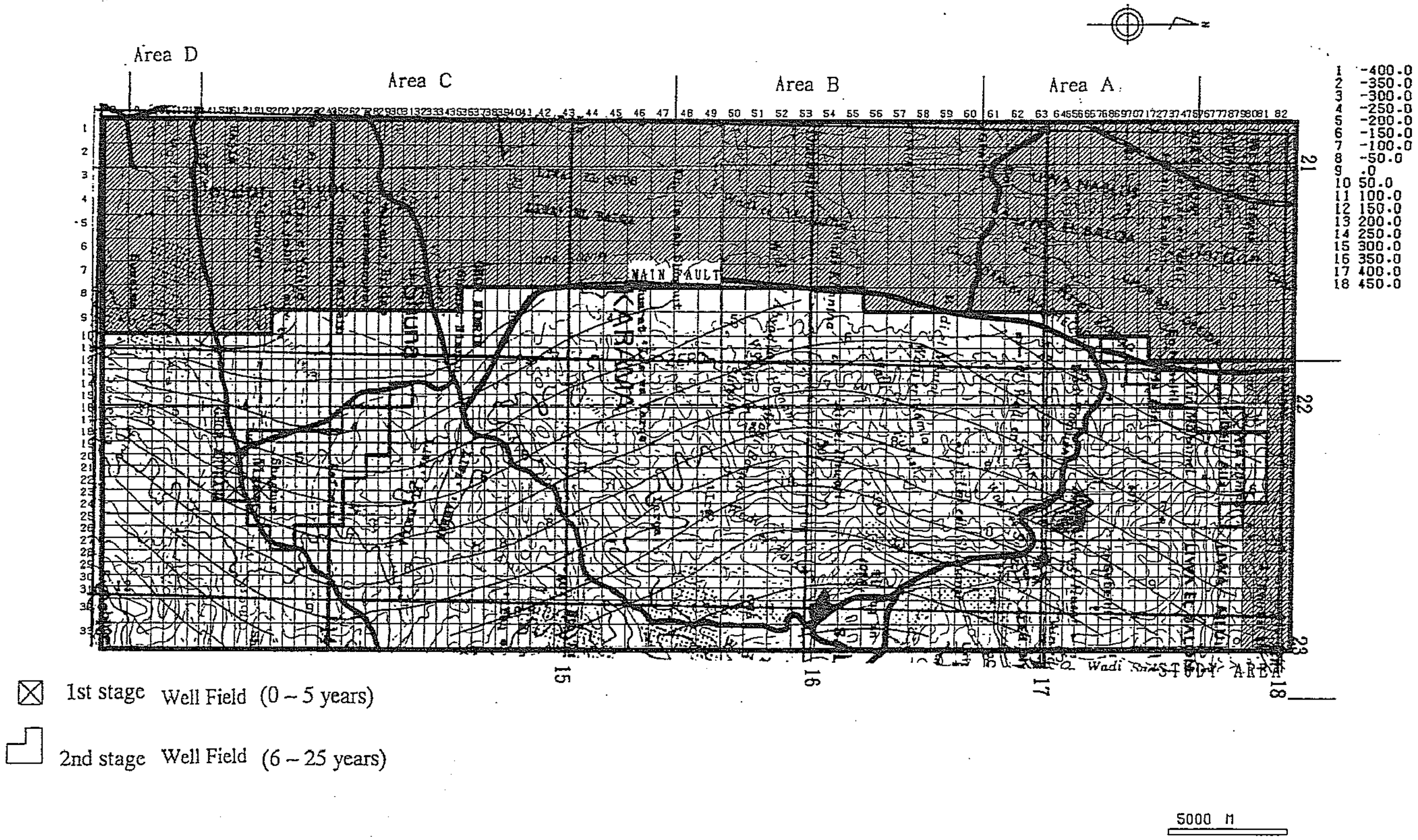


Section "b"

Boundary Condition

▽	head constant
▨	no Flow
▭	flow constant (present simulation) head constant (future simulation)

Fig. I-6.2 Schematic Drawing of Simulation Model



MODFLOW < C-AREA 70MCM >

Fig. I-6.3 Reappearance Results of the Present Piezometric Surface of the Zerqa Group Aquifer

(4) Simulation of the Future Status after the Development

Future simulation on the draw-down of the Zerqa Group aquifer and the influence to the Kurnub Sandstone aquifer was carried out for the several development alternatives using the simulation model which was formed through the trials of the reappearance simulation.

1) Formulation of Tentative Development Alternatives

Development Area

As shown in Table I-6.1, it is assumed that the promising areas for brackish groundwater development are Area A and Area C in terms of the flow amount of brackish groundwater in the Zerqa Group aquifer. Therefore, Area A and Area C were settled for the development areas.

Tentative well fields and well sites are set as shown in Fig. I-6.3 taking not only the hydrogeological condition but also topographic condition for well drilling and trafficabililty for the construction of pipe lines into consideration.

Development Amount

Following four (4) cases are tentatively considered as development amount of the alternatives:

Table I-6.2 Tentative Brackish Groundwater Development Amount

Case	Development Amount (MCM/y)			Remarks
	Area A	Area C	Total	
Case 1	20 MCM/Year (50%)	30 MCM/Year (40%)	50 MCM/Year (45%)	Development will be carried out in both areas
Case 2	25 MCM/Year (60%)	40 MCM/Year (60%)	65 MCM/Year (60%)	Same as above
Case 3	30 MCM/Year (70%)	45 MCM/Year (70%)	75 MCM/Year (70%)	Same as above
Case 4	35 MCM/Year (80%)	55 MCM/Year (80%)	90 MCM/Year (80%)	Same as above

Note: Bracketed figures show approx. percentage of development amount to flow amount of the area
Flow amount .... Area A : 40 MCM/Year, Area C : 70 MCM/Year

Development Staging

The project life is tentatively considered as twenty-five (25) years. Two (2) stages are tentatively considered for implementation of the project. Small scale development will be implemented for five (5) years as first stage in order to see the actual efficiency and working rate of the desalination plant, actual draw-down of the brackish groundwater table and so on. The development amount of the first stage is 6 MCM/year (total amount of Areas A and C is 12 MCM/year). After the first stage, second stage will be implemented according to the scheduled cases shown in Table I-6.2 for twenty (20) years. The future simulation was conducted based on the conditions mentioned above.

2) Future Simulation Results

Future simulation results in 4 (four) cases mentioned above show following maximum draw-down of the Zerqa Group aquifer and the Kurnub Sandstone aquifer after 25 (25) years development.

Table I-6.3 Future Simulation Results

Case	Area	Maximum Draw-down of Brackish Groundwater[1] Table from Piezometric Surface (m)	Maximum Draw-down of Fresh Groundwater[2] Table from Ground Surface
Case 1	A C	-20 -80	No influence -20
Case 2	A C	-30 -110	No influence -30
Case 3	A C	-40 -120	No influence -40
Case 4	A C	-50 -160	No influence -50

1) Zerqa Group aquifer
2) Kurnub Sandstone aquifer

7. Evaluation of the Potential and Quality of Brackish Groundwater

(1) Evaluation of the Maximum Exploitable Amount

1) Criteria for Deciding the Maximum Exploitable Amount

Two types of criteria are considered for deciding the maximum exploitable amount the brackish groundwater as follows:

(i) Criteria on Environment Aspects	- Draw-down effect on the existing wells - Land subsidence - Flow rate decrease of springs and rivers
(ii) Criteria on Development Aspects	- Draw-down depth - Water quality change

It is considered that the draw-down effect on the existing wells can be neglected because there are no production wells tapped into the Kurnub and Zerqa aquifers which would be affected by the brackish groundwater development in the Study area. It is also considered that the brackish groundwater development will not cause land subsidence because the aquifers to be affected are composed of sound bedrock. As the springs are brackish, they are not utilized. Despite that flow of wadis and river may reduce in accordance with the brackish groundwater development, the water quality will be improved.

Considering the criteria on development aspects, it is inferred that the quality will not change greatly during the development period which will be discussed in Section I-7.2.

It is consequently concluded that the draw-down depth of the production wells is the sole criteria for the evaluation of the maximum exploitable amount in the Study. In general, it is reported that the pumping efficiency of an ordinary submergible pump greatly decreases if the lift height is more than 70~80 m. So the permissible draw-down of the production wells should be within 80 m of the ground surface.

For the reasons mentioned above, the depth of the water table in the production wells will be employed as the criteria for deciding the maximum exploitable amount (brackish groundwater potential).

2) Evaluation of Maximum Exploitable Amount

For the estimation of draw-down in the production wells, following characteristics and condition should be considered:

- The Zerqa Group aquifer generally has high artesian pressure
- The water table in the production wells must be lower than the surrounding groundwater surface to collect the groundwater

It is inferred that the optimum discharging rate of the production well tapped into the Zerqa Group aquifer is around 3,000 m^3/day according to the step draw-down pumping test results. It is also inferred from the long term pumping test that the draw-down in the production well will be lower than surrounding groundwater surface by 20 m in case of discharging rate of 3,000 m^3/day.

Considering the conditions mentioned above, the maximum brackish groundwater draw-down to be caused by each alternative is shown in Table I-7.1.

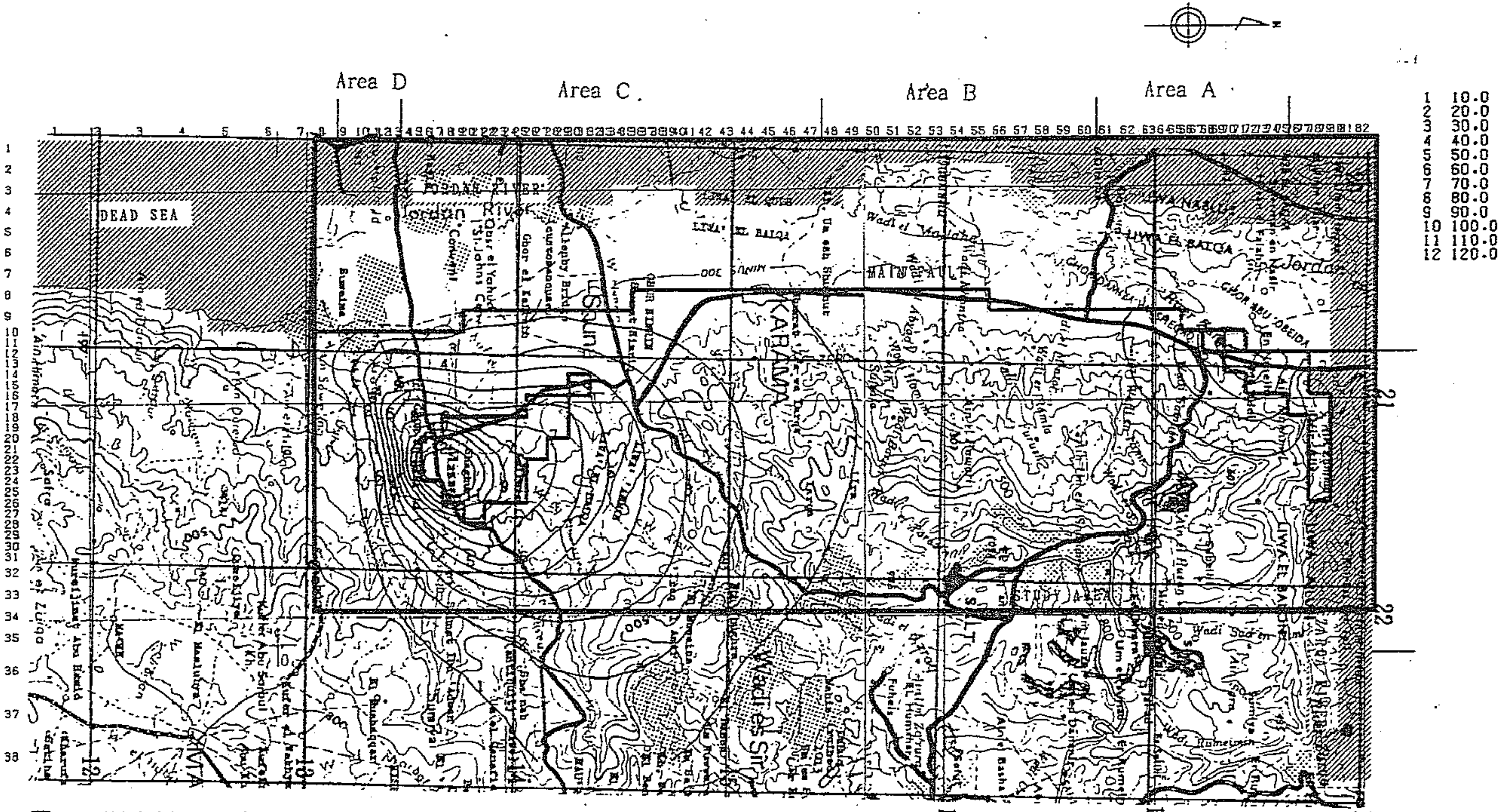
Table I-7.1 Assumed Maximum Draw-down in the Production Wells

Case	Area	A) Maximum Draw-down (m)	B) Piezometric Height at Max. Draw-down Point (from ground surface, m)	C) Draw-down in the Production Wells (m)	D) Maximum Draw-down in the Production Wells (from ground surface, m)
Case 1	A	-20	0	-20	-40
	C	-80	+70	-20	-30
Case 2	A	-30	0	-20	-50
	C	-110	+70	-20	-60
Case 3	A	-40	0	-20	-60
	C	-120	+70	-20	-70
Case 4	A	-50	0	-20	-70
	C	-160	+70	-20	-110

Note: D=A+B+C

Table I-7.1 shows that Case C development may result in a maximum draw-down of -70m in the production wells. Therefore, it is inferred that Case 3 gives the maximum, safe yield of brackish groundwater in the Study area and an amount of 75 MCM/year (Area A: 30 MCM/year, Area C: 45 MCM/year) is reasonable for the brackish groundwater potential of the Study area.

The calculated draw-down of the Zerqa Group aquifer is shown in fig. I-7.1 in Case 3, after 25 years development.



☐ Well Field, Development Amount .... Area A: 30MCM/year, Area C: 45MCM/year
Simulation period: after 25 years

5000 M

MODFLOW < CASE3 75MCM >

Fig. I-7.1 Drawdown Influence on the Zerqa Group Aquifer in Case 3 (end of the Second Stage)

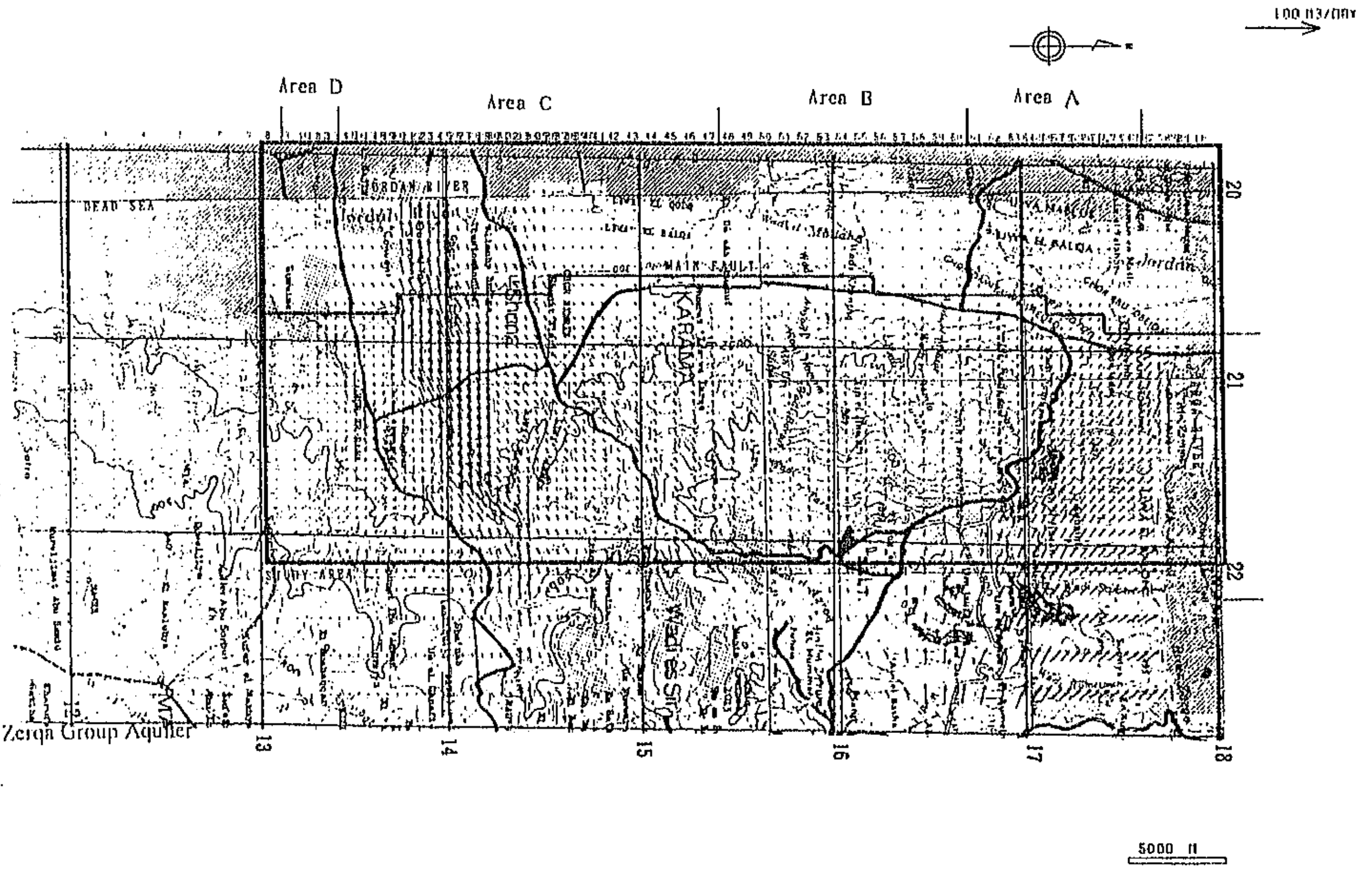
(2) Quality Change of Brackish Groundwater

As shown in Fig. I-7.2, there is no significant change in the natural condition flow vector lines from high salinity area (Area B) to development areas (Area A and Area C) after the development. Therefore, it is inferred that the groundwater quality change (change to higher salinity) by drawing the high salinity water from Area B will not take place during the development.

On the other hand, the recharge of low salinity water from the Kurnub Sandstone aquifer to the Zerqa Group aquifer will be accelerated by the development.

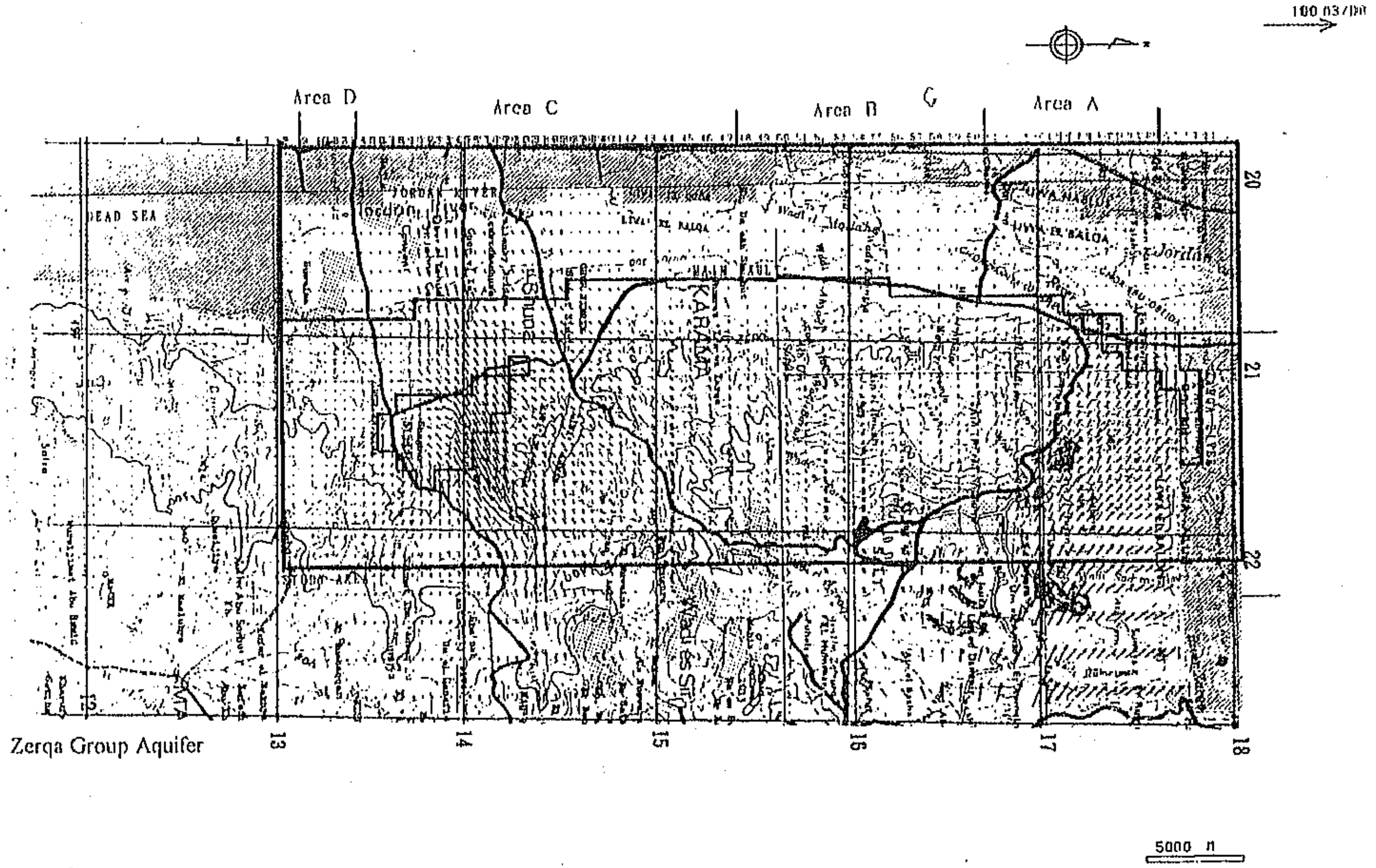
Simulation results show that the increased amount of fresh groundwater (around 500 mg/L in TDS) seepage from the Kurnub Sandstone aquifer is assumed to be about 12 MCM/year in Case 3 (after 25 years).

From the results mentioned above, it is inferred that the quality of the brackish groundwater will not deteriorate but the salinity might slightly decrease during Case 3 development. However, the change will be small.



MODFLOW < PRESENT SITUATION >

Flow Vector in the Natural Condition (before Development)



MODFLOW < CASE3 75MCM >

Flow Vector in Case 3 Development (after 25 years)

Fig. I-7.2 Change of Flow Vector between before and after Development

PART II

Strategy of the Brackish Groundwater Development

Part II: Strategy of the Brackish Groundwater Development

1. Present Water Supply Situation

(1) Water Use and its Sources in the Study Area

1) Outline of the Study Area

The study area of the water supply is the Northern part of Jordan including the Jordan Valley and Amman City for the brackish groundwater desalination development strategy and consists of following five governorates (see Table II-1.1). This study area covers approximately 90% of the national population and approximately 50% of national land and includes the main areas of social and economic activities in Jordan.

Table II-1.1 Population, Area and Gross National Product (GNP)
of the Five Governorates

Governorate	Capital	Population (×1,000)	Area* (km^2)	GNP ('000JD)
Amman	Amman	1,777	9,300	145,690
Zarqa	Zarqa	669	3,800	1,049
Irbid	Irbid	1,041	2,600	10,120
Mafraq	Mafraq	176	26,600	914
Balqa	Salt	257	1,100	1,018
Five governorates		3,920	43,400	158,791
Whole country		4,328	90,000	172,517

* Figures measured from a map of 1/750,000.

2) Water Use and its Sources in the Study Area

Water use in the Study Area, i.e. the five governorates of Amman, Zarqa, Irbid, Mafraq, and Balqa, in 1991 (recent representative water year) was 534 MCM for all irrigation, municipal spillage and industrial uses including the private sector. The sources were surface water, 154 MCM including losses (waste/spillage) of 20 MCM, reuse of municipal sewage treatment effluent, 30 MCM and groundwater, 370 MCM, as shown in Table II-1.2.

The sources available at present are fully utilized. The amount of available water sources, which is fluctuating, depends on the available surface water each year and will limit maximum usage unless a new development can contribute.

Table II-1.2 Water Sources and Use in the Study Area (1990-1991 Water Year)

Unit: MCM/Year

Resource	Amount	Use		Losses
		Irrigation	M/I	
Surface	153.6	124.1	9.5	
Reuse	30.0	30.0	-	
Wells	370.4	226.9	143.5	
Total	554	381.0	153.0	20.0
		534.0		

*1: Surface = Yarmouk to KAC + Zarqa + Side Wadis
*2: Reuse = Effluent from Al Samra Sewage Treatment
*3: Wells includes private wells
*4: Prepared with WAJ/JVA data by JICA Study Team

On the other hand , water use in the Jordan Valley was 190 MCM in 1991. Most of the water, 173 MCM, is used for irrigation purposes. The main source is surface water which provides 153 MCM/year. Municipal and industrial water supply in the Jordan Valley is limited to 7 MCM/year.

Table II-1.3 Water Source and Use in Jordan Valley (1990-1991 Water Year)

Unit: MCM/Year

Resource	Amount	Uses	Amount	Waste/Spillage
Surface:		Irrigation	173.6	
Yarmouk to KAC	89.0	M/I:		
Side Wadis	34.6	to Amman	9.5	
Zarqa River	30.0	in the Valley	7.0	
Total (Surface)	153.6	Total (M/I)	16.5	
Samra Treatment (Re-use)	30.0			
Wells				
Mukheiba to KAC	20.0			
Wells to KAC	0.9			
Wells to WAJ	5.6			
Total (Wells)	26.5			
Total Resources	219.1	Total Used	190.1	20.0

*1: KAC = King Abudulla Canal
*2: M/I Water from Deir Alla to Amman was 33 MCM in 1992 and 31 MCM in 1993.
*3: prepared by JICA Team

3) Water Production and Supply in the Area

In order to fulfill the demand and utilize resources efficiently, water is transferred between governorates or imported from outside. As an example, Table II-1.4 shows that, in 1993,Amman produced 55 MCM/year, imported a total of 47 MCM/year from Zarqa, Zai, and Balqa and exported only 0.25 MCM/year (to Irbid). Water supply facilities in the five Governorates of the study area are linked and operated simultaneously by a trunk main network of 24 inch diameter and larger pipelines connecting the reservoirs and pumping stations.

Locations of the major water supply facilities and trunk main network are shown in Fig. II-1.1.

Table II-1.4 Summary of Conveyance between Governorates

	Production	Supply	Net Import
Amman	54.6	101.1	46.4
Zarqa	29.4	25.2	-4.2
Irbid	30.8	34.4	3.6
Mafraq	35.5	13.3	-22.2
Balqa	17.1	18.0	0.8
Total	167.7	192.2	24.5

Source: WAJ, Information Dept., 1994

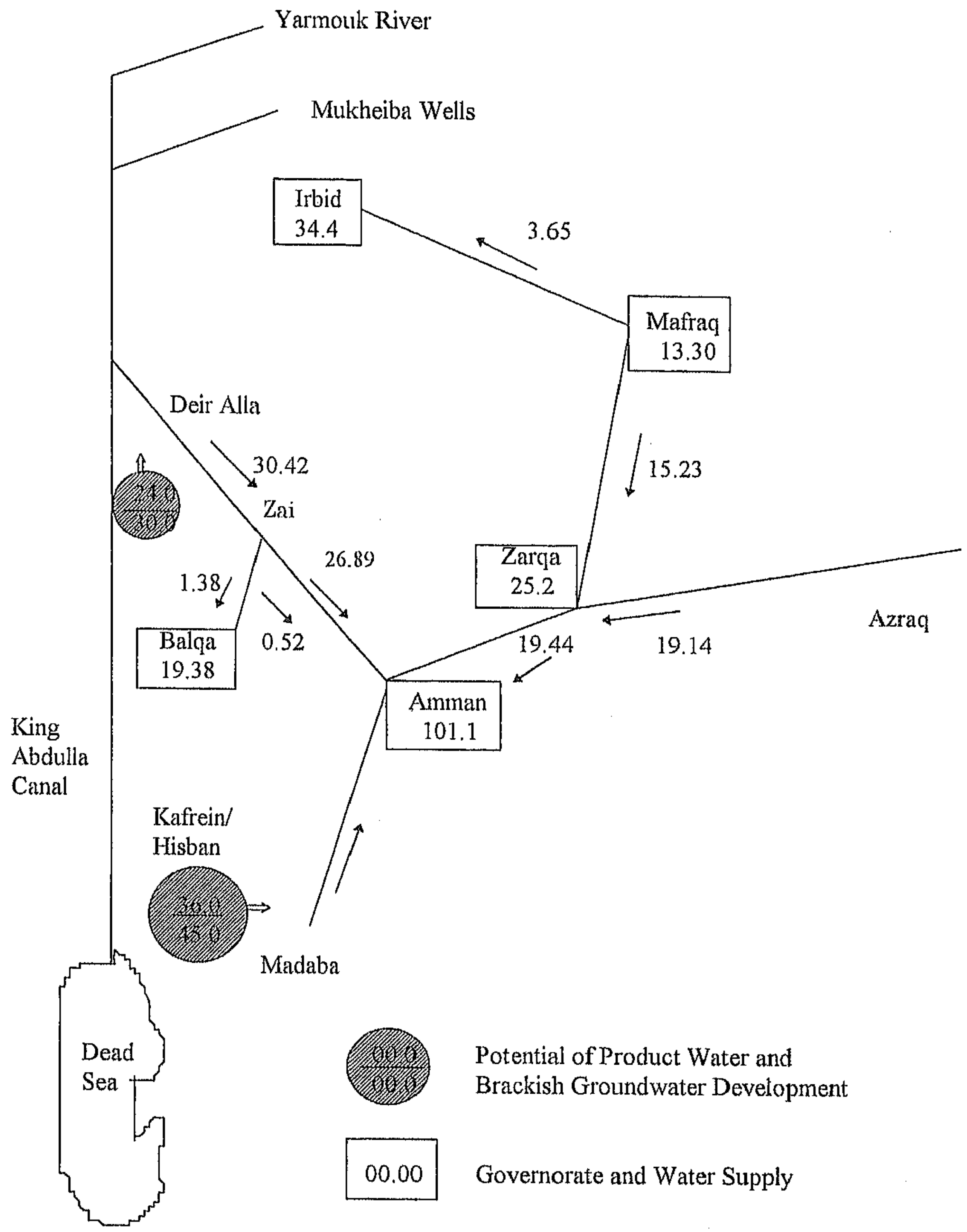


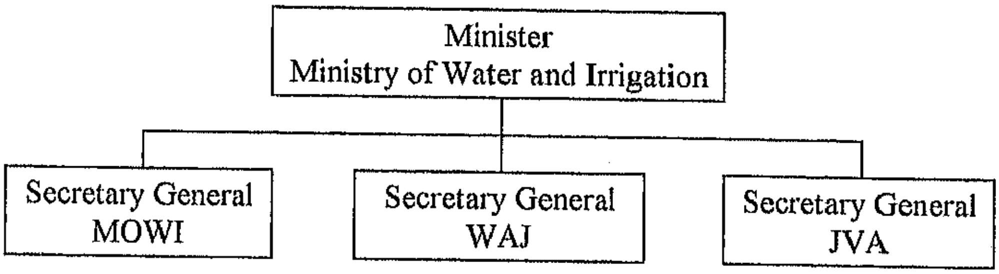
Fig. II-1.1 Inter Governorate Water Conveyance in the Study area in 1993
(Unit = MCM/year)

(2) Water Supply Sector

1) Organization

In Jordan all the water to be supplied for irrigation, municipal and industrial water is managed by the Water Authority of Jordan (WAJ) of the Ministry of Water & Irrigation (MOWI), with the exception of the Jordan Valley and areas lower than +300 m above sea level, which are managed by the Jordan Valley Authority (JVA) of MOWI. JVA manages the water supply for irrigation and the operation and maintenance of surface and groundwater water facilities such the Yarmouk River offtake, Mukheiba Wellfield, King Abdulla Canal, and the side wadis in the Valley.

Schematic relations of the three organizations, MOWI, WAJ and JVA are as shown below. The Ministry of Water and Irrigation was established in 1988, combining the above two authorities and acting as the overall director.



Before the establishment of the Water Authority in 1984, sectors related to water supply were managed independently by the following organizations: National Resources Authority, Drinking Water Establishment, Jordan Valley Authorities, Water and Sewage Authority and Local Municipal Council.

The Water Authority is currently responsible for the following:

- Investigation of water resources
- Development of water resources
- Management of public and private wells
- Planning, construction, operation and maintenance of water and sewage projects
- Research of theoretical and applied engineering involving water and sewage
- Organization and promotion of water preservation and rational water usage

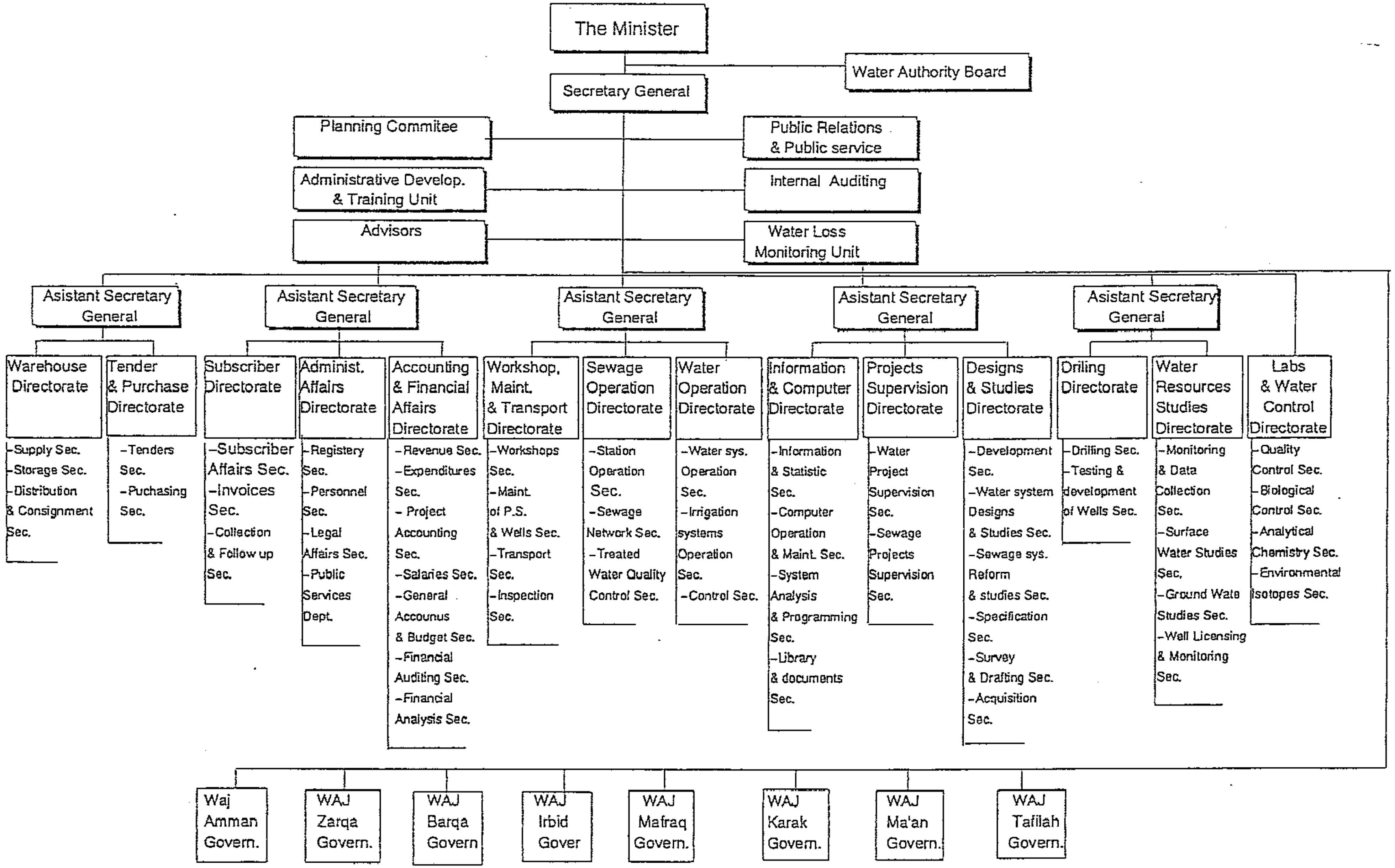


Fig. II-1.2 Organization of Water Authority of Jordan

2) Financial Situation of Water Sector

The financial situation of WAJ, which manages the water supply sector in all of Jordan, except for irrigation water supply in Jordan Valley, is as summarized in Table II-1.5. The water sector suffers losses of more than 35 million JD every year which are compensated by the government. As shown in the table, only personnel and operation and maintenance costs are covered by the income.

Table II-1.5 Financial Status of WAJ

	1992	1993
Annual Total Expenditure	66.99	71.17
Personnel	13.31	15.22
Operation and Maintenance	19.06	19.02
Administration	0.45	0.50
Depreciation	22.33	24.39
Interest of Loans	11.84	12.04
Annual Total Income	27.84	34.82
Annual Total Balance	-39.15	-36.35

Source: WAJ Annual Report 1994

The water supply and management costs of WAJ for the current two years show that, for 200 MCM water supply, the average cost is JD 0.326 per cubic meter, including depreciation of capital investment, and that the average income is JD 0.160 per cubic meter.

Table II-1.6 Average Water Cost

	Unit	1992	1993
Total Water Supply	MCM/year	208	218
Annual Total Income	1000 JD	27,840	34,824
Income per cubic meter	JD/m^3	0.134	0.160
Annual Total Expenditure	1000 JD	66,999	71,165
Water Cost per cubic meter	JD/m^3	0.322	0.326
Annual Total Losses	1000 JD	39,159	36,341
Losses per cubic meter	JD/m^3	-0.188	-0.167

Since WAJ was established in 1984, the tariff system has been revised several times. The latest revision is as shown Table II-1.7. Water bills are distributed every three (3) months and include the sewage fee which corresponds to the consumption of domestic water.

Table II-1.7 Water & Sewage Tariff

Tariff Blocks (Cubic meter for 3 months consumption)	Water Price (Fils/cubic meter)	Sewage Fee (Fils/cubic meter)
from 0 - 20	100	30
21 - 40	190	40
41 - 70	400	100
71 - 100	500	200
101 +	600	250

Source: Information Dept. WAJ 1994

(3) Existing Plans of Water Resources Development

Based on the report of Ministry of Planning in 1988, water resources development plans for the domestic and industrial water supply to the Amman metropolitan area are as listed in Table II-1.8 (revised by Study team according to the actual progress). This table covers the development plans for the remaining main water resources in all of Jordan, except for brackish groundwater, but the total amount is not sufficient to satisfy the future water demand in Jordan.

Table II-1.8 Main Water Resources Development Plans

Plan	Scale of Development (MCM/year)	Remarks
1. Additional Yarmouk River Water through KAC	36	To be realized under Peace Treaty.
2. Mukheiba Groundwater Development	20	Northern part of Jordan. Partly completed and connected to KAC.
3. Wadi Wala Groundwater Development	24	South of Amman. Groundwater development has been progressed and connected with the main network through Madaba. Recharge dam is being planned.
4. Unity Dam	50	Dam for the flood water storage in Yarmouk River. Regional peace is a key factor.
5. Disi Groundwater	75	Southern part of Jordan (350 km from Amman). Development has started for domestic water to Aquaba City and for irrigation water.

KAC: King Abudulla Canal

2. Water Demand Analysis

(1) Water Demand Projection in the Jordan Valley: Domestic, Industry and Tourism

1) Population in the Jordan Valley

Population in the Jordan Valley is said to be around 200,000. The Statistical Yearbook of Jordan, however, stated the population as only 140,000 in 1993. It is understood that this discrepancy is caused by the number of foreign laborers in the Valley who seldom register at the census office. The actual population of the Valley in 1993 was calculated by considering Jordanian locals plus foreign laborers. (See Table II-2.1)

Based on these calculations for the Jordanian population and the number of foreign laborers, the estimation concluded that the actual population in the Valley will be 182,000 in 1995, and 333,000 in 2010.

Table II-2.1 Population in the Jordan Valley

Year	Population ('000)				Foreign Laborers ('000)				
	North	Central	South	Total(1)	North	Central	South	Total(2)	(1)+(2)
Average Growth Rate									
	4.6%	5.1%	3.8%	4.4%					
1995	85	35	33	153	10	8	11	29	182
2000	106	45	39	191	10	8	13	31	222
2005	133	58	47	238	10	8	15	33	272
2010	166	75	47	298	10	8	17	35	333
2015	207	96	69	372	10	8	17	35	407
2020	259	123	83	465	10	8	17	35	500
2025	324	157	100	582	10	8	17	35	617

Source: The Hashemite Kingdom of Jordan, Dept. of Statistics, Statistical Yearbook 1987-93.
Jordan Valley Authority. The Jordan Valley, Dynamic Transformation 1973-1986.
The Hashemite Kingdom of Jordan, Dept. of Statistics, Annual Agricultural Statistics 1986-93.

Note 1: The number of foreign laborers is estimated by multiplying the average number of foreign laborers per dunum by the area of farm land in the Valley.

Note 2.: Population of the Jordan Valley in 1986 estimated by the Jordan Valley Authority was 124,715.

2) Water Demand Projection for the Jordan Valley: Irrigation

By assuming the land development scenario of the Jordan Valley and the improvement of water conveyance efficiency in North Shuna, future water demand for irrigation in the Valley can be estimated. It will increase from 370 MCM at present to 600 MCM by the year 2010 (see Table II-2.2). If we assume the current level of water supply, the water deficit for irrigation will grow from -143 MCM to -373 MCM during the same period.

Table II-2.2 Water Demand and Water Balance for Irrigation in the Jordan Valley

Year	North Shuna	Deir Alla	South Shuna	Total* (MCM/yr.)	Water Balance
1995	175	90	220	485	-258
2000	175	90	258	524	-297
2005	175	90	296	562	-335
2010	175	90	334	600	-373

Source: Estimated by JICA Study Team.

Note*: JVA estimated the agriculture water demand in the Jordan Valley; 370 MCM with 228 thousand dunums and 425 MCM with 360 thousand dunums.

3) Jordan Valley: municipal and industrial water (See Fig. II-2.1.)

Municipal and industrial water demand in Jordan Valley consists of domestic, industrial and tourism demands. Domestic water demand is calculated based on the average population increase rate of 4.4% in Jordan for the present population of 164,000 in Jordan Valley, and the increase in foreign labor.

Planned per capita daily water requirement applied for demand analysis is 150 liters per person per day. Industrial water demand is calculated by applying the rate of population increase to the present industrial consumption. Future demand for tourism is forecast quoting the results of the Tourism Study in East Coast of Dead Sea which is being undertaken by the Ministry.

Finally, water demand in Jordan Valley is summarized in Table II-2.3 as 13.52 MCM/year in 1995 and 26.49 MCM/year in 2010. Domestic water demand is significantly higher than industrial and tourism demand.

However, water supply sources in Jordan Valley are only 10.13 MCM/year. Water supply shortages will soon become critical.

The municipal and industrial water balance in the Jordan Valley can be analyzed by applying the same method as for the study area. The municipal and industrial water shortage in the Jordan Valley is 3.39 MCM/year in 1995. However, the shortage will worsen as the population in the Jordan Valley increases, and will exceed 5 MCM/year by 1998 and 16.36

MCM/year by 2010. If the pilot desalination plant is built before 1998, the water produced by the plant will ease the water shortage in the region.

It needs to be noted that if no water development other than the 5 MCM desalination plant is undertaken, the current level of water shortage will be realized again by 2001.

Table II-2.3 Summary of Domestic and Industrial Water Demand and Water Balance in the Jordan Valley

Year	Water Demand Domestic	 Industry	 Tourism	 Total	Water Supply (MCM)	Water Balance (MCM)
1991	10.66	0.04	-	10.70	8.59	-2.22
1992	10.89	1.06	-	11.95	8.89	-3.06
1993	11.25	0.90	-	12.15	10.13	-2.02
1995	12.54	0.98	-	13.52	10.13	-3.39
2000	15.28	1.22	0.36	16.86	10.13	-6.73
2005	18.68	1.51	0.82	21.01	10.13	-10.88
2010	22.90	2.32	1.27	26.49	10.13	-16.36

Source: JICA Study Team.

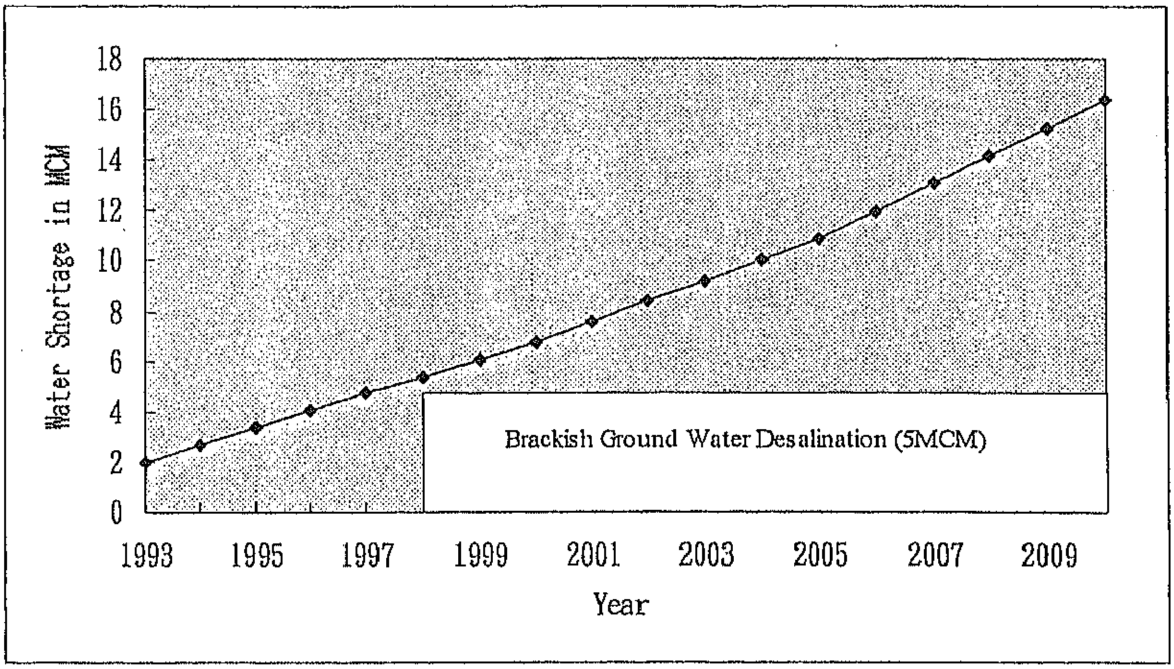


Fig. II-2.1 Municipal and Industrial Water Shortage in the Jordan Valley

(2) Water Demand Projection in the Uplands: Domestic and Industry

1) Population in the Uplands (see Table II-2.4)

The population of the Uplands in 1993 was 3,618,000. The domestic water demand projection in the Uplands has been extrapolated based on population size and population growth rate. The population growth rate is expected to be 3.6 % up to the year 2000, and then the growth rate is assumed to decline gradually to 3 %. Population of the Uplands in 2010 will therefore be 6,289,000.

Table II-2.4 Population Forecast in the Uplands, 1995-2000

	Population in the Uplands						Growth
	Amman	Zarqa	Irbit*	Mafraq	Balqa*	Total	Rate
1995	1,803	688	1,006	179	207	3,883	3.6%
2000	2,152	821	1,200	214	247	4,634	3.6%
2005	2,519	961	1,405	250	289	5,425	3.2%
2010	2,929	1,114	1,629	290	335	6,289	3.0%

Source: Dept. of Statistics, Statistical Yearbook 1987-93, and the estimation by JICA study team
Note*: Population of the Jordan Valley is excluded from these Governorates.
Note**: Gross Water Demand assumes the conveyance loss of 25 percent.

2) Water Demand and Balance in Uplands

Population of Northern five governorates including Amman was 3,618,000 excluding the population of Jordan Valley in 1993. Domestic water supply to this area was 181 MCM/year in 1993 and simple average of daily per capita consumption was 137 liters per day, but it includes almost 60% of unaccounted for water.

Water demand was estimated based on the population growth rate of 3.6% and two scenarios of WAJ for daily per capita water consumption: 150 liters/day and 180 liters/day. Industrial water demand in the area reached 35% of the total industrial demand of Jordan in 1985 and it is assumed that this tendency will continue.

As a result, domestic and industrial demand of Northern five governorates is 308 MCM/year in 1995 for the low consumption scenario and 365 MCM/year for the high consumption scenario and will increase to 517 MCM/year and 609 MCM/year in 2010 respectively.

If the current supply capacity of 181 MCM/year is maintained, shortage of the water balance will be in the range of 127~428 MCM/year.

Table II-2.5 Summary of Domestic and Industrial Water Demand in the Uplands

Year	Domestic Water Demand		Industrial Water Demand	Water Supply	Balance	
	(low)	(high)			(low)	(high)
1993	265	318	15.4	181	-99	-153
1995	285	342	23.3	181	-127	-184
2000	340	408	36.4	181	-195	-263
2005	398	477	43.4	181	-260	-339
2010	461	553	55.5	181	-336	-428

Source: JICA Study Team.

Note*: Water supply of 181 MCM includes 28.3 MCM of treated water through the Deir Alla/Amman pipeline.

(3) Water Balance in the Study Area

1) Study Area: municipal and industrial (See Fig. II-2.2.)

The water balance in the study area during the period between 1993 and 2010 can be demonstrated by plotting the water demands estimated in the previous sections and the water resource development schemes together in the same diagram. Fig. II-2.2 shows the municipal and industrial water shortages in the Jordan Valley and Uplands and the water resource development plans from 1993 to 2010.

The diagram shows that the Peace Treaty water in both the short term and mid-term does not satisfy the municipal and industrial water shortages in the Jordan Valley and Uplands. Complete development of Disi/Muddawara groundwater (100 MCM/year) and brackish groundwater desalination (60 MCM/year) will probably be required to overcome the water shortage in the area. In addition, earlier implementation than the development schedule shown in the diagram is desirable for solving the problem. Unity dam will be needed to meet the demand from 2004 to 2010.

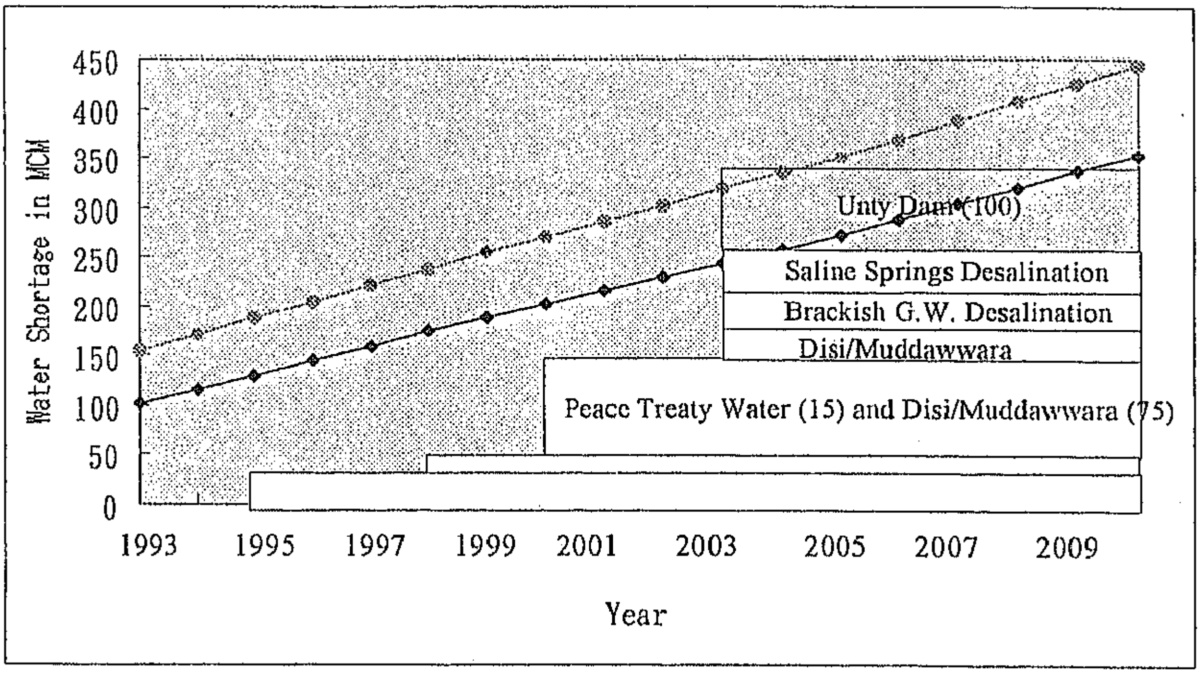


Fig. II-2.2 Municipal and Industrial Water Shortage in the JV and Uplands

Note: Data in the figure are estimated by JICA Study Team and are subject to modification.