6. Hydrogeological Analysis

6.1 Hydrogeological Features of the Study Area

The target aquifer of the study is the brackish groundwater aquifer in the Zerqa Group. Therefore, the stress should be laid on this aquifer in the Study.

6.1.1 Regional System of the Zerqa Group Aquifer

According to existing reports, the hydrogeological classification in the East bank of the Jordan valley can be compiled as shown in Table I-6.1.1.

Table I-6.1.1 Simplified Hydrogeological Classification of the East Bank of the Jordan Valley

Geological Formation or Group	Regional Hydrogeological Classification	Hydrogeological Classification	Lithology	Saturated Thickness (m)
Mio-Plio-Quaternary		Aquifer/aquiclude	Sands/limestones/ clays/conglomerates	10 - 400
Basalt (Ba)		Aquifer	Basaltic lavas	5 - 100
Rijam (B4)	Upper 1) Aquifer Complex (Upper Cretaceous Aquifer)	Aquifer	Limestone	15 - >100
Muwaqqar (B3)		Aquiclude	Marl	50 - 400
Amman-Wadi Sir (B2-A7)		Aquifer	Limestone/chert	50 - >350
Ajlun (A1-6)		Aquiclude	Marl/shale/limestone	200 - 600
Hummar (A4)		Locally aquifer	Dolomitic limestone	40 - 45
Lr Ajlun (A1-6) (South Jordan)		Aquifer	Sandy limestone/sandstone	120
	Aquitard (A1)			
Kurnub (K)	Lower 1) Aquifer Complex	Aquifer	Sandstone	50 - 300
Zerqa (Z)		Aquifer	Limestone/marl/dolomitic limestone	50 - 500
Khreim (Kh)		Aquiclude/Aquitard	Shale/sandstone	200 - 1500
Disi (D)		Aquifer	Sandstone	400 - 3000
Pre-Cambrian Basement		Aquifuge	Granites	-

After "Report on Brackish Groundwater Resources in Jordan, 1991"

1) Interview with Dr. Salameh of Jordan University

As the Zerqa Group aquifer is hydraulically connected to the overlying Kurnub Sandstone aquifer in some areas, they are normally classified as one aquifer complex (lower aquifer complex).

The recharge system and ground water flow of the Zerqa Group aquifer as described in "Water Resources of Jordan, present Status and Future Potential, Elias Salameh & Helen Bannayan , 1993", are explained below.

The schematic hydrodynamic pattern of the Eastern flank of the Jordan Valley is shown in Fig. I-6.1.1. Infiltration occurs over the highland (recharge area) through the outcrops to the upper aquifer complex (Upper Cretaceous aquifer). The ground water divide is formed in the upper aquifer complex lying in the recharge area and the ground water flows Westward (toward the Jordan Valley) in the west of the divide and flows Eastward (toward the desert area) in the East of the divide. The Westward oriented ground water in the upper aquifer complex appears on the escarpment as river base flow and springs. The Eastward oriented ground water in the upper aquifer complex gradually infiltrates downward through the fractures and faults in the several aquiclude / aquitard layers and finally infiltrates (recharges) down to the lower aquifer complex (Kurnub Sandstone and Zerqa Group). When the ground water has infiltrated to the lower aquifer complex, it immediately changes its direction to the West and flows into the Jordan Valley forming the hot and saline springs.

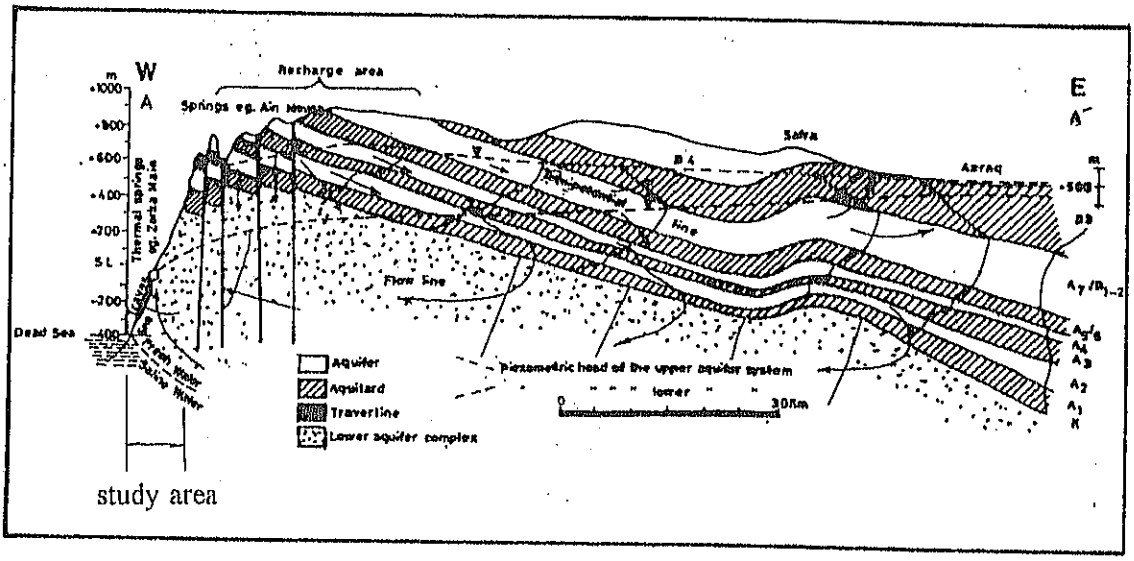


Fig. I-6.1.1 Hydrodynamic Pattern of the East Bank of the Jordan Valley (after Salameh and Udluft, 1985)

The thickness of the lower aquifer complex increases from South to North and from West to East. The lower aquifer complex is assumed to be around 600 m thick. The present day, Westerly oriented, regional gradient of the ground water in the lower aquifer complex equals 0.75% on average (distance from Dead Sea to Azraq = 120 Km, difference in ground water elevations = + 505 - (-400) = 900m).

The infiltration (recharge) was calculated by EL-NASER from the upper aquifer complex to the lower aquifer complex and the calculated average value was 0.017 l/Km2 .s (Groundwater Resources of the Deep Aquifer systems in NW - Jordan, 1991).

The explanation offered by "Water Resources of Jordan, Present Status and Future Potential, 1993" for the heat and salinity of the groundwater of the lower aquifer complex is that they are caused by interaction with the rock matrix through the long flow path and by the geothermal gradient respectively.

6.1.2 Hydrogeological Structure of the Study Area

The hydrogeological map and geological profiles have been prepared based on the existing geological maps and new well data obtained in the Study. These maps are shown in Fig. I-6.1.2 and the Supporting Report respectively.

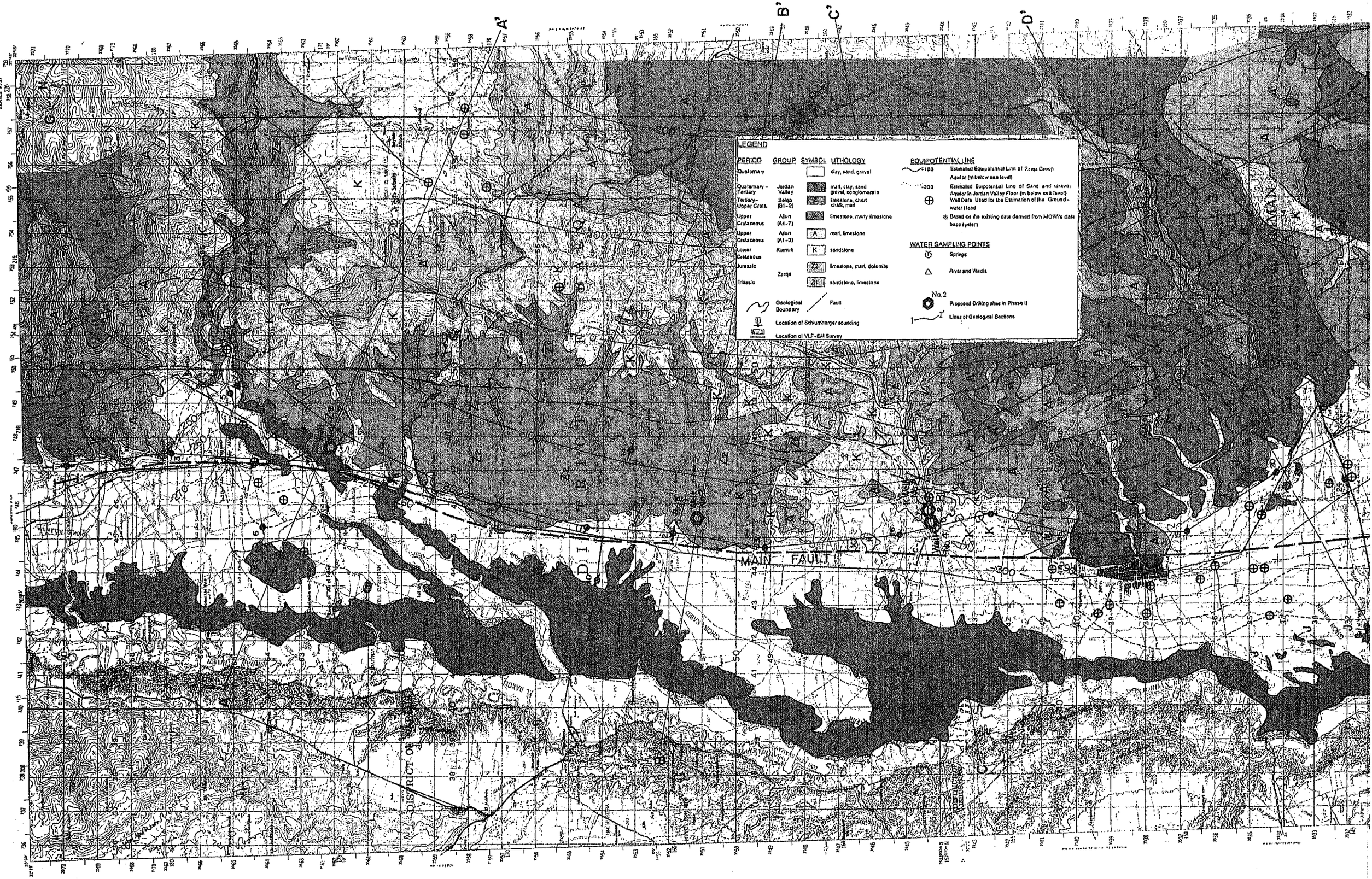
In hydrogeological terms, the study area is composed of the Zerqa aquifer, the Kurnub sandstone aquifer, the Upper aquifer complex (A1 - A6 and B2/A7) and the Jordan Valley Group aquifer. As the Zerqa aquifer, the target aquifer of the Study, contacts with the overlying Kurnub sandstone aquifer and the Jordan Valley Group aquifer at the fault boundary in the West, the discussion that follows will cover all three of these aquifers.

(1) Aquifers

The findings concerning the aquifer properties gotten through the Study are described next.

1) Ram Sandstone Aquifer

Though the target aquifer is the Zerqa Group aquifer in the Study, two wells penetrated the Ram Sandstone aquifer in the southern part of the Study area (refer to Chapter 3.3.2) 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)
limestone, chert chalk, marl
Upper Cretaceous
Ajlun (A4-7)
limestone, marly limestone
Upper Cretaceous
Ajlun (A1-3)
marl, limestone
Lower Cretaceous
Kurnub
sandstone
Jurassic
Triassic
Zarqa
limestone, marl, dolomite
sandstone, limestone
Geological Boundary
Fault
Location of Schlumberger sounding
Location of VLF-EM Survey
EQUIPOTENTIAL LINE
-150
Estimated Equipotential Line of Zarqa Group Aquifer (m below sea level)
-300
Estimated Equipotential 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 MOWR's data base system
WATER SAMPLING POINTS
Springs
River and Wadis
No.2
Proposed Drilling sites in Phase II
Lines of Geological Sections
MAIN FAULT
DISTRICT OF
MAIN

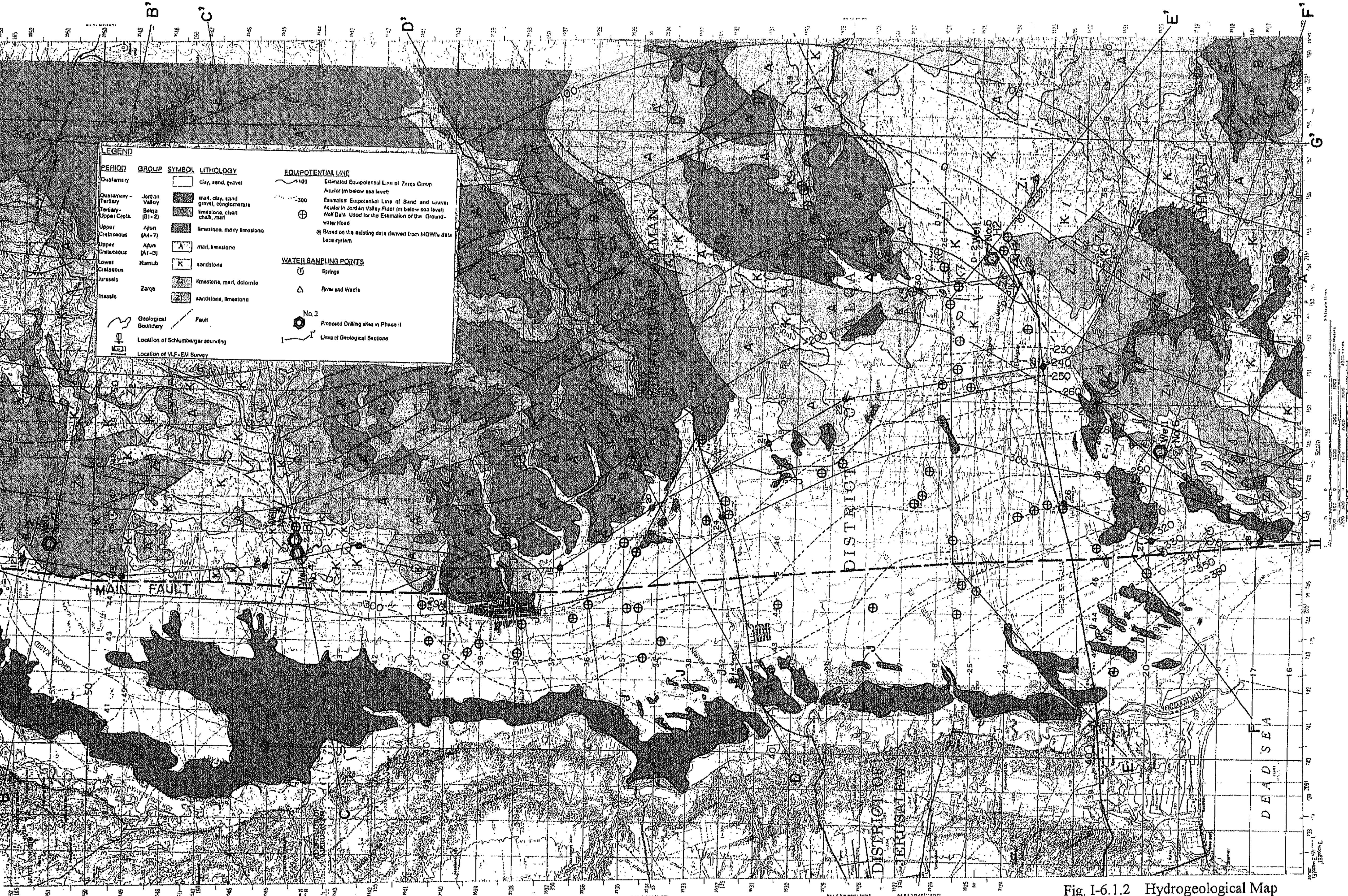


Fig. I-6.1.2 Hydrogeological Map

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, piezometric pressure of the Ram Sandstone aquifer is much higher than the Zerqa Group aquifer by about 70 m in height. The flow amount reached 100 lit/sec (No. 5) to 300 lit/sec (No. 6) during the drilling works. It is suggested that the Ram Sandstone aquifer has higher permeability than the Zerqa Group aquifer comparing Tables I-6.1.2 and I-6.1.3.

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

Table I-6.1.2 Hydraulic Properties of the Ram Sandstone Aquifer

Area[1)]	Well[2)]	Stratigraphy[3)]	Transmissibility (m^2/day)	Permeability[4)] Coefficient (m/day)	Storage Coefficient
C	No. 5	R	205~262	4.1~5.2	4×10^{-3}~6×10^{-4}
D	No. 6	R	120~369	5.2~16.0	1×10^{-6}

1) For the area classification, refer to chapter 5

2) Location of wells is shown in the hydrogeological map

3) R: Ram Sandstone

4) Transmissibility divided by the penetrated thickness of Ram Sandstone aquifer

2) 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.

The permeable layers in this aquifer are arenaceous layers and dolomitic linestone. The flow of groundwater usually starts from these layers during the drilling work.

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

Table I-6.1.3 Hydraulic Properties of the Zerqa Aquifer

Area	Well	Stratigraphy[1)]	Transmissibility (m^2/day)	Permeability Coefficient (m/day)	Storage Coefficient
A	No. 1	Z_2	63~157	0.3~0.7	1×10^{-2}
B	No. 2	Z_2	91~143	0.5~0.6	1×10^{-2}~4×10^{-3}
B	No. 4	Z_2	100[2)]	0.8	1×10^{-3}
C	Hisban No. 1[3)]	Z_1	2,157	21.6	1×10^{-3}

1) Z_1 : Lower Zerqa Group (Main Formation), Z_2 : Upper Zerqa Group (Azab Formation)
2) From the pumping test of the combination wells (Well No. 3 and Well No. 4)
3) Existing well in Wadi Hisban

The total thickness of the Zerqa Group aquifer is estimated to be around 600 m in the northern part (Deir Alla) and it gets thinner by 300 m in the southern part (Wadi Hisban). The Zerqa Group aquifer is underlain by Ram Sandstone.

It was mentioned in Section 6.1.1, Regional System of the Zerqa Aquifer, that the Zerqa aquifer is hydraulically connected with the overlying Kurnub Sandstone aquifer in some areas. The clear difference between them, however, can be observed in the piezometric pressures in Well No. 3 and Well No. 4. The Zerqa Group aquifer is under the artesian condition and has a higher piezometric pressure than the Kurnub Sandstone aquifer. The Zerqa Group aquifer also shows higher salinity than the Kurnub Sandstone aquifer. These phenomena confirm that the Zerqa aquifer and Kurnub sandstone aquifer are hydraulically separated by marly layers in the Study area.

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 it plays the role of "Aquitard" between them.

This layer does not completely separate the two aquifers hydraulically. According to the hydrogeochemical analysis discussed in the Section 6.2.2. There is some hydraulic interrelation was inferred through this layer.

The leakance factor of this layer obtained by the combination pumping test of Well No. 3 and Well No. 4 in area "B" is shown below:

- Leakance Factor of Marly Layers 0.7×10^{-4}/day

For details of the area classification and the combination pumping test, please refer to Chapter 5 "Water Balance Analysis" and Section 3.3.2 "Results of Test Well Drilling", respectively.

4) Kurnub Sandstone Aquifer

The Kurnub Sandstone aquifer is mainly arenaceous and consists of reddish, fine - medium grained sandstone intercalated with siltstone and claystone. The thickness of the Kurnub Sandstone is 200 m to 250 m in the Study area.

Many wells have been drilled which tap the Kurnub Sandstone aquifer in the West of the Study area and to the East of the Study area.

Wells drilled into the Kurnub Sandstone aquifer are under the artesian condition in the foot of the escarpment. Other wells located on the escarpment are generally under the water table condition.

With regard to hydraulic properties, the specific capacity was calculated for many of the existing wells tapped into the Kurnub Sandstone aquifer and these results are shown in Table I-6.1.4 below.

Table I-6.1.4 Specific Capacity of the Wells tapped to the Kurnub Sandstone Aquifer

Specific Capacity (m^2/day)	Number
0 - 50	12
50 - 100	4
100 - 200	9
200 - 300	5
300 - 400	1
400 - 500	1
500 - 600	2
600 - 700	1
2,000 -2,500	1

Note: The data is derived from the MOWI's data base system.

As shown in Table I-6.1.4, the average specific capacity of the wells tapped into the Kurnub Sandstone aquifer is less than 100 m^2/day.

The transmissibility and storage coefficient of the Kurnub Sandstone aquifer were obtained from the pumping test conducted in Well No. 3 and the results are shown in Table I-6.1.5 below.

Table I-6.1.5 Hydraulic Properties of the Kurnub Sandstone Aquifer

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

5) Jordan Valley Group Aquifer (Sand /Gravel aquifer)

The Jordan Valley Group fills the rift valley and forms a wide valley floor. 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 Jordan Valley Group can be divided into three zones which are, from the lower to the upper part: consolidated /cemented conglomerate layers of about 100 m thickness; conglomerate and alternating marl, sand and gravel layers of about 350 m thickness; and alternating marl, clay, chalk, silt and gypsum layers of more than 300 m thickness (Lisan Formation).

The aquifer in the Jordan Valley Group is situated in the middle zone which is intercalated with sand and gravel layers (hereinafter called Sand /Gravel aquifer).

As shown in Fig. I-6.1.4 the piezometric surface (groundwater level contour line) of the Sand/Gravel aquifer inclines from the hill of the escarpment to the Jordan River in parallel with the gradient of the Jordan Valley floor. This implies that there is no groundwater flow from North to South in the Jordan Valley plain and the Sand/Gravel aquifer in Jordan Valley is mainly recharged from the escarpment.

The specific capacity of the Sand/ Gravel aquifer is shown in Table I-6.1.5 based on data derived from MOWI's data base system.

Table I-6.1.6 Specific Capacity of the Wells Tapped into the Sand/Gravel Aquifer

Specific Capacity (m^2/day)	Number
0 - 50	1
50 - 100	0
100 - 200	2
200 - 300	1
300 - 400	0
400 - 500	2

According to Table I-6.1.5, the specific capacity of wells tapping the Sand/Gravel aquifer ranges between 100 to 300 m^2/day in average.

(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 strata are mainly deformed in the form of flexure, and the maximum dislocation of the minor faults is around 20 m. Therefore, it has been assumed that the aquifer extends without any large hydraulic breaks due to faults in the escarpment area.

The strata incline toward the Jordan Valley almost in parallel with the slope of the escarpment as shown in the hydrogeological profiles shown in the Supporting Report. 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.

The contour lines of the bottom and surface of the Zerqa Group aquifer are shown in Fig. I-6.1.3 and Fig. I-6.1.4 respectively. Along Wadi Kaffrein and Wadi Shueib, two synclines run in

a NE-SW direction as shown in Fig. I-6.1.3 and Fig. I-6.1.4. Basin structure (depression of the strata) is also recognized in the synclinal flexure along Wadi Kaffrein (see hydrogeological profile II - II' shown in Supporting Report).

In general, the strata are upheaved in the Northern part and depressed in the Southern part in concordance with the general topographic configuration as shown in hydrogeological profile G - G' attached in the Supporting Report.

It has been assumed that the Main Fault runs along the foot of the escarpment in a N-S direction. The Main Fault cannot be observed because the overburden thickly covers and hides the fault. The Main Fault bounds on the bedrocks to the East and Quaternary Jordan Valley Group to the West.

(3) Piezometric Potential

a. Ram Sandstone Aquifer

According to the drilling results of Well No. 5 and No. 6, it is suggested that the Ram Sandstone aquifer has much higher piezometric pressure than the Zerqa Group aquifer by around 7 kg/cm^2. However, the regional configuration of the piezometric pressure of this aquifer, could not be made clear because of the lack of the data.

b. Zerqa Group Aquifer

The piezometric surface contour line shown in Fig. I-6.1.5 was prepared based on the existing well data, Well No. 1, No. 2, and No. 4 data in the Study area and Suweileh Oil Test Well (PP6) which was drilled in Sahl el Baqa area.