Supporting Report for "Chapter 2 Water Resources Potential and Development Plan"

ANNEX to 2.2
Groundwater

2.2 Groundwater

2.2.1 General Landscape and Geology of Jordan

(1) Landscape

Three major landscapes occur in Jordan. They are: (a) the Lowland Areas; (b) the Highlands and (c) the Eastern Upland Plateau as shown in Fig.A2.2.1-1.

a. The Lowland Areas
It comprise Jordan Valley- Dead Sea- Wadi Araba depression which extends about 360 Kilometers from Lake Tiberias to the Gulf of Aqaba.

In Jordan Valley the land surface is generally flat with ground surface elevation ranges from 200 m to 411m (Dead Sea level) below sea level., as measured in 1998. Jordan River crosses the Valley at its central portion for a distance of about 105-km.

The Dead Sea, which forms the middle zone of the Depression, covers about 997 square kilometers. It is about 80 km long and on average 15 km wide.

In Wadi Araba the landscape is almost flat with slightly rolling terrain at its middle zone between the Dead Sea and the Gulf of Aqaba. The ground surface elevation ranges from 250 meters above sea level to 398 meters below sea level at its northern end near Dead Sea. Its width within Jordanian territory ranges from 5 to 20 Km approximately.

b. The Highlands
It comprises the eastern escarpment, which flank the Jordan Valley-Dead Sea Depression. The eastern escarpment extends from Um Qais on the north and southwards to flank the Wadi Araba area till the northern end of the Gulf of Aqaba..

Small to large canyons cut through the Eastern Highlands bordering the Jordan Valley-Wadi Araba Depression forming intricately dissected ridges and rugged topographic relief.

The eastern highlands are breached by a number of westerns draining valleys in the zone between the Syrian border to the southern end of the Dead Sea. The largest of these are: Yarmouk River, Wadi Zarqa, Wadi Mujib and Wadi Hasa. They are drained eastwards to the upland plateau by small and shallow stream washes.

c. The Eastern Upland Plateau

It borders the Eastern Highlands from the west and extends to the Saudi Arabian border. It is a gently dissected plateau formed from flat lying sediments, which have been eroded to form a cuesta landscape. The ground surface elevation ranges from about 1000 meters at the foothills of the adjacent highlands to less than 600 meters in the Wadi Sirhan depression near the Saudi Arabian border. Mudflats or Playas which form the foci of internal drainage basins occur in the plateau, such as Q'a (Mudflat) Azraq, Q'a Jafr/ and Q'a Dis The land rises northwards from Q'a Azraq towards the Jabal El- Arab in Syria where the land surface elevation reaches up to 1850 meters above sea level.

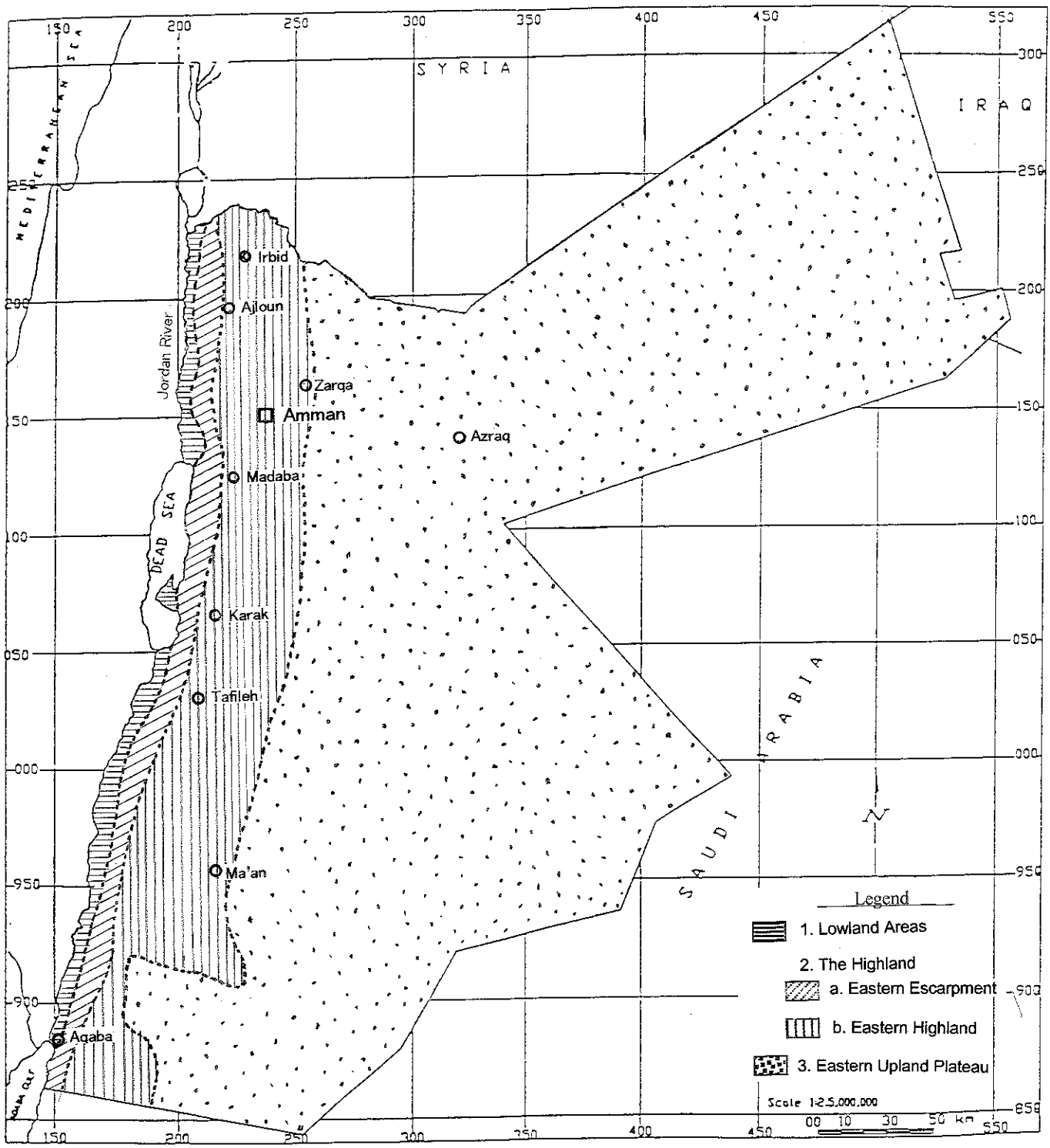


Fig.A2.2.1-1 Geomorphological Map of Jordan

(2) Geology

a. Stratigraphy

Rock units ranging from pre-Cambrian to recent outcrop or exist at the sub surface in Jordan as shown inFig.2.2.2-1 in the main report. In the Eastern Highlands, calcareous sediments of the Upper Cretaceous and lower Tertiary age are exposed. Limestone to dolomitic limestone with marl, shale, chalk and chert of the same age occur in the eastern highlands and the eastern plateau covering an area of about 45000 km^2. Total thickness range is reported to be 150-800 meters.

Sandstone and sandy facies formation with some shale at top covers an area of about 8000 km^2 with about 1900 meters thickness. 1600 meters belong to early Paleozoic and about 300 meters belong to lower Cretaceous.

Basalt outcrops overlie the fluviatile gravels of the Middle Pleistocene. It occurs mainly in the area comprising the southern extension of Jabal El-Arab in Syria till Wadi Sirhan Depression near the Saudi Arabian border.

Coarse to fine clastics of marine to continental origin belonging to Neogene – Quaternary ages occupy a great part of the Wadi Araba – Jordan Valley Depression. They exist also in the flood plains of the main rivers and wades and Jafer and Azraq depressions.

The pre-Cambrian basement complex occupies the extreme southwestern corner of Jordan along the Gulf of Aqaba and in the eastern escarpment of Wadi Araba. The estimated outcrop area is about 70 km^2

b. Structure

The Jordan Valley – Dead Sea – Wadi Araba depression forms the northern extension of the African Rift valley system as a secondary split through the northern extension of the Gulf of Aqaba as shown in Fig.A2.2.1-2. It is primarily a down thrown block or a Graben bordered on both the east and west sides by fault line scraps of major longitudinal faults.

Block folding, undulations and flexures occur to the east of the major structural Graben of Jordan Valley – Wadi Araba. The dominant trends f the structural elements in the northern part of the eastern plateau are NE-SW. The major structural features recognized in Jordan and have direct control on the groundwater occurrence are:

- The NE trending upwarp of the Ajlun Fault Zone with an extensive fault zones units of western flank.
- The Zarqa Fault (flexure) and the Amman Flexure.
- The west-east striking Swaqa Fault System in the central part of Jordan extending for more than 60 km from the Dead sea to Jabal Swaqa and then to Saudi Arabia.
- The major NW-SE fault system, Karak-Wadi El Fiha Fault System extending for about 300 km from wadi Karak into the Saudi Arabian border.
- The Ramtha-Wadi Sirhan Fault System. It comprises a complex series of

faults downthrowing to the northwest and fr about 325 km from Ramtha in the northwest and to Saudi Arabia in the southeast. This fault system is responsible for the Hamza and Azraq Grabens into Sirhan Basin, which extends in Saudi Arabia.

- The most prominent features affecting groundwater flow in south Jordan is the Quweira Mudawwara Structure (Kharawi Dyke) trending WNW-ESE and extends from Quweira towards Mudawwara into Saudi Arabia.
- The Fuluk Fault which extends about 100 km from Azraq into Saudi Arabia. It forms the northern extention of the Hamza-Sirhan graben.

The major Jordan Valley – Wadi Araba Graben forms a big drain to most of the aquifers occurring within the eastern and western highlands bordering the Jordan Valley area.

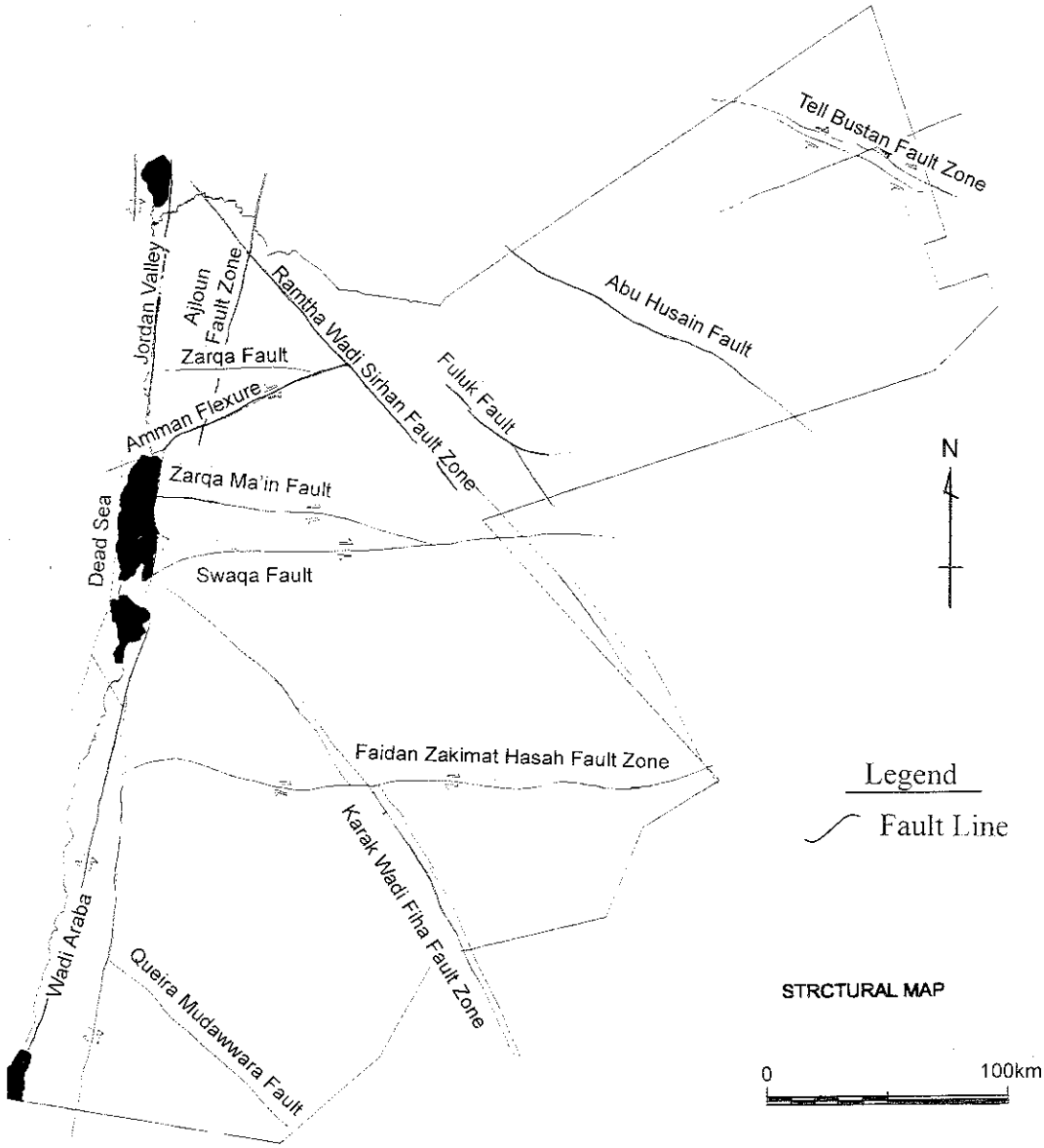


Fig.A2.2.1-2 Geological Structure Map of Jordan

2.2.2 Basin and Aquifer System

(1) Yarmouk Basin

-The main aquifers in the Yarmouk Basin are:

Basalt in Syria, B2/A7, A4 ,A1,2 and Kurnub Sandstone (K).

K is renewable in this basin and hot and mildly saline groundwater was encountered in this aquifer and of artesian conditions.

-Range of groundwater salinity:

300-800ppm

-Range of well depth:

150-1200m

-Range of depth to water:

Flowing in lower Yarmouk,

From 100-280 in the upland area

-Range of well yield:

20-120 m^3 /h in the upland area,

200-500 m^3 /h in Mukheiba and Wadi Arab well fields

-Estimated groundwater recharge:

100-120 MCM/a including base flows, springs and leakage from within the underling and overlying aquifers.

-References cited

Thames Water Int(1987)

O. Judah (1983)

El Nasser (1991)

IWACO, M MCDONALD & SAJDI (1999)

(2) Amman-Zarqa Basin

-The main aquifers in the Amman-Zarqa Basin are:

Kurnub Sandstone (K), A7/B2, B4/B5 and Basalt (Ba)

-Range of groundwater salinity:

400 mg/lit to more than 2,000mg/lit in TDS

Note: The salinity has increased up to 3,000umhos/cm in the northeastern part of the basin.

-Range of well depth:

50m to 500m

-Range of depth to water:

20m to 250m

-Range of well yield:

50m^3/h to 180 m^3/h

-Estimated groundwater recharge:

Aquifer	Recharge Amount (MCM/a)
Kurnub (K)	8
A1,2	5
A4	5

A7/B2	40 to 50
Basalt	28

Note : Groundwater through flow from the Basalt aquifer outside the basin into the A7/B2 aquifer within the adjacent basins is estimated at 23MCM/a. Total estimated groundwater recharge over the entire Amman-Zarqa Basin including Syrian territory is 100MCM/a to 120MCM/a. The actual recharge amount is estimated around 80 MCM/a to 100MCM/a within the Amman-Zarqa Basin in Jordan

-References cited

BGR/WAJ (1994)
IBRD Jordan River Basin Study (1993)
US /ARD Water Resources Policy Support, First Draft Report (May, 2000)

(3) Azraq Basin

-The main aquifers in the Azraq Basin are:
A7/B2, B4/B5 and Basalt (Ba)

-Range of groundwater salinity:
Basalt (Ba) and B4 -- 300mg/lit to 500mg/lit in TDS
1,500mg/lit to 4,000mg/lit * in TDS
A7/B2 (in the south, renewable) -- 1,000 mg/lit to 1,700mg/lit in TDS

*: Salinity has gotten higher because of saline intrusion from the hyper saline water body (100,000mg/lit to 250,000mg/lit) caused by the over abstraction.

-Range of well depth:
Basalt (Ba) and B4 : 25m to 250m
A7/B2 (in the south) : 150m to 500m

-Range of depth to water:
Basalt (Ba) and B4 -- 6m to 40m near Azraq, 75m in mid to north
A7/B2 (in the south) -- 75m to 300m

-Range of well yield:
Basalt (Ba) and B4 -- $20m^3/h$ to $180m^3/h$
A7/B2 (in the south) – $50m^3/h$ to $120m^3/h$

-Estimated groundwater recharge:

Aquifer	Recharge Amount (MCM/a)
Basalt (Ba) and B4*	32 to 38
A7/B2 (in the south)	6 to 9

*: Groundwater recharge is 32MCM/a to 38MCM/a of which about 10MCM/a flows into Wadi Sirhan area.

-References cited

BGR/WAJ (1994)
JRBS (1993)
Thames Intl (1987)

(4) Jordan Valley Basin (Valley Floor Basin)

-The main aquifers in the Jordan Valley Basin are:
Alluvium (Qal) and locally A7/B2 at the foot of the escarpment

-Range of groundwater salinity:
500 mg/lit to 2,500mg/lit in TDS (locally more than 3,000mg/lit)

-Range of well depth : 100m to 300m

-Range of depth to water : 20m to 80m

-Range of well yield : 50m^3/h to 200m^3/h

-Estimated groundwater recharge : 23MCM/a to 29MCM/a

-References cited
Hirzalla Groundwater in Jordan Valley (1973)
Themes Intl (1987)
JRBS (1993)

(5) Rift Side Wadis Basin (Jordan Valley Escarpment Basin)

-The main aquifers in the Rift Side Wadis Basin are:
K, A7/B2, A4, A1-6
Note : A7/B2 in the north,
A4, A1, A2 in the middle,
A7/B2, A1-6, K in the south

-Range of groundwater salinity:
500 mg/lit to 800mg/lit in TDS (locally more than 3,000mg/lit)

-Range of well depth : up to 1,000m in the escarpment

-Range of depth to water : Flowing to 50m in the escarpment

-Range of well yield : 130m^3/h to 250m^3/h

-Estimated groundwater recharge : 17MCM/a to 21MCM/a

-References cited
Hirzalla Groundwater in Jordan Valley (1973)
Themes Intl (1987)
JRBS (1993)

(6) Dead Sea Basin

-The main aquifers in the Dead Sea Basin are:
Escarpment area ---------- mainlyA7/B2 and locally A1-6
Mujib and Hasa basin --- mainly A7/B2, locally All and A1-6

-Range of groundwater salinity:
Escarpment area --------- 600mg/lit to 1,700mg/lit in TDS (A7/B2)
Mujib and Hasa basin --- 500mg/lit to 1,500mg/lit in TDS (A7/B2)

-Range of well depth :
Escarpment area --------- 40m to 175m at foot, 250m to 1,000m at top (A7/B2)
Mujib and Hasa basin --- 150m to 500m (A7/B2)

-Range of depth to water :

Escarpment area --------- 0m to 100m at foot, 200m to 400m at top(A7/B2)

Mujib and Hasa basin --- 75m to 300m (A7/B2)

-Range of well yield :

Escarpment area --------- $50m^3/h$ to $100m^3/h$ (A7/B2)

Mujib and Hasa basin --- $50m^3/h$ to $120m^3/h$ (A7/B2)

-Estimated groundwater safe yield : 50MCM/a to 62MCM/a in total

Note:Total recharge amount is estimated around 84MCM/a to 94MCM/a including the discharge from the nonrenewable Lower Aquifer System (R and K).

-References cited

Themes Intl (1987)

BGR/WAJ (1991)

JRBS (1993)

Arabtech – Jurdaneh – Amra Eng. Office Final Report (1996)

(7) Wadi Araba North Basin and Wadi Araba South Basin

-The main aquifers in the Wadi Araba North and South Basins are:

Wadi Araba North Basin------ mainly All and locally A7/B2

Wadi Araba South Basin------ All

-Range of groundwater salinity:

Wadi Araba North Basin------ 800mg/lit to 5,000mg/lit in TDS (All)

Wadi Araba South Basin------500mg/lit to 700mg/lit, 850mg/lit to 2,000mg/lit in Wadi Araba (All) in TDS

-Range of well depth :

Wadi Araba North Basin------ 50m to 300m

Wadi Araba South Basin------ 250m to 400m

-Range of depth to water :

Wadi Araba North Basin------ 25m to 80m

Wadi Araba South Basin------ 60m to 120m

-Range of well yield :

Wadi Araba North Basin------ $50m^3/h$ to $100m^3/h$

Wadi Araba South Basin------ $30m^3/h$ to $100m^3/h$

-Estimated groundwater recharge:

Wadi Araba North Basin--- 11MCM/a to 18MCM/a including spring flow and base flow from the nonrenewable Lower Aquifer System

Wadi Araba South Basin---- 8MCM/a to 10MCM/a excluding

spring flow and base flow from the nonrenewable Lower Aquifer System

-References cited
Themes Intl (1987)
JRBS (1993)

(8) Jafr Basin

-The main aquifers in the Jafr Basin are:
B4/B5, A7/B2 and A1-6

-Range of groundwater salinity:
A7/B2,B4/B5------500mg/lit to 3,500mg/lit in TDS
A1/A6----------700mg/lit to 2,000mg/lit in TDS

-Range of well depth :
A7/B2,B4/B5------100m to 400m
A1/A6----------Not clarified

-Range of depth to water :
A7/B2,B4/B5------40m to1400m
A1/A6----------Not clarified

-Range of well yield :
A7/B2,B4/B5------150m^3/h to 300m^3/h
A1/A6----------Not clarified

-Estimated groundwater recharge : 10MCM/a to 11MCM/a, mainly B4/B5

-References cited
Themes Intl (1987)
JRBS (1993)

(9) Southern Desert Basin (Disi – Mudawara Basin, mainly Nonrenewable)

- The main aquifers in the Jafr Basin is:
Rum/Disi group Aquifers which contains fossil origin Groundwater,

- Groundwater discharge into theDead Sea basin is estimated at 66MCM/a (steady state)

- Water quality range -------- 200-700mg/lit in TDS

- Well depth range ----------300-1500m

- Depth to water range is about (5-6m above ground level) in Mudawara, to about 100m in Disi-Sahl es Sawan area and about 400m below groundwater level in central Jordan.

- The estimated aquifer yield is 125MCM/a for about 50 years.

(10) Sirhan Basin

-The main aquifers in the Sirhan Basin are:
A1-6[1], A7/B2[1], B4/B5 and Qirma[2] (sandy limestone)

1 : A1-6 and A7/B2 aquifers change to sandy facies and form

one aquifer named Fassu'a Formation.

2 : It is well developed in Saudi Arabia with total groundwater abstraction of about 100mcm/a (ACSAD 1983)

-Range of groundwater salinity :
1,000mg/lit to 2,500mg/lit in TDS (all aquifers)

-Range of well depth :
Qirma and B4/B5----------150m to 700m
A1-A6 and A7/B2 (Fassu'a F.)--------more than 600m

-Range of depth to water :
Qirma----------10m to 30m
B4/B5----------45m to 300m
A1-A6 and A7/B2 (Fassu'a F.)-------100m to 300m

-Range of well yield :
Qirma----------25m^3/h to 40m^3/h
B4/B5----------20m^3/h to 90m^3/h
A1-A6 and A7/B2 (Fassu'a F.)--------40m^3/h to 100m^3/h

-Estimated groundwater recharge :
8MCM/a to 10MCM/a in total

-References cited
Themes Intl (1987)
JRBS (1993)
GIITEC & HIS (1995)

(11) Hammad Basin

-The main aquifers in the Hammad Basin are:
Ba, B4/B5, A1-6 (A7/B2)

-Range of groundwater salinity :
Ba and B4/B5----------500mg/lit to 3,000mg/lit in TDS
A1-A6 and A7/B2 ----------1,500mg/lit to 3,200mg/lit in TDS

-Range of well depth :
Ba and B4/B5----------300m to 700m
A1-A6 and A7/B2----------315m to 750m

-Range of depth to water :
Ba and B4/B5----------45m to 110m
A1-A6 and A7/B2----------250m to 270m

-Range of well yield :
Ba and B4/B5----------20m^3/h to 150m^3/h
A1-A6 and A7/B2 ----------25m^3/h to 50m^3/h

-Estimated groundwater recharge :
7MCM/a to 9MCM/a in total

-References cited

JRBS (1993)
GIITEC & HIS (1995)

2.2.3 Brackish Groundwater in Middle and Upper Aquifer Systems

(1) Azraq Basin

The brackish groundwater is contained in A7/B2 aquifer and the underlying Kurnub Sandstone aquifer in the Azraq Basin. Although the occurrences of these aquifers have not been well assessed in the north to central part of the Azraq Basin. It is supposed that the groundwater contained in both aquifers are of fossil origin and nonrenewable. Renewable brackish groundwater is contained in the A7/B2 aquifer in the southwestern part of the basin adjacent to the well fields in the Dead Sea Basin (Siwaqa, Qatrana and Mahatta el Manzil areas).

1) North to Central part of the basin

i. Kurnub Sandstone aquifer

The groundwater contained in the Kurnub Sandstone aquifer is believed to be nonrenewable in the Basin. Its salinity is expected to range from 1,350mg/lit to 3,000mg/lit in TDS in the Azraq Basin. Storage volume of the brackish groundwater in the Kurnub Sandstone aquifer is estimated around 42 billion cubic meter in the Azraq Basin according to USAID/ARD, 1998.

ii. A7/B2 aquifer

The A7/B2 aquifer is under artesian conditions in the central part of the basin (Qa'El Azraq). The salinity ranges from 1,000mg/lit to 2,500mg/lit in TDS and occasionally contains high concentration of H_2S gas. The groundwater in the A7/B2 aquifer is expected to be nonrenewable in the northern to central part of the Azraq Basin. Storage volume of the brackish groundwater in the A7/B2 aquifer is estimated around 46 billion cubic meter in the Azraq Basin, (USAID/ARD, 1998).

iii. Alluvial aquifer

Hyper-saline groundwater ranging 100,000 to 250,000mg/lit in TDS is encountered in the Alluvial deposits in the centeral part of the basin and used for salt production. Over exploitation of the ground water resources in the Azraq basin in recent years has resulted in the creeping of the hyper-saline water towards the WAJ well field and has caused gradual increase of groundwater salinity.

2) Southwestern part of the basin

i. A7/B2 aquifer

Groundwater in the A7/B2 aquifer, is generally turned into slightly brackish ranging from 1,000mg/lit to 1,700mg/lit in TDS in the southern part of the Azraq Basin. The groundwater in the A7/B2 aquifer is renewable and its safe yield is estimated at around 10MCM/a to 12MCM/a in the southwestern part of the Azraq Basin.

(2) Jordan Valley Basin

1) Alluvial Aquifers

Quaternary aquifers composed of Alluvial deposits and Lisan Formation occurss in the Jordan Valley floor and they are hydraulically connected. The thickness of the Quaternary aquifers is assumed to be more than 2,500m.

According to "Hirzalla, 1973", the salinity of the groundwater gets increase from the foot of the escarpment towards the Jordan River. At the foot of the escarpment, the groundwater is almost fresh and its salinity increases up to 2,500mg/lit in TDS along the Jordan River because of upward movement of the brackish groundwater along the river from the deeper pay horizons. The Quaternary aquifers including Lisan Formation aquifer are renewable in the Jordan Valley and they show clear seasonal fluctuation of the groundwater level.

The groundwater recharge into the Quaternary aquifers, is estimated at 23MCM/a to 29MCM/a and safe yield is around 21MCM/a in the Jordan Valley. Supposing that the distribution area of the brackish groundwater occupies around 80% of the valley floor, hence the safe yield of the brackish groundwater in this area might be around 16MCM/a.

(3) Rift Side Wadis Basin

1) Kurnub Sandstone aqifer

The Kurnub Sandstone aquifer is generally fresh and renewable in the Rift Side Wadis Basin (Jordan Valley Escarpment) because it outcrops widely in the basin. However, the groundwater in the Kurnub Sandstone aquifer locally gets brackish at the foot of the Jordan Valley escarpment and in the Zarqa River Basin. Direct groundwater recharge occurs from the high rainfall that precipitates over the Ajlun-Sweileh mound. This give rises that the brackish groundwater in the Kurnub Sandstone aquifer is renewable in the Rift Side Wadis Basin.

According to JICA,1995, it was found that the groundwater in the Kurnub Sandstone aquifer turned to brackish at the foot of the escarpment due to the upward leakage of the brackish groundwater from the Zarqa Group aquifer and such areas are limited. So, it is inferred that the brackish groundwater in the Rift Side Wadis Basin is originated as a result of being mixed with the brackish groundwater from the underlying Zarqa Group aquifer. Therefore, the amount of the brackish groundwater in the Kurnub Sandstone aquifer may not be huge and extensive.

(4) Dead Sea Basin

1) A7/B2 aquifer

A7/B2 aquifer is the major productive aquifer in the Dead Sea Basin. Slightly brackish groundwater ranging from 1,000mg/lit to 1,700mg/lit is encountered in the A7/B2 aquifer. It occurs in the area from Qatrana to Mahatta el Manzel in the central part of the Dead Sea Basin. The groundwater in A7/B2 is renewable in the Dead Sea basin as a groundwater recharge mound is situated within this basin.

The total safe yield of the A7/B2 aquifer is estimated at 45MCM/a to 57MCM/a. As the proportion of the brackish groundwater distribution area to the total basin area is approximately 20 % (according to "Oil-Shale Project El Lajun, BGR,1987 and WIS data), it is preliminarily estimated that the safe yield of the brackish groundwater from the A7/B2 aquifer is around 9MCM/a to 12MCM/a in the Dead Sea Basin.

(5) Wadi Araba Basin (North and South)

1) Alluvial aquifer

The Quaternary aquifers composed of alluvial deposits and Lisan Formation are the major productive aquifer in the North and South Wadi Araba Basin, the same as in the Jordan Valley Basin. It is reported that the thickness of the Lisan Formation reaches more than 2500m in this basin. Alluvial aquifer and Lisan Formation aquifer are hydraulically connected and contain renewable groundwater.

The groundwater in the Alluvial aquifer and Lisan Formation aquifer is generally brackish ranging from 1,000mg/lit to 7,000mg/lit in TDS excepting within the alluvial fans that occur at the foot of the escarpment where indirect recharge of fresh water takes place from the wadi beds.

The recharge amount to the Alluvial aquifer including Lisan Formation aquifer is estimated at 19MCM/a to 28MCM/a and safe yield is estimated at around 10MCM/a in the whole Wadi Araba basin. Supposing that the brackish groundwater area occupies about 80% of the basin, the safe yield of the brackish groundwater might be in the order of around 8MCM/a.

(6) Jafer Basin

1) Khreim Aquitard

Although the Khreim Group is regarded as aquitard, the upper part is porous and saturated with brackish to saline water ranging from 1,200mg/lit to more than 10,000mg/lit in TDS. The salinity increases from the Saudi Arabian borders in the southwest north wards. The brackish to saline water contained in the Khreim aquitard is supposed to be of fossil origin and stagnant.

The Khreim aquitard is intercalated between the Ram Group aquifer and the Kurnub aquifer separating them hydraulically in the western part of Jordan. At present, the piezometric head of the Ram Group aquifer is higher than the Khreim. The excessive groundwater abstraction from the Ram group aquifer, might reverse the pressure regime resulting in downward leakage of brackish to saline water to the fresh Ram aquifer. Therefore, the abstraction of brackish to saline water from the Khreim might be necessary in future for the sake of conservation and protection of water quality contained in the Ram Group fresh aquifer. In addition, the existing differential head of about 600m between the Southern Jafer and Aqaba may be utilized to install a hydro-powered reverse osmosis plants to desalinate the brackish to saline water contained in the Khreim Aquitards in the southeastern part of the Jafr basin.

The storage volume of the brackish groundwater in the Khreim aquitard is estimated around 88 billion cubic meter in the southeastern part of the Jafr Basin according to USAID/ARD, 1998.

2) Kurnub Sandstone aquifer

The Kurnub Sandstone aquifer in Jafer basin contains brackish nonrenewable groundwater ranging from 1,400mg/lit to 3,000mg/lit in TDS and is probably almost of stagnant nature.

The storage volume of the brackish groundwater in the Kurnub Sandstone aquifer is estimated around 12 billion cubic meters in the Jafr Basin according to USAID/ARD, 1998.

3) A7/B2 aquifer

The A7/B2 aquifer distributes widely in the Jafr Basin. The A7/B2 aquifer is hydraulically connected with the underlying Kurnub Sandstone aquifer. This is because the A1/A6 aquitard separating them changes its litho-face to sandy and forms one aquifer combined with A7/B2 in the Jafer basin.

The groundwater in the A7/B2 aquifer is generally fresh in the Jafer basin. However, TDS increases in the eastern part of the basin to reach 1,000mg/lit to 4,000mg/lit. The brackish groundwater in the A7/B2 aquifer is assumed to be nonrenewable and to be stagnant in this area of the Jafer Basin. Its storage volume is estimated around 1.7 billion cubic meter in the Jafr basin according to USAID/ARD, 1998.

(7) Sirhan Basin

It should be noted that the brackish groundwater potential in the Sirhan Basin described below includes many assumptions because of the very limited available data.

1) A7/B2 aquifer

The groundwater in the A7/B2 aquifer is brackish ranging from 4,500mg/lit to 7,000mg/lit in TDS , nonrenewable and of stagnant nature in the Sirhan Basin. The storage volume of the brackish groundwater in the A7/B2 aquifer is estimated around 32 billion cubic meter in the Sirhan Basin according to USAID/ARD, 1998.

2) B4 aquifer

The groundwater in B4 aquifer is almost brackish ranging from 1,000mg/lit to 2,500mg/lit in TDS. It is mostly under water table conditions and renewable receiving some indirect groundwater recharge in the occasion of intensive flood flashes. The recharge amount to the Aquifer is estimated around 8MCM/a to 10MCM/a and safe yield is about 5MCM/a in the Sirhan Basin.

(8) Hammad Basin

1) A7/B2 aquifer

The groundwater in A7/B2 aquifer is brackish and its salinity range is 1,500mg/lit to 3,200mg/lit in TDS in the Hammad basin. Nonrenewable groundwater and probably of stagnant nature occurs in the A7/B2 aquifer in the Hammad basin. The stored volume of the brackish groundwater in the A7/B2 aquifer is estimated around 16 billion cubic meter in the Hammad Basin according to USAID/ARD, 1998.

2) B4/B5 aquifer

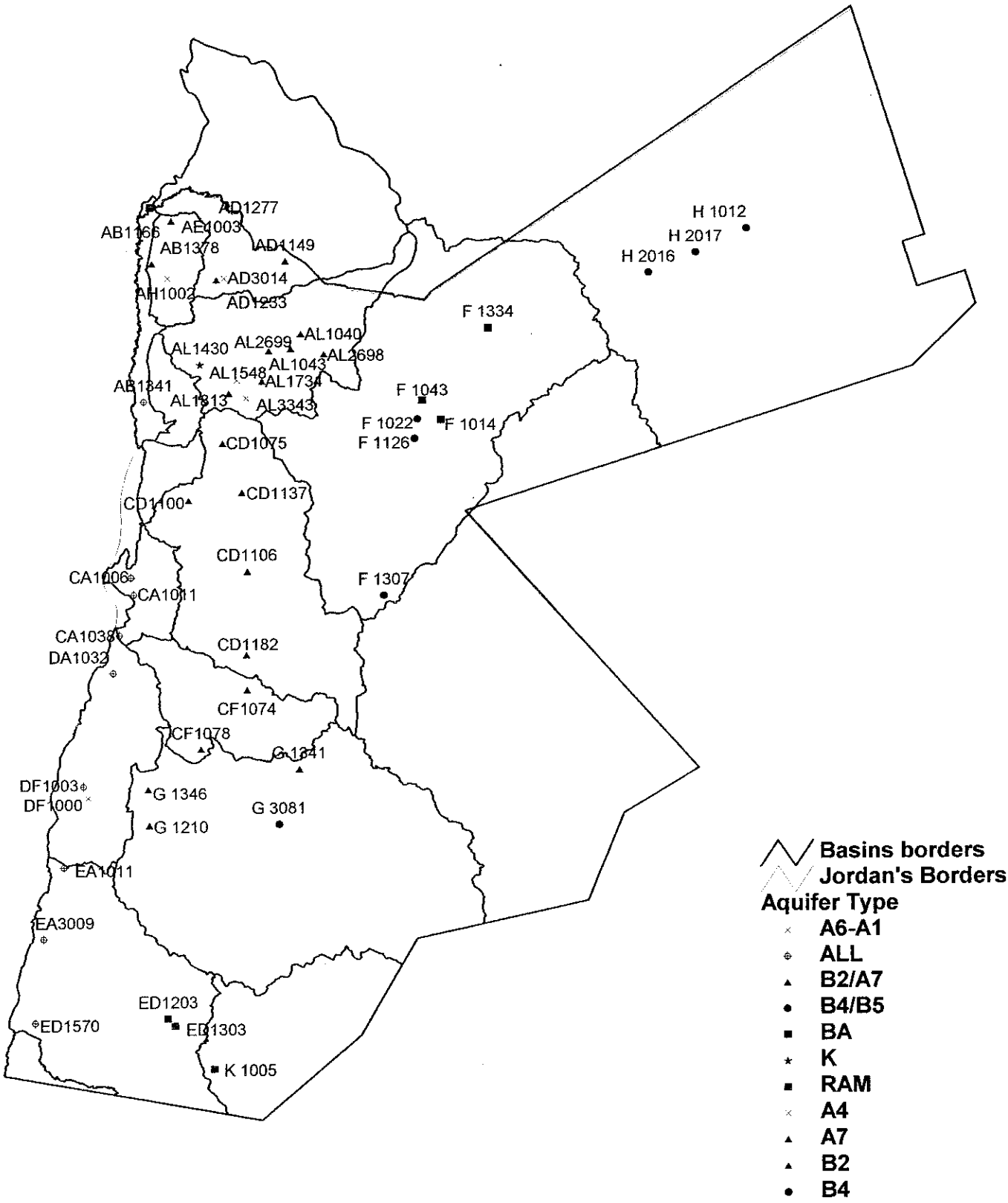
B4/B5 aquifer contains renewable groundwater in Hammad basin. It receives indirect recharge on the occasion of intensive flood flashes and downward leakage from the overlying Basalt (Ba) aquifer. However, the great part of the groundwater in the B4/B5 aquifer turned into brackish ranging generally from 1,000mg/lit to

3,000mg/lit in TDS because of scanty rainfall and high evaporation rate excepting the northern strip area.

The groundwater recharge volume into the B4/B5 aquifer, is estimated at around 7MCM/a to 9MCM/a and safe yield is about 8MCM/a. As the distribution of the brackish groundwater occupies around 90% of the basin, it is believed that the safe yield of the brackish groundwater may be around 7MCM/a in the Hammad Basin.

2.2.4 Groundwater Monitoring Records

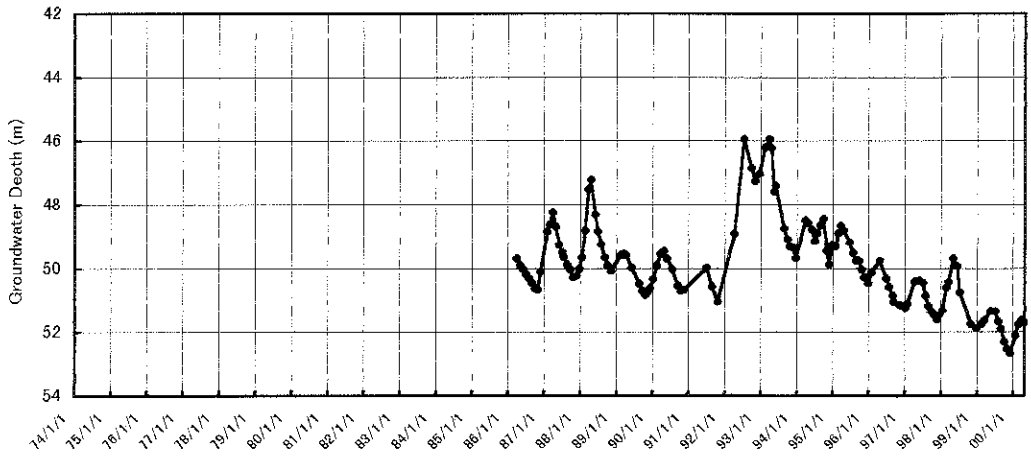
(1) Groundwater Level Monitoring Results



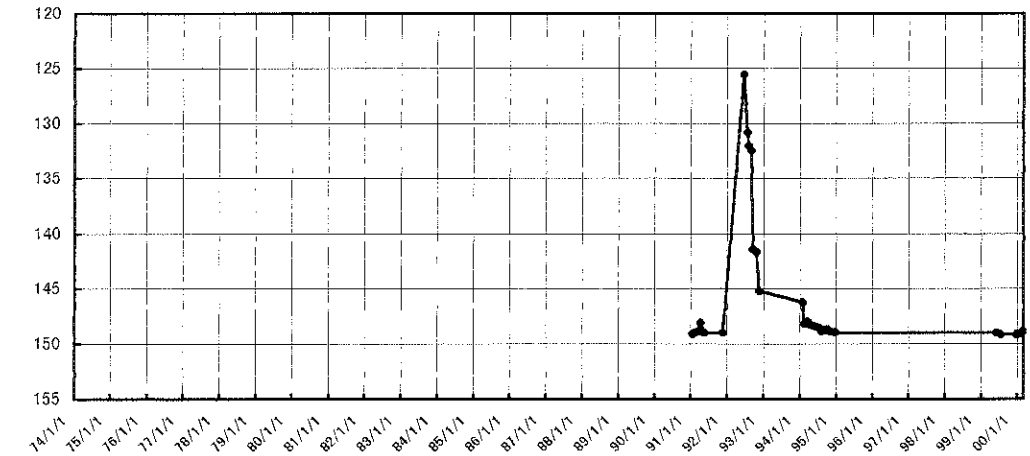
Location Map of selected Ground Water Level Monitoring Wells

Groundwater Level Monitoring Records in Yarmouk Basin

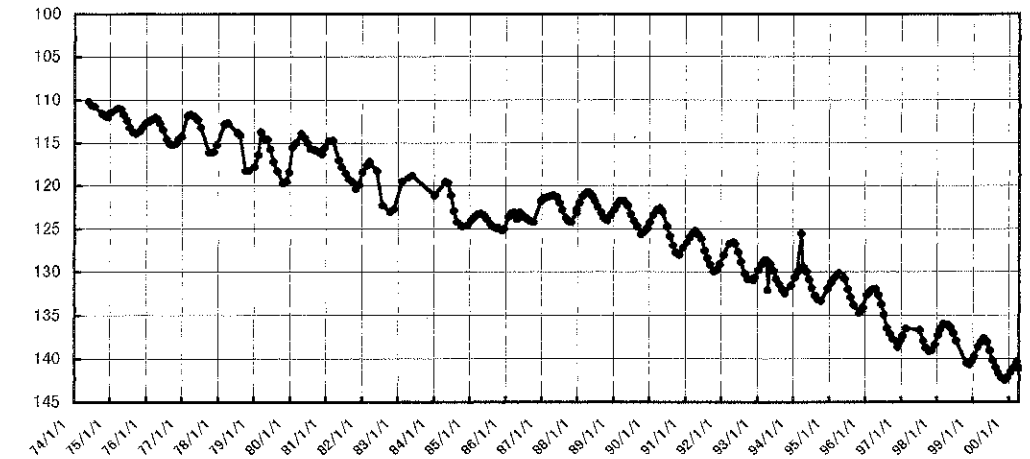
YARMOUK - AD1277 (B2/A7)



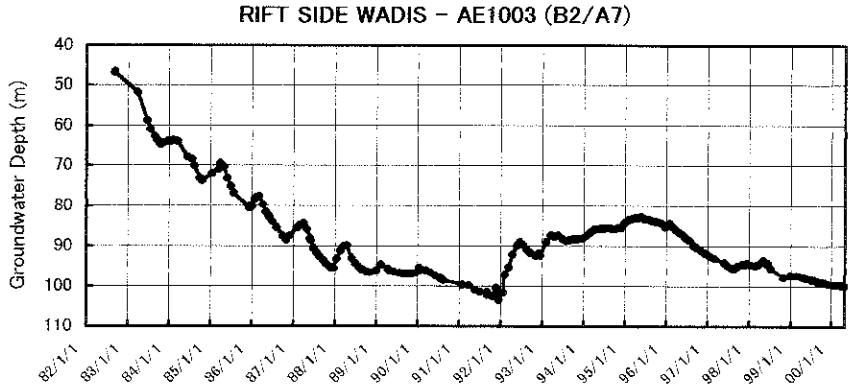
YARMOUK - AD1233 (B2/A7)

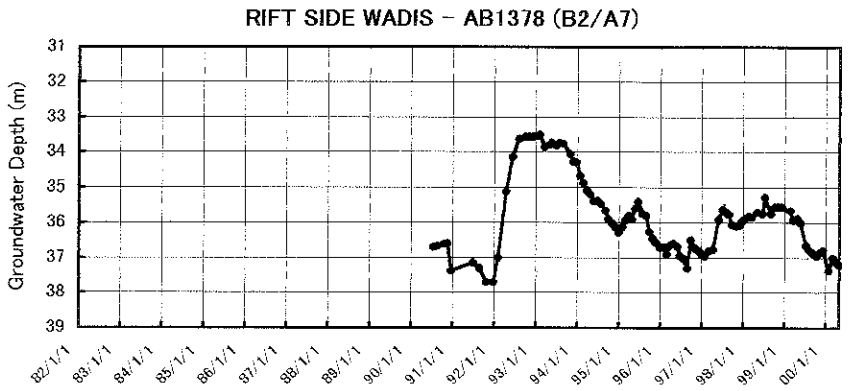


YARMOUK - AD1149 (B2/A7)

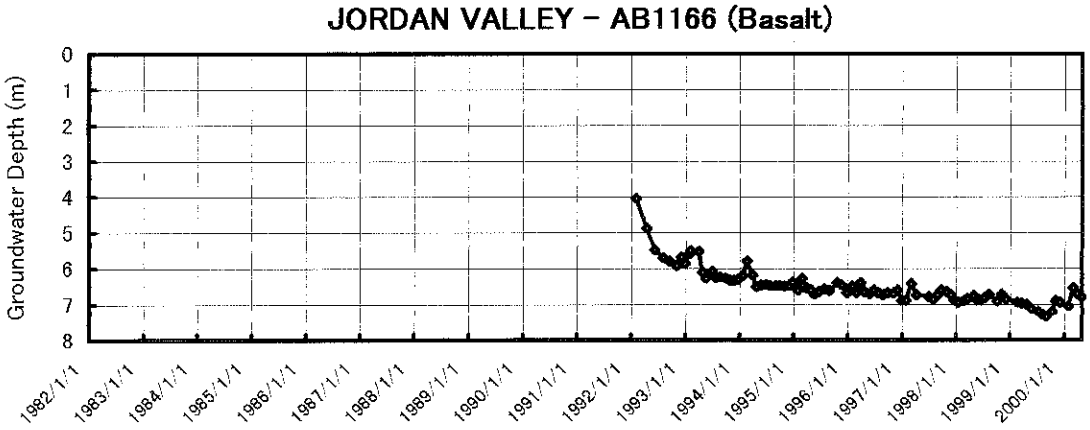


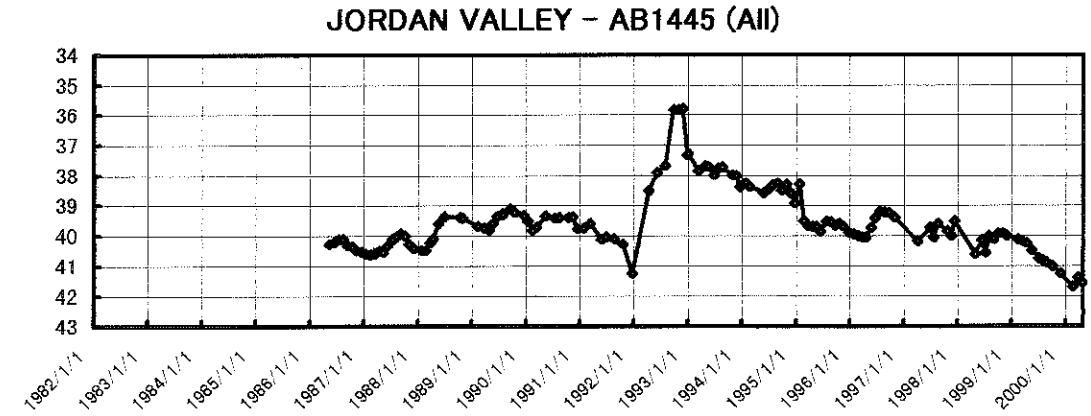
Groundwater Level Monitoring Records in Rift Side Wadis Basin

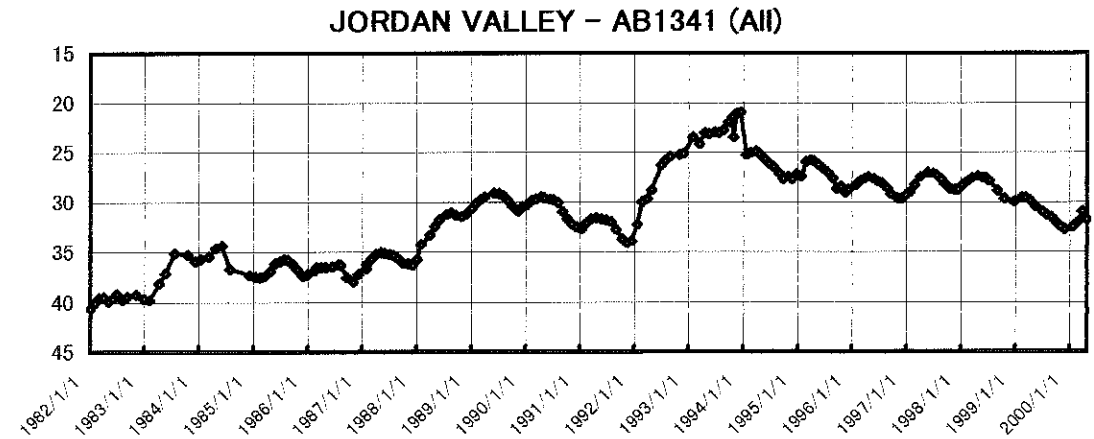




Groundwater Level Monitoring Records in Jodan Valley Basin

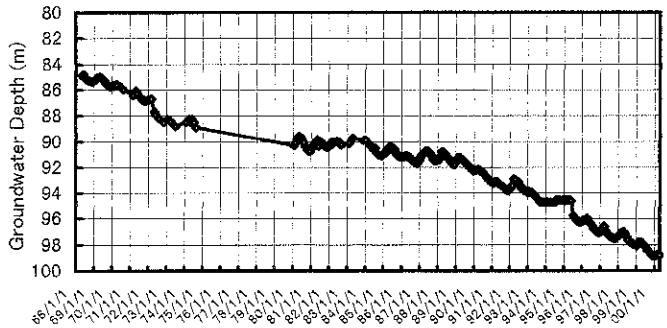




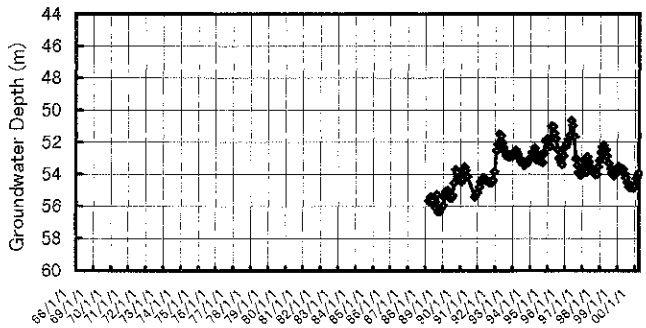


Groundwater Level Monotoring Records in Amman-Zarqa Basin

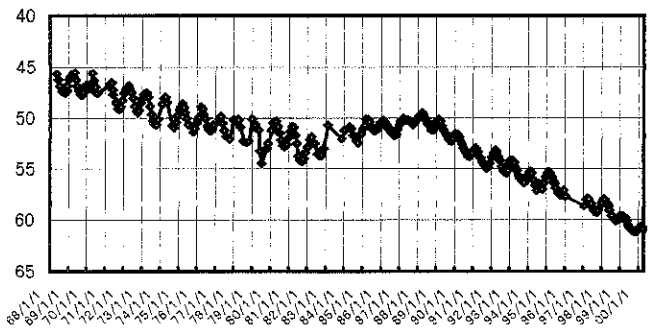
AMMAN-ZARQA - AL1040 (B2/A7)



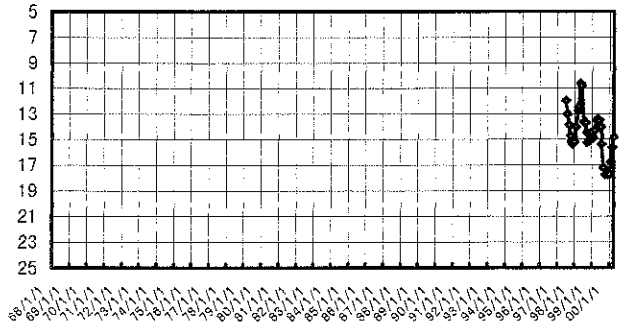
AMMAN-ZARQA - AL1734 (B2/A7)



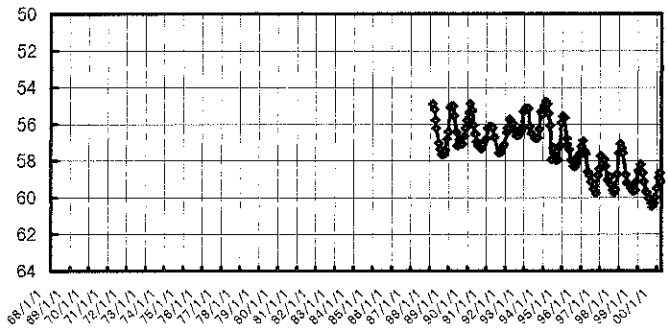
AMMAN-ZARQA - AL1043 (B2/A7)



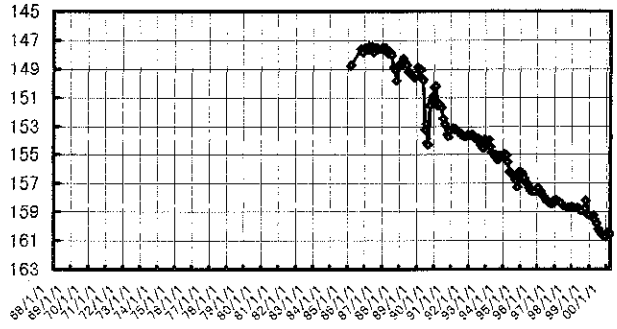
AMMAN-ZARQA - AL1813 (B2/A7)



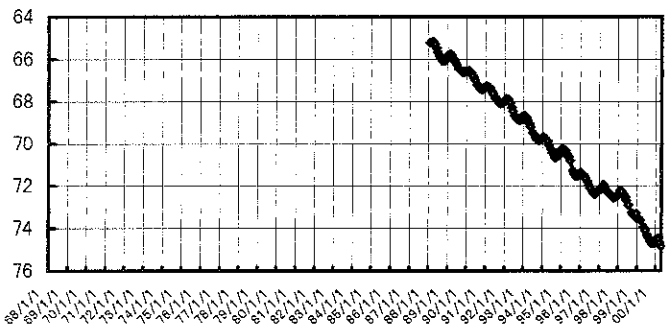
AMMAN-ZARQA - AL2699 (B2/A7)



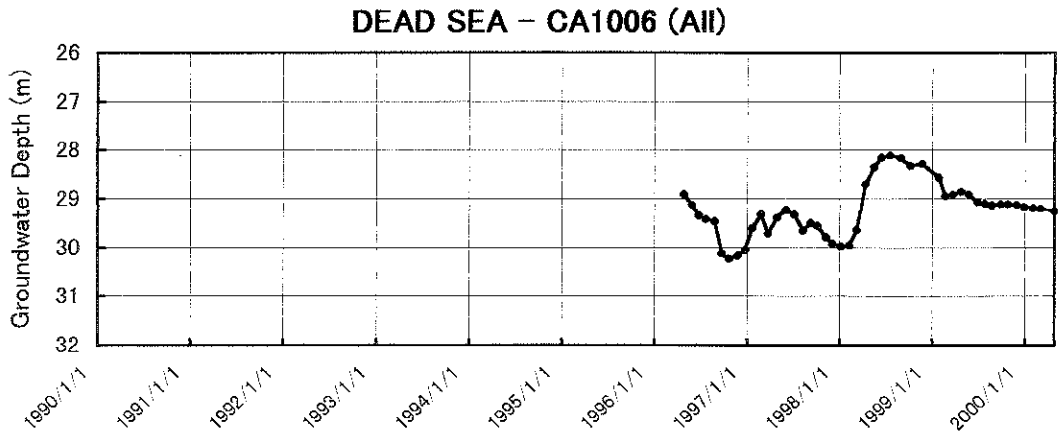
AMMAN-ZARQA - AL1430 (Kurnob)

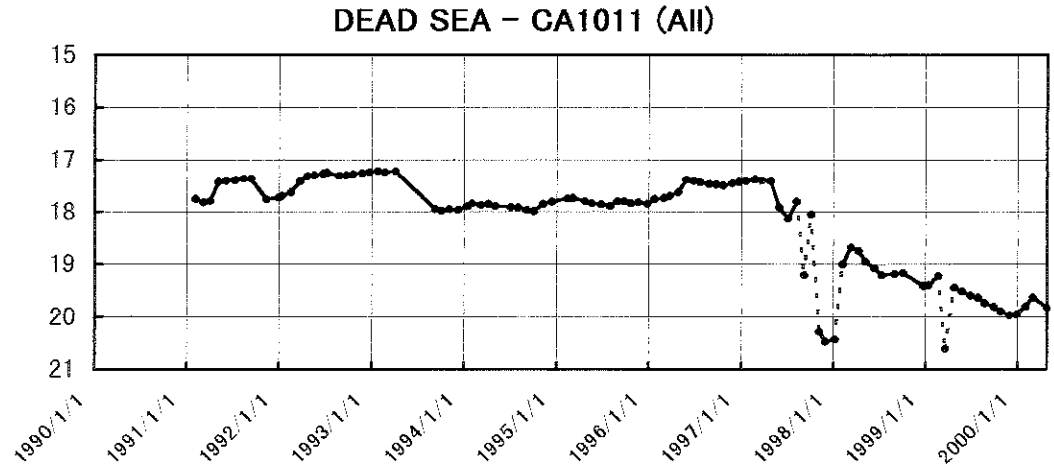


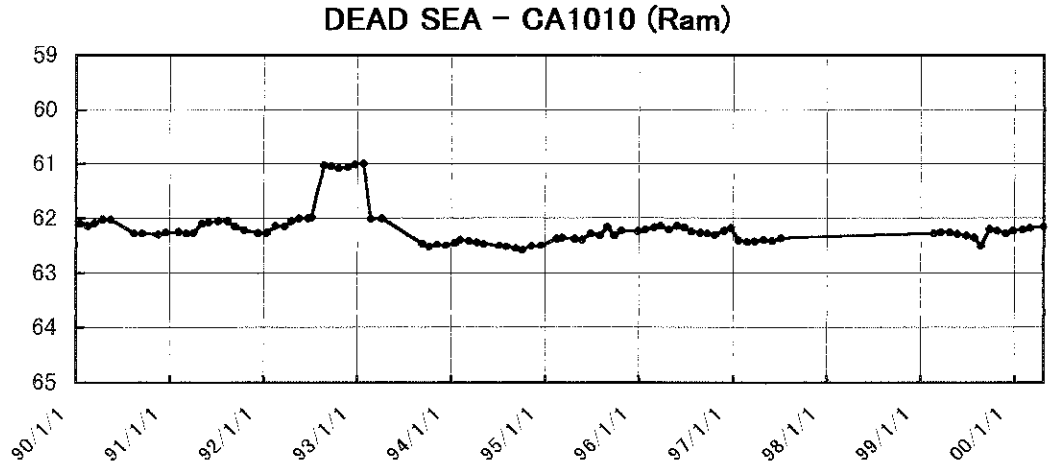
AMMAN-ZARQA - AL2698 (B2/A7)



Groundwater Level Monitoring Records in Dead Sea Basin (1)

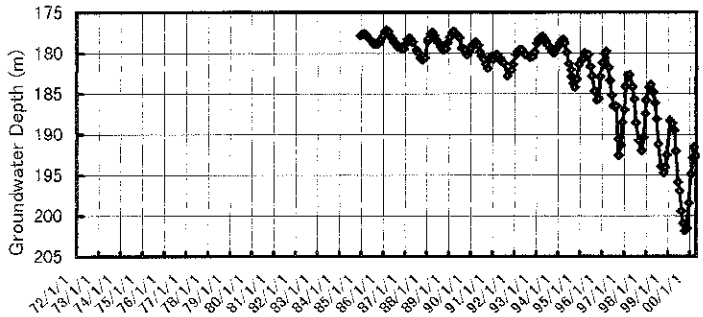




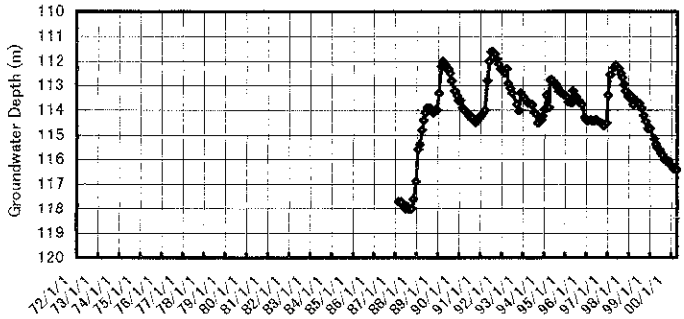


Groundwater Monitoring Records in Dead Sea Basin (2)

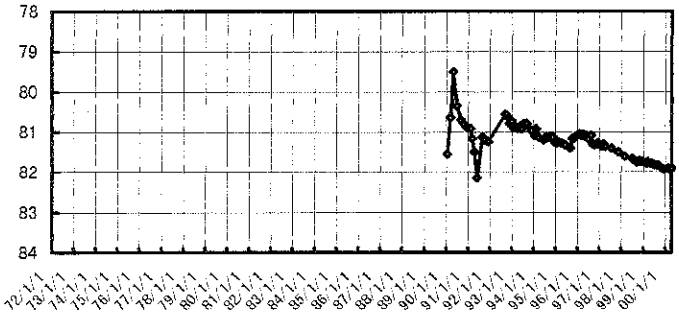
DEAD SEA - CD1075 (B2/A7)



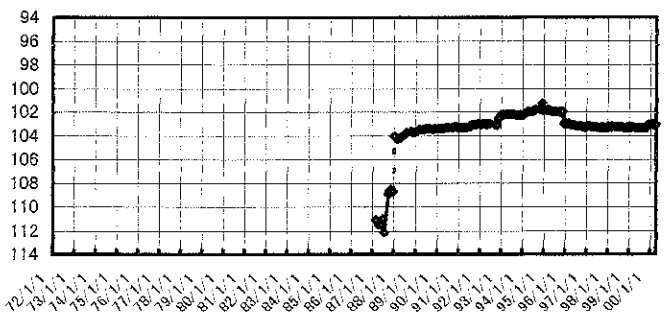
DEAD SEA - CD1182 (B2/A7)



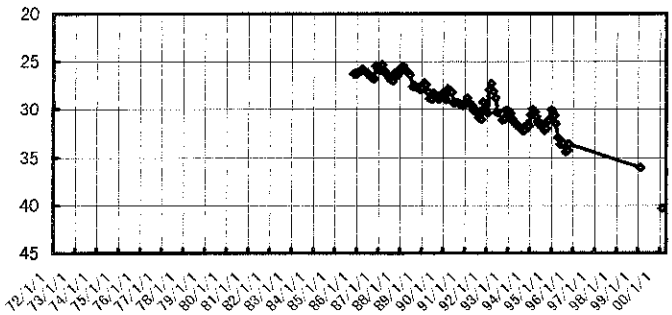
DEAD SEA - CD1137 (B2/A7)



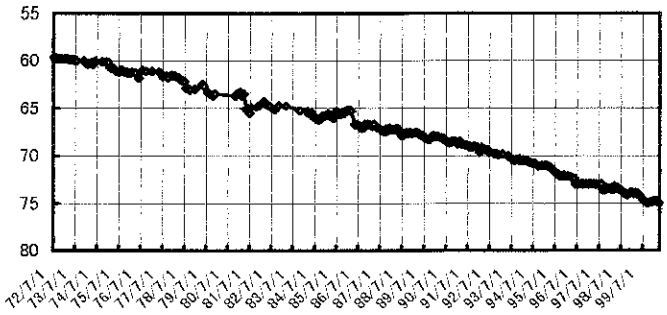
DEAD SEA - CF1074 (B2/A7)



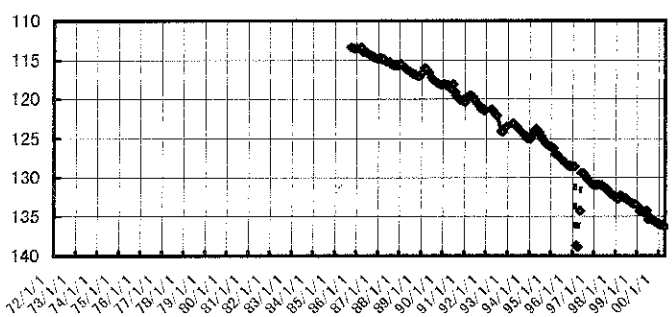
DEAD SEA - CD1100 (B2/A7)



DEAD SEA - CF1078 (B2/A7)

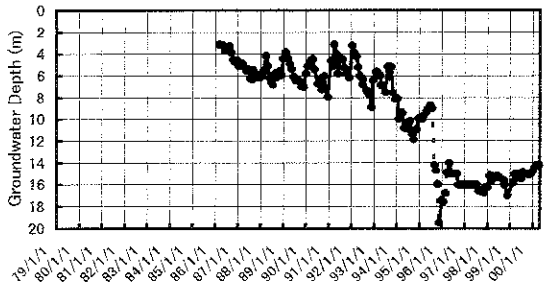


DEAD SEA - CD1106 (B2/A7)

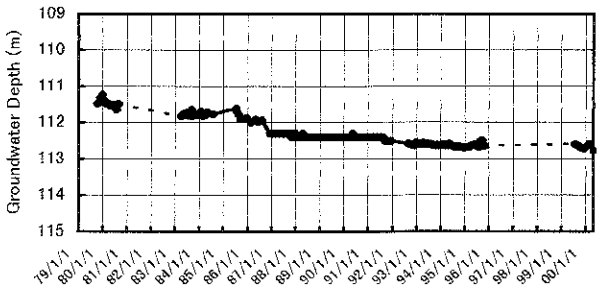


Groundwater Level Monitoring Records in Wadi Araba Basin

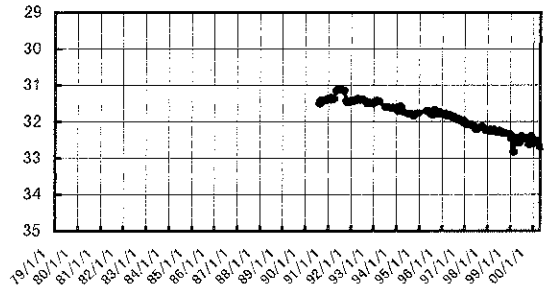
NORTH WADI ARABA – CA1038 (All)



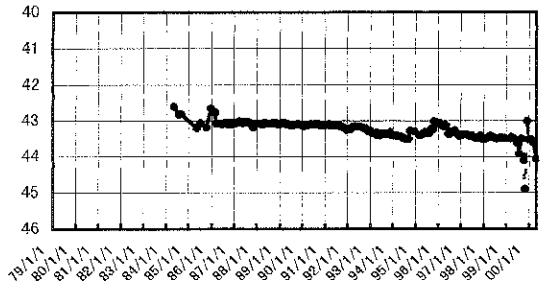
NORTH WADI ARABA – DF1000 (A1/6)



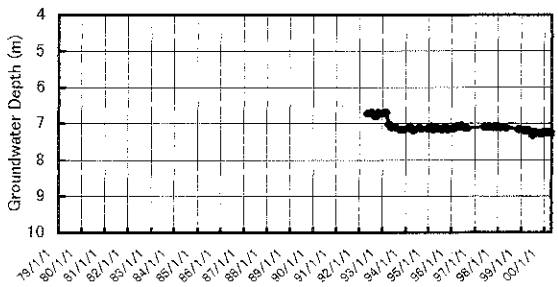
NORTH WADI ARABA – DA1032 (All)



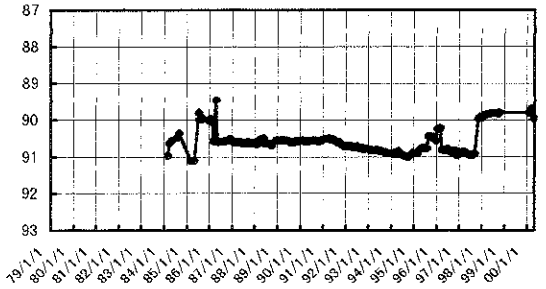
NORTH WADI ARABA – DF1003 (All)



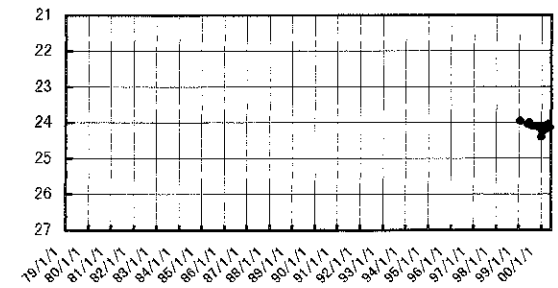
SOUTH WADI ARABA – EA3009 (All)



NORTH WADI ARABA – EA1011 (All)

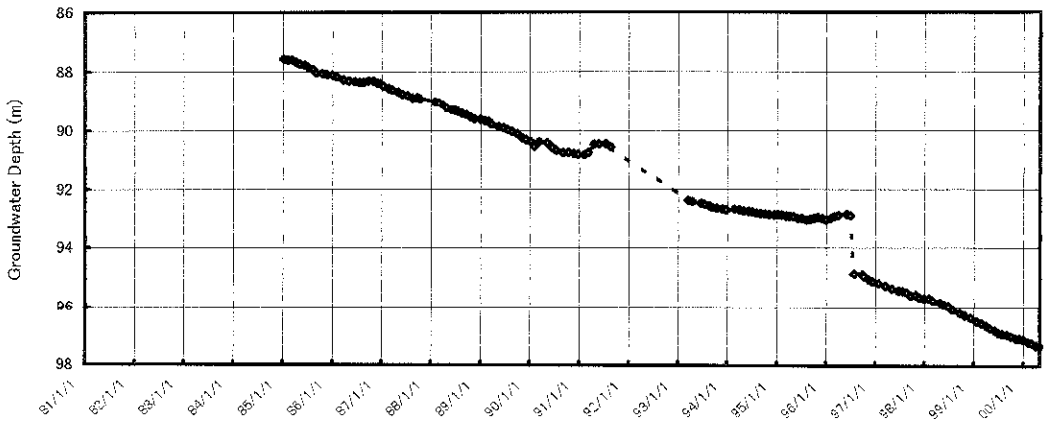


SOUTH WADI ARABA – ED1570 (All)

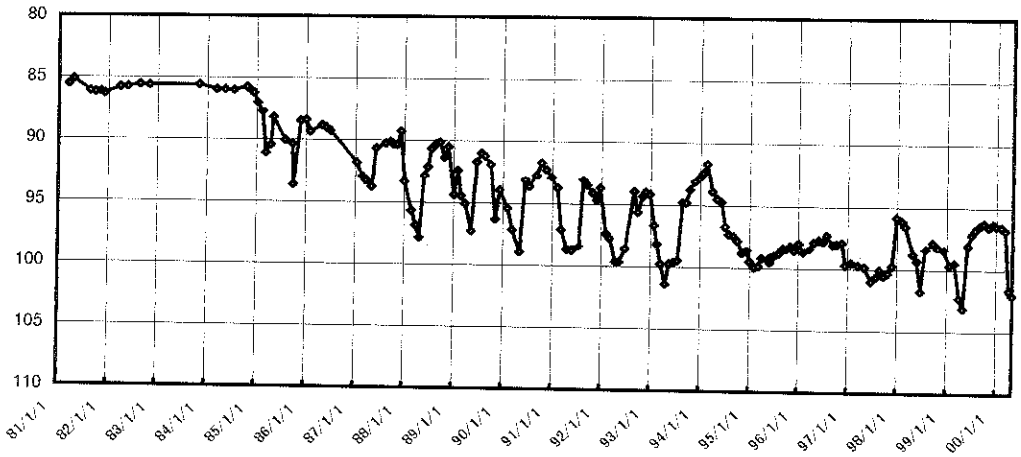


Groundwater Level Monitoring Records in Disi Basin

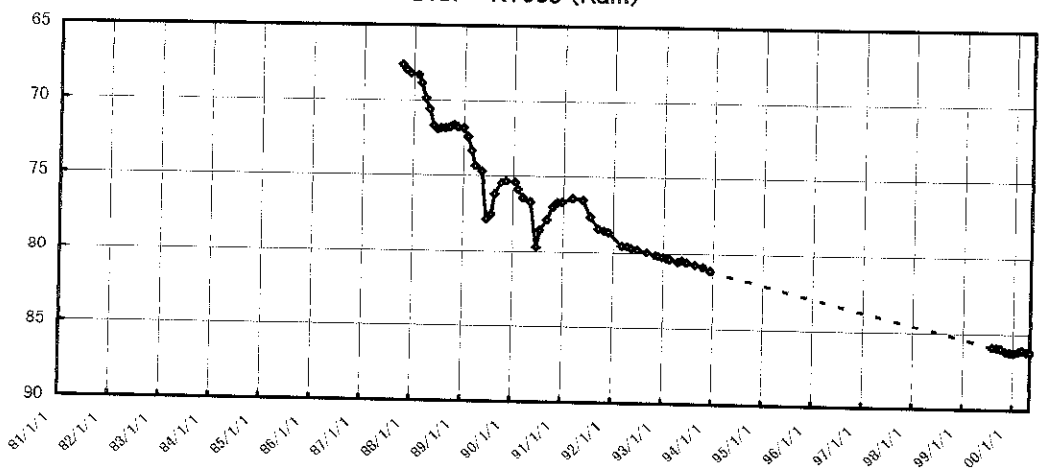
DISI – ED1203 (Ram)



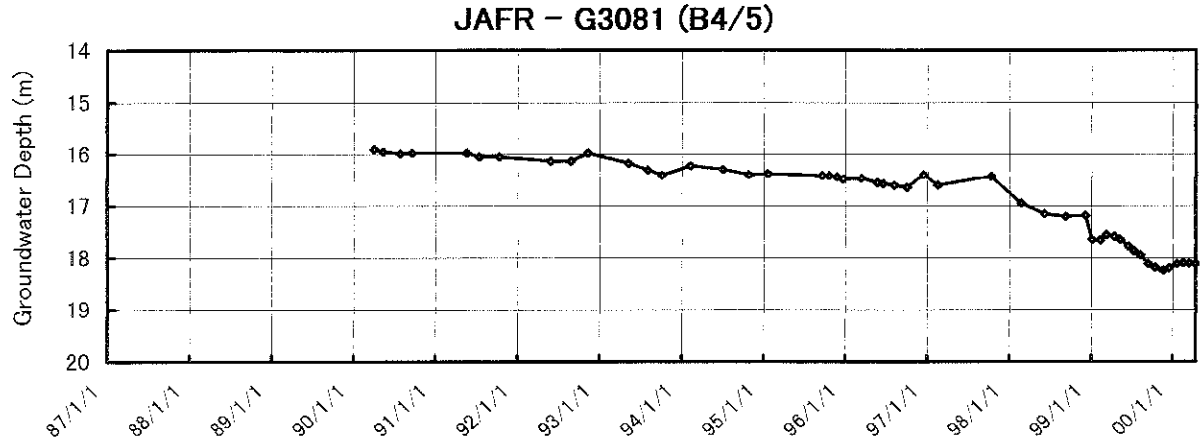
DISI – ED1303 (Ram)

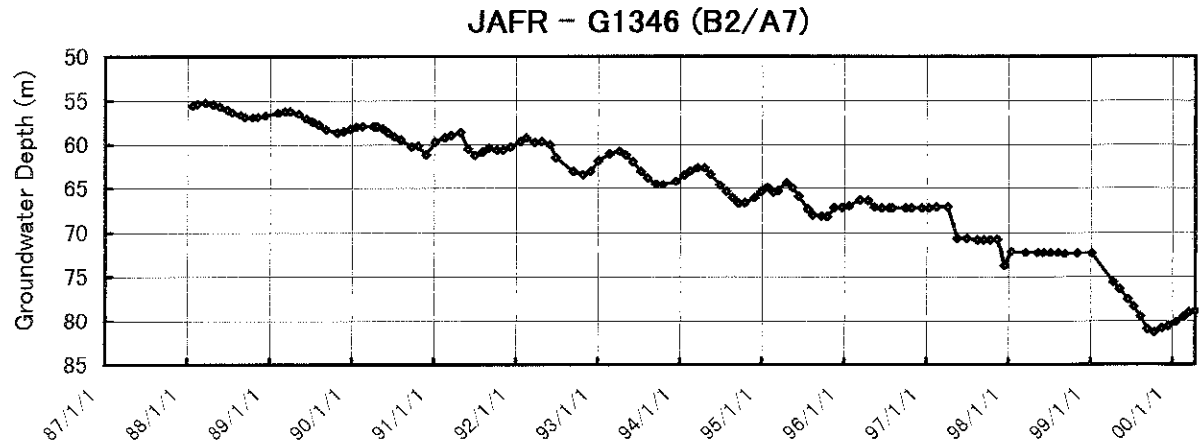


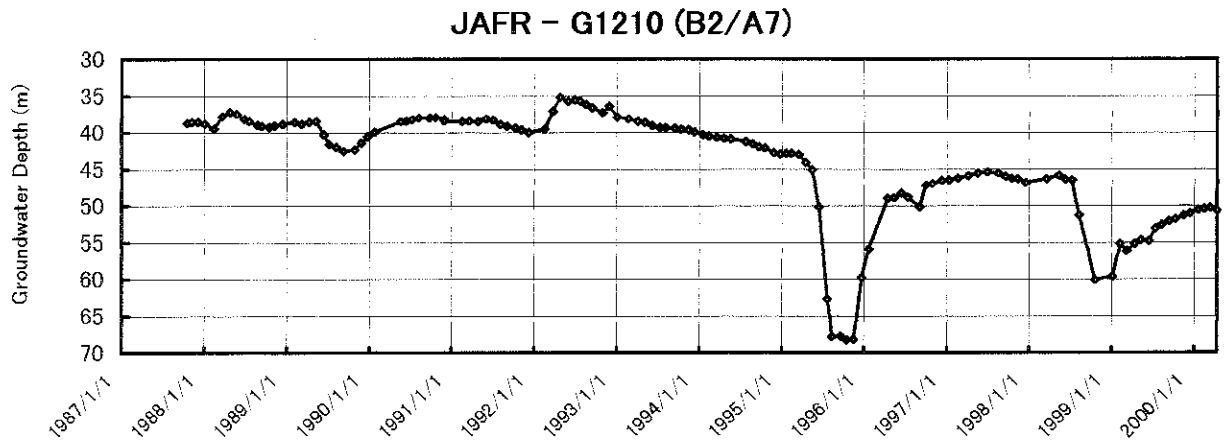
DISI – K1005 (Ram)



Groundwater Level Monitoring Records in Jafr Basin

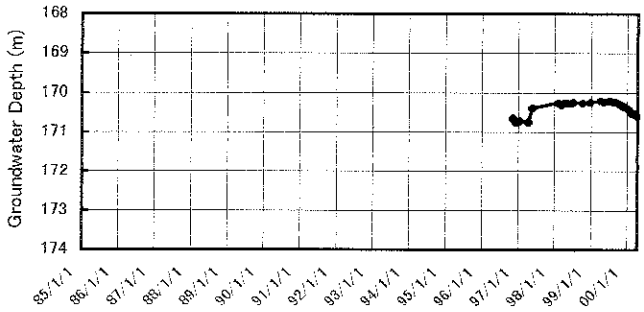




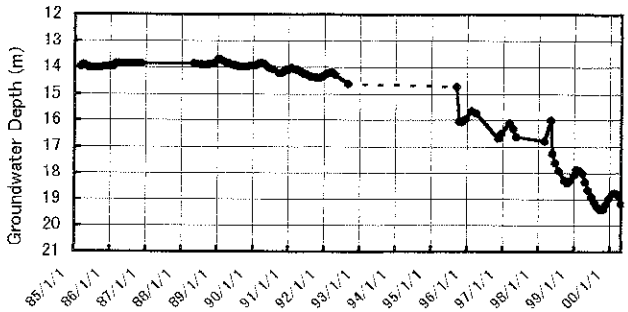


Groundwater Level Monitoring Records in Azraq Basin

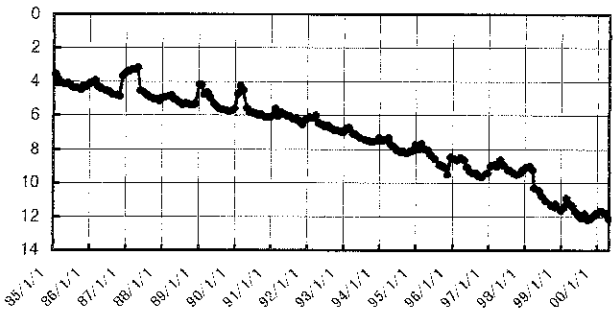
AZRAQ – F1334 (Basalt)



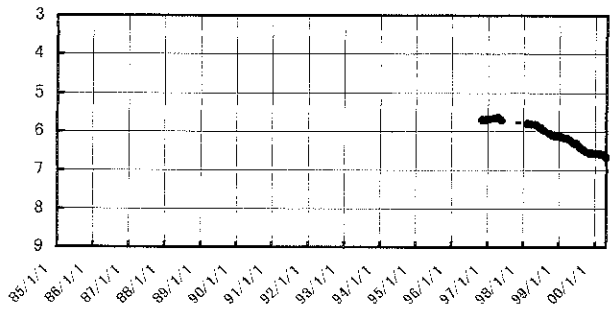
AZRAQ – F1022 (B4/5)



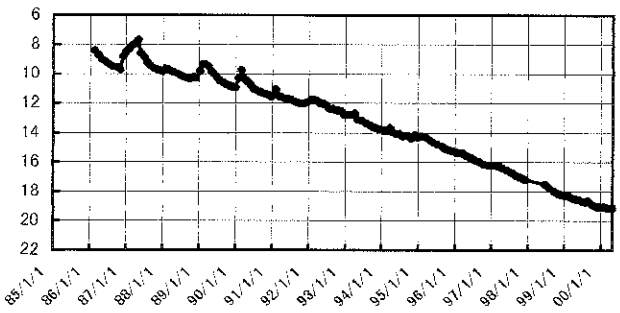
AZRAQ – F1280 (Basalt)



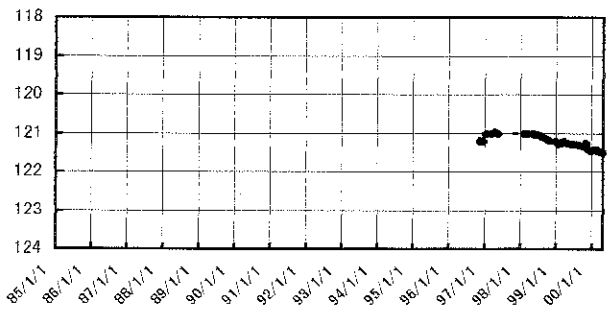
AZRAQ – F1126 (B4/5)



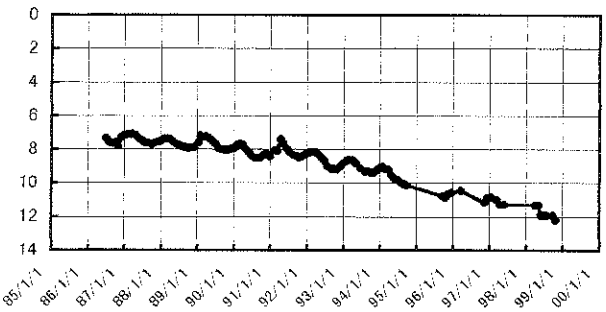
AZRAQ – F1043 (Basalt)



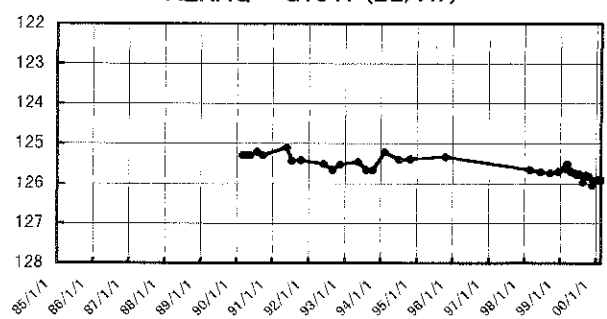
AZRAQ – F1307 (B4/5)



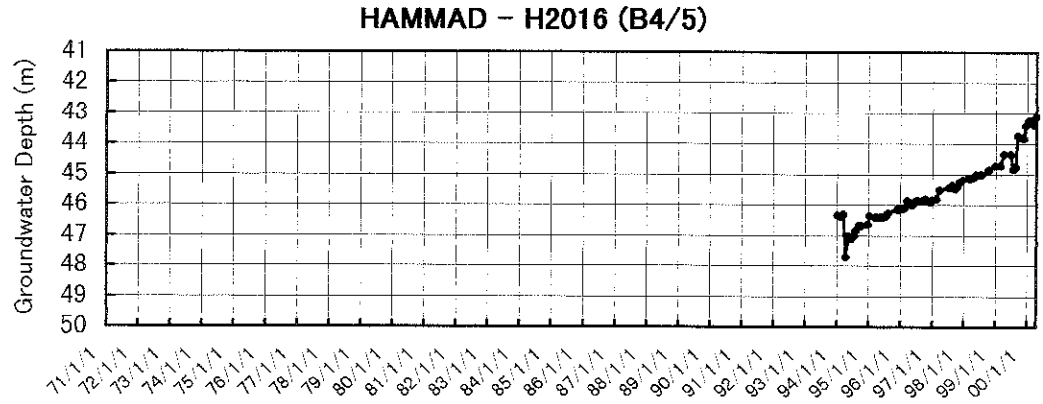
AZRAQ – F1060 (Basalt)

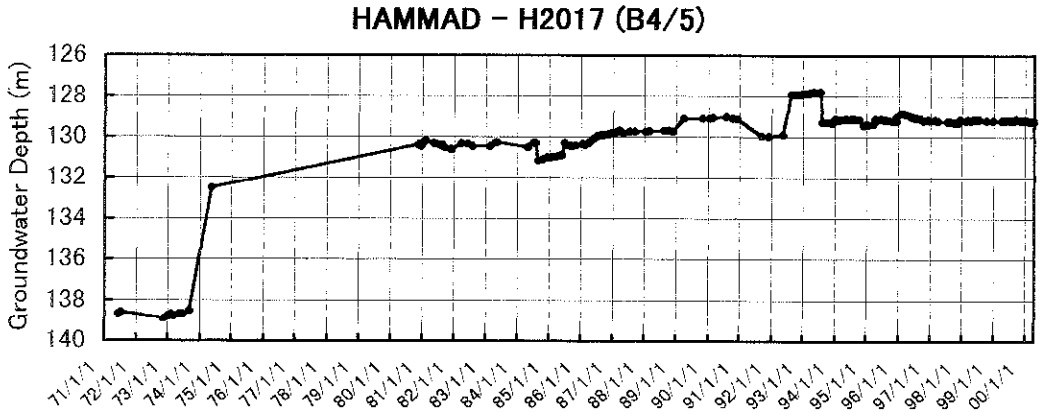


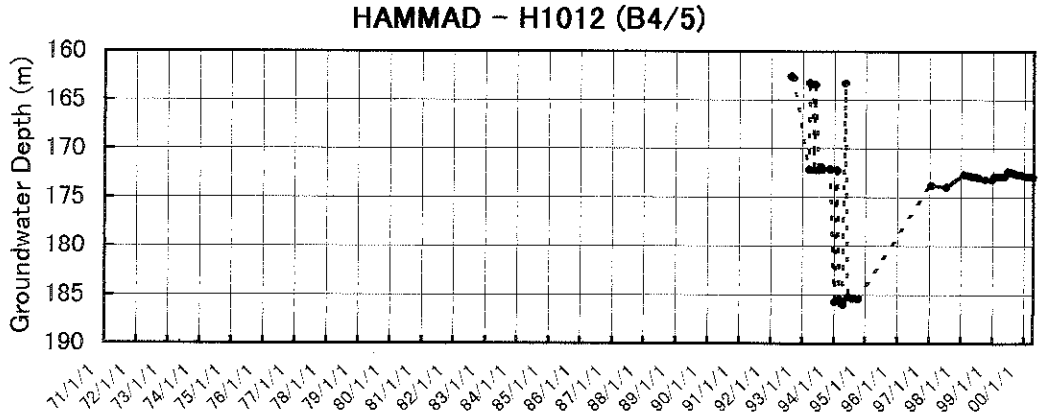
AZRAQ – G1341 (B2/A7)



Groundwater Level Monitoring Records in Hamad Basin

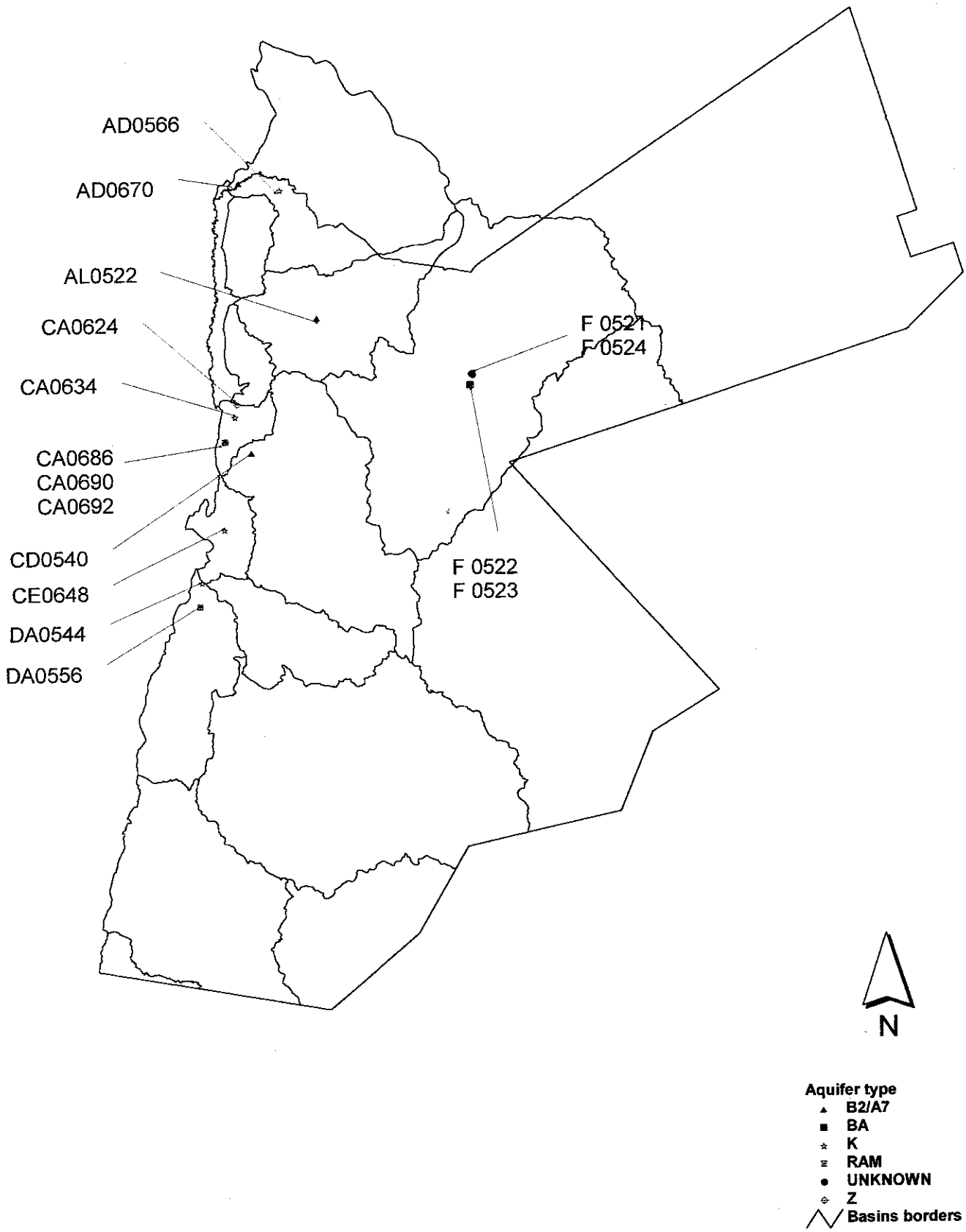






(2) Spring Flow Measurement Records

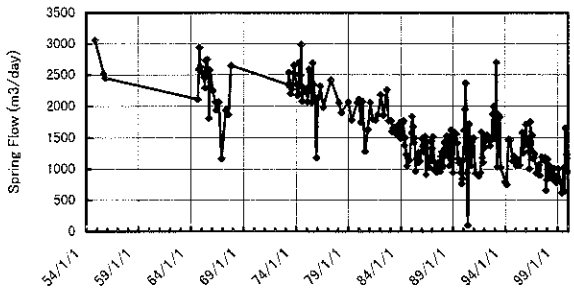
Location map of selected springs



Spring Flow Monitoring Records

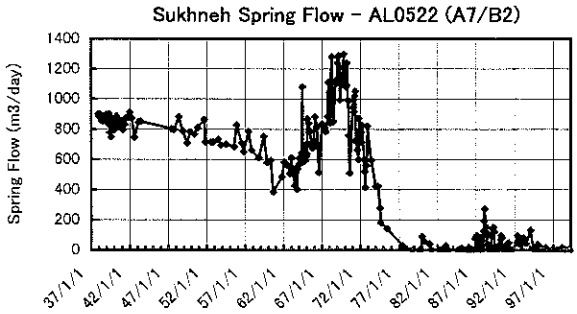
Yarmouk Basin

Hammam Spring Flow – AD0670 (A7/B2)



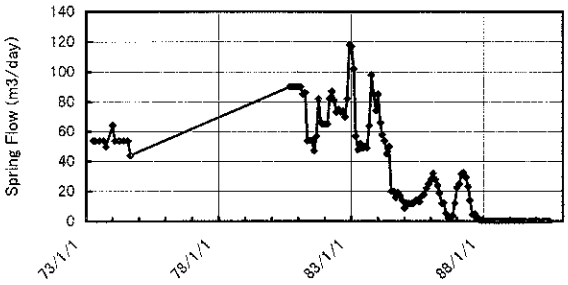
Amman –Zarqa Basin

Sukhneh Spring Flow – AL0522 (A7/B2)

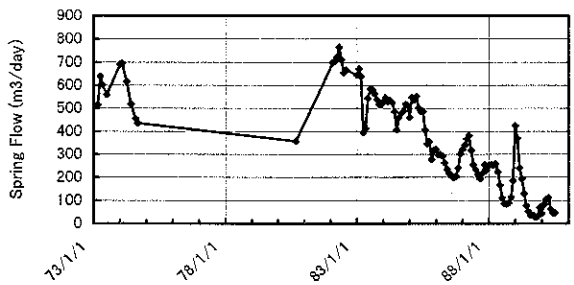


Azraq Basin

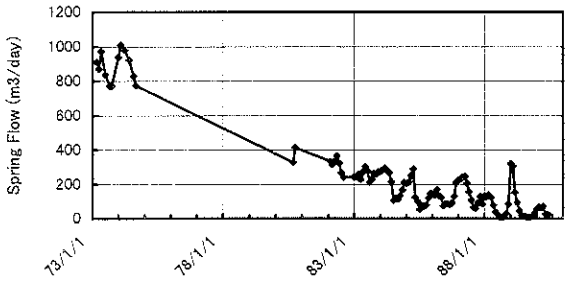
Mustadhema Pool Spring – F0521(Ba)



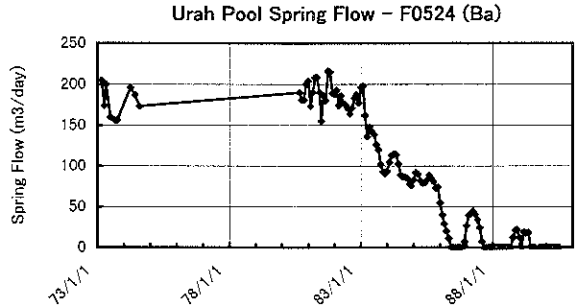
Qeisiyeh Pool Spring – F0522 (Ba)



Soda Pool Spring – F0523 (Ba)

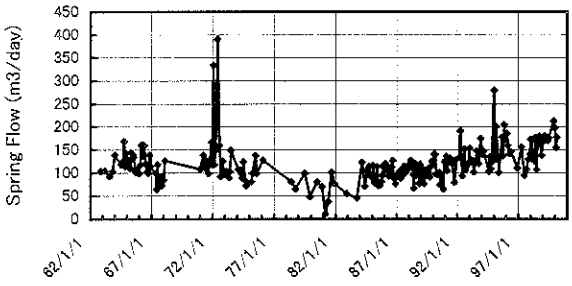


Urah Pool Spring Flow – F0524 (Ba)

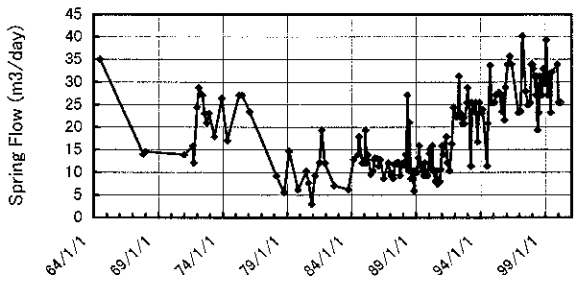


Jordan Valley Basin

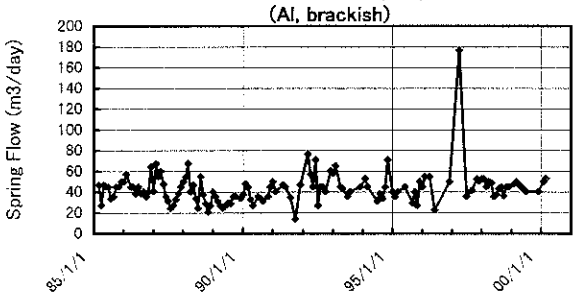
Suweima Spring – CA0638 (Al, brackish)



Hajjar Spring – CA0642 (Al, brackish)

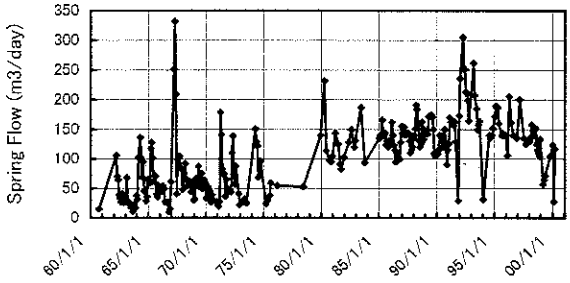


Al Odheima At Suweimah Spring – CA0841 (Al, brackish)

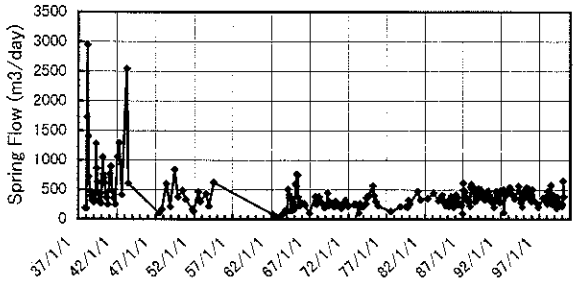


Spring Flow Monitoring Records in Rift Side Wadis Basin

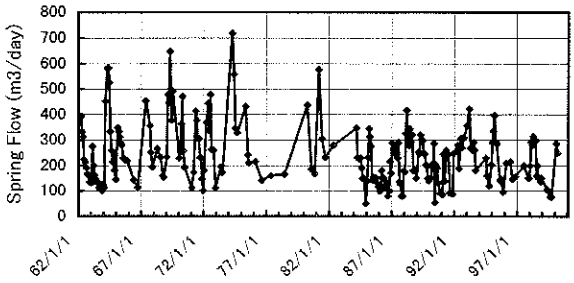
Hazzir Spring – AM0512 (A1/A6)



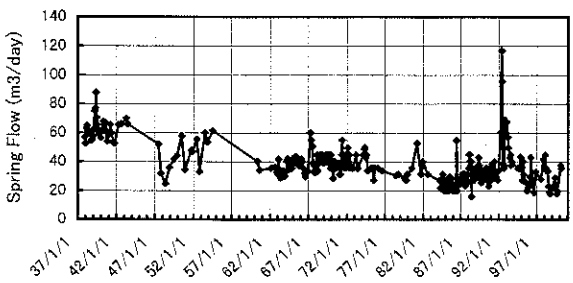
Wadi es Sir Spring – AN0534 (A1/A6)



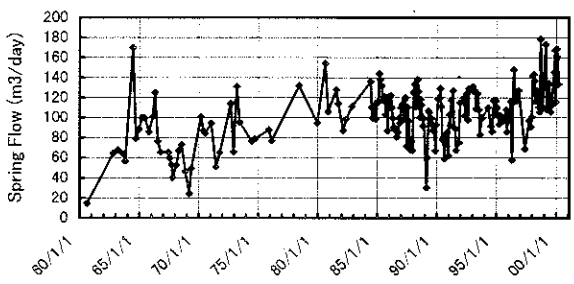
Al Azraq (Fuheis) Spring – AM0526 (A1/A6)



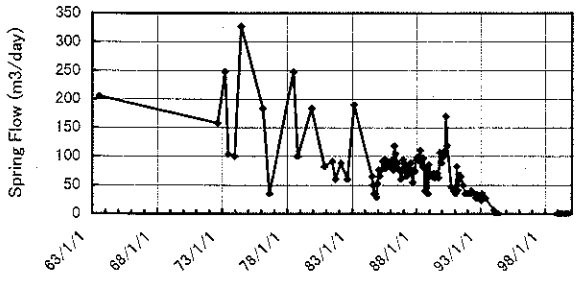
Mahis Spring – AM0534 (A1/A6)



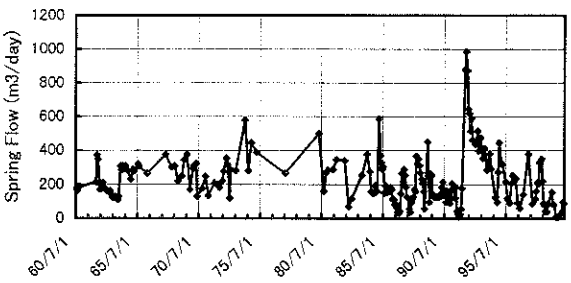
Deirel Tahta Spring – AN0544 (A1/A6)



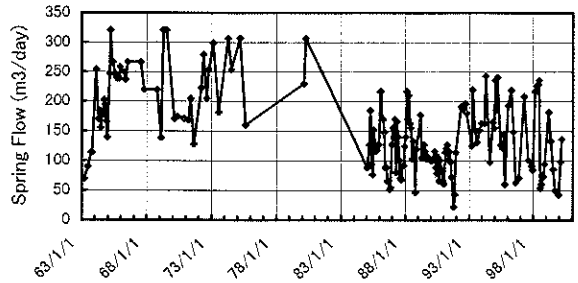
Ain Wadi Kufrein Spring – AN0566 (Kurnub)



Faria Spring – AP0506 (A1/A6)

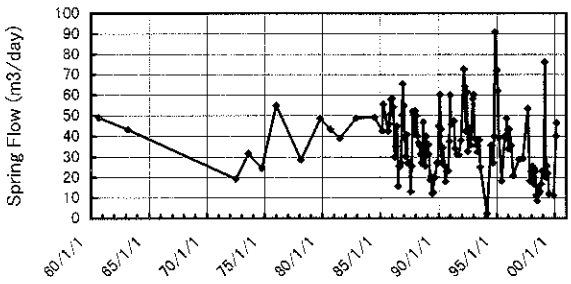


Mbeirdeh Spring – AP0518 (A1/A6)

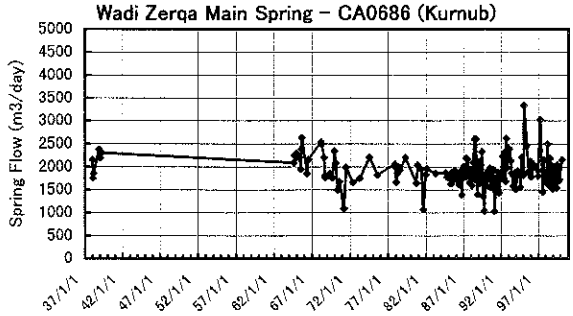


Spring Flow Monitoring Records in Dead Sea Basin

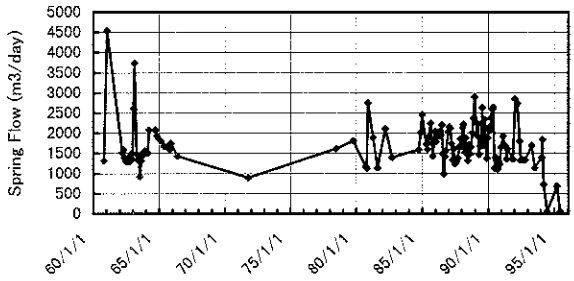
Hirreh No.1 Spring – CA0622 (Kurnub)



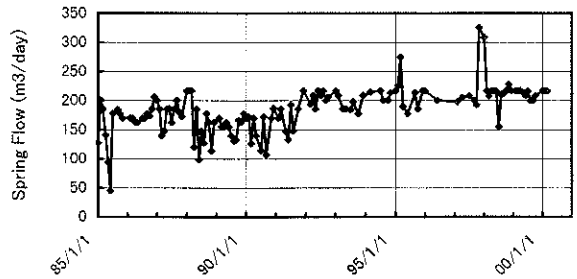
Wadi Zerqa Main Spring – CA0686 (Kurnub)



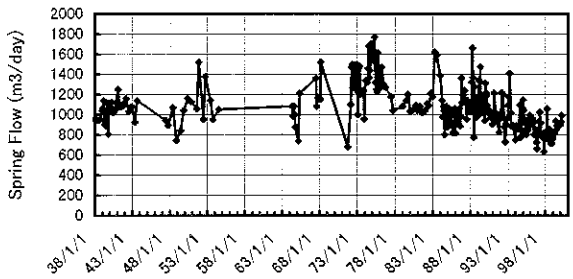
W. Haidan Spring – CD0540 (A7/B2)



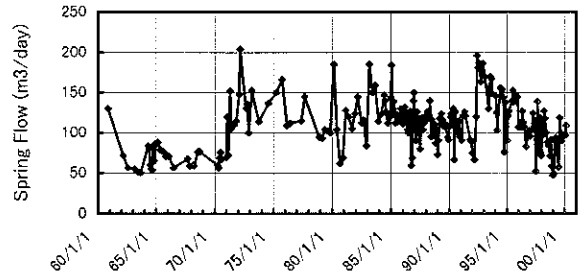
Zara No.7 Spring – CA0532 (Kurnub)



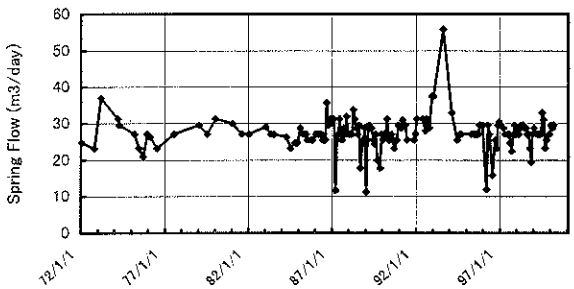
El Hadeitheh Spring – CA0502 (A7/B2)



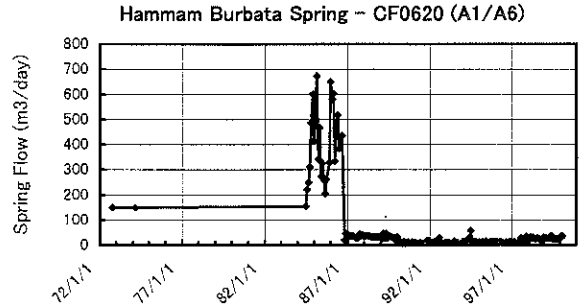
El Fara'a Spring – CA0778 (A7/B2)



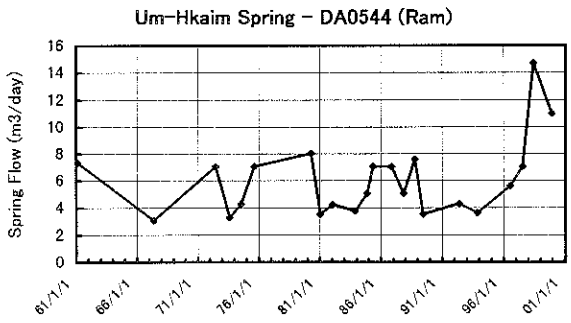
Hammam Weida Spring – CE0648 (Kurnub)

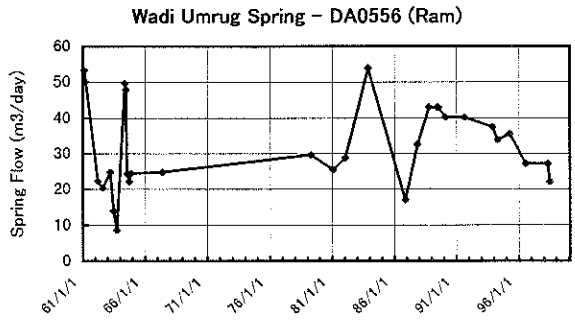


Hammam Burbata Spring – CF0620 (A1/A6)



Spring Flow Monitoring Records in Wadi Araba North Basin





(3) Groundwater Abstraction Records in 1998

Groundwater Abstraction by Aquifer Type in 1998

Aquifer Type	Abstruction (MCM)	Well Number
Alluvial (All)	12,347,148	91
Basalt (BA)	67,383,072	194
B4/B5	5,562,384	63
A7/B2	213,706,188	832
A1/A6	19,070,832	122
Kurnob (K)	9,495,936	72
Zarqa (Z)	138,816	3
RAM	28,947,648	58
Unknown	127,790,616	872
Total	**484,442,640**	**2,307**

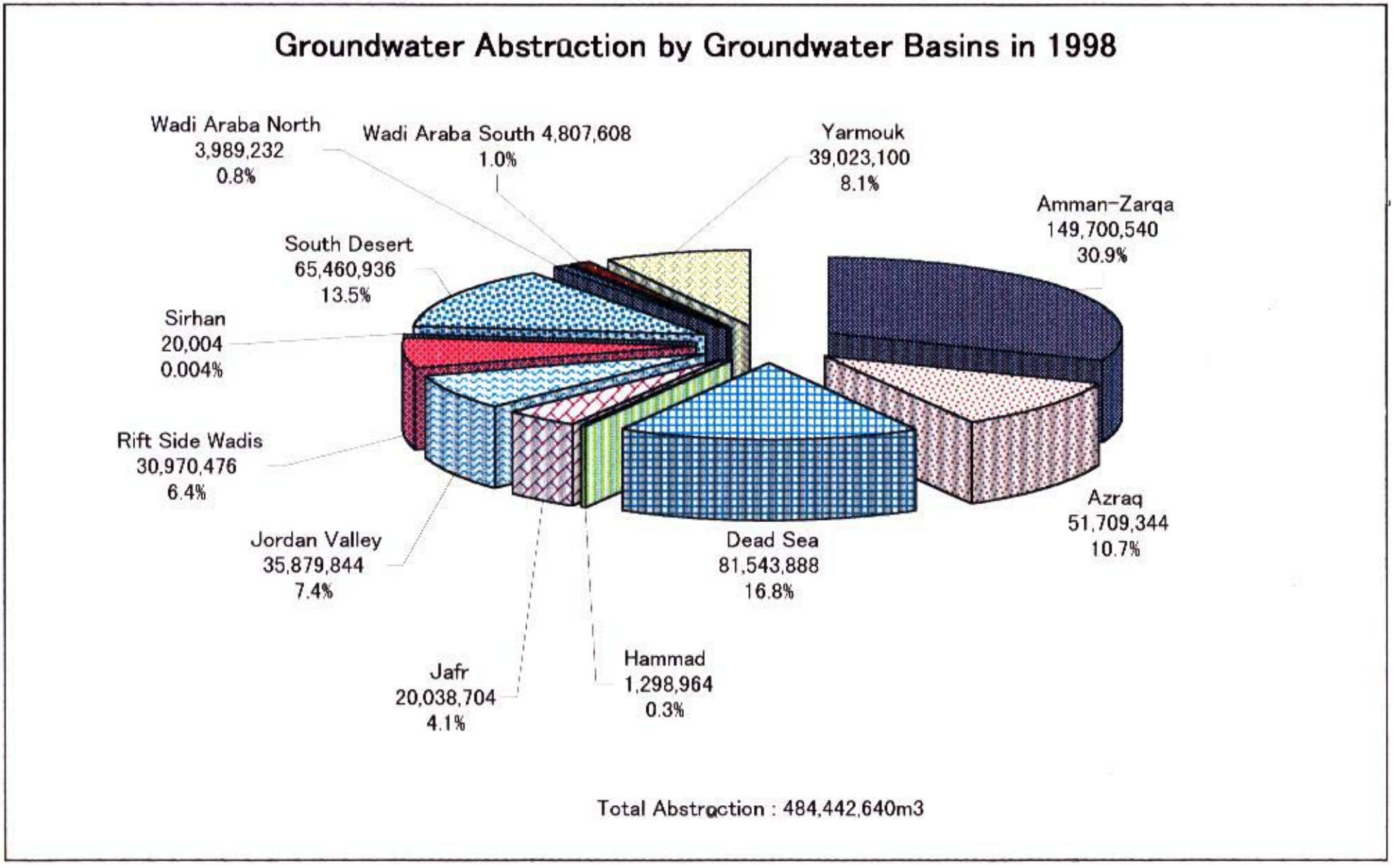
Groundwater Abstraction by Groundwater Basin in 1998

Groundwater Basin	Abstruction (MCM)	Well Number
Amman - Zarqa	149,700,540	683
Azraq	51,709,344	542
Dead Sea	81,543,888	342
Hammad	1,298,964	15
Jafr	20,038,704	102
Jordan Valley	35,879,844	215
Rift Side Wadis	30,970,476	83
Sirhan	20,004	1
South Desert	65,460,936	74
Wadi Araba North	3,989,232	31
Wadi Araba South	4,807,608	47
Yarmouk	39,023,100	172
Total	**484,442,640**	**2,307**

Abstractions from wells per groundwater basin in 1998

BASIN NAME	AQUIFER CODE	PRODUCTION (MCM)
AMMAN ZARQA		149,700,540
	ALL	*1,522,884*
	BA	*46,160,652*
	B4/B5	*210,624*
	A7/B2	*63,661,092*
	A1/A6	*14,604,708*
	K	*7,951,416*
	Z	*63,816*
	Unknown	*15,525,348*
AZRAQ		51,709,344
	ALL	*24,996*
	BA	*21,222,420*
	B4/B5	*1,483,776*
	A7/B2	*6,818,088*
	Unknown	*22,160,064*
DEAD SEA		81,543,888
	ALL	*3,453,996*
	B4/B5	*150,000*
	A7/B2	*66,488,208*
	A1/A6	*806,856*
	RAM	*47,004*
	Unknown	*10,597,824*
HAMMAD		1,298,964
	B4/B5	*1,100,112*
	A7/B2	*99,204*
	K	*99,648*
JAFER		20,038,704
	B4/B5	*1,821,720*
	A7/B2	*12,542,436*
	K	*90,000*
	Unknown	*5,584,548*

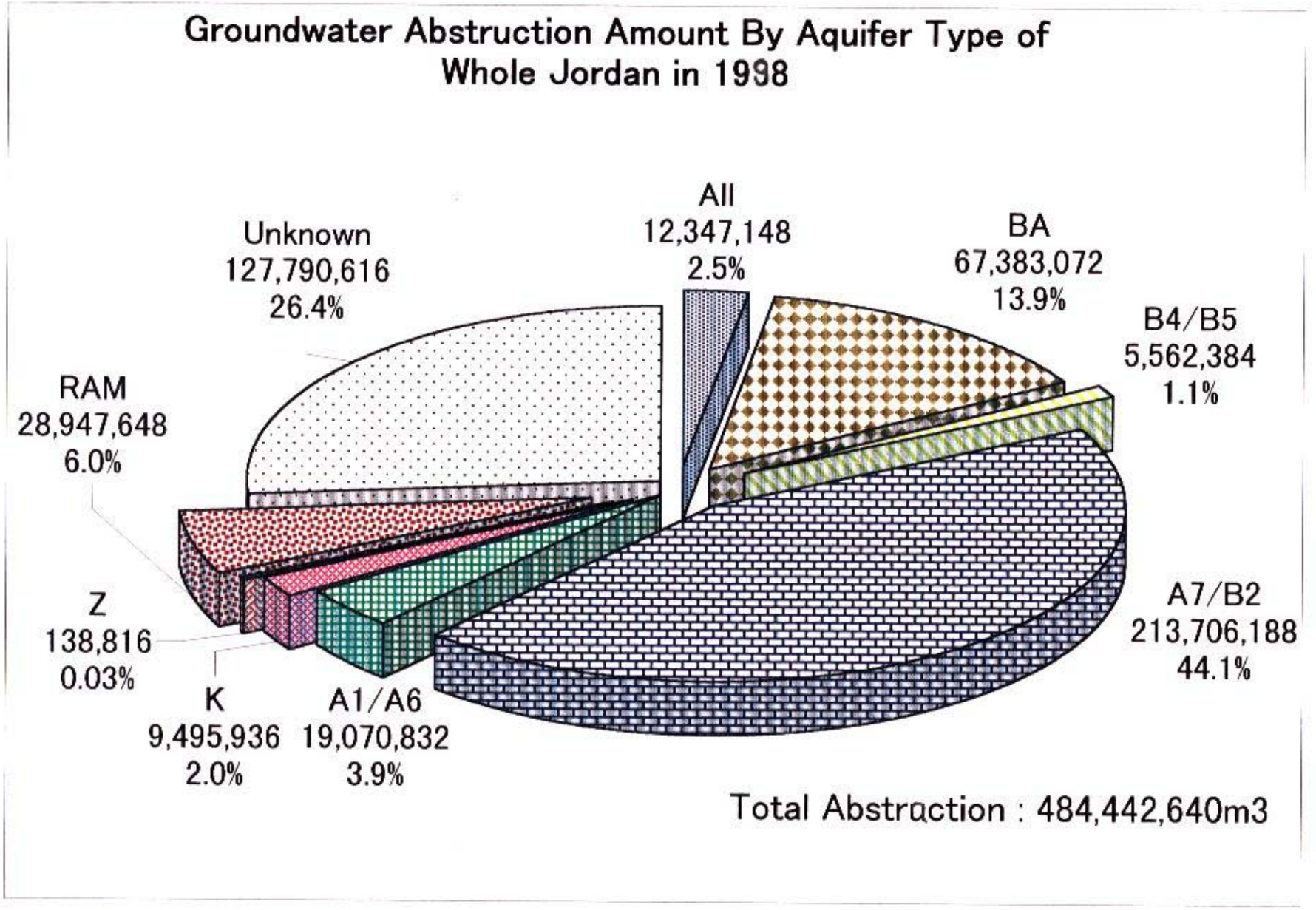
JORDAN VALLEY		35,879,844
	ALL	*5,553,000*
	A7/B2	*2,848,344*
	A1/A6	*1,519,932*
	K	*150,000*
	Z	*75,000*
	Unknown	*25,733,568*
RIFT SIDE WADIES		30,970,476
	ALL	*195,000*
	A7/B2	*21,445,716*
	A1/A6	*1,988,064*
	K	*1,204,872*
	Unknown	*6,136,824*
SIRHAN		20,004
	B4/B5	*20,004*
SOUTHERN DESERT		65,460,936
	ALL	*7,260*
	A7/B2	*255,348*
	RAM	*24,952,296*
	Unknown	*40,246,032*
WADI ARABA NORTH		3,989,232
	ALL	*1,266,588*
	B2/A7	*1,583,292*
	Unknown	*1,139,352*
WADI ARABA SOUTH		4,807,608
	ALL	*323,424*
	RAM	*3,948,348*
	Unknown	*535,836*
YARMOUK		39,023,100
	B4/B5	*776,148*
	A7/B2	*37,964,460*
	A1/A6	*151,272*
	Unknown	*131,220*
Total abstraction in 1998 from wells (m^3)		**484,442,640**


Groundwater Abstraction by Groundwater Basins in 1998
Wadi Araba North
3,989,232
0.8%
Wadi Araba South 4,807,608
1.0%
Yarmouk
39,023,100
8.1%
Amman-Zarqa
149,700,540
30.9%
South Desert
65,460,936
13.5%
Sirhan
20,004
0.004%
Rift Side Wadis
30,970,476
6.4%
Jordan Valley
35,879,844
7.4%
Jafr
20,038,704
4.1%
Hammad
1,298,964
0.3%
Dead Sea
81,543,888
16.8%
Azraq
51,709,344
10.7%
Total Abstraction : 484,442,640m3

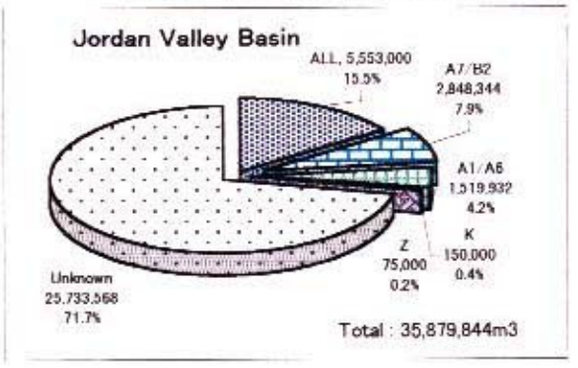
Abstractions from Wells by Groundwater Basin in 1998

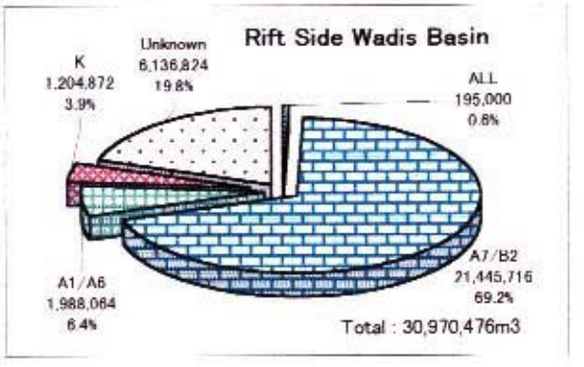
BASIN_NAME	AQUIFER_ CODE	PRODUCTION (MCM)	Well Number
AMMAN ZARQA		149,700,540	683
	ALL	*1,522,884*	*16*
	BA	*46,160,652*	*172*
	B4/B5	*210,624*	*1*
	A7/B2	*63,661,092*	*241*
	A1/A6	*14,604,708*	*100*
	K	*7,951,416*	*66*
	Z	*63,816*	*2*
	Unknown	*15,525,348*	*85*
AZRAQ		51,709,344	542
	ALL	*24,996*	*1*
	BA	*21,222,420*	*22*
	B4/B5	*1,483,776*	*28*
	A7/B2	*6,818,088*	*70*
	Unknown	*22,160,064*	*421*
DEAD SEA		81,543,888	342
	ALL	*3,453,996*	*17*
	B4/B5	*150,000*	*1*
	A7/B2	*66,488,208*	*274*
	A1/A6	*806,856*	*3*
	RAM	*47,004*	*1*
	Unknown	*10,597,824*	*46*
HAMMAD		1,298,964	15
	B4/B5	*1,100,112*	*12*
	A7/B2	*99,204*	*2*
	K	*99,648*	*1*
JAFER		20,038,704	102
	B4/B5	*1,821,720*	*14*
	A7/B2	*12,542,436*	*47*
	K	*90,000*	*1*
	Unknown	*5,584,548*	*40*

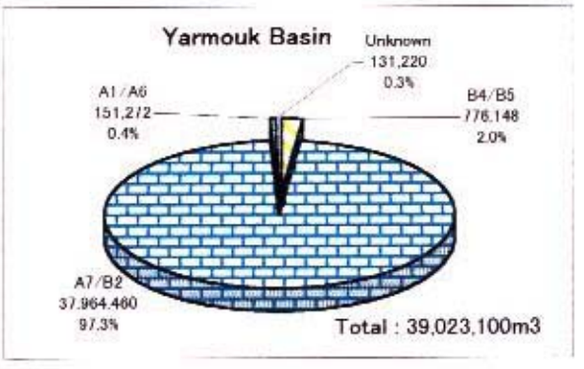
JORDAN VALLEY		35,879,844	215
	ALL	*5,553,000*	*31*
	A7/B2	*2,848,344*	*6*
	A1/A6	*1,519,932*	*5*
	K	*150,000*	*1*
	Z	*75,000*	*1*
	Unknown	*25,733,568*	*171*
RIFT SIDE WADIES		30,970,476	83
	ALL	*195,000*	*1*
	A7/B2	*21,445,716*	*22*
	A1/A6	*1,988,064*	*10*
	K	*1,204,872*	*3*
	Unknown	*6,136,824*	*47*
SIRHAN		20,004	1
	B4/B5	*20,004*	*1*
SOUTHERN DESERT		65,460,936	74
	ALL	*7,260*	*2*
	A7/B2	*255,348*	*1*
	RAM	*24,952,296*	*26*
	Unknown	*40,246,032*	*45*
WADI ARABA NORTH		3,989,232	31
	ALL	*1,266,588*	*11*
	B2/A7	*1,583,292*	*9*
	Unknown	*1,139,352*	*11*
WADI ARABA SOUTH		4,807,608	47
	ALL	*323,424*	*12*
	RAM	*3,948,348*	*31*
	Unknown	*535,836*	*4*
YARMOUK		39,023,100	172
	B4/B5	*776,148*	*6*
	A7/B2	*37,964,460*	*160*
	A1/A6	*151,220*	*4*
	Unknown	*131,220*	*2*
Total abstraction in 1998 from wells (m^3)		**484,442,640**	**2,307**

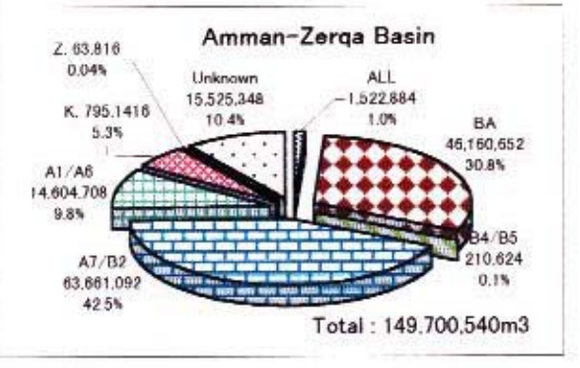

Groundwater Abstruction Amount By Aquifer Type of Whole Jordan in 1998
Unknown
127,790,616
26.4%
All
12,347,148
2.5%
BA
67,383,072
13.9%
B4/B5
5,562,384
1.1%
RAM
28,947,648
6.0%
Z
138,816
0.03%
K
9,495,936
2.0%
A1/A6
19,070,832
3.9%
A7/B2
213,706,188
44.1%
Total Abstruction : 484,442,640m3

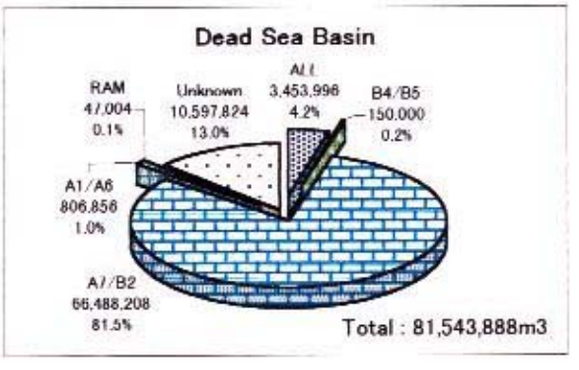
Groundwater Abstraction in each Groundwater Basin in 1998 (1)

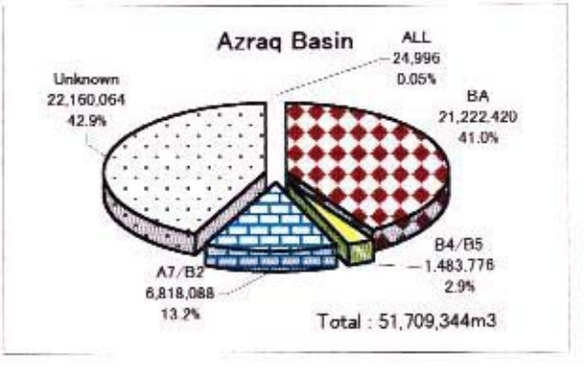


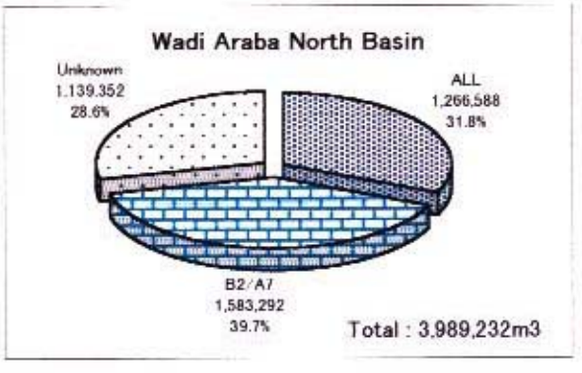


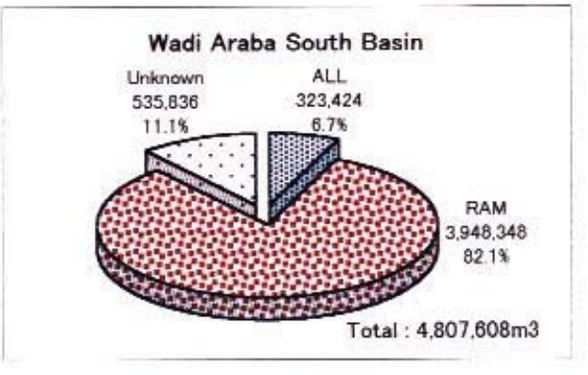












Groundwater Abstraction in each Groundwater Basin in 1998 (2)