The Study on Water Resources Management in the Hashemite Kingdom of Jordan

FINAL REPORT VOLUME I

MAIN REPORT PART-A
WATER RESOURCES MANAGEMENT MASTER PLAN

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CHAPTER 2

WATER RESOURCES POTENTIAL AND DEVELOPMENT PLAN

CHPTER 2 WATER RESOURCES AND DEVELOPMENT PLAN

2.1 Surface Water

2.1.1 Hydrology and Climatology

2.1.1.1 General Features of Climatological Conditions

The climate of Jordan ranges from the Mediterranean Sea (semi-humid, annual rainfall is 500mm/yr to 600mm/yr) to the desert (annual rainfall is less than 100mm/yr). Dry summer with average maximum annual temperatures of 38.8 ^{o}C occurs during April to October. In summer, the average daily mean temperature of Amman Airport and Deir Alla are 22.3 ^{o}C and 28.2 ^{o}C respectively (AD 1981-1998). On the other hand, in winter months from November till March, the average minimum annual temperature is 0.5 ^{o}C. In winter, the average daily mean temperature of Amman Airport and Deir Alla are 10.3 ^{o}C and 17.0 ^{o}C respectively (AD 1981-1998).

The Rift Valley and the highlands belong to the semi-arid to arid climate zone largely affected by moist westerly air masses from the Mediterranean Sea in winter. In summer, dry easterly desert winds affect the whole country. In winter, winds are generally westerly to southwesterly.

The temperature ranges from a few Celsius in winter to around 46 ^{o}C in summer. The average temperature in the wet season rises from the Mediterranean Sea to the Jordan Valley and falls again to the eastern plateau. With respect to evaporation, annual Class A pan evaporation ranges from 2,042 mm in Zarqa to 5,038 mm in Ma'an, from 2,594 mm in the Jordan Rift Valley to 3,516 mm in the eastern hills, and 3,214 mm in the Desert area (Jafr).

Seasonal uneven and fluctuating rainfall affects the country during the period from October until mid May. Eighty (80) % of the annual rainfall takes place during December-March period. Average annual rainfall ranges between less than 25 mm in the eastern desert to approximately 600 mm over Ajloun heights.

Based on the rainfall distribution, Jordan can be classified into the categories as shown on Table 2.1.1-1.

Table 2.1.1-1 Classification by Rainfall Distribution

Classified Zone	Annual Rainfall (mm/yr)	Catchment Area (km^2)	Area Ratio (%)	Rainfall Volume (AD1937 – 1998) (MCM)
Semi-humid	500 - 600	620	0.7	425
Semi-arid	300 - 500	2,950	3.3	1,170
Marginal	200 - 300	2,030	2.2	530
Arid	100 - 200	20,050	22.3	2,950
Desert	< 100	64,350	71.5	3,425
Total		90,000	100.0	8,500

Source: WIS database of MWI

The above-mentioned figures indicate that 93% of the total area of Jordan is arid or desert land with an average annual rainfall of below 200 mm/yr. Of course, this signifies the importance of the limited water resources as an instrumental factor in the overall socio-economic planning at the nationwide level.

Rainfall is the main source of water supply in Jordan to recharge surface and groundwater. Fluctuating, scarcely and unevenly distributed water resources are resulted from the uneven distribution of rainfall over the country. The mountainous highlands along the Jordan Valley - Dead Sea - Wadi Araba depression receive the majority of total rainfall volume. The calculated long-term average annual quantity of rainfall over the whole country is around 8,500 MCM (AD 1937 - 1998) as shown in Table2.1.1-1.

The annual rainfall has been under the long term average in these three years. However, though the general tendency of decreasing of the annual rainfall cannot be detected according to the long term observation records, the future potential of the surface water was estimated without considering the global climatic change.

2.1.1.2 Rainfall and Evaporation

(1) Observatory

The monitoring of rainfall and the climatic parameters are carried out periodically throughout the meteorological networks. Table 2.1.1-2 and Table 2.1.1-3 (see Annex 2-1) show the summary of existing rain-gauge and evaporation stations respectively. Accordingly, there exist one hundred seventy-seven (177) rain-gauge stations and twenty-two (22) evaporation stations all over the country.

Among these stations, the representative ones of fifty-nine (59) rain-gauge stations in total recognized were selected and applied to the Study. With respect to data to be analyzed, Fig.2.1.1-1 and Fig.2.1.1-2 roughly show the available records of data by bar graph.

(2) Data Homogeneity

Using the double-mass curve method, the homogeneity of annual rainfall mentioned above were checked and illustrated as shown from Fig.2.1.1-3 till Fig.2.1.1-14 (see Annex 2-1). According to these figures, the following factors can be recognized:

1) High homogeneity

Double mass curve is almost in accordance with the linear approximate. Almost no lack was observed. Therefore, data records with long-term period and high accuracy, that is, measurement activities are much needed. Among fifty-nine (59) rain-gauge stations mentioned above, 38 rain-gauge stations belong to this group.

2) Medium homogeneity

Double mass curve accords approximately with the linear approximate. There are eleven (11) rain-gauge stations belonging to this group. Some lack observations occasionally occur and small fluctuation can be judged from mass curves. However, these data can also be smoothly applied to the Study as well as that of high availability.

3) Low homogeneity

The period with available records is so short, that is, lack observation often occurs during the wet season. Furthermore, data records are not available over 2 or 3 years. Even these phenomena are so obvious, the limited data are also considered available for statistics with allowable accuracy.

In conclusion, rainfall data are suitable for the study on Master Plan. On the other hand, records of evaporation measurement are not enough in comparison to that of rain-gauging stations. However, evaporation analysis can be smoothly applied to the Study as well as the available rainfall data.

Table 2.1.1-4 (see Annex 2-1) summarized the long-term monthly average and annual rainfall. It is clear that there is no rainfall during dry season, especially in June, July and August. With respect to the rainfall distribution, isohyetal map for long-term period (AD1937-1996) was illustrated as Fig.2.1.1-1. In general, rainfall decreases from west to east and from north to south. The area where rainfall is less than 100 mm almost command about 70% of the territory. Furthermore, rainfall more than 600 mm per year can be expected in the highland areas of Ajloun, Balqa and Jarash Governorates. On the other hand, rainfall is less than 25 mm in most areas in Ma'an Governorate.

To grasp the rainfall trend, 2-year, 5-year and 10-year moving average of annual rainfall was also analyzed for the selected rainfall stations. From the viewpoints of the target year of the water resources management plan (up to 2020), the 10-year moving average one was summarized on Fig.2.1.1-2 by governorates. Based upon this figure, rainfall shows nearly no trend in both of Jarash and Zarqa Governorates. Moreover, remarkable declining trends can be judged in the other governorates, especially average decrease over 100 mm occurs in Irbid, Balqa and Madaba Governorates.

Furthermore, most droughty year can be judged as the water year of 1998/99 with annual rainfall about 200 mm as summarized on Table 2.1.1-5 shown in Annex 2-1, so-called water crisis in Jordan. On the other hand, as for the southern governorate such as Madaba, Karak, Ma'an, Tafielah, and Aqaba where annual average rainfall is normally less than 50 mm, 1972/73 can be considered as the most droughty water year.

Table 2.1.1-6 (see Annex 2-1) summarized the long-term monthly average and annual evaporation by Class A pan. The annual evaporation potential varies from about 2,000 mm in the northern governorates as a minimum to more than 5,000 mm in the south governorate such as Ma'an (station ED0026). About 60% of the annual evaporation is recorded during dry season from May to September. These rates reach almost 80 times the average amounts of rainfall.

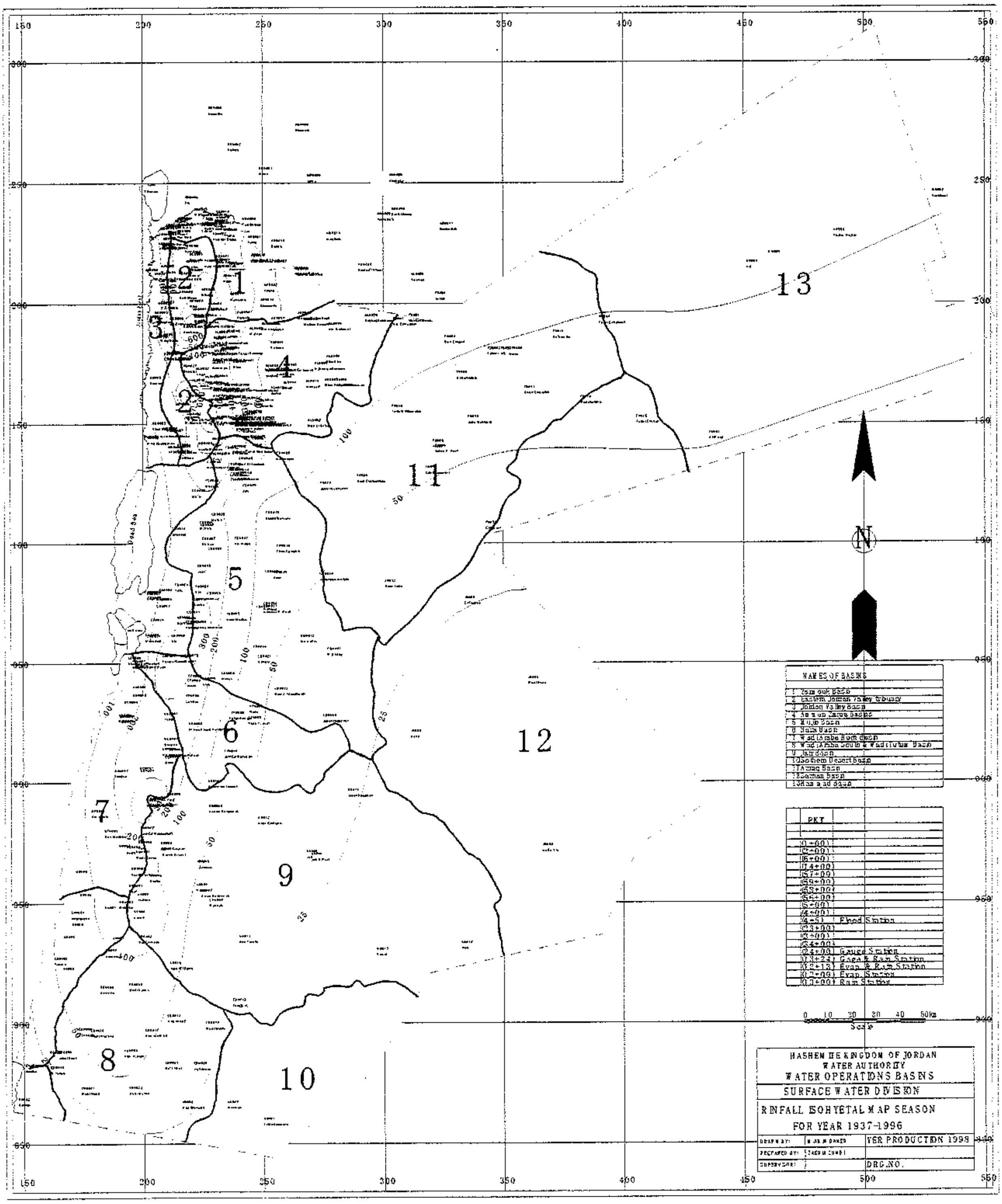


Fig.2.1.1-1 Isohyetal Map for Long-term Period (AD1937-1996)

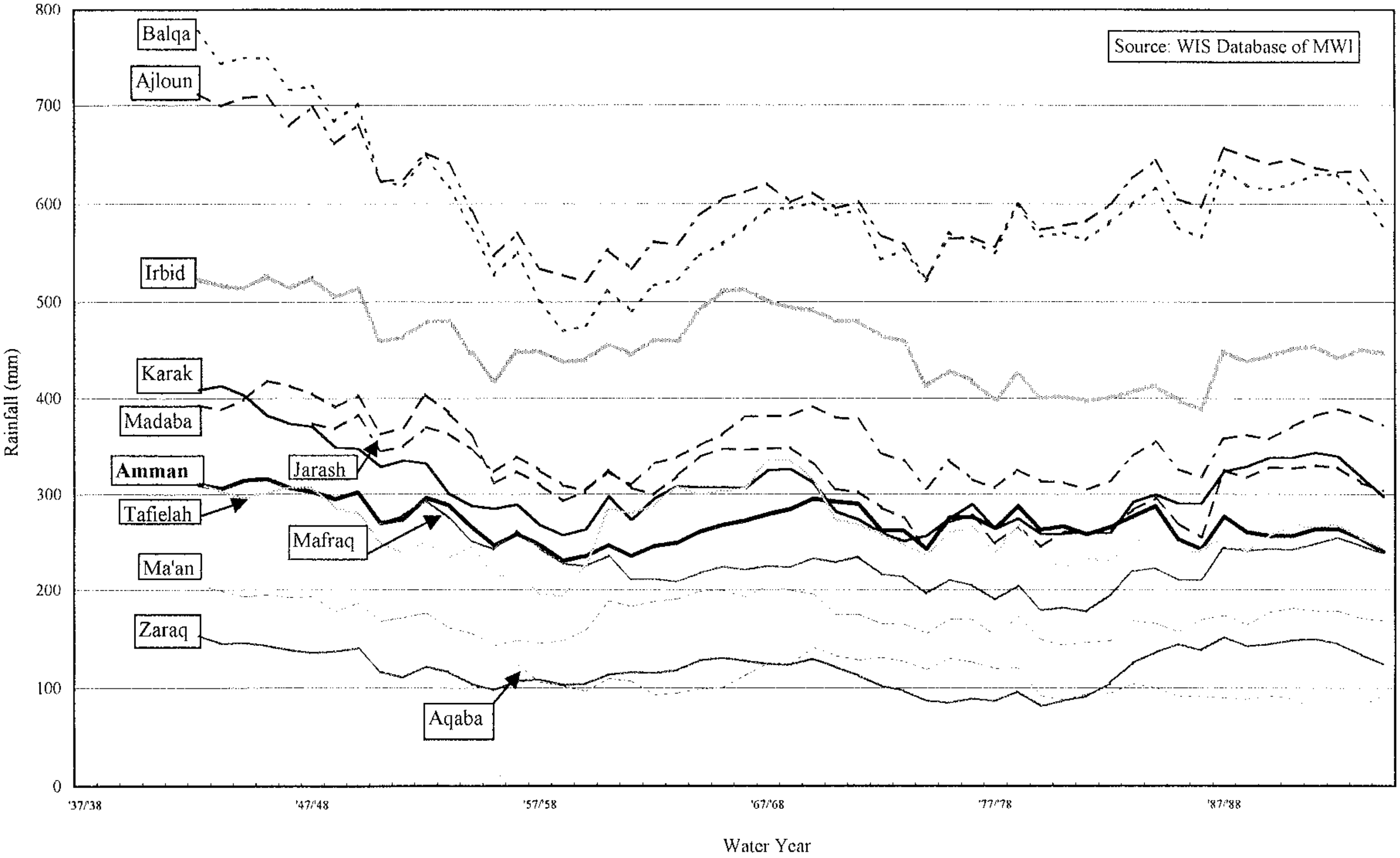


Fig. 2.1.1-2 10-Year Moving Average of Annual Rainfall at the Selected Rain Gauge Stations Representing the Governorates

2.1.1.3 Stream Flow

(1) Gauging Station

The surface water potential is regarded as most important resources in Jordan, therefore, hydrometry is vigorously carried out in comparison to that of the other countries. Table 2.1.1-7 (see Annex 2-1) shows the summary of river/wadis gauging stations including the closed ones.

In accordance with the main river/wadis basin, gauging stations play a role as the control point indispensable for the Study and were thus selected from the existing stations. With respect to data to be analyzed, Fig.2.1.1-17 (see Annex 2-1) roughly shows the available discharge records by bar graph. Some fragmentary records are too obvious, however, the limited records can be judged enough for the Study on Master Plan.

(2) Data Homogeneity

Using the double-mass curve method, the homogeneity of annual runoff for the above-mentioned main gauging stations was checked. Fig.2.1.1-18 (see Annex 2-1) only shows the representative ones. In general, runoff records show lower accuracy in comparison to that of annual rainfall mentioned before. However, most gauging stations show good accuracy such as Adasiya, Maqaren, Ziglab and etc. As for the other gauging stations, double mass curves accord nearly with the linear approximate. In conclusion, most gauging stations show desirable accuracy.

2.1.2 Surface Water Basins

The major topographic and geomorphologic features in Jordan control the drainage pattern. The general trend of this pattern is mainly in an east-west direction. The overall drainage system in Jordan consists of two main flow patterns. The first one drains rainfall towards the Jordan Rift Valley, through deeply incised wadis and rivers dissecting the Jordan Valley-Dead Sea escarpment, to ultimately discharge into the Dead Sea. The second one drains rainfall through those wadis that generally run eastwards from the western highlands towards the internal desert depressions and mudflats.

Based upon the prevailing topographic terrain, fifteen (15) catchment areas can be recognized in the country. Table 2.1.2-1 presents the major surface water basins and their main features in Jordan. In what follows is a brief note on the main catchment areas covering the Kingdom.

Table 2.1.2-1 Surface Water Resources in Jordan

No.	Surface Water Basin: Basin/Area			Surface Water Basin: Name		Symbol	Catchment Area (km^2)	Average Annual Rainfall (mm)	Estimated Runoff Coefficient (%)	Long-term (1937-1998) Rainfall Average (MCM/a)
1	Dead Sea Basin	Jordan River Subbasin	Northern Areas	Yarmouk		AD	1,426	308	5.1	439
2				Amman-Zarqa		AL	3,739	248	2.9	926
3				Jordan Valley		AB	780	298	1.9	233
4				Jordan Valley Side Wadis	North	AE, AF, AG AH, AJ,AK	946	618	2.9	584
5					South	AM, AN, AP	736	398	3.4	293
6		Dead Sea Subbasin	Central Areas	Mujib		CD	6,727	131	4.0	884
7				Hasa		CF	2,603	128	2.8	334
8				Dead Sea Side Wadis		C	1,508	192	2.5	290
9				North Wadi Araba		D	2,953	136	0.7	403
10	Eastern Desert Basin			Azraq		F	12,400	70	2.7	866
11				Hammad		H	18,047	114	0.7	2,050
12				Sirhan		J	15,733	28	1.9	445
13				Jafer		G	12,363	44	1.5	545
14	Southern Basins			Soth Wadi Araba		E	3,742	37	1.3	138
15				Southern Desert		K	6,296	16	1.0	102
Total							90,000			8,532

Note : Areas are within Jordan Territory Source : from WIS database

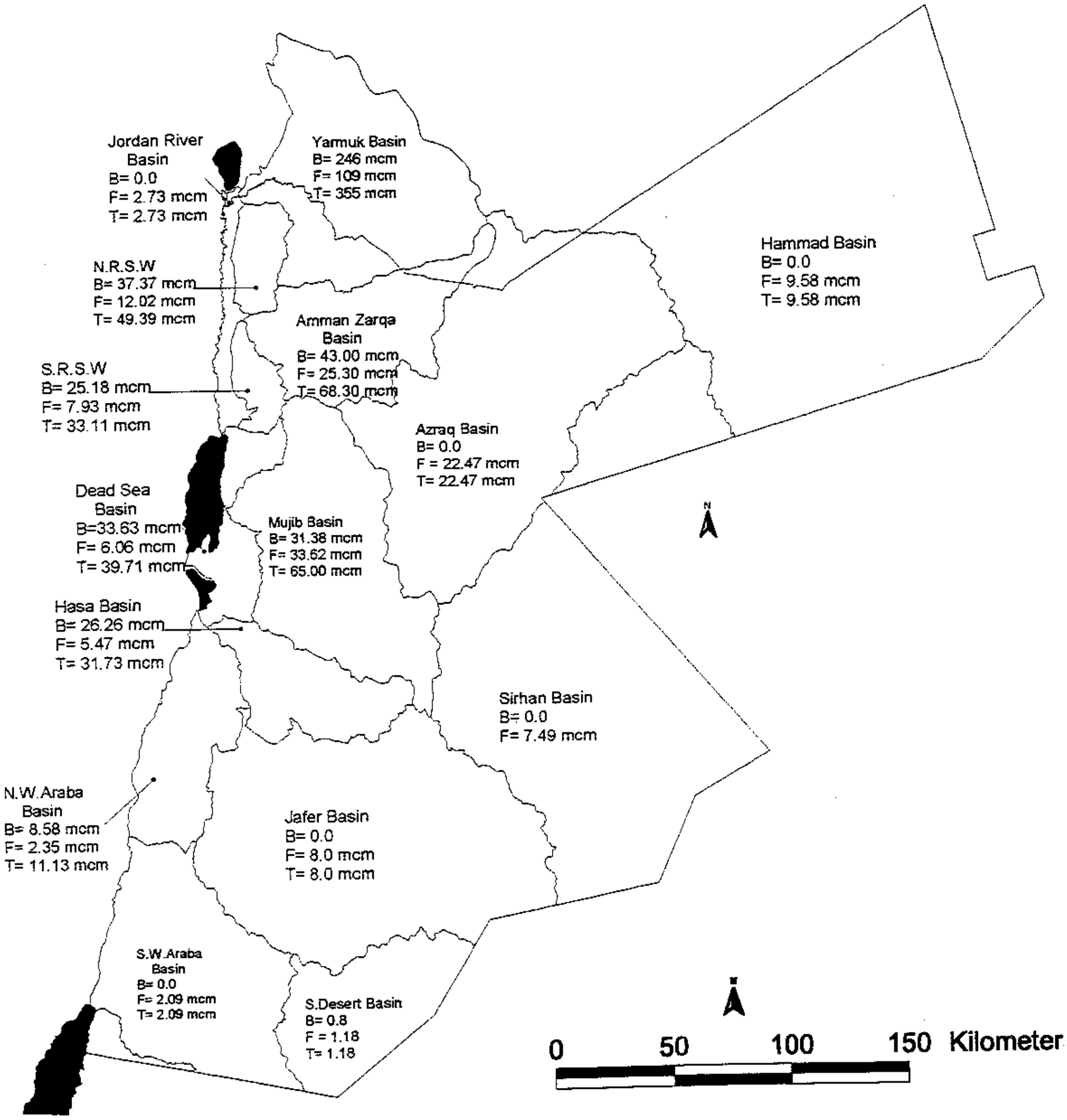


Fig. 2.1.2-1 Surface Water Basins

2.1.2.1 North Basins

The northern basins consist of the catchment areas of: River Yarmouk (Shared by Jordan and Syria), Amman-Zarqa basin which is almost totally within Jordan, eastern Jordan Valley floor, north Jordan Valley side wadis and south Jordan Valley side wadis.

(1) The Yarmouk River Basin

It has a total catchment area of about 7,250 km^2. Only 1,426 km^2 is in Jordan territory. The Yarmouk River is a component of the available surface water resources in Jordan. Most of its water in territory flow westwards to the Jordan River and then is discharged into the Dead Sea.

Over the total area of the Yarmouk basin, the mean annual rainfall volume was estimated at about 3,146 MCM. Only about 439 MCM falls over the catchment area within Jordan territory. The mean annual precipitation over the area ranges from over 500 mm (rainfall and snow) in the Jabel El Arab area and decreases towards east and south with a mean rainfall of over 100 mm. The overall annual average rainfall within Jordan is about 293 mm. The mean annual potential evaporation ranges from 1,240 - 1,490 mm in the Yarmouk basin and increases eastwards from Jabel El Arab area in Syria.

Most of the wadis in Yarmouk basin are ephemeral or intermittent and are subjected to flash flood. The main wadis draining the Yarmouk basin exist in the Syrian territory. They are mainly: Wadi Al Dahab, Wadi El Zeidi, Wadi Al-Raggad, Wadi Allan and Wadi Al-Harrer. Wadis Al-Shallalah and Wadi Al Mahasi drain the catchment area within Jordan territory.

Surface water resources of the Yarmouk basin contribute remarkably to the overall available water resources in Syria. Several dams have been constructed within the basin in both countries.

The Yarmouk River total flow is 355 MCM/a of which the base flow is 246 MCM/a and 109 MCM/a is the flood flow. King Abdulla Canal (KAC) is presently conveying the Yarmouk River water of 106MCM/a through Adasiya diversion and 20 MCM/a from the Lake Tiberius which is the return flow of the Yamouk river. The Yarmouk river water is used for irrigation purposes in Jordan Valley and for domestic supply to Greater Amman area.

Plans to develop the surface water resources within the basin are underway, particularly the construction of Wehda Dam on the River Yarmouk (see Table2.1.5-3).

After dam construction, an additional water flow from the Yarmouk River would be around 108 MCM/a. Routing for the additional water would be through Jordan valley via Deir Alla intake. Routing through the Northern Jordan, Irbid Governorate, is questionable at this stage. Pre-qualification for dam construction tender has been opened on 2 May 2000. Construction of the dam is expected to be completed by the beginning of AD 2004.

(2) Amman Zarqa Basin

Amman Zarqa Basin has a total catchment area of about 3,725 km^2. The drainage pattern is primarily towards west into the Jordan Valley area. The Zarqa River is the main drainage course and originates from the Amman area conveying the As-Samra Treatment Plant effluent via Wadi Dhleil where meets Zarqa River near Suknah Town and flowing into the King Talal Reservoir (KTR). It supports the irrigation water supplies in the Jordan Valley floor.

Amman has a temperate climate of warm dry summer with temperature ranges from about 38^{o}C to cool winters during which most of the annual rainfall 300 - 500 mm occur with occasional snowfall in some winters. The conditions in the Zarqa Valley are drier and slightly warmer in the lower reaches of the basin and lower rainfall average to about 150 mm/a. Over the basin, the annual average volume of rainfall based on long-term (AD1937-1998) average isohyetal map is estimated at 926 MCM and the mean annual rainfall is about 248 mm.

Average annual surface runoff in the Zarqa River as measured at New Jarash Bridge is around 68 MCM (43 and 25 MCM for base flow and flood flow respectively) for the period (AD1969-1999) records. In addition to the natural flows, the total flow of the Zarqa River into the KTR includes large volume of wastewater effluent from As-Samra Treatment Plant as well as some flows from Jarash, Abu Nseir and Baqa'a treatment plants.

(3) Jordan Valley and Side Wadis

Jordan River basin within Jordan may be divided into two main sub-basins: 1) The Jordan Valley floor and 2) the eastern escarpment. The Valley floor is situated in the area between Lake Tiberius on the north to the Dead Sea on the south. It stretches about 110 km long and about 10 km wide on average.

The rainfall over the Jordan Valley Basin is of orographic type and seasonal. The area receives most of Jordan's rainfall. The average annual rainfall over the basin ranges from about 100 mm, on the northern end of the Dead Sea to about 600 mm on the eastern highlands of the Jordan Valley. The overall annual average over the Jordan valley basin is estimated at 300 mm or 233 MCM/a.

Rainfall over the area occurs mostly during November through March. This period is characterized by the conditions which are relatively favorable for runoff of groundwater recharge. Also the highlands flanking the valley from east sides are deeply cut by side wadis outcropping the highly fractured karstic and fissured carbonate rocks of the Ajloun and Balqa groups. This will either sustain the surface runoff of the groundwater effluent or direct recharge from rainfall. Mean annual rainfall decreases from north to south from about 400 mm near Lake Tiberius to about 150 mm in the vicinity of the Dead Sea. It exceeds 500 mm on the elevated eastern escarpment between the Zarqa and the Yarmouk Rivers.

The average annual surface water runoff of the Jordan River measured at King Hussein Bridge is in the order of 1,000 MCM. It ranges from a low flood of 350 MCM in a droughty year to about 1,600 MCM during a rainy year (Hirzalla 1973 based on the work of the Natural Resources Authority, Mc Donald & Partners in AD 1965, and Energy Project in AD 1966 using the average rainfall during the period of AD 1931-1960). Most of the surface runoff originates from the Upper Jordan Valley sub drainage area which forms 16% of the total area of the valley basin, and the two major tributaries of the Jordan River: 1) the Yarmouk River and 2) the Zarqa River. No data is available regarding the Jordan River flow since 1967 due to the present political situation.

The rest of the Jordan River runoff is from the base flows of the perennial to intermittent side wadis that issue from the flanking highlands on both sides. These wadis are El Arab, Ziglab, Jurum, Yabis, Kufrinja, Rajib, Shu'eib, Kafrein and Hisban, from the eastern escarpment, also from the other wadis that issue from the western escarpment. Table 2.1.2-2 shows the flows of the main rivers and side wadis that contribute to Jordan River runoff. It also shows the catchment areas and the average rainfall over each area.

Stream flow records are available at the MWI files and WIS water database for different periods with variable reliability. These records showed that the stream flows are generally composed of two distinct components. The base flow that is almost steady before and after storm rainfalls. The other is the flood flow component, which is derived from these storms and flashy in character.

Table 2.1.2-2 River and Wadis in the Jordan Valley and Escarpment

River or Wadis	Gauging Station	Catchment Area (km^2)	Average Rain Fall ('37-'98)		Long-Term Average (MCM/a)		
			(mm/a)	(MCM/a)	Total Flow	Base Flow	Flood Flow
Yarmouk	Adasiya	6,974 (1,426)	393	2,738.0	355.00	246.00	109.00
Arab	North Shunah	246	531	130.6	5.70	1.70	4.00
Ziglab	Ziglab Dam (Upst.)	100	490	49.0	8.02	7.64	0.38
Jurum	Entrance (KAC)	23	391	9.0	8.82	8.53	0.29
Yabis	Entrance (KAC)	122	536	65.4	3.99	2.50	1.49
Kufrinja	Entrance (KAC)	103	594	61.2	7.99	6.91	1.08
Rajib	Entrance (KAC)	95	501	47.6	6.11	4.99	1.12
Zarqa	Deir Alla	4,154 (3,379)	236	980.0	68.30	43.00	25.30
Shueib	South Shuneh	193	398	76.8	9.88	7.92	1.96
Kafrein	Entrance (Ghor Kafrein)	159	475	75.6	15.20	12.40	2.80
Hisban	Entrance (Ghor Romeh)	88	273	24.0	4.69	3.46	1.23
Total		12,257			493.70	345.05	148.65

Note : Bracketed figures show the catchment area within Jordan territory Source : WIS database

In general, surface water resources are well developed in Jordan Valley and the eastern side wadis except of Wadi Mujib and Wadi Hasa. Each of the rivers and wadis in the basin serve irrigation and domestic demands within its specific basin area and to a certain extent, the urban centers in the highlands. In addition to the King Talal Dam which was constructed on the Zarqa River with storage capacity of 82MCM. Several reservoirs have been completed on the other wadis: such as El Arab, Ziglab, Shu'eib, Kafrein and Karameh with storage capacity of 20, 4.3, 1.4, 8.5 and 55 MCM respectively. Diversion weirs were installed on the following wadis: Wadi Jurum, Wadi Yabis, Wadi Kufrinja, Wadi Rajib and Wadi Hisban. Other newly reservoirs are planned to be constructed on the Wadis Yabis and Kufrinja to store surface runoff and any unused water in the King Abdulla Canal (KAC), which should be pumped to the proposed reservoirs.

The KAC is the main water conveyer for irrigation use in the Jordan Valley floor. At present, it conveys good quality water from the Yarmouk River, Mukheiba well field and Dajania diversion canal in the north at a rate of about 150 MCM/a (1998 estimate) for irrigation and industrial use in the Jordan Valley and for domestic waterworks via Deir Alla intake to the Zai Water Treatment Plant for the Greater Amman area.

2.1.2.2 Central Basins

The basins lie entirely within Jordan and consist of the catchment areas of several wadis that flow directly into the Dead Sea. The table below presents the main catchment areas composing the Dead Sea sub-basin with their average annual base and flood flows through these main wadis.

Table 2.1.2-3 Summary of Central Basins

Basin Name	Stream Flow (MCM/a)		Total (MCM/a)
	Base Flow	Flood Flow	
Wadi Mujib + Wala	31.38	33.62	65.00
Wadi Hasa	26.26	5.47	31.73
Wadi Zarqa Ma'in	17.24	2.95	20.19
Wadi Ibn Hammad	10.50	1.84	12.34
Wadi Karak	5.89	1.29	7.18
Total	91.27	45.17	136.44

Source: WIS database of MWI

(1) Basin of Wadi Mujib and Wadi Hasa

The wadis of Mujib and Hasa are the main catchment areas in the Dead Sea sub-basin. The Mujib Wadi system comprises the Wala, Swaqa, Heidan and Mujib proper. The total catchment area is about 6,700 km^2. On the other hand, Wadi Hasa catchment area is about 2,603 km^2 and lies at elevation, between 400 m at the basin outlet near Al Tannur up to 1,250 m in the eastern highlands.

Both drainage systems of Mujib and Hasa have almost perennial flow only in down stream reaches where ground surface elevation is less than 400 m. Sources of base flow are dependent on the continuous array of springs that are found within the Dead Sea escarpment and takes water partly from the Ajloun Series aquifer system and partly from the lower sandy aquifer systems (K and R/D).

In the Dead Sea sub-basin, the general trend of the drainage pattern is towards the Dead Sea. The upper reaches of the Wadi lying in the eastern desert area are flat, while they tend to be narrow and moderately incised in the western highlands flanking the Dead Sea.

In the basin most of the available water resources are under development and presently utilized for domestic water supply for Amman, Madaba, Ma'an, Karak, and Tafielah Governorates. Industrial water demand, primarily for the phosphate mines at Hasa and Abyad, are being met from the potential surface and groundwater resources in the Basin. In addition, private irrigation activities are also presently supplied from the available groundwater resources within the Basin.

(2) North Wadi Araba Basin

It forms the southern sub-basin of the Dead Sea. It extends from the southern end of the Dead Sea in the north to almost the middle region of Wadi Araba, where the surface water divide between the Dead Sea and the Red Sea basin occurs. The catchment area of this sub-basin is about 2,975 km^2 lies within Jordan territory. The average annual rainfall on this sub-basin in Jordan is about 135 mm. The long-term average rainfall volume is estimated at 403 MCM. The long-term annual average runoff volume is about 11.13 MCM/a (see Table 2.1.2-4).

The perennial surface water flow is very modest in the main wadis issuing from the eastern Wadi Araba escarpment, as indicated below.

Table 2.1.2-4 North Wadi Araba Catchments

Basin Name	Stream Flow (MCM/a)		Total (MCM/a)
	Base Flow	Flood Flow	
Restricted Area	0.80	0.52	1.32
Wadi Feifa	3.91	0.39	4.30
Wadi khueizira	1.43	0.57	2.00
Wadi Dahel	0.00	0.22	0.22
Wadi Feedan	1.64	0.18	1.82
Wadi Bweirdh	0.80	0.22	1.02
Wadi Musa	0.00	0.17	0.17
Wadi Huwwar	0.00	0.28	0.28
Total	8.58	2.55	11.13

Source: WIS database of MWI

The available surface water resources in this sub-basin are very well developed and mostly utilized in agriculture in south Ghor Safi area. Plans to construct dams on Wadi Feedan (6 MCM/a, from "Investment Program 2000 to 2010") is considered.

2.1.2.3 Eastern Desert Basins

(1) Azraq Basin

Its area within Jordan is around 12,400 km^2 (about 95% of the total basin area) with an average annual rainfall volume of 866 MCM. All non-perennial streams and wadis are draining the surface runoff from over the basaltic soil on the north and carbonate rocks on the south and east in the basin. The Azraq basin is a depression surrounded by hilly relief and encompasses the drainage areas of the wadis: Rajil, Useikhim, Mudeisisat, Unqiya, Jesha, Hassan, Er-ratam, Ghadaf and Al-botum. They are characterized by wide shallow washes with generally of low slopes. It is a closed basin where main wadis drains its water into the Azraq Playa where it may remain for one or two months before it evaporates. The long-term annual average runoff volume over the Azraq basin was estimated at 22.5, and 13.3 MCM drought years as shown in Table 2.1.3-2.

(2) Sirhan Basin

Sirhan Basin is a closed basin with drains converging into low-lying zone of salt flats, lakes and mud flats in Saudi Arabia along the southeastern Jordanian borders. Its area within Jordan is around 15,700 km^2. The drainage pattern within the basin is generally to the northeast and to the southwest in Saudi Arabia. Topographic elevations range from 800 - 900 m in the southwest falling to about 600 m along the Jordan/Saudi Arabian border. In the north Sirhan, elevations range from 600 - 800 m to 500 m in Saudi Arabia where the low-lying mud flats are found, 20 - 30 km apart from the Jordanian borders.

The basin encompasses seven (7) major catchment areas within Jordan. They are the wadis of Hadraj, Fakk, El-Garra, Bayir, Husseida and Qattafi. The wadis are of well-defined wide channels with fluvial sands and gravels and drain the limestone outcrops of B_4/B_5 (Rijam/Shallala) in the west, while the Basalts in the north is being drained by Wadi Qattafi into the Rijam (B_4) limestone cover in the southeastern part of the Basin.

Rain over the Basin falls between October and May with the heaviest monthly rainfall being between December to March. It ranges from less than 0.1 mm to an annual average of 28mm. The long-term annual volume of rainfall is estimated at 445 MCM and runoff coefficient of 1.9%. The long-term average annual runoff volume is estimated of about 7.49 MCM (see Table 2.1.3-1).

(3) Hammad Basin

The basin comprises the northeastern desert region of the Kingdom. Jordan, Syria, Iraq and Saudi Arabia share the basin area, about 18,150 km^2 area lies within Jordan. The western part of the Hammad basin is dominated by an elevated ground surface at the Tlul El Ashaqif where the basalt covers most of the basin area. Ground elevation ranges from 800 - 1,000 m and drains into low-lying mudflats in the center at about 700 m. The main wadis in the east Hammad drain the basalt cover into the extensive mudflats of Wadi Ruweishid in a well-defined channel over the hilly areas in the northeast and to a lesser extent in the southeast Hammed. The main wadis capturing the annual floods over the basin within Jordan are: Wadi Ruweishid, Wadi Abu Hifna, Wadi Ruweishin, Wadi Abu Al-Trafi and Wadi Rishaat/Umm Rijam. The estimated annual rainfall average is 112 mm and the estimated annual long-term average volume of rainfall is in the order of 2,050 MCM. Two existing small dams in the basin with total storage capacity of 2.8 MCM, namely, Al-Sha'lan and Ruweishid dams harvest water for livestock and grazing purposes.

(4) Jafer Basin

The Jafer basin is located in the southern part of the central Jordan upland areas to the east of the western Highlands. It has an area of about 12,400 km^2, most of which is classified as an arid desert. The average annual rainfall volume is about 545 MCM of which the estimated annual runoff volume is about 8.00 MCM. The mean annual rainfall over the basin ranges from about 300 mm in the western highlands to less than 50 mm in its eastern parts giving rise to annual average rainfall over the whole basin to about 43 mm.

The drainage pattern is almost radial from the encircling highlands towards the central Jafer Mudflat area. Ground elevation ranges from about 850 m in the Jafer Playa to about 1,750 m in the western highlands. The basin encompasses several catchment areas. These are: Wadi Jurdaneh, Wadi Wheida, Wadi Huseinan, Wadi Shidiya and Wadi el Ghubeya are the main ones in this area. An earth-type dam with storage capacity of about 2.3 MCM has been already constructed to harvest the annual runoff in Wadi Jurdaneh for watering of livestock in Ma'an Governorate.

2.1.2.4 Southern Basins

South Wadi Araba and the Southern Desert surface water basins are the main catchment areas composing this region.

(1) South Wadi Araba

The South Wadi Arab sub-basin extends from the middle region of Wadi Araba in the north to the Gulf of Aqaba in the south. Its area within Jordan is about 3,725 km^2. It is extremely arid with an annual average rainfall of about 37 mm and average rainfall volume of 138 MCM/a resulting in an estimated runoff volume of about 2.09 MCM/a. Wadi El Yutum is the main drainage course towards Aqaba in this basin.

Other wadis in the basin drain also the western catchments from south Israel into Wadi Araba in addition to the wadis that issue from the Wadi Araba eastern escarpment. The final destination of surface water runoff from the western and eastern wadis, including Wadi Araba itself, is towards the Dead Sea.

(2) Southern Desert

Southern desert (Disi-Mudawara) area is also extremely arid. Its area is about 6,300 km^2. Average annual rainfall volume is about 234.5 MCM and runoff volume is estimated at 1.18 MCM/a.

The drainage pattern of the south desert catchment areas is radially towards the mudflats that occur in Jordan or cross the Jordanian - Saudi Arabian borders. Surface water resources in the southern basins are almost non-existent. It occurs only in the form of flash floods during the rainy season.

2.1.3 Surface Water Potential

Table 2.1.3-1(1) shows the long-term average annual surface water flow volumes measured at the main gauging stations on the various rivers and wadis in the kingdom. Table 2.1.3-1(2) shows the flow volume allocated to each governorate.

2.1.3.1 Base Flow

Surface water resources in Jordan consist of two main categories. The first of which is the base flow originating from the discharge of ground water through springs, and was considered in the previous section as an integral part of the groundwater resources. These waters constitute the base flow in valleys and ever-flowing rivers. This type of surface water depends: for its quantity, quality, continuity and fluctuations of its discharge rates, on the characteristics of the aquifer systems recharging it. Thus the quantity and quality of the base flows are directly affected by any variations in the groundwater systems recharging it, which may come as a result of human activities to develop these systems. Due to the relatively extended reliability of base flow and modes of investments required to develop it for domestic, agricultural, and industrial purposes, this water type is almost totally utilized in Jordan, with established water rights since a long time ago.

As a result of projects and activities carried out to develop groundwater resources in addition to excessive pumping of such water, the discharge rate and water quality of the base flow suffered a setback. It is expected that such a setback will only deteriorate with the increase in the water quantities being pumped from water wells.

In some cases, when favorable hydrological conditions prevail (i.e. when the spring discharge widely fluctuates seasonally and during dry seasons), practices were deliberately exercised to trap such springs flow replacing them by wells in order to get a relatively uniform groundwater production rate. Such measures were practiced to increase the groundwater reservoir recharge rate in wet seasons. The annual average base flow for all wadis and floodwater in Jordan is about 451 MCM/a, of which 246 MCM/a as base flow measured at Adasiya gauging station, comes from the Yarmouk River.

2.1.3.2 Flood Flow

Floodwater resulting from rainfall in winter is the second category of surface water. The relatively scarce, uneven and fluctuating features of rainfall in Jordan are reflected in the resulting floodwater. This calls for special projects to store and manage these quantities of water until the time of need.

The total annual quantity of floodwater in all valleys in Jordan, amounts to about 256 MCM/a. About 109 MCM/a come from the Yarmouk River and originates mostly in Syria.

Table 2.1.3-1(1)Long-term* Surface Water Potential by Basin

Basin			Catchment Area (km2)	Average Rainfall (MCM/a)	Base*** Flow (MCM/a)	Flood Flow (MCM/a)	Total Flow (MCM/a)
No.	Name	ID No.					
1	Yarmouk	AD	6,974	2,738.0	246.00	109.00	355.00
	A) Jordan Part B) Syrian Part		1,426 5,548	43.9 2,299			
2	Jordan River (near Ghor)	AB1	780	233.0	0	2.73	2.73
3	N.R.S.Wadis (North Zarqa R.)	A1	946	584.0	37.37	12.02	49.39
A	Restricted Area	AB2	257	110.0	5.10	3.65	8.75
B	Wadi Arab**	AE	246	154.0	1.70	4.00	5.70
C	Wadi Ziglab	AF	100	70.0	7.64	0.38	8.02
D	Wadi Jurum	AG	23	15.0	8.53	0.29	8.82
E	Wadi Yabis	AH	122	85.0	2.50	1.49	3.99
F	Wadi Kufrinja	AJ	103	80.0	6.91	1.08	7.99
G	Wadi Rajib	AK	95	70.0	4.99	1.12	6.11
4	N.R.S. Wadis (South Zarqa R.)	A2	736	293.0	25.18	7.93	33.11
A	Restricted Area	AB3	296	80.0	1.40	1.93	3.33
B	Wadi Shueib	AM	193	90.0	7.92	1.96	9.88
C	Wadi Kafrein	AN	159	88.0	12.40	2.80	15.20
D	Wadi Hisban	AP	88	35.0	3.46	1.23	4.69
5	Amman/Zarqa (W. Zarqa)	AL	4,154	926.0	43.00	25.30	68.30
	A) Jordan Part B) Syrian Part		3,739 415				
6	Dead Sea (Southern Wadis)	C	1,508	290.0	33.63	6.08	39.71
A	Restricted Area (Ibn Hammad, others)		1,040	180.0	10.50	1.84	12.34
B	Zarqa Ma'in	CC	269	67.0	17.24	2.95	20.19
C	Wadi Karak	CE	199	43.0	5.89	1.29	7.18
7	Mujib (& Wala)	CD	6,727	884.0	31.38	33.62	65.00
8	Hasa	CF	2,603	334.0	26.26	5.47	31.73
9	North Wadi Araba	D	2,953	403.0	8.58	2.55	11.13
A	Restricted Area	DA	1,257	72.0	0.80	0.52	1.32
B	Wadi Feifa	DB	162	30.0	3.91	0.39	4.30
C	Wadi Kuneizerh	DC	217	38.0	1.43	0.57	2.00
D	Wadi Dahel	DD	107	20.0	0	0.22	0.22
E	Wadi Fidan	DE	287	51.0	1.64	0.18	1.82
F	Wadi Bweirdh	DF	513	125.0	0.80	0.22	1.02
G	Wadi Musa	DG	165	30.0	0	0.17	0.17
H	Wadi Hawwar	DH	245	37.0	0	0.28	0.28
10	South Wadi Araba	E	3,742	138.0	0	2.09	2.09
A	Restricted Area	EA	1,068	35.0	0	0.77	0.77
B	Wadi Abu Barqa	EB	141	12.0	0	0.46	0.46
C	Wadi Rukaya	EC	210	18.0	0	0.34	0.34
D	Wadi Yutum	ED	2,323	73.0	0	0.53	0.53
11	South Desert (& Qa'a Disi)	K & EDI	6.296	103.0	0	1.18	1.18
12	Azraq	F	13,173	866.0	0	22.47	22.47
	A) Jordan Part B) Syrian Part		12,400 773				
13	Sirhan	J	15,733	445.0	0	7.49	7.49
14	Hamad	H	18,047	2,050.0	0	9.58	9.58
15	Jafer	G	12,363	545.0	0	8.00	8.00
Total Jordan Part			**90,000**	**8,533.0**	**451.40**	**255.51**	**706.91**
Total Basin Area			**96,735**				

Source : from WIS database , * : Long-term means up-to 1998/1999,
** : Period of Wadi Arab is from 1985 till 1996, ***: Base flow includes wastewater

Table 2.1.3-1(2)Long-term* Surface Water Flow by Governorate

Governorate	River or Wadis	Base Flow (MCM/a)	Flood Flow (MCM/a)	Total Flow (MCM/a)
Amman	*	0.00	0.00	0.00
Zarqa	Wadi Butum	0.00	0.92	0.92
Mafraq	Wadi Ruweished	0.00	8.45	8.45
	Azarqa	0.00	22.47	22.47
	Total	0.00	30.92	30.92
Irbid	Yarmouk River	246.00	109.00	353.00
	Wadi El Arab	1.70	4.00	5.70
	Wadi Ziglab	7.64	0.38	8.02
	Wadi Yabis	2.50	1.49	3.99
	Wadi Kufrinja	6.91	1.08	7.99
	Wadi Jurum	8.53	0.29	8.82
	Restricted Area	5.10	3.65	8.75
	Jordan River	0.00	2.73	2.73
	Total	278.38	122.62	401.00
Ajloun	Wadi Rajib	4.99	1.12	6.11
Jerash	Wadi Zarqa	43.00	25.30	68.30
Balqa	Wadi Kafrein	12.40	2.80	15.20
	Wadi Shueib	7.92	1.96	9.88
	Wadi Hisban	3.46	1.23	4.69
	Restricted Area	1.40	1.93	3.33
	Total	25.18	7.92	33.10
Madaba	Wadi Mujib + Wadi Wala	31.38	33.62	65.00
Karak	Wadi Karak	5.89	1.29	7.18
	Wadi Ibn Hammad & Others	10.50	1.84	12.34
	Wadi Hasa	26.26	5.47	31.73
	Wadi Khuneizerh	1.43	0.57	2.00
	Wadi Zarqa Ma'in	17.24	2.95	20.19
	Total	61.32	12.12	73.44
Ma'an	Wadi Jurdah	0.00	0.22	0.22
	Wadi Fidan	1.64	0.18	1.82
	Qa'a Disi + South Desert	0.00	1.18	1.18
	Jafer	0.00	8.00	8.00
	Sirhan	0.00	7.49	7.49
	Total	1.64	17.07	18.71
Tafielah	Wadi Dahel	0.00	0.22	0.22
	Wadi Feifa	3.91	0.39	4.31
	Wadi Musa	0.00	0.17	0.17
	Wadi Buweirdh	0.80	0.22	1.02
	Wadi Hawwar	0.00	0.28	0.28
	Restricted Area	0.80	0.52	1.32
	Total	5.51	1.80	7.31
Aqaba	Wadi Yutum	0.00	0.53	0.53
	Wadi Abu Barqa	0.00	0.46	0.46
	Wadi Rukaya	0.00	0.34	0.34
	Restricted Area	0.00	0.77	0.77
	Total	0.00	2.10	2.10
Grand Total		**451.40**	**255.51**	**706.91**

* : not enough data for estimation — Source : WIS database

2.1.3.3 Surface Water Potential in Drought Year

With respect to drought year, two cases were applied to the Study;

1) drought occurs in the northern half area of Jordan (including central area)
2) drought occurs in the southern half area of Jordan

Next table summarized the estimated drought year surface water potential.

Table 2.1.3-2 Drought Year Surface Water Potential

Basin			Catchment Area (km2)	Estimated Run off (MCM/a)	
No.	**Name**	**ID No.**		**Drought in the Northern Area**	**Drought in the Southern Area**
1	Yarmouk	AD	6,974	**225.30***	**355.00**
2	Jordan River (near Ghor)	AB1	780	**1.73**	**2.73**
3	N.R.S.Wadis (North Zarqa R.)	A1	946	**16.13**	**49.39**
A	Restricted Area	AB2	257	2.29	8.75
B	Wadi Arab	AE	246	1.94	5.70
C	Wadi Ziglab	AF	100	3.89**	8.02
D	Wadi Jurum	AG	23	4.28	8.82
E	Wadi Yabis	AH	122	0.34**	3.99
F	Wadi Kufrinja	AJ	103	1.99**	7.99
G	Wadi Rajib	AK	95	1.40**	6.11
4	N.R.S. Wadis (South Zarqa R.)	A2	736	**5.73****	**33.11**
A	Restricted Area	AB3	296	0.54	3.33
B	Wadi Shueib	AM	193	1.59	9.88
C	Wadi Kafrein	AN	159	3.04**	15.20
D	Wadi Hiaban	AP	88	0.57**	4.69
5	Amman/Zarqa	AL	4,154	**68.30**	**68.30**
6	Dead Sea (Southern Wadis)	C	1,508	**39.71**	**39.71**
A	Restricted Area		1,040	12.34	12.34
B	Zarqa Ma'in	CC	269	20.19	20.19
C	Wadi Karak	CE	199	7.18	7.18
7	Mujib (& Wala)	CD	6,727	**65.00**	**29.97**
8	Hasa	CF	2,603	**31.73**	**14.63****
9	North Wadi Araba**	D		**11.13**	**4.63**
A	Restricted Area	DA	1,257	1.32	0.78
B	Wadi Feifa	DB	162	4.30	2.54**
C	Wadi Kuneizerh	DC	217	2.00	1.18
D	Wadi Dahel	DD	107	0.22	0.13
E	Wadi Fidan	DE	287	1.82	1.08
F	Wadi Bweirdh	DF	513	1.02	0.60
G	Wadi Musa	DG	165	0.17	0.10
H	Wadi Hawwar	DH	245	0.28	0.17
10	South Wadi Araba**	E	3,742	**2.09**	**1.23**
A	Restricted Area	EA	1,068	0.77	0.45
B	Wadi Abu Barqa	EB	141	0.46	0.27
C	Wadi Rukaya	EC	210	0.34	0.20
D	Wadi Yutum	ED	2,323	0.53	0.31
11	South Desert (& Qa'a Disi)	K & EDI	6.296	**1.18**	**0.70**
12	Azraq	F	13,173	**22.47**	**13.27**
13	Sirhan	J	15,733	**7.49**	**4.42**
14	Hamad	H	18,047	**9.58**	**5.66**
15	Jafer	G	12,363	**8.00**	**4.73**
Total Jordan Part			**90,000**	**515.58**	**594.16**
Total Basin Area			**96,735**		

* : use the average figures of last 10 years, ** : by 20-year return period, Source : from WIS database

2.1.3.4 Reservoirs

Twenty-two dams were constructed on wadis and valleys with a storage capacity of about 190 MCM to harvest floodwater. Table 2.1.3-3 and Table 2.1.3-4 present the existing dams and their briefs in Jordan. Fig.2.1.5-1 shows location of the main dams.

Table 2.1.3-3 Existing Dams in the Upland Area

Gover-norate	No.	Name of Dam	Comp-letion Year	Dam Type	Dam Height (m)	Catchment Area (km^2)	Live Storage (MCM)	Purposes
Amman	1	Siwaqa	1993	Earth	19	450	2.5	Artificial recharge & Livestock watering
Zarqa	2	Al-Lihfi	1967	Earth	8	-	2.3	same as above
	3	Rajil	1992	Earth	9	3,243	3.5	same as above
	4	Abu Swanih	1962	Earth	4	-	0.25	same as above
Mafraq	5	Sama Al-Sirhan	1966	Concrete-faced Earth	8	150	1.2	same as above
	6	Borqu'o	Archeo-logical	Earth	6	-	1.5	same as above
	7	Ghadeer Abyad	1966	Concrete	11	153	0.4	Artificial recharge & Livestock watering
	8	Dair Al-Kahf	1950	Rock-fill	5	-	0.05	same as above
	9	Al-Sh'alan	1970	Earth	3	-	1	Irrigation
	10	N. Ruweished	1993	Earth	7	4,750	10.7	Multi-purpose
	11	Khaldeyeh	1983	Earth	15	400	1.1	-
	12	Al-Ithni	1995	Earth	3	-	0.65	-
Irbid	13	Al-Buweida	1967	Concrete	9.5	-	0.015	Artificial recharge & Livestock watering
Karak	14	Al-Qatrana	1962	Earth	12	1,490	0 (Full of sediments)	same as above
	15	Al-Sultani	1962	Earth	8	950	0.5	same as above
Ma'an	16	Jurdeneh	1997	Earth	15	171	2.3	-
Total Storage Capacity							29.77	

Note : "-" means data not available Source : from MWI

Table 2.1.3-4 Existing Dams in the Jordan Valley

Gover-norate	No.	Name of Dam	Comp-letion Year	Dam Type	Dam Height (m)	Catchment Area (km^2)	Live Storage (MCM)	Purposes	Water Resource
Irbid	1	Wadi El-Arab	1986	Earth	83.5	262	16.9	Irrigate 12,500 dunum in north J.V. , domestic and power generation	From KAC in winter and the flood of Wadi El-Arab
	2	Wadi Ziglab	1967	Earth	48	106	3.9	Irrigate 12,500 dunum in north J.V.	From the flood of Wadi Ziglab
Jerash	3	King Talal	1998	Earth	108	3,700	75	Irrigate 82,000 dunum in north J.V., domestic and power generation	Zarqa R. + As-Samura TP wastewater
Balqa	4	Kafrein	1996	Earth	37	163	8.5	Irrigate1,274 dunum in upstream of KAC	Base flow of Wadi Kafrein and flood
	5	Wadi Shueib	1969	Earth	32	178	2.1	Irrigate 2,500 dunum in G. Nimren and recharge	From W. Shueib base flow and flood
	6	Al karameh	1997	Earth	44.5	61.2	55	Irrigate 40,000 dunum in the southern J.V.	Surplus water from KAC in winter
Total Storage Capacity							160.7		

Source : from MWI

King Talal Dam (KTD) is considered the most important of the already constructed dams. KTD impounds the Zarqa River, surface runoff and flows. It was constructed as early as the 1970's and has been raised to its current height of 108 m in 1986. The dam storage is subject to the annual sediment loads in the stream flow. The estimated live storage of the KTD in 1994 was about 75 MCM. The storage volume fluctuates according to the irrigation demand and annual volume of surface runoff.

Surface water impounding activities are underway in the Central Basins. Mujib Dam (35 MCM), Tannur Dam (16.8 MCM) and Wala Dam (9.3 MCM) are presently under construction. According to the JVA's engineer, nine (9) dams excepting Wehda Dam are ready for construction (Feedan, Qa', Wheidi, Karak, Meddien, Ibn Hammad, Wadi Musa, Abu Borqa and Rahma) with about 24 MCM storage capacity in total.

The aim of Karameh Dam is to sore the extra amount of flood water taken from KAC and to be use to irrigate the 14.5 km extension of KAC which has an area of 6,000 ha in winter season. It is inferred that the flood flow will reduce After the completion of the Wehda Dam because Wehda Dam will catch the flood flow in the Yarmouk River. However, large catchment area will still remain in the downstream of the Wehda Dam and much flood flow will be borne from this area. The area of the remaining catchment is about 365 km^2. The amount of the flood flow from the remaining catchment area is calculated as follows:

Table 2.1.3-5 Flood Flow Amount from the Remaining Catchment Area after the Completion of the Wehda Dam

	Rainfall Volume (MCM/a)	Runoff Coef. (%)	Runoff (MCM/a)
Dry Year	56.25	4	2.25
Normal Year	87.50	10	8.75
Wet Year	90.28	18	16.25

As shown above, it is concluded that the Karameh Dam will satisfactory function even after the completion of the Wehda Dam.

2.1.4 Present Development of Surface Water

Surface water includes river/wadi run-off, spring water and peace water and excludes wastewater in this chapter. Surface water development including peace water and excluding wastewaterin1998 is summarized in the table of present use of surface water attached in Annex Report 2-1. As Shown in this Table, total use amount of the surface water is around 334MCM in 1998 and use for irrigation occupied about 83% of total development of surface water based on WIS. Water from Yarmouk river to KAC (King Abdulla Canal) through Adasiya diversion weir is approximately 106MCM in 1998 and it occupied 32% of total surface water development in 1998. Surface water use in 1998 is summarized by purpose and by governorate in next figures.

Note :
-including peace water
-excluding wastewater

Fig. 2.1.4-1 Surface Water Development in 1998 (From WIS)

(1) Surface Water Development by Purpose

As shown above, surface water of 277 MCM was developed for irrigation and it occupied more than 80% of total surface water development amount as mentioned before. Among them, around 196MCM was used in the Jordan Rift Valley (JRV) and around 81MCM was used for irrigation in the Upland in 1998. Water use for irrigation in the Southern Ghor, which is the southern part of JRV, was estimated by around 38MCM in 1998.

Surface water for municipal use of 56 MCM included part of the Peace Water delivered from outside of Jordan. The total peace water amounted to 31MCM including irrigation use and around 10 MCM was allocated for municipal use in 1998. Water for municipal use of 36MCM, which included Peace Water of 10MCM, was conveyed from Jordan Valley to Zai treatment plant in the Upland through Dier Alla pumping station and served to Amman-Zarqa area in 1998. Part of the spring water was also used for the municipal use and it amounted to about 20MCM in 1998.

(2) Surface Water Development by Governorate

As shown in the above figure, surface water consumption was largest in Irbid and Balqa

Governorates in 1998. The water use in both governarates amounted to 178MCM which occupied 53% of total surface water use because of the high consumption of water for the irrigation in the Jordan Valley.

It is considered that the developed surface water including spring water is locally consumed in the same governorate because the greater part of the surface water is used for irrigation. However, the condition is different in Irbid and Balqa Governorates because 36MCM/a was conveyed from Irbid Gov. to Balqa and Amman Govs. through Zai treatment plant for municipal purpose in 1998. It included a part of groundwater from the Mukheiba well field. According to the records of Zai treatment plant in 1998, treated surface water supplied to Balqa Gov. was about 5MCM and to Amman Gov. was about 31MCMexcluding the losses during the treatment.

About 60MCM including groundwater from Mukheiba well field was also released to flow to Balqa Gov. from Irbid Gov. through KAC in 1998. Water balance in KAC including groundwater from Mukheiba and wastewater from As-samura in 1998 is schematically shown in Fig.2.1.4-2 based on the information from JVA. From this figure, it is inferred that approximately 220MCM which included groundwater and wastewater was used and stored for irrigation purpose in the Jordan Valley and along the Zarqa river in 1998.

Note : including Wastewater, Peace Water
and Groundwater from Mykheiba

Fig.2.1.4-2 Water Balance of KAC in 1998 (from JVA data)

2.1.5 Existing Development Scheme

Table 2.1.5-1 shows the existing development scheme for the surface water. The total incremental yield of the surface water can be expected about 143 MCM/a including long term water harvesting projects. Moreover, most projects will be completed before AD 2005. As the development amount of surface water is around 303MCM in 1998, it is expected that the total development amount will reach to 446MCM/a after the completion of the all projects listed below.

Table 2.1.5-1 Planned Surface Water Development Projects

File No.	Project Name	Expected Completion Year	Expected Incremental Yield (MCM/a)	Remarks
15	Tanur Dam	2001	8	completed
14	Wala Dam	2002	5	on-going
13	Mujib Dam* (including base flow development)	2003	12	on-going
26	Feedan Dam	2004	3	
62	Al Wehda Dam	2005	93	
18	Small Dams (Ibn Hamad, Karak, Meddien)	2008	7	
19	Water Harvesting, Badia Region	2010-2020	15	
Total Additional Water			143	

Source : Investment Program 2000 to 2010, *: The total development amount of Mujib Dam and Mujib base flow development is 42 MCM/a. 30MCM/a of 42MCM/a will be mixed with saline water from W. Zarqa Ma'in and Zara Spring and will be desalinated at Suweima. Therefore, 30MCM/a from Waji Mujib is categorized in desalinated water described in section 2.2.4.

An agreement was concluded lately with the Syrian Arab Republic to construct the Wehda Dam at Al-Maqaren site on the Yarmouk River. This dam is the most important of dams to be built, with a storage capacity of up to 225 MCM. The dam water will be used in the long term to satisfy water demands for domestic, industrial and irrigation.

There are two plans to activate the floodwater storage which were cancelled in the Investment Program 2000 to 2010 as shown in the above table. One of them is "Storage in Jordan River and Side Wadis" which is composed of construction of storage system on the Jordan River and side wadis, construction of conveyer system and increasing the efficiency of King Abdullah Canal. Though this project is not categorized in "Surface Water" but in "Peace Water" in this report, it is not listed in above table. The study for this project is being done by EC but it has been delayed so far. However, this project should be implemented as a long-term project in order to satisfy the future water demand.

Another project is "Water Harvesting, Badia Region" which aims to identify practical techniques for artificial recharge impounding of the flood flow at the dykes in the Badia (desert) region. This project is also necessary for the development of the remained surface water potential and it should be implemented as a long-term project too.

Table 2.1.5-2 and Table 2.1.5-3 present the dams under construction and planned dams and their briefs in Jordan. The location of the damsites is shown in Fig. 2.1.5-1. The estimated storage capacity of the dams, which are presently under construction, is about 61 MCM in total. Plans to construct more dams, of which the total storage capacity is about 249 MCM, are waiting to be implemented.

Table 2.1.5-2 Dams Under Construction

No.	Project Name and Expected Compl. Year	Prime Purposes	Type	Water Resource	Dam Height (m)	Storage Capacity (MCM)
1	Wala Dam (Feb., 2002)	-3MCM/a for irrigation -Groundwater recharge -Flood control & water quality conservation	R.C.C. & Earth fill	Floods	45.0	9.3
2	Mujib Dam (July, 2003)	-8MCM/a for industrial, irrigation in S. Ghor -Flood control & water quality conservation	R.C.C. & Earth fill	Floods	62.0	35.0
3	Al Tanur Dam on Wadi Hasa (July, 2001)	-for irrigation in S, Ghor	R.C.C.	Floods	60.0	16.8
Total Storage Capacity						61.1

Source : from MWI and JVA

Table 2.1.5-3 Dams to be Constructed

No.	Project Name and Expected Compl. Year	Prime Purposes	Type	Water Resource	Dam Height (m)	Storage Capacity (MCM)
1	Al Wehda Dam	-for irrigation of 33,500 Dunum in Jordan Valley -50MCM for Amman Zarqa area -for irrigation of 5,000 Dunum in the Upland -Generation of electricity	Concrete & Rock-fill	Floods of Yarmouk River	100	225
2	Al Qa'a Dam (Not included in the Investment Program)	-Irrigation and livestock watering	Earth	Floods	9	0.53
3	Al Wheidi Dam (Not included in the Investment Program)	-Irrigation and livestock watering	Earth	Floods	18	1.77
4	Al Feedan Dam	-Irrigation -Groundwater recharge	Earth	Baseflow & Floods	37	10.0
5	Karak Dam (Small Dam Project)	-Irrigation -Groundwater recharge	R.C.C. + Earth	Baseflow & Floods	33	2.1
6	Al Meddien Dam (Small Dam Project)	-Irrigation -Groundwater recharge	Earth	Floods	25	1.5
7	Ibn Hamad Dam (Small Dam Project)	-Irrigation -Groundwater recharge	Earth	Baseflow & Floods	48.5	5.0
8	Wadi Musa (including G.W. development)	-Touristic demand for Petra	Earth	Floods	25	2.0
9	Abu Borqa	-Irrigation -Groundwater recharge	Earth	Floods	15	0.15
10	Rahma	-Irrigation -Groundwater recharge	Concrete-faced Earth	Floods	17.5	0.65
Total Storage Capacity						248.70

Source : from MWI and JVA

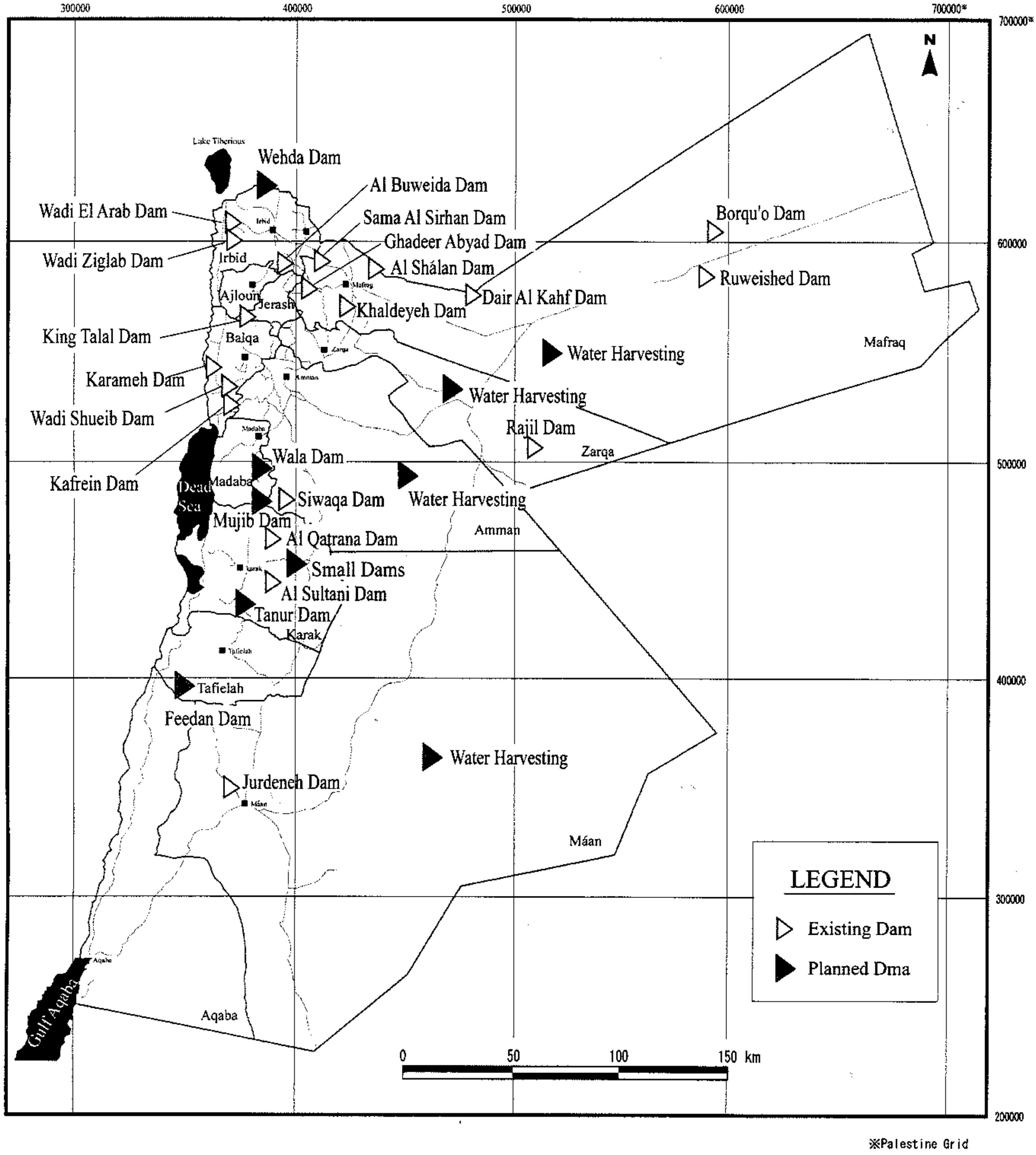
Surface water flow amount in Jordan is estimated at around 707MCM/a as shown in Table 2.1.3-1. Total development amount of surface water including long term projects is around 446MCM/a as shown in Table 2.1.5-4. However, the total development amount shown in table 2.1.5-4 dose not include the Wadi Mujib surface water of 30 MCM/a which will be mixed with brackish water from Wadi Zarqa Ma'in and Zara Spring and will be desalinated at Sweima. This amount is counted for the brackish groundwater development described in section 5.3. The total development amount of the surface water will become 476MCM/a by adding the Wadi Mujib surface water of 30 MCM/a to be desalinated and it will occupy at 68% of total flow. It is assumed that it is almost the maximum limit for safe development of the surface water resources because of the climatic, economical and geographic constraints. Therefore, the further large scaled development of surface water may not be possible and this is the optimum development amount of the surface water in terms of "Sustainable Water Resources Development".

As shown in Table 2.1.5-4, surface water potential will concentrate in Irbid Governorate and it will occupy about 54% of the total potential. The surface water potential will amount to about 162MCM/a and about 284MCM/a in Upland and JRV respectively.

Table 2.1.5-4 Summary of Developable Surface Water Potential by Governorates

Governorate	Present Develop. Amount (1998) (MCM/a)	Future Incremental Yield (MCM/a)	Total Developable Amount (MCM/a)	Planned Future Projects
Amman	7 (UP:7, JRV:0)	3 (UP:3, JRV:0)	10 (UP:10, JRV:0)	after 2010, Water Harvesting in Badia Region (UP), 3MCM/a
Zarqa	16 (UP:16, JRV:0)	2 (UP:2, JRV:0)	18 (UP:18, JRV:0)	-after 2010, Water Harvesting in Badia Region (UP), 2MCM/a
Mafraq	2 (UP:2, JRV:0)	7 (UP:7, JRV:0)	9 (UP:9, JRV:0)	-after 2010, Water Harvesting in Badia Region (UP), 7MCM/a
Irbid	150 (UP:40, JRV:110)	93 (UP:0, JRV:93)	243 (UP:40, JRV:203)	-2005, Wehda Dam (JRV), 93MCM/a
Ajloun	11 (UP:9, JRV:2)	0	11 (UP:9, JRV:2)	
Jerash	20 (UP:12, JRV:8)	0	20 (UP:12, JRV:8)	
Balqa	27 (UP:7, JRV:20)	0	27 (UP:7, JRV:20)	
Madaba	5 (UP:5, JRV:0)	5 (UP:0, JRV:5)	10 (UP:5 JRV:5	-2001, Wala Dam (JRV), 5MCM/a
Karak	54 (UP:18, JRV:36)	27 (UP:20, JRV:7)	81 (UP:38, JRV:43)	-2001, Al-Tanur Dam (JRV), 8MCM/a -2003, Mujib Dam (JRV), 12MCM/a -2008, Small Dams (UP), 7MCM/a
Ma'an	4 (UP:4, JRV:0)	3 (UP:3, JRV:0)	7 (UP:7, JRV:0)	-after 2010, Water Harvesting in Badia Region (UP), 3MCM/a
Tafielah	7 (UP:4, JRV:3)	3 (UP:3, JRV:0)	10 (UP:10, JRV:3)	-2004, Al-Feedan Dam (JRV), 3MCM/a
Aqaba	1 (UP:1, JRV:0)	0	1 (UP:1, JRV:0)	
Total	303 (UP:124, JRV:179)	143 (UP:38, JRV:105)	446 (UP:162, JRV:284)	

Source: Information from MWI and JVA, Investment Program 2000-2010
UP: Upland, JRV: Jordan Rift Valley,
JRV is defined as the areas below 300m in elevation (above sea level).



Fig, 2.1.5-1 Location of the Main Dams

2.1.6 Consideration on Sector Policy

A Water Strategy has been formulated by the MWI, and was adopted by the Council of Ministers on April 26th, 1997. Policy papers were issued under the umbrella of the Strategy.

For the surface water resources, specific policy paper was not provided but utility policies of the surface water were mentioned in "Water Utility Policy"

In this policy paper, stress was put on :

a. scarcity of surface water resources in Jordan and limited remaining potential

b. development of limited remaining potential for rapidly increasing demands

c. implementing a comprehensive monitoring and assessment program for quantity, quality and uses to enhance the resources

d. optimizing the development and use

e. pursuing the development of sustainable management plans in the Jordan Valley

As discussed in Chapter 2.1.7, the surface water development will be necessary in the Badia (remote desert area) region in future. This program is included in policy "b" mentioned above. The surface water quality monitoring program recommenced in the same chapter is included in policy "c".

Therefore, It is conclusively considered that the priority should given to the implementation of policy "b" and "c" for the solution of the problems which are presently most prominent in Jordan.

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2.2 Groundwater

2.2.1 General Hydrogeology of Jordan

(1) General

Extensive hydrogeological investigations have been carried out in Jordan as early as the 1960's. A detailed National Water Master Plan was prepared in cooperation with GTZ in 1977. The plan involved a comprehensive assessment of the available and potential water resources, present and future water demands, formulation of medium (1985) and long – term (2000) water policies and guidelines for the exploitation, utilization and appropriate allocation of Jordan's water resources.

Most of the text, which is presented bellow relies on the previous hydrogeological investigations and relevant studies that have been carried out in the country since the preparation of the 1977 National Water Master Plan. Particular references were made to: Howard Humphrys(1986a), Groundwater Study in the Shadiya area and (1986b) Aquifer Modeling of the Disi-Saq sandstone aquifer. Japan International Cooperation Agency (JICA, 1987) Hydrological and water use study of the Mujib Watershed and (JICA, 1990) Water resources study of the Jafer Basin. Thames Water International (1988), Water Treatment and Water Resources Planning, vol. 2. Federal Institute for Geosciences and Natural Resources (BGR/WAJ), Groundwater Resources of Southern Jordan, vol.1, (1991) and Groundwater Resources of Northern Jordan, Draft (1995). Water Sector Review, IBRD, vol. 1 Main Report (1997). Water Resources Management and Policy Reform for the HKJ, by Dr. H. El-Naser, (1999) and Conveyance Systems Project, IWACO, Mott MacDonald and CEC/Jordan, final interim report, (1999).

In addition to the above-cited references, WAJ/JVA unpublished reports and files were used, together with the verbal discussion made on relevant issues, with the competent Officials of the MWI, WAJ and JVA.

(2) Aquifer Systems

Based on the various hydrogeological investigations carried out, the following are the major aquifer systems in Jordan:

- The Upper Aquifer System, Quaternary – Tertiary Aquifers
- The Middle Aquifer System, Carbonate Rocks Aquifers
- The Lower Aquifer System, Sandy Facies Aquifers

Table2.2.1-1 shows the hydrogeological characteristics of the main aquifers and their extent in Jordan and Fig 2.2.1-1 shows the simplified hydrogeological map of Jordan.

1) Upper Aquifer System (Quaternary-Tertiary Aquifers)

a. The shallow aquifer system

The shallow aquifer system consists of sedimentary rocks and alluvial valley fills of tertiary and quaternary ages, such as the valley fills of Jordan valley and Wadi Araba and limestone, chalk, marl and sand and gravel layers in Jafer, Azraq and Sirhan areas. Groundwater encountered in this aquifer originates from the Wadi floods and from the subsurface groundwater flow from the highland areas. Groundwater quality is highly variable and relies on the

Table 2.2.1-1 Hydrogeological Litho-Stratigraphy of Jordan

GEOLOGIC TIME SCALE				STRATA				
ERA	**PERIOD**		**EPOCH**	**Formation**	**Group**	**Symb.**	**Lithology**	**Aquifer Charact.**
CENOZOIC	Quarter-nary		Holocene Pleistocene	Alluvium	Fuviatile Lacst&Eolian	Rc	soil, sand, gravel	poor to good
	Tertiary	Neogene	Pliocene and	J.Valley	Jafer-Azraq	Ja-Az	marl,clay and evaporites conglomerate with silicious sand, gravel, Basalt	poor fair
			Miocene	Volcanics	Basalts	Ba	Basalt	good
		Paleogene	Oligocene	Volcanics	Basalts	Ba		good
			Eocene	Balqa	W.Shallah	B5	limestone, chalk, marl	poor
			Paleocene		Rijam	B4	chert, limestone, chalk, marl	good
MESOZOIC	Cretaceous	Upper	Meastrichtiar		Muwaqar	B3	marly limestone, shale	poor
			Campanian		Amman	B2	chert, limestone, phosphate	good
			Santonian		W.Ghudran	B1	chalk, marl, marly limestone	poor
			Taronian ? ?	Ajlun	W.Sir	A7	limestone, dolomite &chert	very good
					Shueib	A5,6	limestone, marly limestone	poor
			Cenomanian		Hummar	A4	dolomote, dolomitic limestone,	fair to good
					Fuheis	A3	marl, marly limestone	poor
					Naur	A1,2	limestone, dolomitic limestone	good
		Lower	Albian Aptian ? ? Neocomian	Kurnub	Subeihi	K2	sand and shale clay and sandy limestone	
			Berriasian				sandstone	fair to good
	Jurassic	Malm	Tithomian Kimmeridgian Oxfordian	?	Aarda	K1	marl and shale	
		Dogge	Callovian Bathonian	Zarqa	Azab(Huni)	Z2	limestone, marl, sandstone	
		Lias	Bajocian Toarcian				and shale	
	Triassic	Upp.						poor to fair
		Mid.			Main	Z1	limestone, shale, sandy limestone, marl and evaporites	
		Low.	?					
PALEOZOIC	Permian Carboniferous			?	?			?
	Devonian Silurian Ordovician			Khreim		Kh	sandstone, silt, shale	poor
	Cambrian			Ram		R	quarzite sandstone, arkose sandstone	very good
PRECAMBRIAN						Bc	Basement Complex	--

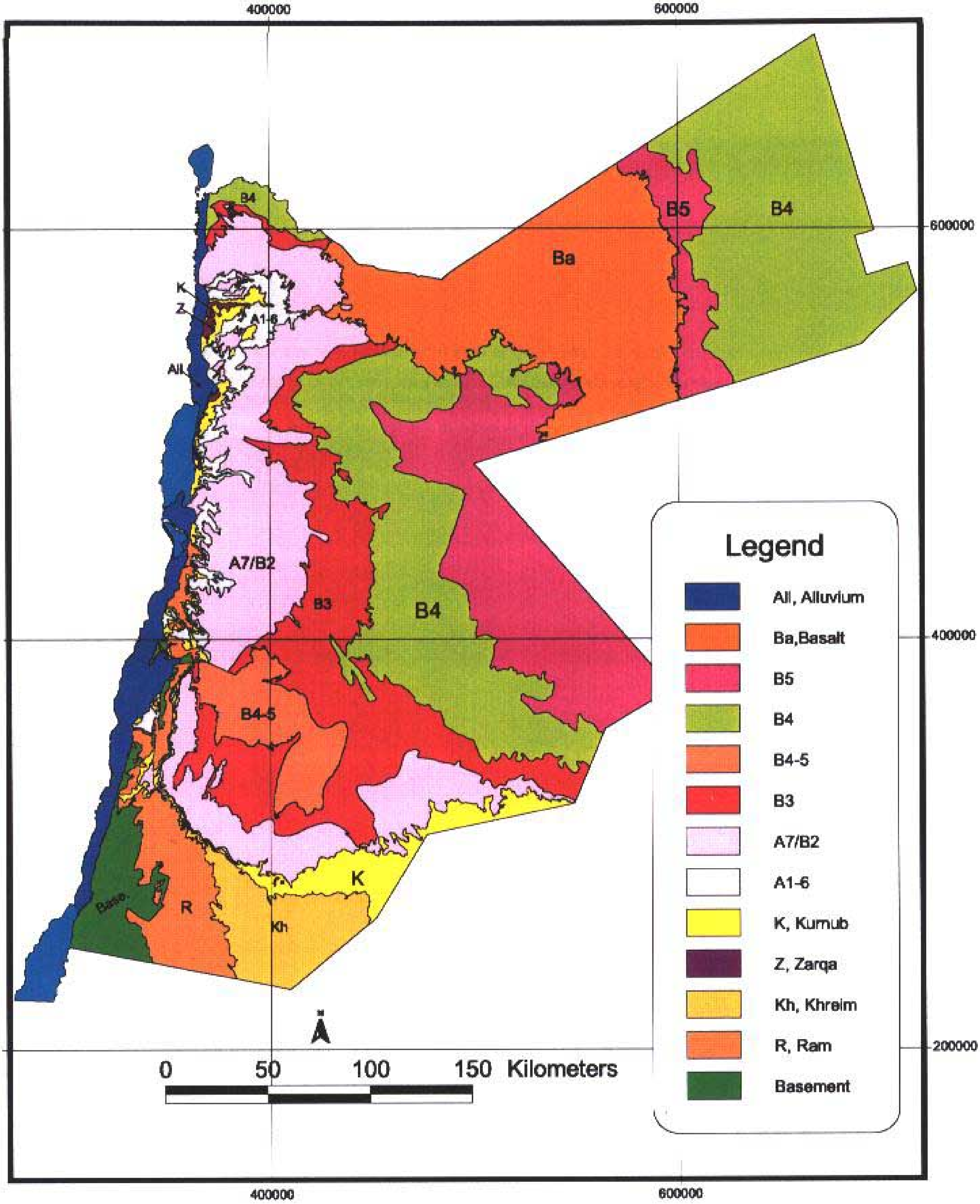


Fig 2.2.1-1 Simplified Hydrogeological Map of Jordan (from WIS)

recharge modes, the salt contents within the aquifer like in the Jordan Valley and Azraq areas and the rate of evaporation like in Azraq Basin.

Aquifer parameters are also variable and rely on the percentage of the fine material content.

b. Basalt Aquifer

It extends from the Syrian Border Southwards to the Azraq and Wadi Dhuleil areas and occupies about 11000 square Kilometers in northeastern Jordan. It contains groundwater of very good quality and in some localities it possesses extremely high permeability that makes it possible to extract large quantities of water. The aquifer is naturally discharged as baseflow in three main zones: the upper Yarmouk River Basin, the Wadi Dhuleil-Wadi Zarqa basin and the Azraq basin. It is generally a water table aquifer and hydraulically connected with the underlying chert – limestone aquifer particularly in Wadi Dhuleil area. In Azraq area the Basalt aquifer is in connection with other tertiary and quaternary water bearing sediments forming almost one aquifer system.

Aquifer parameters are extremely variable relying on thickness of the scoriaceous basalt within the aquifer. The specific capacity of wells drilled in the aquifer ranges from 0.07 to 3352 m^3 /hr/m. The transmissivities range from 2 to 113000 m^3 /hr/m or even more. Water quality is often good (500-1000 mg/lit in TDS).

2) Middle Aquifer System (Carbonate Rocks Aquifers)

a. Amman-Wadi Sir aquifer system (A_7/B_2)

Limestone, chert limestone, sandy limestone of the upper cretaceous, generally known as Amman-Wadi Sir aquifer system (A_7/B_2) forms the most important aquifer, which has the largest extent in Jordan. Groundwater contained in this aquifer originates from the high rainfall zones of the highland areas. Indirect recharge may occur from other aquifers. The vertical boundaries of the aquifer are composed of thick marls of the overlying Muwaqqar (B_3) and the underlying Shueib formation (A5/6). The aquifer parameters are variable as they are a function of the rate of fracturing and solution channels (karstic channel) within the carbonate rocks. The transmissivity (T) ranges from 1-46000m^3/d/m. The specific capacity recorded from the wells drilled in this aquifer ranges from 0.02-2100m^3/hr/m. The storage coefficient is in the order of 1 to 10 per cent depending on the degree of karstification.

The Amman-Wadi Sir Aquifer is underlain by a sequence of marls and limestone, locally marked as A_1 to A_6 members. The limestone layers of Hummar (A_4) and Na'ur Formations ($A_{1,2}$) form potential aquifers of local importance. Direct recharge of these aquifers is limited due to small outcrop areas. They are almost under artesian conditions with piezometric level at or close to the ground surface in some localities.

Groundwater flow in the A_7/B_2 aquifer system is directed from the recharge mounds within the highland areas towards the eastern plateau and westwards to the Jordan Valley through the main tributaries of River Jordan such as Yarmouk, Zerqa, Mujib and Hasa.

Depth to water in the carbonate aquifer is generally within economic reach of Jordan, often less than 180 meters. Groundwater quality is generally good (less than 1,000 mg/lit in TDS). In the eastern desert region especially in Sirhan Basin, the aquifer has been proved to encounter groundwater of poor quality. Its groundwater potentiality has not yet been assessed.

3) Lower Aquifer System (Sandy Facies Aquifers)

It is the deepest and the oldest water bearing formations in Jordan. They are composed of two groups: The Ram Disi and the Kurnub Zarqa Groups. The deep aquifers in some areas out crop and become the upper aquifer, in other areas become deep to very deep aquifer depends on stratigraphy.

a. Kurnub – Zarqa Group Aquifer

It extends almost over the whole Jordan. It consists of sand, sandy limestone with clay and shale of cretaceous – Jurassic age. It crops out in the lower Zarqa River and along the eastern flanking escarpment of the Jordan Valley – Dead Sea – Wadi Araba Graben. In south Jordan Kurnub sandstone overlies the Disi Group aquifer system. Wells drilled in this aquifer are poor yielding wells and of poor water quality more than 2000 ppm of T.D.S. except in Baq'a area where the Kurnub – Zarqa aquifer is being well exploited and has better water quality and well yield.

The Kurnub-Zarqa Aquifer system is underlain by the Khreim Group (Sandstone, siltstone, and shales) separates it from the underlying Disi Group aquifer.

The sandy facies aquifer system (Kurnub – Ram Disi) forms a huge groundwater reservoir of great extent in East Jordan. The drilling depths impose restrictions on its development; high pumping lifts which render water abstraction uneconomic and finally the contained water quality.

Source of recharge of unknown extent may be by downward seepage from the overlying carbonate aquifer system, but it has not been clarified yet.
Natural groundwater discharge occurs as subsurface outflow to the east and reappears along the rift valley as spring discharge and base flows. Groundwater in these aquifers is considered as of fossil origin (El-Naser, 1993).

b. Ram/ Disi Aquifer

It is of Paleozoic age consisting mainly of sandstones and quartzites with average thickness of about 1000 m. The major outcrops of the aquifer occur in the south western part of Jordan in a strip extending about 20 Km wide on the eastern edge of the basement outcrop between Ras en Naqb in the north and the Um Sahm mountains in the south. It is believed to exist at great depth underlying the Mesozoic – Cenozoic sediments in the eastern plateau area, but it may contain saline water. It forms the most important fresh-water producing aquifer in the area that extends from Upper Wadi Yutum-Qa Disi – Mudawara in South Jordan. Depth to water ranges from 60-80 meters. Groundwater quality ranges from 170-1020 ppm of TDS. Aquifer permeability ranges from 0.34-1.0 m/d. Long – term pumping test data indicated that the mean transmissivity of this aquifer system is 720 m^3 /d/m and the mean storage coefficient ranges from 0.01 to 0.03.

(3) Regional Groundwater Flow in Jordan

In recent years, the deep exploratory drilling by the NRA in search of hydrocarbons has considerably extended and it has been found that the aquifer systems described above and it has been found that the aquifer systems changed in east Jordan. Namely, the Kurnub Sandstone aquifer and Zarqa aquifer are separated from the Disi aquifer by the Khreim aquitard and they are hydraulically connected with the Middle Aquifer System in the eastern part of Jordan because the Lower Ajlun aquitard (A1/6) changes into sandy facies to form an aquifer of low productivity with the A_7/B_2 aquifer (Fassu'a Formation) which is hydraulically connected with the Kurnub Sandstone aquifer and Zarqa aquifer.

These findings are summarized in next Table:

Table2.2.1-2 Litho-facies Change of the Aquifers between Western and Eastern Parts

Western Part

Aquifer System	Hydrogeological Unit
Upper Aquifer System	Alluvium (All) Basalt (Ba) Shallala (B5) Rijam (B4)
Aquitard	Muwaqqar (B3)
Middle Aquifer System	Amman-Wadi Sir (A7/B2)
Aquitard	Lower Ajlun (A1/6)
Lower Aquifer System	Kurnub Zarqa (thin-out in the south Disi
Basement	

⇔

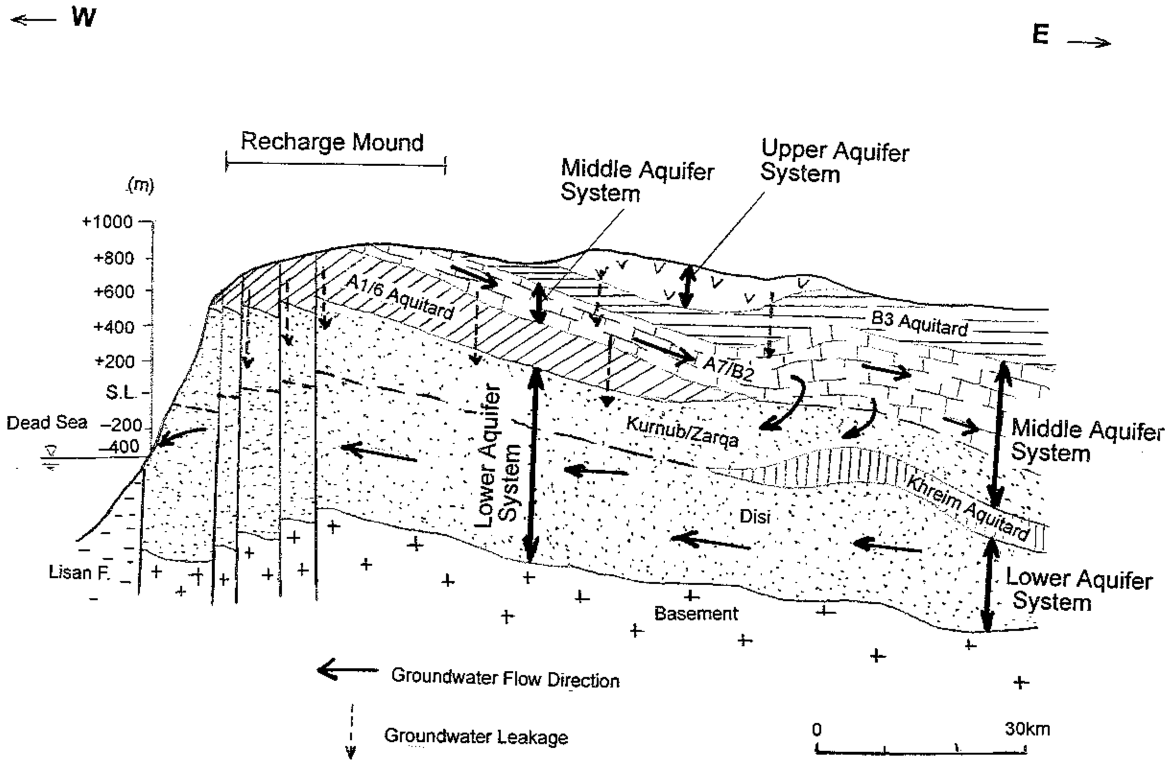
Eastern Part

Aquifer System	Hydrogeological Unit
Upper Aquifer System	Alluvium (All) Basalt (Ba) Shallala (B5) Rijam (B4)
Aquitard	Muwaqqar (B3)
Middle Aquifer System	A7/B2 (Fassu'a F.) A1/6 (Fassu'a F.) Kurnub Zarqa (thin-out in the south)
Aquitard	Khreim
Lower Aquifer System	Disi
Basement	

It is generally regarded that the Upper and Middle Aquifer Systems contain renewable groundwater and the Lower Aquifer System contains nonrenewable groundwater. However, it is inferred that the Middle Aquifer System plays a role as some kind of groundwater channel connecting the renewable groundwater and nonrenewable groundwater in the eastern part of Jordan.

The regional groundwater is schematically shown in Fig.2.2.1-2. This figure shows that the groundwater infiltrated in the recharge mound located in the west flows toward east in the Upper and Middle Aquifer Systems. On the contrary, the groundwater flows from east to west in the Lower Aquifer System.

It is inferred that the groundwater in the Middle Aquifer System leaks into the Lower Aquifer System through the Fassu'a Formation in the eastern part of Jordan and fractures in the A1/6 aquitard. Therefore, it is considered that the Lower Aquifer System is not strictly fossil origin and nonrenewable and it may receive some recharge from the upper aquifer systems. The leaked groundwater from the upper aquifers is mixed with fossil origin groundwater in the Lower Aquifer System and changes flow direction to the west. It is finally discharged to the Dead Sea.



Note : Location of the section is central part of Jordan

Fig. 2.2.1-2 Schematic Section Showing Regional Groundwater Flow in Jordan

2.2.2 Fresh Groundwater Resources

2.2.2.1 Groundwater Basin and Aquifer System

(1) Groundwater Basins

Based on the renewable groundwater divides configuration as anticipated by the various investigators, twelve major groundwater basins were defined (see Fig.2.2.2-1) on which the main renewable groundwater flow pattern within the upper aquifer system is shown.

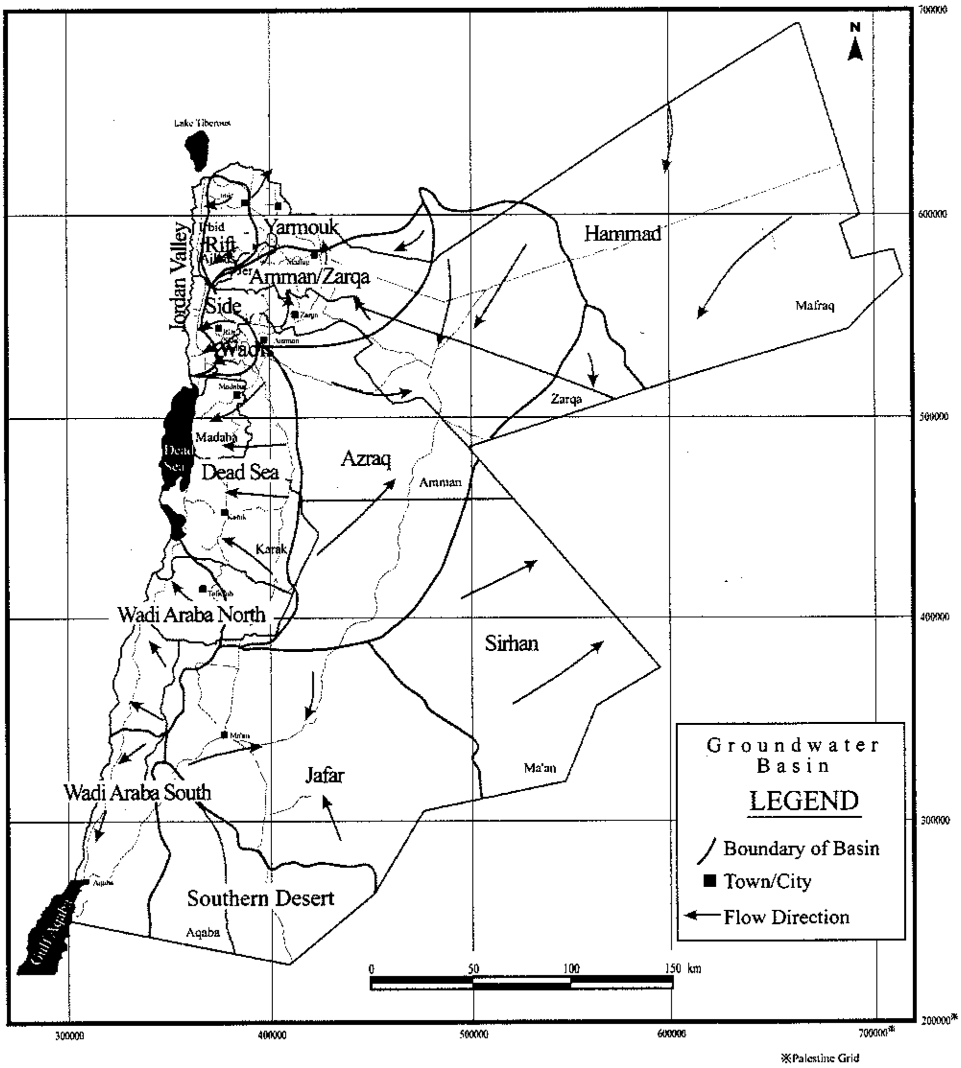


Fig. 2.2.2-1 General Flow System and Groundwater Basins in Jordan

(2) Aquifer System of the Groundwater Basins

The general conditions of the aquifer systems in each groundwater basin are described in this section. The detailed aquifer conditions are summarized in Annex Report.

1) Yarmouk Basin

The Yarmouk river basin, total catchment area of around 7250 km^2, is shared by Jordan and Syria. It underlies an area within Jordan of about 1400 km^2. The Yarmouk River is the main source of surface water in north Jordan including the Greater Amman area. Groundwater recharge into this basin in Jordanian territories is primarily from the northern highlands of Jordan and from Jabal el Arab in south Syria.

The aquifer system receives direct groundwater recharge from infiltration of rainfall over the unconfined section of the aquifer occurring in the upland areas and as subsurface inflow from the adjacent aquifers , mainly from the eastern and northern boundaries. Other inflows originate from Kurnub aquifer in the western part of the basin. Groundwater discharge from the aquifer system takes place mainly through spring and baseflow in the side wadis and as subsurface outflows towards Jordan Valley. The main aquifer system in the basin within Syrian territory is composed of Basalt and B2/A7 chert/limestone, Basalt and B5/B4. The deeper aquifer members of the Ajlun group merge with the upper B2/A7 aquifer to form one hydraulically connected aquifer in northwestern part of the basin.

The total thickness range of the aquifer is from 180m, in the eastern and southern border of the basin up to more than 400m in the lower Yarmouk gorge.

In the western part of the basin, groundwater resources from two major well fields (wadi Arab and Mukheiba, drilled during 1981-3), furnish almost a reliable source for irrigation and domestic water supplies in North Jordan including Greater Amman. Mukheiba spring flow and Tabaqat Fahl (spring) wells are other sources available in North Jordan.

Mukheiba Spring flow was reduced from 18MCM/a (1981, highest) - 11MCM/a (1986, lowest) as a result of exploiting the two well fields in the basin. General water level decline was observed in both well fields (26m-42m).

2) Amman-Zarqa Basin

Amman-Zarqa basin comprises the Greater Amman, Dhuleil, upper Zarqa, Baqa'a and Jerash areas. Groundwater resources in most of these areas are highly developed and over exploited. Groundwater potential in the basin is mostly utilized for irrigation in the areas of upper Zarqa, Baqa'a, Dhuleil and Jerash.

The main contributing aquifers within the basin are Amman/Wadi Sir (A7/B2) in most of the area and the overlying Basalt aquifer in the northeast of the basin. The Kurnub Sandstone aquifer outcrops in Baqa'a and Jerash areas and it bears renewable fresh groundwater in these areas.

The well fields scattered over the Amman-Zarqa basin furnish one of the major water supply components for the Great Amman area, in addition to other external resources, which originates in the adjacent groundwater basins. Spring flows of Ras Al-ain, Salt springs and Azraq (Huhais) are being utilized for domestic water supply within the basin. General water level decline was observed in almost all wells (5m-15m depletion).

3) Azraq Basin

The Azraq groundwater basin is a little larger than its surface water catchment area. It extends into Syrian territory where it receives a good percentage of its annual groundwater recharge.

The main exploited aquifer is the Basalt aquifer (Ba) which is hydraulically connected overlying Rijam aquifer (B4). Ba is mainly recharged in Jabel El Arab located in Syrian territory and flows into Jordan. The groundwater from Syria finally discharges in Azraq in the form of springs and used to form oasis (swamp and lakes). However, the springs and oasis have been dried up as of 1985 due to over abstraction of groundwater.

Groundwater level has been depleted in almost all wells since 1980's because over abstraction has been conducted in the basin. Salinity has also gotten higher in the central part of the basin. It is reported by Tareq Al-Zabet in 1999 that saline intrusion has been induced from the hyper saline water body (100,000mg/lit to 250,000mg/lit in TDS) which occurs under the Azraq mudflat at shallow depth by over abstraction. As the intrusion has been occurred by the over abstraction of the groundwater from Ba and B4, it is feared that more exploitation of groundwater may lead to further salinization in the well fields. Of course other mechanisms of the salinity increase could be considered such as salt infiltration from the ground surface. In addition to this, high saline water reached 20,000mg/lit distributes in B3 at Azraq depression.

A7/B2 and Kurnub Sandstone aquifers also occur at the depth exceeding 800m in the central part of the basin and they contain brackish groundwater (A7/B2--about 2,000mg/lit, Kurnub--1,350 mg/lit to 3,000mg/lit I TDS). It is inferred that the recharge for both aquifers is very limited and probably under the nonrenewable condition.

Renewable A7/B2 aquifer distributes in the southern part of the Azraq Basin is slightly saline (1,000mg/lit to 1,700mg/lit in TDS). The groundwater of this aquifer is recharged in the recharge mound running in N-S direction.

4) Jordan Valley Basin (Valley Floor Basin)

It extends from Yarmouk River in the north to Dead Sea in the south. It is composed of the Valley Floor. Groundwater in the Valley Floor is presently utilized for irrigation and domestic supplies for several settlements in the area. The resources are very well developed in the Valley Floor particularly in the area between Deir Alla to Sweima. Groundwater of good quality is encountered at the alluvial fans at the foothills of the Jordan Valley Escarpment and deteriorates in south and westwards (along the Jordan River).

By 1965, huge amount of groundwater had been discharged and severe decline of the groundwater level (about 25m) had occurred due to over abstraction. Several hundreds of wells were abandoned either due to quality deterioration (increase of salinity, more than 3,000mg/lit in TDS) or went dry because of overexploitation condition prevailing in the Valley Floor as the result of over abstraction. A law was enacted in 1968 that permitted controls, and recharge dams were constructed. Although these countermeasures has mitigated water level depletion to a certain extent, the groundwater abstraction amount still exceeds the safe yield in the Jordan Valley Basin.

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

In the Rift Side Wadis Basin (Jordan Valley Escarpment Basin) , most of the aquifer systems is developed. Several wells were drilled within the escarpment as per the exploration program between River Yarmouk to Dead Sea.

Carbonate aquifers of the Middle Aquifer System that belong to Balqa and Ajlun series are tapped in the area between Wadi Arab to Deir Alla. Kurnub Sandstone aquifer (K) becomes renewable and relatively fresh in this area. The groundwater level has dropped 1993 by 5m to 50m because the groundwater abstraction amount has exceeded the safe yield.

Some wells were drilled in the same area to explore the groundwater potential in deep sandy aquifer (Zarqa Group aquifer of the Lower Aquifer System, Z). In the area south of Deir Alla to Karameh, sandy facies aquifers are tapped but of poor quality water (brackish groundwater, 3,000mg/lit to 5,000mg/lit in TDS). The brackish groundwater in this area has not been exploited yet. For the detail of the brackish groundwater resources in this area, please refer to Chapter 2.2.4.

6) Dead Sea Basin

It is composed of Dead Sea escarpment, Mujib and Hasa basins where the sedimentary sequence forms the primary aquifers which occur in the area. Groundwater flow direction in this basin is mainly to the east. The aquifers which are occurring within the escarpment are being drained by deeply incised wadis in a westerly direction towards the Dead Sea. In this basin one of the main potential water resources (ground- and surface water) is being utilized for Amman, Madaba and Karak governorates domestic and industrial water supplies and partially for irrigation purposes in these areas.

Over exploitation of the available groundwater resources during the last decade, has resulted in water level declines and ceasing off some of spring and base flows, particularly in Mujib basin. The groundwater level depletion ranges 5m to 25m.

7) Wadi Araba North Basin and Wadi Araba South Basin

Groundwater resources in both basins are not well developed and not identified. Groundwater occurs mainly within the valley fill deposits. Water quality is generally fair to poor. It occurs in the southern Ghors with water level at or very close to ground surface (< 50m). The depth to water level in Wadi Araba ranges from 20-80m. Exploratory drilling in the area indicates low to moderate well yields.

Although little groundwater level depletion is observed in some observation wells, the groundwater level is almost constant within these ten years in both basins.

8) Jafer Basin

It extends from the western highlands to the Sirhan basin along the Saudi Arabian borders on the east. Renewable groundwater resources of limited annual recharge primarily from flash floods which occur over the basin exist within the shallow aquifers in the area. Nonrenewable groundwater resources do occur in the deeper sandy aquifer system (Lower Aquifer System, K and Z) in the basin.

Groundwater resources are well developed in the basin mainly for irrigation purposes. Mining the potential resources from the deeper aquifers are earmarked for industrial demand of Shidia phosphate mines.

Continuous groundwater level depletion has been taking place in the basin due to over abstraction of groundwater. Groundwater depletion ranges 2m to 25m and water quality deterioration (salinity increase) due to the infiltration of irrigation return water is also observed.

9) Southern Desert Basin (Disi – Mudawara Basin)

Alluvial deposits and A7/B2 bear renewable fresh groundwater. But, their distribution is very limited and their potential is almost absent.

The major aquifer in this basin is what locally known as Ram Aquifer (R/D) and it is of fossil origin. (10-30, thousand years old). For the detail of this aquifer, please refer to Chapter 2.2.3.3.

Groundwater recharge into this aquifer is almost negligible as the area is generally of scanty rainfall (<50mm/a). The R/D aquifer is generally underlying most of Jordan at various depths, which increase towards north. Groundwater flow direction within this aquifer is from south-southeast to north-northwest and discharging into the Dead Sea Basin at an estimated rate of about 66MCM/a. Groundwater subsurface flow continues towards northern directions underneath the Jafer and Sirhan basins. The non-renewable groundwater resources occur in this basin, are considered as one of the major water supplies on a countrywide scale. Plans to develop and utilize these resources for domestic use are underway in Jordan. As reported the estimated groundwater storage in the aquifer system within Jordan is about 6 billion cubic meters. At present, about 65MCM/a is being abstracted.

10) Sirhan Basin

Sirhan basin is a closed one with an area within Jordan of about 15,300 km^2 out of total area of about 50,000 km^2 shared by Jordan and Saudi Arabia. It is located to the east of Jafer basin. The main aquifers in Sirhan Basin are A1-6 and A7/B2 which are hydraulically connected each other forming one aquifer system named Fassu'a Formation. In addition, B5/4 aquifer locally known as Rijam Formation also dose occur in the Basin. Like in Hamad basin, the groundwater resources in Sirhan is mildly brackish and not yet developed in Jordan while it is being utilized in the Saudi Arabian territory. Groundwater resources in this basin have not been developed and not clearly identified.

Mean annual rainfall in the basin is 40-50 mm. Groundwater flow direction within the basin has two trends: an eastward one from Jordan and a westward one from Saudi Arabia. They both merge in the central part of the basin which lies 10-15 km eastward away from Jordan borders in Saudi Arabia. Renewable groundwater recharge may originate from the flash floods during the recent past through the alluvial deposits along the wadi beds crossing the basin.

11) Hamad Basin

The basin covers an area of about 18,250 km^2 out of the total basin area in which Jordan, Iraq, Saudi Arabia and Syria are sharing. Most of the groundwater resources in Hamad basin is mildly brackish. The TDS increases in the same trend of the groundwater flow direction from west to east. It coincides with the general flow lines within the aquifer. Annual rainfall over the basin ranges from 60-90 mm.

Basalt is the main aquifer, which is hydraulically connected with the underlying Shallalah (B5) in the western part of Hamad Basin and extends and thins towards the south into Sirhan Basin and then into Saudi Arabia. Nonrenewable groundwater occurs in A7/B2.

Groundwater recharge may flow into the Basalt aquifer from the flash floods through the wadi beds crossing the basaltic area. The groundwater level depletion has not been observed in this basin because large scale groundwater development has not been done.

2.2.2.2 Renewable Groundwater Potential

(1) Renewable Groundwater Potential by Groundwater Basin

For the computation of the renewable groundwater potentiality in each hydrogeological balance area, the natural and artificial discharges, rate of evapo-transpiration, subsurface outflow, natural and artificial recharges and subsurface inflows were parameters considered by the investigators. Natural groundwater discharge was determined through the mean annual baseflow measured at the gauging stations during the dry season and adding the upstream consumed irrigation waters in addition to the springs flow. Artificial discharge was computed through the estimation of groundwater abstractions by private and public wells in each groundwater area.

Natural recharge through direct precipitation and/or infiltration from surface runoff into the aquifers was determined and balanced with the reappeared discharged waters. Returned water through physical losses and leakage from delivery water supply networks into the aquifers plus the subsurface inflow from the adjacent aquifers were items also considered by the investigators in the ground water potentials estimation.

Table 2.2.2-1 presents a summary of the groundwater resources situation as computed by most of the previous investigations carried out in Jordan. It is worth mentioning here that most of the groundwater flow regime in Jordan, especially in the north-western part of the country, discharges as surface water baseflow. Hence, by the groundwater exploitation in the Upland areas, the spring and stream baseflow have generally been affected as indicated by the general decline or even drying up some of these flows within the Eastern Highlands flanking the Rift Valley. This includes the Al Mukheiba, Azraq, Sukhneh, Wala spring flows and others.

Although great efforts have been spent so far, by various investigators for the ground water budget computations, sources of errors are still there in some balance areas. These sources are mainly attributed to inadequacy and occasional unreliability of data employed in these computations, such as : spring and baseflow measurement, irrigation water and well abstractions, in and out subsurface flows based on ill-defined aquifer parameters and the estimated natural recharge into these aquifers.

The safe yield is not recharge amount. The safe yield means the sustainable development amount of the groundwater without the exhaustion of the groundwater resource. The safe yield includes the base flow and spring flow. Therefore, the base flow and spring flow will consequently reduce even in the case that the groundwater development will remain within the safe yield.

As in the table, the safe yield of the renewable groundwater is estimated 271MCM/a to 286MCM/a in whole Jordan according to the existing studies and literatures (refer to Annex Report). Therefore, 275MCM/a is employed for total safe yield of the renewable groundwater in whole Jordan in this Study.

Table 2.2.2-1 (1) Renewable Groundwater Potential

Groundwater Basin		*Reported Groundwater Potential (MCM/a): Recharge	*Reported Groundwater Potential (MCM/a): A) Safe Yield (S.Y.)	Aquifer Type	Range of Salinity (TDS,mg/lit)	Range of Well Depth (m)	Range of Depth to Water (m)	Average Well Yield (m^3/hr)	B) Abstraction in 1998 (MCM/a) based on WIS	Balance (MCM/a) A-B	Remarks
Yarmouk		***100 to 120*** [note] (including spring flows)	***40***	Ba in Syria, B4/B5, A7/B2 & K in Jordan	300 to 800	150 to 1,200	100 to 280	20 to 120 in the uplands, 200 to 300 in Mukheiba	***39*** Ratio to S.Y. ***98%***	***1***	Mukheiba wells are flowing with yield of about 500m3/hr
Amman - Zarqa		***80 to 100***	***87***	All, Ba, A7/B2 A1/A6 K (renewable)	400 to 1,000 500 to 1,200 locally>2,000 500 to 800	50 to 500	20 to 250	50 to 180	***150*** Ratio to S.Y. ***172%***	***-63***	Most of wells are fed from A7/B2 Aquifer. Severe G.W. level decline is recognized in the whole basin. K (Kurnub) is renewable in this basin.
Azraq	North to Central	32 to 38	24	Ba and B4	300-500, in the center of basin (Qa-Azraq) exists hyper-saline water ranging 100,000 to 250,000	25 to 250	5 to 75	20 to 180	45 Ratio to S.Y. 188%	-21	Underflow to Sirhan Basin is About 10MCM/a, providing water to Amman. Salinity is increasing due to creeping of hyper-saline water to the well field by over abstraction.
		not yet assessed	not yet assessed	A7/B2	1,000 to 2,500	300 to 500	50 to 80	80 to 100	0		not yet developed, non-renewable
		not yet assessed	not yet assessed	K	1,350 to 3,000, locally >5,000	>650	<90	not yet assessed	0		not yet developed, non-renewable
	South-west	6 to 9	5 to 7	A7/B2	1,000 to 1,700	150 to 500	75 to 300	50 to 120	7 Ratio to S.Y. 100% to 140%	0 to -2	①The groundwater potential of Mujib Hasa surface water basin is re-allocated to Azraq groundwater basin in proportion to the area
	Total	***38 to 47***	***29 to 31***	-	-	-	-	-	***52*** Ratio to S.Y. ***144% to 153%***	***-21 to -23***	
Jordan Valley		***23 to 29***	***21***	All and A7/B2	500 to 2,500, locally >3,000	100 to 300 in the Valley floor	20 to 80 in the Valley floor	50 to 200	***36*** Ratio to S.Y. ***171%***	***-15***	Groundwater is mostly discharged for irrigation in the Valley Floor
Rift Side Wadis		***85**** (Total measured base-flow excluding from Zarqa aq., JRBS 1993)	***15*** [1]	A1/A6 and K (K is renewable in this basin)	500 to 800	Up to 1,000 in the Escarpment	Flowing to 50 in the Escarpment	130 to 250	***31*** Ratio to S.Y. ***206%***	***-16***	1: Remained potential (around 70MCM/a) shall be kept for baseflow in side wadis. Brackish gw. stored in Z & R. K is almost renewable
Dead Sea	Escarp-ment	50 to 55 (including discharge from Ram)	not assessed	A7/B2, A1/A6, K (Kurnob) and R (Ram)	600 to 1,700, locally 7,000	40 to 175 in Lower Reach, 250 to 1,000 in Upper Reach	Flowing to 100 in the foot of the Escarpment, 200 to 400 in the East	50 to 100	not assessed		Needs more investigations & assessment. Part of K and R outflow is non-renewable.
	Mujib & Hasa Basin	34 to 39	not assessed	All, A7/B2 and A1/A6 (mainly A7/B2)	500 to 1,500	150 to 500	75 - 300	50 to 120	not assessed		Potential is re-allocated same as ①. Qastal, Swaqa, Qatrane & Sultane well fields provide G.W. from A7/B2 to Amman.
	Total	***84 to 94*** (including baseflow from Ram)	***50 to 62*** [excluding Deep Sandstone Aquifer, (Ram and Kurnob)]	-	-	-	-	-	***82*** (excluding R) Ratio to S.Y. ***132% to 164%***	***-20 to -32***	General groundwater level decline was observed in the whole basin.

Table 2.2.2-1 (2) Renewable Groundwater Potential

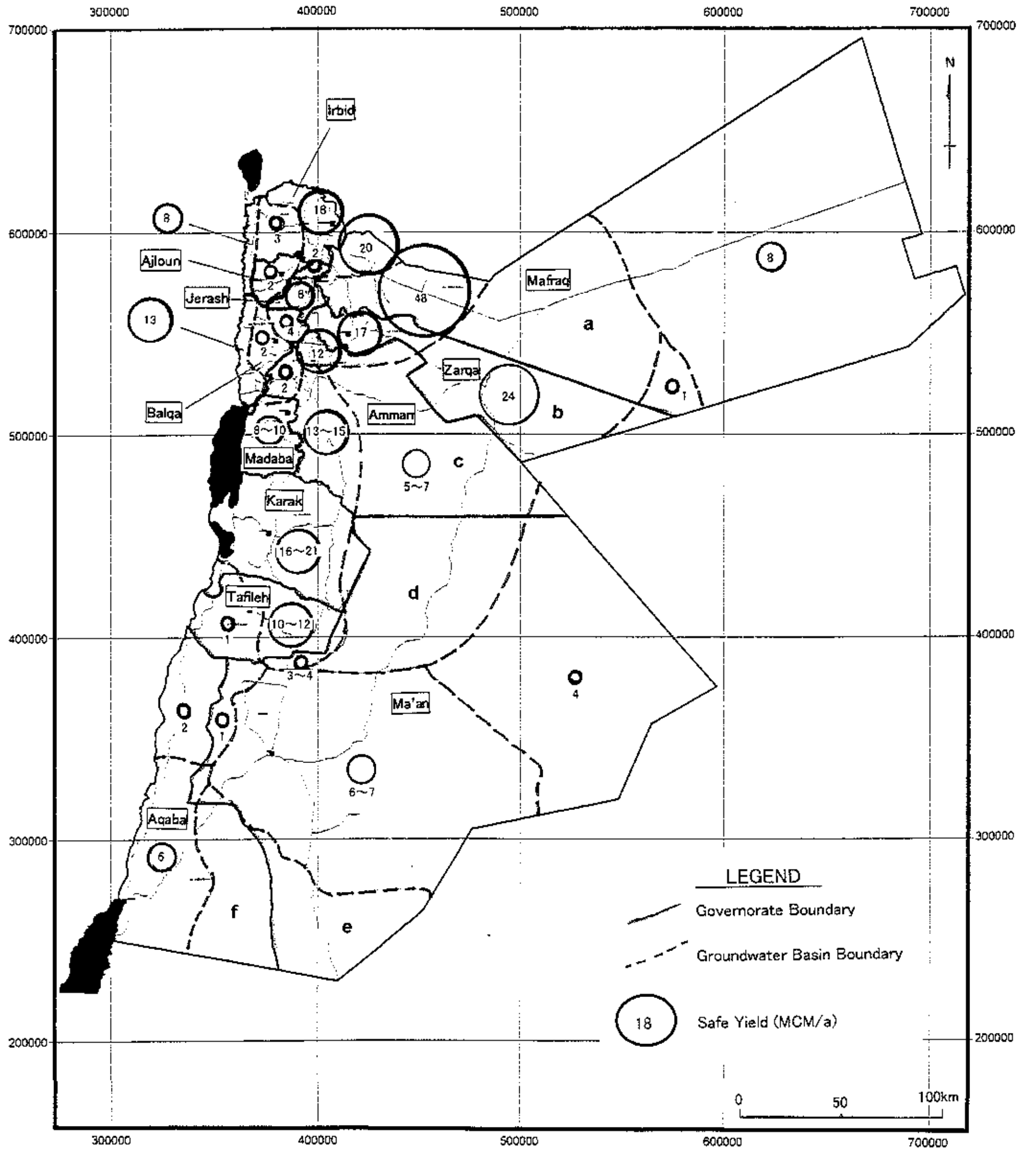
Groundwater Basin	*Reported Groundwater Potential (MCM/a)		Aquifer Type	Range of Salinity (TDS,mg/lit)	Range of Well Depth (m)	Range of Depth to Water (m)	Average Well Yield (m^3/hr)	B) Abstraction in 1998 (MCM/a) based on WIS	Balance (MCM/a) A - B	Remarks
	Recharge	A) Safe Yield (S.Y.)								
Wadi Araba North	***11 to 18*** (including spring and baseflow)	***4*** excluding K and R	All, A7/B2, K	800 to 5,000, locally >5,000,	50 to 300	25 to 80	50 - 100	***4*** (excluding R) Ratio to S.Y. ***100%***	***0***	Exploration program and assessment of the groundwater potential in this area is underway.
			R	Brackish?						
Wadi Araba South	***8 to 10*** (excluding Ram)	***6*** excluding Ram	All and R (Rum)	500 to 700, 850 to 2,000 in Wadi Araba	250 to 400	60 to 120	30 to 100	***0.9*** (excluding R) Ratio to S.Y. ***15%***	***5***	G.W. resources are being exploited mainly for private sector irrigation.
Jafer	***10 to 11*** (Local) [mainly B4/B5, (non-renewable : 15 to 18)]	***6 to 7*** (Local) mainly B4/B5	B4/B5, A7/B2	500 to 3,500	100 to 400	40 to 100	150 to 300	***20*** (excluding K, R) Ratio to S.Y. ***285% to333%***	***-13 to -14***	G.W. resources have been preliminary developed for industry demand (phosphate). Partially mining G.W. development. Generally brackish in A1/A6 and K. Only B4/B5 is renewable.
			A1/A6	700 to 2,000	uncertain	uncertain	uncertain			
			K	1,400 to 3,000	uncertain	uncertain	uncertain			
			R	400 to 600	>900	200 to 350	uncertain			
Southern Desert (Disi - Mudawara)	***less than 1*** (non-renewable : 100 to 125)	***less than 1*** (from very limited All & A7/B2)	very limited All and A7/B2 (mainly from Ram)	250 to 500 in Ram	300 to 1,000 in Ram	Flowing to -100 in Ram	200 to 500 in Ram	***0.3*** (All, A7/B2) Ratio to S.Y. ***30%?***	***0.5***	G.W. resources of Ram for Aqaba Water Supply and for private sector irrigation project. Mining only from Ram aquifer.
Sirhan	***8 to 10*** (mainly B4/B5)	***5*** (mainly B4/B5)	Qirma	1,000 to 2,500	150-700	10 to 30	25 to 40	***0.02*** (B4/B5) Ratio to S.Y. ***<1%***	***5***	G.W. potential is not yet totally assessed. It is generally of fossil origin except in the upper aquifer system. A7/B2, A1/A6 are un-renewable. In SA hot and saline G.W. was encountered from K/Saq.
			B4/B5			45 to 300	20 to 90			
			A7/B2, A1/A6, K		>600	100 to 300	40 to 100			
			Ram		uncertain	>350 in W.,100 to 200 in E.	180 to 300			
Hammad	***7 to 9***	***8***	Ba, B4/B5	500 to 3,000	300 to 700	45 to 110	20 to 150	***1.2*** (B4/B5, A7/B2) Ratio to S.Y. ***15%***	***7***	G.W. resources are being utilized for private farming and livestock. No significant G.W. recharge in the Middle and Lower Aquifer Systems including A7/B2 and A1/A6. G.W. is generally of fossil origin and poor quality except Ba and B4/B5.
			A7/B2, A1/A6, K and Z	1,500 to 3,200	315 to 750	250 to 270	25 to 50			
			Ram	uncertain	>2,000	>400	180 to 350			

	Recharge	A) Safe Yield	B) Abstraction in 1998	Balance (A - B)
Renewable Groundwater Total (MCM/a)	***454 to 533***	***271 to 286***	***416*** (Excluding Nonrenewable GW)	***-130 to -145*** ***(145% to 153%)***

Note : 52MCM measured at Adasiya in last 10 years.
106MCM diverted to KAC in 1998 including spring flow of 40MCM/a within the Yarmouk Basin.

(2) Renewable Groundwater Potential by Governorate

It is difficult to estimate the renewable groundwater potential by governorate basis because the area of the governorate has no relationship with the hydrogeological aspects. However, the Master Plan for water resources management should be formulated by governorate basis. Therefore, the renewable groundwater potential was allocated to each governorate by area ratio of the groundwater basins to each governorate in this Study. The results are shown in Fig. 2.2.2-2 and Table 2.2.2-2.



Note : The safe yield of the domain "a" is estimated almost nil because excessive abstraction has been done in the domain "b" (Azraq well field) which is located in the downstream of domain "a".

Much higher safe yield is given to the domain "b" despite of small area because it is inferred that the almost of the renewable groundwater has flown into this domain due to excessive abstraction mentioned above. From this reason, the safe yield in the domain "c" is little bit reduced.

For the domain "d", "e" and "f", the safe yield is estimated almost nil because the distribution of the renewable aquifers are very limited in these domains.

Fig 2.2.2-2 Map Showing the Renewable Groundwater Safe Yield in Each Governorate

Table 2.2.2-2 Safe Yield of the Renewable Groundwater by Governorate

Governorate	Yarmouk	Amman-Zarqa	Azraq	Jordan Valley	Rift Side Wadis	Dead Sea	Wadi Araba North	Wadi Araba South	Jafer	Southern Deserts	Sirhan	Hammad	Total
	Groundwater Basin												
Amman		12 (14%)	6 [(a)]		2 (13%)	14 (24%)							*34*
Zarqa		17 (19%)	24 [(b)]		6 (41%)								*47*
Mafraq	20 (50%)	48 (55%)									1 (8%)	8 (100%)	*77*
Irbid	18 (45%)			8 (38%)	3 (19%)								*29*
Ajloun					2 (13%)								*2*
Jerash	2 (5%)	6 (7%)											*8*
Balqa		4 (5%)		13 (61%)	2 (14%)								*19*
Madaba						9 (15%)							*9*
Karak						16 (35%)							*16*
Ma'an						3 (6%)	1 (14%)		6 (100%)	<1 (57%)	4 (92%)		*14*
Tafielah						11 (20%)	1 (35%)						*12*
Aqaba							2 (47%)	6 (100%)		<1 (43%)			*8*
Total	40	87	30	21	15	53	4	6	6	<1	5	8	*275*

Note: Bracketted figures show the ratio of the area of the groundwater basins in the governorates. The potential of the renewable groundwater is divided into governorate based on the distribion rate of the groundwater basin areas in the governorates.

a : Distribution area of A7/B2 aquifer in the Azraq Basin is limited to the southern part of the Amman Governorate.
b : As the renewable groundwater in the central to northern part of the Azraq Basin is mainly abstructed in Zerqa governorate (Al Azraq) and abstruction amount has exceeded the its safe yield (24MCM/a), all of the safe yield is given to Zarqa governorate.

2.2.2.3 Fresh Fossil Groundwater Potential

Fresh fossil groundwater will be described in this Chapter. The major aquifer of fresh nonrenewable groundwater in Jordan is what locally known as Ram Group Aquifer (R/D) and it is of fossil origin. (10-30, thousand years old). R/D aquifer is widely distributed in Jordan. However, this aquifer is mainly exploited in the the South Wadi Araba Basin and Southern Desert Basin (Disi-Mudawara Basin) because the aquifer is located at shallower depth in both basins.

Groundwater recharge into this aquifer is almost negligible as the area is generally of scanty rainfall (<50mm/a). The R/D aquifer is generally underlying most of Jordan at various depths, which increase towards north. Groundwater flow direction within this aquifer is from south-southeast to north-northwest and discharging into the southern part of the Dead Sea Basin at an estimated rate of about 136MCM/a (see Fig. 2.2.3-2). Groundwater subsurface flow continues towards northern directions underneath the Jafer and Sirhan basins. Well depth ranges from 300m to1,500m, depth to water ranges about several meters above ground level in the Southern Desert Basin.

The water quality is excellent and salinity ranges between 200mg/lit and 300mg/lit in the Southern Desert Basin excepting some abnormalities (up to 700mg/lit). However, the salinity gradually increases in the course of flowing toward northwestward and it gets brackish in the other basins.

Water level are continuously declining with use and the accumulated decline up to present is 10m to 15m. But water quality has not been changed so far.

The nonrenewable fresh groundwater resources in this basin are considered as one of the major and important water supplies on a countrywide scale. Plans to develop and utilize these resources for domestic use are underway in Jordan. It is inferred that the estimated groundwater storage in Disi-Mudawara Aquifer System within Jordanian territory is about 16 billion cubic meters according to "Qa Disi Aqifer Study, 1995". At present, about 70MCM/a is being utilized in Jordan. About 55TMCM/a of groundwater resources are presently used for irrigation in Disi-Mudawara area and about 15MCM/a for domestic and industrial use in Aqaba. The depth to the groundwater level is 5m to 6m above ground level in Mudawara area.

The R/D aquifer in Saudi Arabia is utilized more extensively and its abstraction amount is estimated at around 650MCM/a in 1995.

It is expected that an annual abstraction of about 125MCM in Jordan can be sustained for a period of 50 years if Saudi abstraction is limited to their current uses, and their wells remain at least 50km away from the Jordan borders. However, another study conducted in 1995 (Qa Disi Aquifer Study) has indicated that 155MCM/a to 225MCM/a would be available provided planning horizon of 40 to 100 years according to the three-dimensional mathematical modeling.

2.2.2.4 Groundwater Abstraction and Remained Potential

(1) Groundwater Abstraction

Total number of registered wells in Jordan is about 2,300 and total abstraction amount from them is about 484MCM in 1998 based on the data stored in Water Information System (WIS). Detailed break down of the groundwater abstraction in 1998 is shown in Annex Report.

1) Well Number

As shown in Fig.2.2.2-3, the production wells are concentrated in the Amman-Zarqa Basin and Azraq Basin. The well number in both basins occupied almost 50% of total well number in Jordan.

The number of wells of each aquifer type shows that the unidentified aquifer wells occupy about 40% of total wells. These wells are without pumping test or tapped multi aquifers. It is inferred that such wells might mainly tap A7/B2 in the Amman-Zarqa Basin and Basalt (Ba) in the Azraq Basin. Excluding such wells, the wells tapped A7/B2 aquifer is an overwhelming majority and they occupy about 35% of total wells.

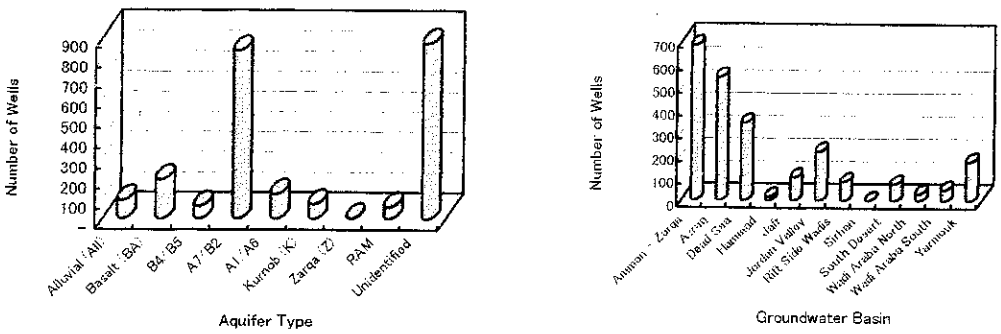
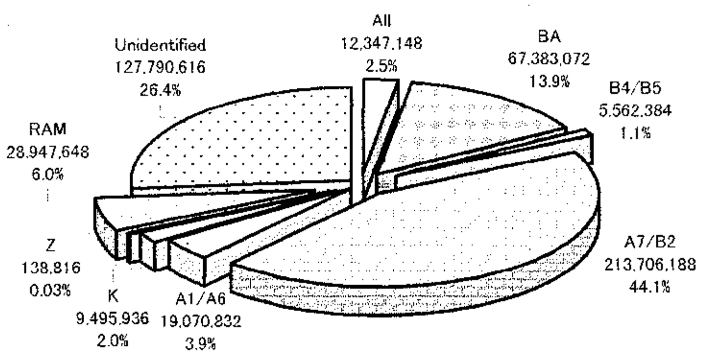


Fig.2.2.2-3 Number of Wells in 1998

2) Groundwater Abstraction Amount

The groundwater abstraction amount by aquifer type is shown in next figure.



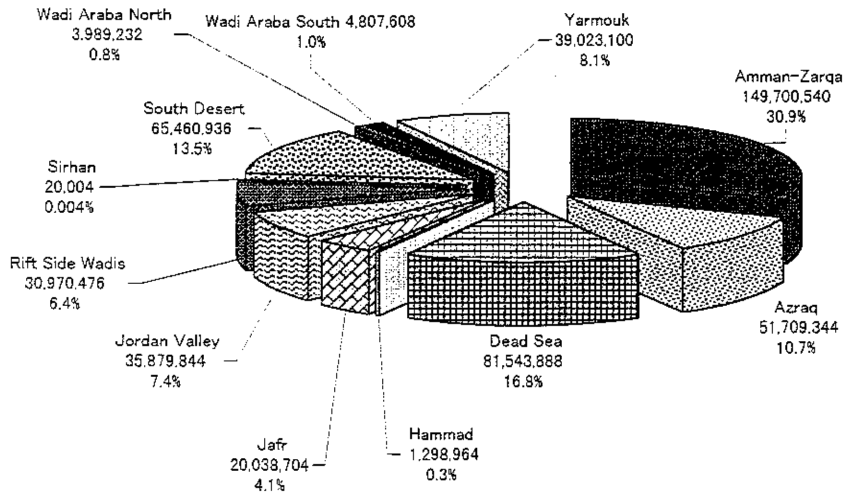
Total Abstraction : 484,442,640m^3

Fig.2.2.2-4 Groundwater Abstraction Amount by Aquifer Type in 1998

As shown above figure, the groundwater is abstracted mainly from A7/B2 and its amount occupies about 44% of total groundwater abstraction amount in Jordan. The largest abstraction next to A7/B2 is done from the basalt aquifer (Ba) and it occupies about 14% of total abstraction. Abstraction from aquifer unidentified wells occupies about 26% of total amount. It is inferred that the wells of aquifer unidentified might mainly abstract groundwater from All, Ba, A7/B2 and Rum aquifer (R/D) because these aquifers are main aquifers in the basins where most of such wells are located.

The abstraction amount from the Ram Aquifer in 1998 is estimated around 68MCM/a according to WIS database (refer to section (2), 2) Remained Potential of the Nonrenewable Fresh Groundwater). It is consequently supposed that the total abstraction amount of the renewable groundwater in 1998 is 416MCM/a (484MCM/a – 68MCM/a = 416MCM/a).

The groundwater abstraction amount by groundwater basin is shown in next figure.



Total Abstraction : 484,442,640m^3

Fig.2.2.2-5 Groundwater Abstraction Amount by Groundwater Basin in 1998

As shown above, the basin of the highest groundwater abstraction is Amman –Zarqa Basin in which about 30% of total abstraction has been being done. Next highest abstraction basin is the Dead Sea Basin (about 17%) and third one is the Southern Desert Basin (about 14%) where fresh nonrenewable groundwater is mainly exploited from Ram aquifer (R/D).

The groundwater abstraction components by aquifer type of each groundwater basin are shown in Annex Report.

(2) Remained Groundwater Potential

1) Remained Potential of the Renewable Groundwater

The balance between the safe yield of renewable groundwater and actual renewable groundwater abstraction amount is shown in Table 2.2.2-3 based on the Table2.2.3-1.

Table 2.2.2-3 Remained Renewable Groundwater Potential in Jordan

Groundwater Basin	Safe Yield (MCM/a)	Abstraction in 1998 (MCM/a)	Balance (MCM/a)
Yarmouk	40	39	1
Amman-Zarqa	87	150	–63
Azraq	29 to 31	52	–21 to –23
Jordan Valley	21	36	–15
Rift Side Wadis	15	31	–16
Dead Sea	50 to 62	82	–20 to –32
Wadi Araba North	4	4	0
Wadi Araba South	6	1	5
Jafr	6 to 7	20	–13 to –14
Southern Desert	less than 1	less than 1	0
Sirhan	5	less than 1	5
Hammad	8	1	7
Total	**271 to 286**	**416**	**–130 to –145**

As shown above, it is quite clear that the present abstraction amount of renewable groundwater extremely exceeds the safe yield. The declining tendency of the groundwater level has been clearly identified in the governorates where the groundwater abstraction is larger as shown in groundwater level fluctuation graphs attached in Annex Report. These facts also reinforce the over abstraction of the renewable groundwater.

Therefore, it is concluded that the large scaled groundwater development is completely impossible in future and the groundwater abstraction should be remained within its safe yield. Otherwise, the precious groundwater resources will be exhausted in near future.

Although the small potential of the groundwater still remains in the remote areas which are Sirhan Bsin and Hammad Basin, the remained potential should be utilized for local demand because their potential is very limited.

2) Remained Potential of the Nonrenewable Fresh Groundwater

As stated in Section 2.2.2.3, the estimated potential of the nonrenewable fresh groundwater in the Ram aquifer ranges from 125MCM/a to 225MCM/a according to the existing studies in the Wadi Araba Basin and Southern Desert Basin (Disi-Mudawara Basin) for period of 40 years to 100years.

The abstraction amount from the Ram aquifer in both basins is around 29MCM/a in 1998 as shown in Fig.2.2.2-4. In addition to this amount, there is abstraction from aquifer unidentified wells which amounts to around 40MCM/a in the Southern Desert Basin in 1998. As there is no promising aquifer except the Ram aquifer in this basin, most of the abstraction should be counted into the amount from the Ram aquifer. Therefore, it is assumed that the abstraction amount of the nonrenewable fresh groundwater from the Ram aquifer is estimated at around 70MCM/a in 1998.

As the potential of the nonrenewable fresh groundwater is estimated at more than 125MCM/a, it is consequently considered that the nonrenewable fresh groundwater of more than 55MCM/a are presently retained for the future development. If the potential of the nonrenewable fresh groundwater in the Lajoun area will be studied in detail, its potential will be much more than present estimation.

2.2.3 Brackish Groundwater

Brackish groundwater potential is discussed in this section based on the existing reports. The existing reports mainly referred to are as follows:

- Groundwater Resources of Southern Jordan, BGR 1991
- The Study on Brackish Groundwater Desalination in Jordan, JICA 1995
- Groundwater Investigations in the Hammad and Sirhan Basins, GITEC 1995
- Groundwater Resources of Northern Jordan, BGR 1995
- Proposal for an Exploration Drilling Program of the Ram Group Aquifer in the Dead Sea – Amman Area, BGR 1996
- Assessment of Brackish Groundwater in Jordan, USAID 1998
- Finite Element Flow and Solute Transport Modeling Combined with G.I.S Technique, Tareq Al-Zabet, Unpublished Ph.D. thesis, Wurzburg University, 1999.

The brackish groundwater is the sole water resource remaining almost undeveloped in Jordan. However, previous studies of brackish groundwater resources are limited. Therefore, the potential of the brackish groundwater is preliminarily evaluated in this section based on the existing reports incorporating the up-dated information.

2.2.3.1 Basin and Aquifer System

(1) Basin

Most of the previous investigations carried out in Jordan, have indicated that the brackish groundwater potential occurs mainly in the Lower Aquifer systems(sandy facies aquifer). The brackish groundwater in the Middle and Lower Aquifer system flows crossing the groundwater basins because it is almost fossil origin. Therefore, the concept of the groundwater basin cannot be applied for the brackish groundwater in the Lower Aquifer system.

The Upper and Middle Aquifers system (alluvium, basalt and carbonates), contains substantial volumes of renewable and nonrenewable brackish groundwater but of limited spatial extent within Jordan. The brackish groundwater flow in the Upper and Middle Aquifer System is controlled by the groundwater basin as mentioned in the section 2.2.2.1.

(2) Aquifer System

1) Brackish Groundwater in the Lower Aquifer System

a. Groundwater flow regime within the Lower Aquifer System

The Lower Aquifer System is regarded as almost of fossil origin receiving some downward leakage from the Middle Aquifer System. The age of the groundwater of the Lower Aquifer System was dated around BP 1,500 years to BP 22,000years in the southern Jordan Valley based on Carbon-14 analysis (JICA,1995). The Lower Aquifer System generally contains brackish groundwater except in Disi-Mudawara area located in the Southern Desert groundwater basin and Lajoun and Shidiya areas located in the Dead Sea groundwater basin.

As mentioned before, the Lower Aquifer System consists of the Ram Group aquifer separated from the Middle Aquifer System by the Khreim aquitard in the east and south- east of Jordan. The Lower Aquifer System changes its composition to consist of the Ram Group aquifer, the Zarqa Group aquifer and the Kurnub Sandstone aquifer. It is separated from the Middle Aquifer System by A1/A6 aquitard in the central to west of Jordan.

The fossil origin fresh groundwater in Ram Group aquifer inflows from Saudi Arabia across the south-eastern border with Jordan. It flows toward north-western direction through the Lower Aquifer System. It discharges finally into the Dead Sea receiving the vertical renewable groundwater recharge from the overlying Middle Aquifer System along the course of its flowing.

It is obvious that the groundwater in the Lower Aquifer System is flowing in spite of the fact that it is almost of fossil origin. The reasons for this phenomenon are inferred as follows:

① Fossil hydraulic gradient of the last humid period of about 5,000 years ago and still remains (It is assumed that the Lower Aquifer System was completely saturated at that time)

② Downward leakage from the Middle Aquifer System to the Lower Aquifer System

③ Inclination of the Lower Aquifer System toward Dead Sea due to the tectonic movement (downward warping) of the Rift Valley

④ Lowering of the Dead Sea level (base level) which result in an induced hydraulic gradient which facilitates groundwater discharge from the Middle and Lower Aquifer systems into the Dead Sea.

It is more realistic that the reason "①" mentioned above is believed to be the main mechanism for flowing of the fossil origin groundwater. According to "Groundwater Resources of Southern Jordan, BGR 1991" the simulation of long-term depletion of the Lower Aquifer System (sandy facies aquifer system), showed that: although the gradient of the Lower Aquifer System has been decreasing since 5,000 years ago, groundwater will still be flowing to the Dead Sea after 5,000 to 6,000 years later. Therefore, it is assumed that the groundwater flowing in the Lower Aquifer System will not be greatly changed within the forthcoming hundreds years and it may be regarded as constant for the duration of the development project life.

b. Groundwater flow assessment

i. Downward leakage from the overlying Middle Aquifer System

According to BGR 1991, flow-net calculations in the Lower Aquifer System (Sandstone Aquifer System), indicated that the groundwater throughput from the southern desert towards the north, amounted to about 50MCM/a. On the other hand, inflow from the assumed flow path reached almost 140MCM/a towards the discharge area near the Dead Sea as shown in figure 2.2.3-1.

The "gain" of 90MCM/a may have originated from the overlying Middle Aquifer System. Downward leakage from the Kurnub Sandstone aquifer to the underlying Zerqa Group aquifer, which is also reported in JICA study,1995. According to JICA study, the Zerqa Group aquifer receives about 1.5MCM/a from the overlying Kurnub Sandstone aquifer which is separated by marly layer of low permeability in the southern corner of the Rift Side Wadis basin (area of about 300km^2) based on the three dimensional groundwater seepage simulation. Groundwater in the Kurnub Sandstone aquifer is renewable and fresh in this area.

As mentioned above, it is obvious that the Lower Aquifer System receives downward leakage from the upper aquifers in the course of flowing and such leakage to the fossil origin groundwater, might be one of the reasons explaining the flowing phenomena of the groundwater within the Lower Aquifer System.

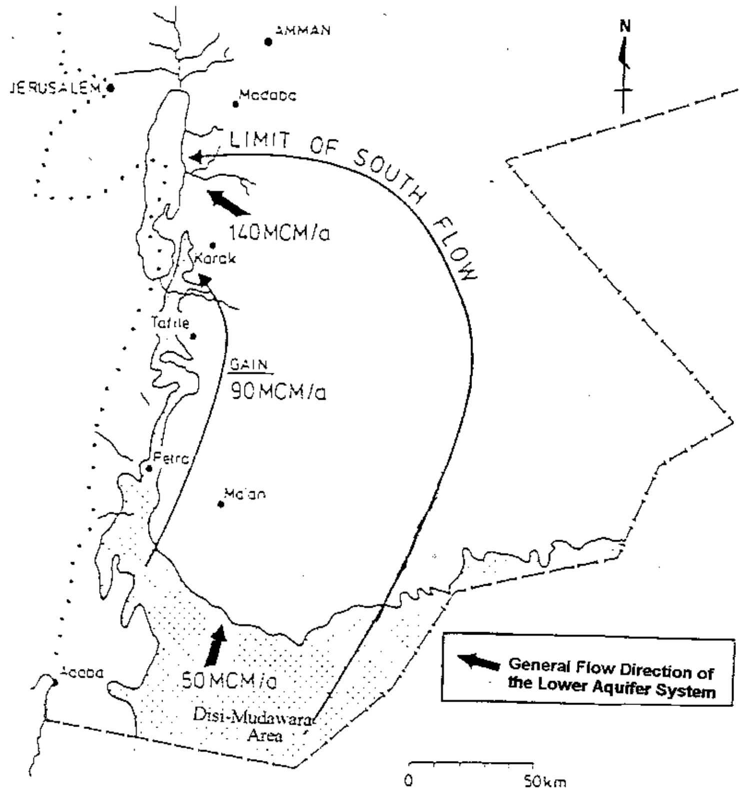


Fig.2.2.3-1 Groundwater Flow Regime within the Lower Aquifer System. (After BGR, 1991)

ii. Groundwater underflow to the Dead Sea and Southern Jordan Valley

The amount of groundwater outflow from the Lower Aquifer System to the Dead Sea and the Southern Jordan Valley is summarized according to BGR, 1991 and JICA, 1995 in Fig 2.2.3-2.

Inflow amount to the Dead Sea was calculated using flownet technique by BGR 1991. The inflow amount to the Southern Jordan Valley from Dier Alla to Kafrein was estimated through baseflow and spring flow measurement and three dimensional groundwater seepage simulation by JICA, 1995.

As per the map shown on Fig (2), the total groundwater inflow amount from the Lower Aquifer System to the Dead Sea and southern Jordan Valley was estimated at about 444.4MCM/a. (BGR 1991 and JICA 1995).

In the area that extends from central to southern Dead Sea escarpment, the Lower Aquifer System consists of Ram Group aquifer and the Kurnob Sandstone aquifer as the Khreim aquitard which normally separates the two aquifer systems, has been thinned-out in this area. In the Jordan Valley and northern Dead Sea escarpments, the Lower Aquifer System consists of Ram Group and Zarqa Group aquifers, because the Zarqa Group aquifer is intercalated between the Ram Group and the Kurnub Sandstone aquifers. It is also, hydraulically separates them by the impervious marly layer that occurs in it. Furthermore, the Zarqa group aquifer hydraulically connects with the underlying Ram Group.

Inflow to the southern half of the Dead Sea is originated from the South through the Southern Desert Basin. As for the origin of the inflow to the northern half of the Dead Sea and Jordan Valley, no distinctive data is available. It is thought that the inflow to the northern part might have originated from the North and from the East.

iii.Depth to the Lower Aquifer System

Figure 2.2.3-3 shows the depth to the Lower Aquifer System. In the northern Jordan Valley escarpment (north to the Zarqa River), the Lower Aquifer System inclines towards north and the depth is around 500m to 1,000m. In the escarpment that extends from the southern Jordan Valley to the Dead Sea, the Lower Aquifer System is outcropped or located at shallow depths, less than 500m.

The escarpment of Wadi Araba Basin, which is located in the south to the Dead Sea may receive inflow from the Ram aquifer and Kurnub aquifer of the Lower Aquifer System. The depth to the Lower Aquifer System is also shallow ranging from 0m to 500m. In the highland and desert areas, the depth to the Lower Aquifer system is expected to range from 1,000m to 2,000m.

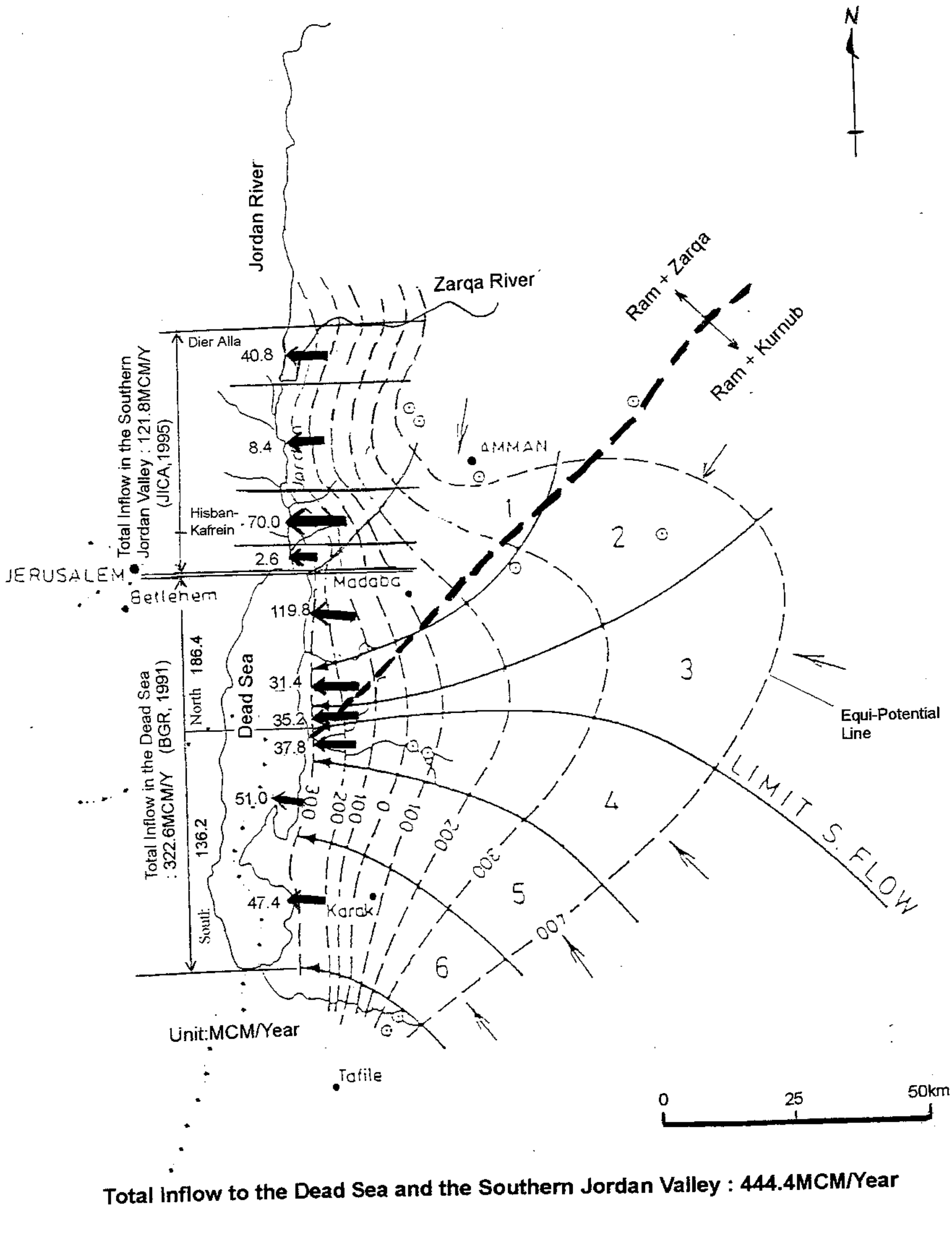


Fig.2.2.3-2 Inflow Amount from the Lower Aquifer System to the Dead Sea and Southern Jordan Valley (BGR, 1991 and JICA, 1995)

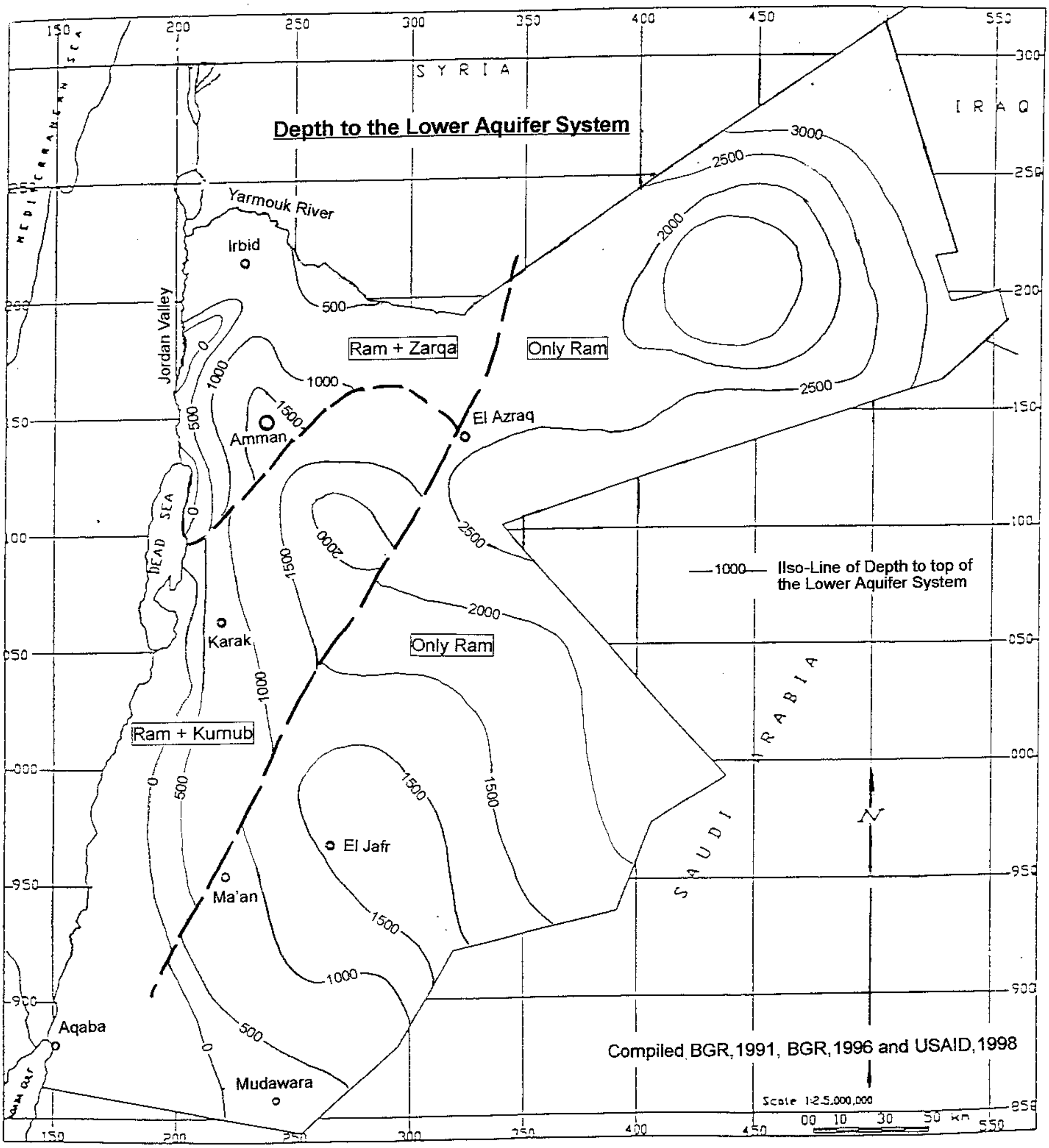


Fig.2.2.3-3 Depth to the Lower Aquifer System (BGR 1991, BGR 1996, USAID 1998)

c. Groundwater salinity encountered in the Lower Aquifer System.

Salinity distribution pattern within the Lower Aquifer System occurring in the groundwater flowing into the Dead Sea and the southern Jordan Valley is summarized in figure 2.2.3-4 below based on the limited data.

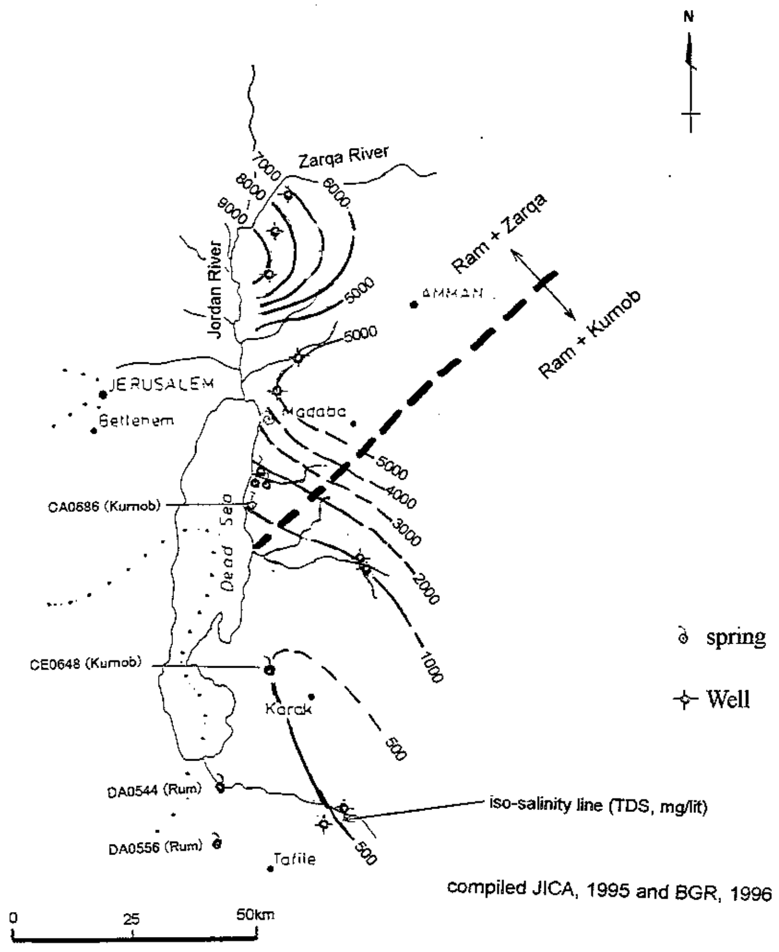


Fig.2.2.3-4 Groundwater Salinity Pattern in the Lower Aquifer System in the Dead Sea and Southern Jordan Valley Escarpment

Figure shown above indicates that the groundwater is almost fresh in the upstream of the Lower Aquifer System. The salinity gradually increases in the same trend of the groundwater flow direction from southeast to northwest. Downward leakage of brackish groundwater from the overlying Middle Aquifer System and dissolution of salt from the evaporates contained in the aquifers, are the main reasons for the trend of water quality distribution. The salinity distribution shows the tendency of being increased towards the north. However, as the data is very limited, further investigation and studies will be required to verify such tendencies.

2) Brackish Groundwater in the Middle and Upper Aquifer Systems

The Middle Aquifer System is composed of A7/B2 aquifer, hydraulically separated from the Upper Aquifer System by the B3 aquitard and from the Lower Aquifer System by the A1/A6 aquitard. The Upper Aquifer System is composed of B4/B5 aquifer, Basalt aquifer and Alluvial aquifer overlying and separated from the Middle Aquifer System by B3 aquitard.

As mentioned earlier, the Zarqa Group aquifer and the Kurnub aquifer are classified as the Middle Aquifer System in the eastern part of Jordan. Renewable brackish groundwater is mainly contained in the Upper Aquifer System and nonrenewable brackish groundwater (not flowing and stagnant) is mainly contained in the Middle Aquifer Systems. Explanation of the brackish groundwater contained in Middle and Upper aquifer systems are given in Annex Report. A brief account is shown in next table in the different groundwater basins and aquifer systems in Jordan.

Table 2.2.3-1 Brackish Groundwater Potential in Mid. & Upper Aquifer Systems

Groundwater Basin	Aquifer	Storage Amount of Nonrenewable (Billion m^3)	Assumed safe yield of Renewable (MCM/a)	Salinity Range (mg/lit in TDS)
Azraq	A7/B2 (North to Central)	46		1,000 to 2,500
	A7/B2 (South)		10 to 12	1,000 to 1,700
	Kurnub	42		1,350 to 3,000
Jordan Valley	All		16	1,000 to 2,500
Dead Sea	A7/B2		9 to 12	1,000 to 1,700
Wadi Araba (North & South)	Al		8	1,000 to 7,000
Jafer	A7/B2	1.7		1,000 to 4,000
	Kurnub	12		1,400 to 3,000
	Khreim	88		1,200 to >10,000
Sirhan	B4		5	1,000 to 2,500
	A7/B2	32		4,500 to 7,000
Hammad	B4/B5		7	1,000 to 3,000
	A7/B2	16		1,500 to 3,200
Total	**--**	**237.7**	**55 to 60**	**--**

Source : After "Assessment of Brackish Groundwater in Jordan, WQIC, 1998"

2.2.3.2 Brackish Groundwater Potential

The brackish groundwater can be largely classified into "Renewable" and "Nonrenewable". Furthermore, the nonrenewable brackish groundwater can be divided into " Flowing" and "Stagnant" conditions as shown below:

Table 2.2.3-2 Classification of the Brackish Groundwater

Brackish Groundwater		
Renewable	Nonrenewable	
	Flowing	Stagnant

(1) Summary of the Brackish Groundwater Potential in Jordan

The brackish groundwater potential based on the classification mentioned above, in the whole Jordan may be summarized as follows:

Table 2.2.3-3 Brackish Groundwater Potential of whole Jordan

a. Renewable[a]	Safe Yield : 55MCM/a to 60MCM/a
b. Nonrenewable/Flowing[b]	Exploitable Amount : 265MCM/a to 300MCM/a
c. Nonrenewable/Stagnant[a]	Exploitable Volume : 24billion cubic meter*

Source : After "Assessment of Brackish Groundwater in Jordan, WQIC, 1998" and JICA 1995

* 10% of the total storage amount

a: The depth to the aquifers and thickness of aquifers greatly differ place to place

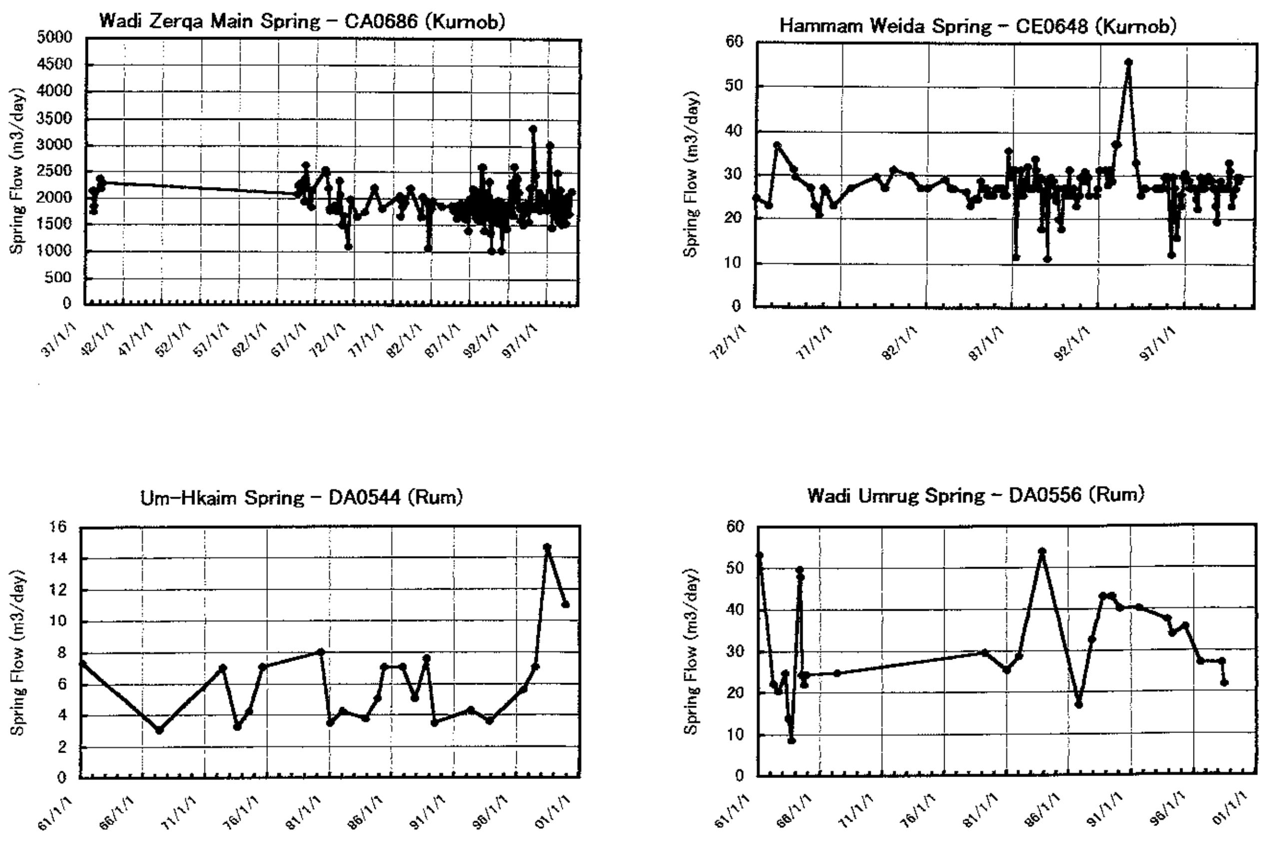
b: The depth to the deep aquifer system is shown in Fig.2.2.3-3, the thickness of the deep aquifer system is more than 1,000m including Ram/Disi aquifer

1) Renewable Brackish Groundwater

In spite of the fact that the safe yield of the renewable brackish groundwater reaches around 60MCM/a, it has been almost fully developed in the southeastern part of the Azraq basin, Jordan Valley basin, Dead Sea basin and North Wadi Araba basin, as shown in Table2.2.2-1. The potential areas for the development of the renewable brackish groundwater are limited in the South Wadi Araba basin, Sirhan basin and Hammad basin. Total safe yield of these basins is expected to be around 10MCM/a to 15MCM/a.

2) Nonrenewable/Flowing Brackish Groundwater

Nonrenewable/flowing brackish groundwater inflows mainly into the Dead Sea and southern Jordan Valley. Total inflow amount is estimated at around 432MCM/a and its exploitable amount is estimated at around 265MCM/a to 300MCM/a (about 60% to 70% of inflow amount). The spring flow measurement records show that the brackish groundwater flow rate from the Lower Aquifer System has not been changed since 1930's in the Dead Sea escarpment as shown in Figure 2.2.3-5.



From WIS, Location of the springs is shown in "Salinity Map of the Lower Aquifer System"

Fig.2.2.3-5 Historical Change of the Spring Flow Rate in the Dead Sea Escarpment from the Lower Aquifer System (sandy facies aquifers)

It is obvious that the spring flow rate from the Lower Aquifer System (Kurnub Sandstone aquifer and Ram Group aquifer) has not been affected by the large-scaled abstraction from the same aquifer system in the Disi-Mudawara area.

3) Nonrenewable/Stagnant Brackish Groundwater

The storage volume of the nonrenewable/stagnant brackish groundwater is expected to be of huge amount and reaches around 238 billion cubic meter. Supposing that 10% of the storage is exploitable and development duration is limited for 50years, the exploitable amount of the nonrenewable/stagnant brackish groundwater is about 400MCM/a to 500MCM/a. This needs further investigations and studies for the nonrenewable/stagnant brackish groundwater. It should be also noted that the development of the nonrenewable/stagnant brackish groundwater is typical mining of the groundwater resources.

Table 2.2.3-4 Renewable Brackish Groundwater Potential in the Upper and Middle Aquifer System

Groundwater Basin	Aquifer Type	A) Assumed Safe Yield (S.Y., MCM/a)	B) Abstraction in 1998 based on WIS (MCM/a)	Balance (A-B, MCM/a)	Range of Salinity (TDS, mg/lit)	Range of Well Depth (m)	Range of Depth to Water (m)	Average Well Yield (m3/hr)
Amman - Zerqa	Ba, A7/B2	13	23	-10	1,000 to 2,500	50 to 500	20 to 250	50 to 180
Southwest of Azraq	A7/B2	10 to 12	7	3 to 5	1,000 to 1,700	150 to 500	75 to 300	50 to 120
Jordan Valley (Floor part)	All	16	40	-24	1,000 to 2,500	100 to 300	20 to 80	50 to 200
Dead Sea	A7/B2	9 to 12	16	-4 to -7	1,000 to 1,700	150 to 500	75 to 300	50 to 120
Wadi Araba (North & South)	All	8	4	4	1,000 to 5,000	50 to 400	40 to 120	18 to 108
Sirhan	B4/B5	5	0	5	1,000 to 2,500	150 to 700	45 to 300	20 to 90
Hammad	B4/B5	7	1	6	1,000 to 3,000	300 to 700	45 to 110	20 to 150
Total		**68 to 73**	**91**	**-18 to -23**				

Table 2.2.3-5 Nonrenewable/Stagnant Brackish Groundwater Potential in the Upper and Middle Aquifer System

Groundwater Basin	Aquifer Type	Assumed Storage Volume (billion c. m.)	Exploitable Volume (10% of Storage Volume, billion c.m.)	Range of Salinity (TDS, mg/lit)	Range of Well Depth (m)	Range of Depth to Water (m)	Average Well Yield (m3/hr)
North to Central part of Azraq	A7/B2	46	4.6	1,000 to 2,500	300 to 500	50 to 80	80 to 100
	*K	42	4.2	1,350 to 3,000	>650	<90	not yet assessed
Jafr	A7/B2	1.7	0.2	1,000 to 3,500	100 to 400	40 to 100	150 to 300
	*K	12	1.2	1,400 to 3,000	uncertain	uncertain	not yet assessed
	Khreim	88	8.8	1,200 to 5,000	170 to 500	100 to 250	not yet assessed
Sirhan	A7/B2	32	3.2	4,500 to 7,000	(>600) assumed	(100 to 300) assumed	(40 to 100) assumed
Hammad	A7/B2	16	1.6	1,500 to 3,200	320 to 700	250 to 270	25 to 50
Total		**238**	**23.8**				

*: Kurnub is classified into Middle Aquifer System in the eastern Part of Jordan

Table 2.2.3-6 Nonrenewable/Flowing Brackish Groundwater Potential in the Lower Aquifer System

Area		Aquifer Type	Reported and Assumed Potential (MCM/a)		Range of Salinity (TDS, mg/lit)	Range of Well Depth (m)	Range of Depth to Water (m)	Average Well Yield (m^3/hr)	Remarks
			Inflow Rate	Exploitable Amount					
Southern Jordan Valley Escarpment	Dier Alla	Z + R (Z receives upward leakage from underlying R)	40	30	7,500	350 to 400	20	>150	Detailed study was conducted by JICA in 1995.
	Hisban - Kafrein	Same as Above	70	45	5,000	350 to 400	Flowing (max. +80m above G.L.)	130 to 200	
	Other Areas	Same as Above	11	0 (not productive due to high salinity and low permeability)	6,000 to 9,000	350 to 400	Flowing	<100	
Dead Sea Escarpment	North	Z + R (+K) (Z receives upward leakage from underlying R)	186	110 to 130 (supposing 60% to 70% of Inflow Rate)	1,000 to 5,000	50 to 700	Flowing	300 to 1,000	Negative impacts to Zara and Ma'in springs should be assessed.
	South	K + R (Z is thin-out, K and R hydraulically connected)	136	80 to 95 (supposing 60% to 70% of Inflow Rate)	1,000 to 2,000 (locally <1,000?)	100 to 770	Flowing or near to surface	not yet assessed	Slightly brackish to almost fresh groundwater might be anticipated.
Total			444	265 to 300					

Note, K : Kurnub Sandstone Aquifer
Z : Zarqa G. Aquifer
R : Ram Aquifer

2.2.4 Groundwater Development Plan

(1) Total Groundwater Potential in Jordan

The total groundwater potential estimated based on present available data is summarized in Table 2.2.4-1 by governorate. Distribution of the groundwater potential is further divided into "Upland (UP)" and "Jordan Rift Valley (JRV)".

Table 2.2.4-1 Summary of Groundwater Potential by Governorates (Unit : MCM/a)

Gover-norate	Area	Renewable GW Potential	Assumed Fresh Non-renewable GW Potential	Assumed Brackish GW Potential	Assumed Total GW Potential	Remarks
Amman	UP	34	0	0	34	
	JRV	0	0	0	0	
	Total	34	0	0	34	
Zarqa	UP	47	0	0	47	
	JRV	0	0	0	0	
	Total	47	0	0	47	
Mafraq	UP	77	0	0	77	
	JRV	0	0	0	0	
	Total	77	0	0	77	
Irbid	UP	21	0	0	21	
	JRV	8	0	0	8	
	Total	29	0	0	29	
Ajloun	UP	2	0	0	2	
	JRV	0	0	0	0	
	Total	2	0	0	2	
Jerash	UP	8	0	0	8	
	JRV	0	0	0	0	
	Total	8	0	0	8	
Balqa	UP	6	0	0	6	1: after JICA, 1995
	JRV	13	0	75[1]	88	
	Total	19	0	75	94	
Madaba	UP	8	0	0	8	2 : from Deep Sandstone Aquifer
	JRV	1	0	120[2]	121	
	Total	9	0	120	129	
Karak	UP	15	11[3]	0	26	3 : from Lajoun Area (Deep S.S. Aq.)
	JRV	1	0	75[4]	76	
	Total	16	11	75	102	4 : from JV Escarpment (Deep S.S. Aq.)
Ma'an	UP	13	80[5] (>80)	0	93	5 : from Disi (Deep SS Aq.)
	JRV	1	5[6]	0	6	
	Total	14	85	0	99	6 : from new areas in Badia (Deep S.S. Aq.)
Tafielah	UP	11	0	0	11	
	JRV	1	0	0	1	
	Total	12	0	0	12	
Aqaba	UP	6	45[7] (>45)	0	51	7 : from Disi (Deep S.S. Aq.)
	JRV	2	0	0	2	
	Total	8	45	0	53	
Total	UP	248	136	0	384	
	JRV	27	5	270	302	
	Total	275	141 (>141)	270	686	

Note : JRV is defined as the areas below 300m in elevation.

(2) Renewable Groundwater Development

As described in section 2.2.2 and 2.2.3, the remained groundwater resources are very limited in Jordan. Since the abstraction of the renewable groundwater has exceeded its safe yield in Jordan, further development should be suspended principally. Furthermore, the reduction measures of abstraction should be taken immediately for the renewable groundwater resources.

However, the development of the renewable groundwater resource has been planned and some of them are included in the Investment Program. The renewable groundwater development schemes are as follows:

Table 2.2.4-1 Renewable Groundwater Development Schemes in Future

Project Name	Gover-norate	Status	Develop. (MCM/a)	Comp. Year	Project Outline	*Over Draft in Gov. (MCM/a)
Wadi Mousa Water Supply	Ma'an	on-going	6.6	2000	GW development of A7/B2 for tourism, surface water is also to be developed	9
Corridor Water Supply	Mafraq	under plan	9	2001	GW development of Basalt for Greater Amman area	14
El Lajoun Oil Shale Project	Karak	under exam.	13	up to 2020	GW development of A7/B2 for oil shale project, private sect.	13
Electric Power Station	Zarqa	under exam.	1	2005	GW development of A7/B2 for electric power st., private sect.	42
Industrial Park	Irbid	under exam.	7.5	2005	GW development of A7/B2 for industry, private sector	17

*Necessary reduction amount of groundwater abstraction in the Governorate
Source : Investment Program 2000 to 2010

It is very obvious that the Corridor Project will accelerate the groundwater level decline in the region because the present abstraction has greatly exceeded its safe yield by 14MCM/a. Therefore, the Corridor project should be regarded as urgent development for mitigating the water shortage in the capital area in the draught year.

Concerning the groundwater development for oil shale project at Lajoun, the BGR report in 1987 suggested that only the amount of about 5MCM/a can be withdrawn from A7/B2 aquifer, but even such small extraction will create a mining situation. Further, this report also recommended that the groundwater development of Kurnub-Ram aquifer (nonrenewable deep groundwater) should be done for this project instead of renewable groundwater development. In fact, it is expected that the nonrenewable/flowing brackish groundwater potential of 80MCM/a to 95MCM/a might exist in this area as shown in Table 2.2.3-6.

For other projects, the other water resources should be supplied in stead of the renewable groundwater.

It is strongly recommended that further development of the renewable groundwater should be restricted and be substituted by other water resources as much as possible even for the domestic and industrial purposes in order to prevent the precious renewable groundwater resource from its exhaustion.

(3) Development of Fresh Groundwater of Fossil Origin

It is anticipated some fresh groundwater resources is still remained in the deep aquifers.

1) Disi Amman Water Conveyer

As described in section 2.2.2, the potential of the nonrenewable fresh groundwater in the Ram aquifer is estimated at more than 125MCM/a for period of 50 years to 100 years. As the abstraction amount from the Ram aquifer is estimated at around 68MCM in 1998, it is considered that more than 57MCM/a are presently retained for the future development.

The water conveyance project of this water resource from Disi to Amman is in progress and it is scheduled to be completed in 2006. Its development amount is scheduled 125MCM/a by 2020.

2) Lajoun Wells

Three deep wells of more than 1,000m in depth were drilled recently in Lajoun area in Karak Governorate by Ministry of Water and Irrigation to investigate the deep groundwater contained in Ram aquifer. According to the drilling results, it is reported that abundant fresh groundwater was found in Ram Aquifer in this area.

Based on these findings, the deep groundwater development scheme named "Lajoun Wells" has been formulated and listed in the Investment Program. Five deep wells has been drilled and conduction pipe line has been constructed from Lajoun to Amman through Karak in August, 2001 in this scheme. The development amount is 11 MCM/a.

3) Deep Groundwater Development in Wadi Araba Area

Wadi Araba area is also one of the potential area for development of Ram aquifer. It is anticipated that the deep groundwater contained Ram aquifer may be fresh and high potential in Wadi Araba area. The study is on-going by Ministry of Water and Irrigation.

In addition to the inflow of the deep groundwater from the Jordanian side, it is inferred that the groundwater is flowing into the southern part of Wadi Araba from the Israeli side. Despite the impervious basement rocks crops out in Jordanian flank, some parts of the valley floor get wet because the groundwater table is very close to the ground surface. This phenomena shows that the groundwater recharge may be borne from the west (from Israeli flank) in these areas, since the precipitation is too low to form such wet lands in Wadi Araba area (less than 50mm/a).

Although, it is highly anticipated that the groundwater potential might exist in Wadi Araba area and its quantity and quality might be promising, the estimation of the potential cannot be done in this Study because of the lack of the data. Further study has been being waited in this area.

(4) Brackish Groundwater Development

In addition to the fresh groundwater of fossil origin, the brackish groundwater resource has not been intensively exploited yet and its potential will be promising.

1) Sustainability of Brackish Groundwater Development

From the standing point of the Sustainable Development, the mining development should be avoided as much as possible. In this sense, the development of the nonrenewable/stagnant brackish groundwater should be sustained at present and be reserved for the future water resources as mentioned in section 2.2.3.

The renewable brackish groundwater has been almost fully developed and the remaining potential is limited as mentioned in section 2.2.2.4. Therefore, the renewable brackish groundwater resources should be used to satisfy the local demands.

The nonrenewable/flowing brackish groundwater has not been exploited yet. It is anticipated that the natural inflow rate will be almost constant within at least hundreds years. In spite of the nonrenewable condition, the draw-down of the groundwater level caused by the development will reach stable condition if the abstraction amount will be restricted within the flowing amount. Therefore, it is concluded that the sustainable development of the nonrenewable/flowing brackish groundwater will be possible in the Dead Sea escarpment and southern Jordan Valley Escarpment area.

However, special attention should be paid for the intrusion of hyper-saline water from Dead Sea to the production wells in case that the well fields will be located along the Dead Sea coast.

2) Priority Areas for the Brackish Groundwater Development

The nonrenewable/flowing brackish groundwater mainly inflows into the Dead Sea and the southern Jordan Valley. These areas are the potential sites for the brackish groundwater development.

The potential of the brackish groundwater in the southern Jordan Valley (Hisban-Kafrein area) has been studied by JICA 1995. However, it is anticipated that much more potential might also remain in the Dead Sea Escarpment area as described below.

It seems that the groundwater salinity in the Lower Aquifer System may decrease southward as shown in Fig.2.2.3-4. Therefore, the southern Dead Sea escarpment area might be more promising than southern Jordan Valley area as the priority site for the brackish groundwater development if such tendency shown in Fig.2.2.3-4 is true. According to limited existing data, the groundwater salinity in the Lower Aquifer System might range around 1,000mg/lit to 1,500mg/lit and locally less than 1,000mg/lit in the southern Dead Sea escarpment as shown in Fig.2.2.3-4. If this figure represents actual condition, it is inferred that such low salinity brackish water can be utilized for all purposes including municipal uses by blending with other fresh water resources without desalination process.

In addition to the lower salinity, the brackish groundwater flow is a huge amount which reaches around 136MCM/a in this area as shown in Fig.2.2.3-2.

However, the data is very limited in the Dead Sea Escarpment area and the comprehensive study should be necessary to confirm the brackish groundwater potential in the Dead Sea Escarpment area.

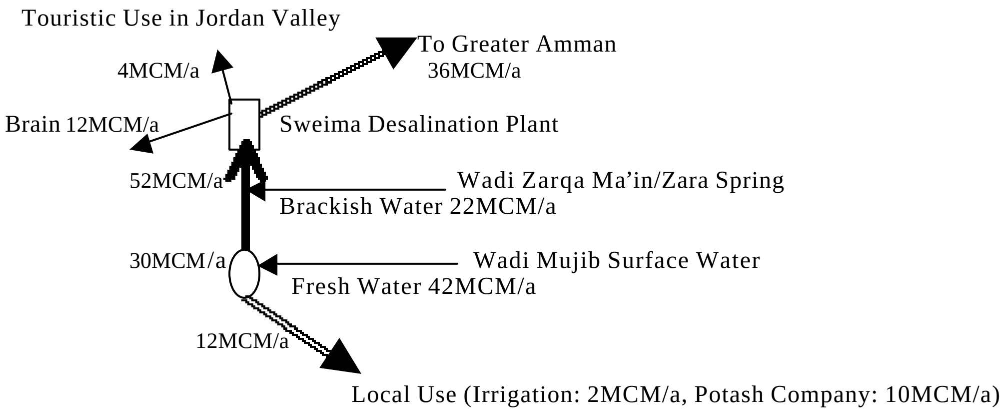
3) Brackish Groundwater Development Project

a. Hisban and Kafrein Desalination Plant

This project is planned based on the JICA Study conducted in 1995. Its maximum exploitable amount is 45MCM/a of about 5,000mg/lit in TDS according to the JICA study. The brackish groundwater will be abstracted and desalinated in Hisban and Kafrein area in this project. Desalinated water is scheduled to be pumped up to the Greater Amman area. The brine is planned to discharge to the Dead Sea through the open channel along Wadi Ijarfa.

b. Wadi Zarqa Ma'in, Zara Spring Project

This project aims to develop the brackish water from Wadi Zarqa Ma'in/Zara Spring and surface water from Wadi Mujib. The brackish spring water and fresh surface water will be mixed to decrease the salinity and desalinated at Sweima in South Jordan Valley. Desalinated water will be conveyed to the Greater Amman area through Hisban and Kafrein area as mentioned above. Planned development amount (incremental yield) is around 40MCM/a in which the surface water of 30MCM/a from Wadi Mujib will be included. Feasibility study is on-going by USAID. The schematic plan of this project is shown below:



c. Brackish Groundwater Development in Jordan Valley Floor

Abundant brackish groundwater is contained in Alluvium and Lisan Formation in the floor of the Jordan Valley. Its salinity ranges about 1,000mg/lit to 10,000mg/lit. Brackish groundwater in Jordan Valley floor is desalinated and used for irrigation by some private farmers. The amount of the desalinated water is still small around 1.5MCM/a, however it will be raised in future because the utilization of the desalinated water for the irrigation is economically viable according to the farmers.

d. Brackish Groundwater Development in Lajoun Area

The Fresh Fossil Groundwater has been exploited in the Lajoun area and it is anticipated that the potential of the brackish groundwater may be also high in the Kurnub Sandstone Aquifer in this area. Hence the potential of the brackish groundwater has not been clarified yet in this area, the detailed study should be done in future.

2.2.5 Groundwater Level Decline

(1) Tendency of Groundwater Level Decline

Hydrographs of the groundwater level are shown in Annex Report by groundwater basin. These figures show that the groundwater level decline can be recognized in every groundwater basin excepting Hammad Basin. The groundwater decline is still in progress. It seems that the groundwater level decline has already taken place in 1960's (ex. AL-1040 in Azraq basin) .

Declining rate of the groundwater level differs well to well and the largest declining rate is recorded by 1.6m/year at CD-1106 in Dead Sea Basin.

The historical flow rate change of the main springs are also shown in Annex Report by groundwater basin. It is notable that the main springs have dried up or severely reduced their flow rate in Yarmouk Basin, Amman-Zarqa Basin and Mujib Basin. The spring flow rate has not greatly reduced in general in the other basins except for few springs.

It is obvious that the regional groundwater level decline has been caused by over abstraction of the groundwater. However, it should be noted that the spring flow must be reduced even if the abstraction amount is kept within the safe yield because the groundwater potential includes the spring.

Continuous groundwater level decline is also observed at the rate of 0.6m/a to 1.5m/a in the Ram aquifer in the Southern Desert Basin because of its nonrenewable characteristics. The careful observation should be continued in order to verify the existing examination results for the determination of the safe yield of the Ram aquifer.

(2) Reduction Amount for Stopping the Groundwater Level Decline

It is obvious that the reduction of the renewable groundwater abstraction in the Upland is the sole solution to stop the regional groundwater level decline. The renewable groundwater resources must be exhausted and spoiled in future unless the reduction measures will be undertaken.

The renewable groundwater abstraction amount must be reduced to the safe yield. Table 2.2.5-1 shows the safe yield, actual abstraction amount and necessary reduction amount of groundwater abstraction by governorate.

As shown in this table, the reduction of the renewable groundwater abstraction should be done in almost all governorates excepting Jerash, Tafielah and Aqaba governorates. The necessary reduction amount is estimated at around 160 MCM/a at least in whole Jordan. Among them, the severe reduction will be required in Amman, Zarqa and Balqa governorates.

But, it is truly difficult to reduce the renewable groundwater abstraction because many complicated social effects will be raised if it will be implemented. Of course the reduction must be possible if drilling of the new wells and re-drilling of the old wells will be strictly prohibited because the life of wells are 20years to 30years in general. However, the reduction of the renewable groundwater abstraction will directly affect the farmer's life. The measures for the reduction of the renewable groundwater abstraction will be discussed in section 7.3 considering the institutional, legislative and social aspects.

Table2.2.5-1 Safe Yield, Actual Abstraction Amount and Necessary Minimum Reduction Amount of the Renewable Groundwater by Governorate

Governorate	Safe Yield (MCM/a)	a) Abstraction Amount in 1998 (MCM/a)	b) Necessary Minimum Reduction Amount (MCM/a)	Reduction Ratio (b/a, %)
Amman	34	62	28	45
Zarqa	47	89	42	47
Mafraq	77	91	14	15
Irbid	29	46	17	37
Ajloun	2	2	0	0
Jerash	8	4	0 (+4)	0
Balqa	19	47	28	60
Madaba	9	14	5	36
Karak	16	29	13	45
Ma'an	14	23	9	39
Tafielah	12	3	0 (+9)	0
Aqaba	8	6	0 (+2)	0
Total	**275**	**416** (Excluding Ram)	**156**	**38**

Note : The safe yield of the renewable groundwater is divided into governorates based on the distribution rate of the groundwater basin area in the governorates.

The figures of the safe yield employed median value in case that the values are ranging (ex. 14MCM/a to 18MCM/a → 16MCM/a).

Safe Yield means the sustainable development amount without causing continuous groundwater level decline.

2.2.6 Consideration on Sector Policy

Series of policies for the mitigation of the groundwater problems in Jordan are listed in "Groundwater Management Policy" issued in February, 1998. Sixty six (66) policies are presented in eleven fields as follows:

① On Resource Exploitation, ② On Monitoring,

③ On Resource Protection, Sustainability, and Quality Control,

④ On Resource Development, ⑤ On Priority of Allocation,

⑥ On Regulation and Control,

⑦ On Legislation and Institutional Arrangements,

⑧ On Research, Development and Technology Transfer,

⑨ On Shared Groundwater Resources, ⑩ On Public Awareness,

⑪ On Private Sector Participation

The policies cover all related fields and it is believed that the present problems on the groundwater encountered in Jordan will be almost solved after the successful implementation of these policies.

The present serious problems on the groundwater are "i. Regional groundwater level depletion caused by over abstraction exceeding its safe yield" and "ii. Regional groundwater quality deterioration such as increase of salinity and nitrate concentration caused by human activities including irrigation and sewage discharge". Such tendencies are mainly found in Amman/Zarqa Basin.

It is clear that the execution of the policies for solving these problems are urgent tasks in Jordan. The policies for solving the problems mentioned above are as follows and the higher priority should be given for execution of them.

(1) For Regional Groundwater Level Depletion / Over-abstraction

Policy No.

3., 11., 15.Reinforcement of monitoring system through a network observation wells

7. Assessment of the potential of the brackish groundwater as new resources

20. Limitation of withdrawal from the wells within their permit rate by force

43. Waging of campaigns against illegal well drilling

45. Installation of water meter on all wells

46. Prohibition of well licensing for agricultural purposes

47. Application of fee and charge system to control of over-pumping

(2) For Regional Groundwater Quality Deterioration

Policy No.

3, 11, 15. Reinforcement of monitoring system through a network observation wells

8. Protection of recharge areas against pollution caused human activities

24. Regulation of the type and application rate of fertilizers, pesticides, and sludge usage within the recharge areas

In addition to policy 24, the policies designated in "Irrigation Water Policy" should be implemented for the sake of groundwater quality protection in parallel with execution of the Groundwater Management Policies mentioned above. It is inferred that the infiltrated irrigation return water including leaching water might be one of the main causes of the regional groundwater quality deterioration. The policies related to the groundwater quality protection included in "Irrigation Water Policy" are as follows:

Policy No. of Irrigation Water Policy

3. Sustainability of agriculture shall be compromised only if it threatens the sustainable use of groundwater resources. Potential pollution of underlying depleted aquifers is one of the reasons to prompt such compromise.

14. Application of advanced methods such as drip irrigation, spray irrigation, micro-sprinkler irrigation for reduction of irrigation water

16. Improvement of irrigation network operation system

20. Encouragement of farmers to monitor soil moisture to determine the timing for irrigation water application

32, 36. Metering of irrigation water

44. Discouragement of planting of high water requirement crops

48. Pursuit of irrigation network automation to detect and to reduce the leakage losses