MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

GROUNDWATER MANAGEMENT COMPONENT

Outline Hydrogeology of the Amman-Zarqa Basin

May, 2000

The Water Resource Policy Support activity is supported by the
United States Agency for International Development (USAID) through a contract
with Associates in Rural Development Inc. (ARD):
USAID/ARD Contract No. LAG-I-00-99-00018-00

TABLE OF CONTENTS

OUTLINE HYDROGEOLOGY OF THE AMMAN- ZARQA GROUNDWATER BASIN

The Amman-Zarqa Basin covers 4710 km^2 of area, 468 km^2 of which are in Syria. A summary hydrogeological map of the Basin is presented in Figure 1. The basin is bordered by the Yarmouk Basin to the North, the Azraq Basin to the East and South, the Dead Sea Basin to the South-West, and by the Reft Sidis Basin to the West. Within the Amman-Zarqa Basin, the most important aquifer is the Amman-Wadi Sir (B2/A7) system. The saturation limit of the B2/A7 aquifer is defined in Figure 2.

1. HYDROGEOLOGY

The rock units, which have been geologically described in Appendix 1, form a sequence of aquifers and aquitards. These are listed in terms of their location within oldest to youngest formations:

Zarqa	(Z)
Kurnub	(K)
Na‘ur	(A1/2)
Hummar	(A4)
Amman- Wadi Sir	(B2/A7)
Rijam	(B4)
Basalt	(BS)

1.1 The Zarqa Aquifer (Z)

The aquifer is composed mainly of sandstone, marls, dolomite shale and limestone, with a higher proportion of limestone and dolomite in the upper part. The sandy facies dominates in the lower part. The Zarqa aquifer outcrops mainly in the deeply eroded wadis in the Zarqa Valley area. Flow occurs along the western highlands in the basin. A groundwater divide directs flow west towards the Jordan Valley. Flow from the east of the divide is directed eastwards towards the Azraq basin. Recharge to the aquifer occurs in the outcropping areas such as Jerash, Baqa, and along the Zarqa River.

Transmissivity: 27.0-290.0 m^2/d
Storage coefficient: 0.0001-0.02

1.2 The Kurnub Aquifer (K)

The Kurnub sandstone is a regional aquifer in Jordan. Recharge is limited to small outcrop areas in Baqa, Jerash and the Zarqa River. The aquifer is also recharged by leakage from the overlying carbonate aquifers. The estimated total recharge to both the Kurnub and the underlying Zarqa aquifer within the basin is about 8 MCM/year.

The aquifer is separated from the underlying Zarqa aquifer by bluish-green shale and marls of the upper Zarqa formation, and is confined by the overlying Nau‘r marls.

Transmissivity: 3.0-1700 m^2/d
Storage Coefficient: 0.001-0.10

Figure 1 not available in electronic form.

Figure 2 not available in electronic form.

1.3 The Nau‘r Aquifer (A1/2)

The base of the Nau‘r Aquifer consists of marl which confines the underlying Kurnub. Recharge occurs in the areas outcropping west and southwest of Amman. The estimated amount of recharge within the basin area is about 4.5 MCM/y, much of which emerges as spring flow.

Transmissivity: 4-10 m^2/d.
Storage Coefficient: 0.0006

1.4 The Fuheis Aquitard (A3)

Within the basin, this consists of 70-80m of olive- green marl intercalated with marly limestone, which confines the Nau‘r aquifer.

1.5 The Hummar Aquifer (A4)

This is a productive local aquifer in the Amman-Zarqa and Sukhna areas. It is an important source of water supply in the Amman-Zarqa syncline. Elsewhere, its productivity is limited. The aquifer is artesian in two synclinal areas, and the hydraulic pressure is high enough to sustain flows from wells. However, water levels have been declining in recent years, suggesting that the aquifer may be overexploited.

The flow is controlled by a divide, which extends between Amman and Wadi Sir northwards to Sweilih. West of the divide, the flow direction is south-westwards to Wadi Sir. East of the divide, the flow is to the south-east towards Amman and then to the east and north-east. The flexure of south Amman, which strikes NE-SW, forms the south-eastern limit of the flow.

The estimated direct recharge is limited to an outcrop of about 20 km^2 extending from the south-western edges of the Amman-Zarqa syncline (Bayadir Wadi Sir to Sweileh through Sukhna). Estimated recharge is approximately 5 MCM/y. In the northern part of the basin, the permeability is low and receives little recharge.

Transmissivity: 230-2800 m^2/d
Storage Coefficient: 0.01-0.10

1.6 The Shueib Aquitard (A5/6)

Within the basin, the Shueib formation is a well-known aquitard. The shale and marl formation confines the underlying Hummar aquifer and separates it from the overlying B2/A7 aquifer. In the south-western part, vertical leakage through this aquitard from the Hummar is possible.

1.7 The Amman-Wadi Sir Aquifer System (B2/A7)

This is the most important aquifer in the Basin. It has a large and continuous extent, and a relatively high permeability. It receives the highest amount of modern recharge and is considered to be the principal source of fresh water for domestic as well as for irrigated agriculture in the Plateau. The delineation of the Amman-Zarqa Groundwater basin is based on the configuration and properties of this aquifer in the basin area.

Groundwater from the Amman recharge mound flows in four directions. A flow component is directed north-eastwards down the Amman-Zarqa Syncline to discharge into the upper Wadi

Zarqa Valley. The second component is directed westwards and gives rise to Wadi Sir springs. The third component is directed southwards to contribute to the base flow of Wadi Mujib and Wadi Zarqa Ma'in. The fourth component is directed eastwards into the Azraq Basin. In the Qihati fault, the maximum displacement is about 300 meters, which places the impermeable Muwaqqar aquitard against the B2/A7 aquifer. This forms a groundwater barrier, which separates water discharging to the upper Wadi Zarqa Valley from groundwater flowing to the Azraq Basin.

Recharge occurs in the western highlands. In particular, a recharge mound is developed on the high outcrop area of the western highlands. The crest of the mound is a few kilometers to the west of Amman. Most of the direct recharge enters the aquifer in this high rainfall zone. Estimated total recharge within the basin is about 40-45 MCM/y. Prior to aquifer depletion, an additional amount of about 23 MCM/y used to be transferred to the B2/A7 from the basalt aquifer in the upper Zarqa valley area.

Transmissivity: 9.0-900.0 m^2/d.
Storage Coefficient: 0.01-0.30

1.8 The Muwaqqar Aquitard (B3)

This aquitard, consisting of a thick sequence of chalk and marl, forms a groundwater barrier in the eastern limit of the basin along the Qihati fault.

1.9 The Rijam Aquifer (B4)

This occurs in the eastern part of the basin, where it is dry, being above the saturation zone.

1.10 The Basalt Aquifer (BS)

The estimated recharge to the whole Basalt aquifer in Jordan is about 45 MCM/y of fresh water, suitable for all types of usages. Of that amount, only 28 MCM/y are available within the Amman-Zarqa Basin in Jordan, while the rest discharges into the Azraq basin.

Transmissivity: 2- 113,000 m^2/d
Storage Coefficient: 0.0001-0.003

Table 1 summarizes the hydraulic characteristics of aquifers in the Amman-Zarqa Basin. Transmissivity values are derived from averages of pumping tests.

Table 1: Hydraulic Parameters of aquifers in the Amman- Zarqa Basin.

Aquifer	Average Thickness (m)	Transmissivity m^2/d	Storage Coefficient (S)	Recharge MCM/y
V (Basalt)	220.0	2.0-113,000.0	0.001	28.0
B2/A7	220.0	9.0-900.0	0.01-0.30	40.0-45.0
A4	50.0	230-2,800.0	0.01-0.10	5.0
A1/2	220.0	4.0- 10.0	0.004	4.5
K	280.0	3.0- 1,700.0	0.001-0.10	4.5
Z	350.0	27.0- 290.0	0.0001	3.5

Sources: various, including MWI files

The wide variation in permeability and transmissivity as shown in Table 1 is attributed to the variation in lithology and thickness, and facies changes. Locally, structures such as faults and fractures affect permeability, especially in fault zones where secondary porosity is developed.

Total recharge to the Amman-Zarqa basin is approximately 88 MCM/y according to Salameh, 1993. Table 2 shows the increase in abstraction and overdraft above the safe yield.

Table 2: Groundwater Overdraft During the period 1989- 1998

Year	Abstraction (MCM)	Overdraft (MCM)	Abstraction as % of safe yield
89	135.675	48.175	155.057
90	135.890	48.390	155.302
91	136.115	48.615	155.456
92	136.334	48.834	155.810
93	136.557	49.057	156.065
94	136.775	49.275	156.314
95	136.996	49.496	156.567
96	137.215	49.715	156.817
97	137.436	49.936	157.069
98	137.656	50.156	157.311

Source: WAJ, March 2000

1.11 Declines In Water Levels

In the late 70's and early 80's, declines in water levels in the basalt and in the B2/A7 aquifer in the Dhuleil, Hallabat and Mafraq areas were noticed in both government and private wells. The extent of the decline and annual rate of decline varies considerably. Declines in water level of the B2/A7 aquifer range between 0.67m and 2.0m per year.

The A4 Aquifer, which is partially confined in the basin and was known for its springs, is no longer artesian. The decline in water level is known to have exceeded 70 meters in Ain Ghazal, north of Amman.

The A1/2 Aquifer did not experience any significant decline in its water level in the basin. Springs from this aquifer on the western part of the basin are still flowing.

The Kurnub Aquifer in the Baqa and Ain el Basha areas is excessively depleted. The wells are very close to each other (150-500m). A total decline of water level in this aquifer is about 70 meters during the last 30 years.

Declines in the water levels of the Zarqa aquifer have not been observed.

2. HYDROCHEMISTRY

Prior to groundwater overdraft, historical data up to 1970 show that groundwater in all aquifers of the Amman-Zarqa basin was of fairly good quality and that it was suitable for all uses. In the late 70's, both private operators and the government started deepening wells, especially in the B2/A7 and the basalt aquifers, which were the main sources of water supply in the Basin for domestic and irrigated agriculture. Since then, the decline of water levels was accompanied by a deterioration in water quality. Deeper aquifers of lower quality were penetrated by many wells

and production from more than one aquifer resulted in the disturbance of the hydraulic equilibrium. The following is a brief description of the chemistry of groundwater in the Basin.

2.1 The Zarqa Aquifer

The Zarqa aquifer is generally brackish. For example, in the Jerash area, the total dissolved solids (TDS) in the Al-Majdal Well water is about 4000 ppm. Only in limited areas where the aquifer receives modern recharge as in Ain el Basha, Baqa', and in limited localities along the Zarqa River, is the groundwater of good quality.

2.2 The Kurnub Aquifer (k)

The greater part of the Kurnub water is of good quality. TDS values of 600- 700 ppm have been measured in wells in Baqa', Jerash and Kafrein (source: WAJ open file reports).

2.3 The Nau'r Aquifer (A1/2)

The water quality remains good. Wells drilled in 1999 encountered water with TDS between 500 and 600 ppm.

2.4 The Hummar Aquifer (A4)

The water quality is currently good and is suitable for all uses (230-525 ppm). However, organic and industrial pollution is becoming a threat to this valuable source.

2.5 The Amman-Wadi Sir Aquifer (B2/A7)

Prior to excessive abstraction, the TDS value ranged from 260 to 680 ppm, and the water type was calcium and magnesium bicarbonate. Table 3 summarizes salinity levels.

Table 3: Salinity of B2/A7 water.

Area	Salinity (EC)		
	1970	1980	1998
Dhuleil	562	1860-4550	2580- 6400
Mafraq	455-880	950-3500	4000-5640

Nowadays, a salinity build-up is occurring in the north, north-east and eastern part of the basin. In some private wells in the north-east, TDS currently exceeds 2700 ppm.

2.6 The basalt Aquifer

TDS ranges between 200-530 ppm. For wells drilled in 1997 in the conduit fractured area (the corridor wells), TDS values ranged between 202 and 240 ppm.

REFERENCES

1. Abu Ajamieh, M.M., 1998. Mineral Resources of Jordan Chapter III. Groundwater P. 107-133.

2. Abu Ajamieh, M.M., 1989. Assessment of Brackish Groundwater in Jordan. A report submitted to the USAID and to the MWI by Development Alternatives, Inc.

3. Abu Ajamieh, M.M., 1999. The Emergency Wells for the Summer of the year 1999. A report submitted to the Ministry of Water and Irrigation in October, 1999

4. Parker, D.H., 1970. Investigation of the Sandstone Aquifers of East Jordan. AGL: SF/JOR9, Technical Report 2, FAO, UNDP.

5. National Water Master Plan of Jordan, 1977. (Groundwater Resources Volumes)

6. Natural Resources Authority of Jordan (NRA): Open file reports.

7. Water Resources Authority (WAJ): Annual Reports of 1989- 1998.

8. Ministry of Water and Irrigation (MWJ): Water Data Bank.

9. JICA (1996): The Study on the Improvement of the Water Supply System for the Zarqa District in the Hashemite Kingdom of Jordan (Final Report).

Appendix 1

GEOLOGY

LITHOSTRATIGRAPHY

Zarqa Group (Z)

The oldest exposed rocks in the basin are the Zarqa Group (Triassic/Jurassic), which reaches a maximum thickness of about 1800 meters along the northwestern borders with Syria. On the basis of lithology and fossils, the Group is divided into four formations.

(1) The Hudieb Formation (Permian)

The Hudeib Formation, which belongs to the Permian, has been recently added to the Zarqa Group. The Formation is limited to the northwestern highlands, the basalt plateau, and the Hamad basin. The Hudeib consists of sandstone, shale and limestone. In Irbid, its thickness is about 250 meters.

(2) The Ramtha Formation

The Ramtha Formation unconformably overlies the Hudeib and older formations. It consists of a succession of gypsum, anhydrite and halite interbedded with shale, limestone, and dolomite; this is overlain by pelitic limestone, followed upwards by shale interbedded with siltstone and minor marl intercalation. The Ramtha Formation is one source of salt for groundwater. In one of the deep wells in the Hamad basin, 57 meters of halite were encountered in the formation.

(3) The Main Formation Z1 (Triassic)

This consists of sandstone, marl, shale, gypsiferous marl and dolomite. The sandstone is medium to fine-grained and it is vari-colored. The Main Formation (Z1) outcrops on the banks of the Zarqa River. A complete section, 184 meters thick, is exposed outside the basin in Wadi Zarqa Main. The Formation was encountered in a deep well in Baq‘a (Baq‘a oil exploration well) at 250 meters depth. Several deep water wells in Baq‘a and Jerash penetrated the formation. The formation wedges out from north to south and is missing in Wadi Mujib outside the basin.

(4) The Azab Formation Z2 (Jurassic)

This is exposed in the Ain el Azab area where it consists of 293 meters of a succession of shale, grey limestone, dolomite, silicified sandy marl and sandstone. On the northern side of the Zarqa River (in Wadi Huni) the formation is 220m thick. The formation wedges out to the southwest and is missing between Wadi Hisban and the northern end of the Dead Sea. In a water well at Ain el Basha, 128m of the formation were penetrated. The penetrated section consists of sandstone, dolomite, shale and limestone.

The Kurnub Sandstone K (Lower Cretaceous- Neocamian-Albian)

Within the Basin, the Kurnub sandstone outcrops in the eroded part of Sweilih anticline in Baq‘a Safut and Ain el basha. It crops out on both banks of the Zarqa River and in the Jerash areas.

The Arda Formation (K1)

This consists of white sandstone with cross bedding, and is occasionally pale yellow. It is fine to coarse-grained, massive in part with intercalation of grey-green shale, of yellow brown, hard, sandy dolomite, and of yellow- brown marl.

Thickness: 198m. in Arda (outside the basin); in Amman (Wadi Rimam well) it is 123m; and in Zarqa it is over 184m.

The Subeihi Formation (K2)

This consists of varicolored, thinly bedded sandstone, friable with intercalations of grey-green shale, yellow- brown, sandy hard dolomitic limestone, marl, clay and siltstone.

Thickness: 132m in Subeihi: 127m on the southern bank of the Zarqa River; 132m and 157m in Zarqa and Amman boreholes, respectively.

The Ajlun group (Cenomanian-Turonian)

Within the Basin, the Ajlun Group is a carbonate sequence. It consists mainly of a repetition of limestone, marl, dolomitic limestone and shale and dolomite. The group forms extensive outcrops and the thickness is only 600 m. (well S90, at Ramtha crossroad). In north and northwest Jordan, Wolfart (1959) and Mac Donald et al. (1965) recognized seven subdivisions of the group. But within the Amman- Zarqa Basin, only 5 units are recognized in outcrops and in brothels. These units are described from base to top as follows:

(1) The Na‘ur Formation (A1-2)

The formation consists of two, thick, nodular grey limestone and dolomitic limestone beds, separated by marl and shale. The lower part of the formation, which overlies the Kurnub Sandstone, consists of about 60m. of marl and shale. The formation is about 220m thick near the town of Na‘ur.

(2) The Fuheis Formation (A3)

The A3 consists of marl intercalated with marly limestone and limestone. It is about 80m thick at Fuheis.

(3) The Hummar Formation (A4)

The formation consists of light grey and dark grey dolomitic limestone. Its thickness ranges between 40m. and 60 meters in Amman.

(4) The Shueib Formation (A5-6)

Within the Basin, this consists of marly limestone, shale and marl. Its thickness ranges from 40m in Zarqa to 100m in Na‘ur. In the Jerash area, it is 60m thick. At Zarqa (in boreholes) it consists of 98m of marl, marly limestone and limestone. At Hallabat, it is 119m thick. At Ain Ghazal in Greater Amman, it consists of 121m of marl with thin limestone bands.

(5) The Wadi Sir Formation (A7)

This represents the uppermost unit of the Ajlun group and it is Turonian in age. The A7 consists of massive bedded limestone containing chert nodules in the upper part. The formation is 90m thick in Amman, 100m in Zarqa, and 80m in Ain Ghazal.

The Belqa Group (Santonian - Upper Eocene)

The group consists of a sequence of clastic and non-clastic, predominantly carbonate, rocks. They are well exposed and form extensive outcrops in a large area of the basin. The group is conformable with the underlying Ajlun group, but is regarded as a separate group because of the occurrence of abundant chert. In Northern Jordan, five units are recognized in the group. However, in the basin, only four units can be identified where the Belqa unit is considered the lower member of the B2 unit, i.e. the B1-2 unit.

The B1 unit is known as Wadi Ghudran Formation, which consists of a sequence of chalk and marl, and forms the lowest lithological unit of the Belqa group. It is recognized as a unit in Northern Jordan. It thins southwards and is then included in the overlying B2 unit.

The Amman Formation B2 (Santonian – Campanian)

This consists of cyclic deposits of chalk, phosphate, silicified phosphate, limestone and chert. The limestone is occasionally silicified. In the Amman-Ruseifa and Zarqa areas, two members of the formation are recognized:

- upper chalk-marl and phosphate member (26-27m thick in Ruseifa)
- lower chert-limestone member (about 90m east of Amman).

In the Amman area, the lower 10m of marl and chalky marl are the B1. The B2 thickness in Mafraq is 165m, while at Ramtha cross roads (well S-90) it is 118m. In Ajlun and Irbid, the thickness is about 80m. The formation thickens southwards to 245m. at Wadi Mujib.

The Muwaqqar Formation (B3)

The B3 is of Maastrichtian-Lower Eocene in northeast Jordan and Maastrichtian-Paleocene in the southeast. The B3 consists of chalk and marl with limited brown and black chert, and limestone. At depths the marl is bituminous. Its thickness is 200-240m in Irbid and about 200m in Wadi Slallala.

The Rijam Formation (B4) (Eocene-Pliocene)

This consists of limestone, chalky limestone, marls and chert. The marls are locally bituminous. It outcrops in the northeastern part of the basin, and continues to outcrop beyond the basin, extending north and northeast across the borders with Syria.

The Basalt (Oligocene- Pleistocene)

Basalt flows with accompanying pyroclastics outcrop in the northeastern part of the basin. Dykes, sills, volcanic plugs and cones also occur. Six major flows consist of alkali basalt. Clay and gravel layers occur in the inter-flows. In boreholes, thin layers of clay and gravel containing chert and limestone pebbles have been encountered between the successive flows.

Scoriacous basalt was identified in the third flow. The thickness of the basalt is variable as it wedges towards the periphery of the flows. In the north and northeastern part of the basin, the basalt overlies the Rijam Formation (B4). In the Mafraq and Wadi Dhuleil areas, the basalt overlies the B2 and the A7 formations.

Geological Structures Affecting Groundwater

The following structures are important in groundwater movement.

1. Sweilih Anticline

The axis of this anticline strikes NE-SW. In its care, erosion has exposed the Kurnub Sandstone Aquifer in Ain el Basha and Baqa north of Sweilih. Modern recharge in this relatively high rainfall area directly and indirectly reaches the Kurnub and the underlying Zarqa aquifers.

2. Amman- Zarqa Syncline

The axis of this syncline strikes NE-SW. It extends from the southwestern side of Greater Amman to a point about 6.60 km southeast of Zarqa. The syncline is about 30 km long by 10-15 km wide. This synclinal zone is the highest potential area in the Hummar aquifer.

3. The Amman- Zarqa Monoclinal Flexure

The axis of this structure is parallel to the Amman-Zarqa syncline. It is to the southeast of the synclinal axis. They are 6.5-19 km apart. This monoclinal flexure and associated faulting form a hydraulic barrier to the eastward movement of water within the Hummar (A4) aquifer.

4. The Qihati fault

This is a major fault near the northeastern limit of the Amman-Zarqa Basin. Its maximum vertical displacement reaches about 300 meters. Its forms a groundwater barrier for water moving in the B2/A7 to the southeast towards the Azraq Basin.

Minor Faults

Several faults striking in different directions have been mapped in the areas of the B2/A7 and the underling carbonate aquifers (A4 and A1/2). In these localized fault zones, fracturing, solution channels and kastification have developed, resulting in permeable zones in the aquifers through the development of secondary porosity in the limestones (which are the main aquifer rocks).