4.3 Hydro-Geological Environment of Study Area

4.3.1 Hydrogeology and Aquifer System

Geological stratigraphy of the Study Area is shown in Table 4.3.1, while the Study Area's geological and hydrogeological maps are presented in Figure 4.3.1 and Figure 4.3.2, respectively.

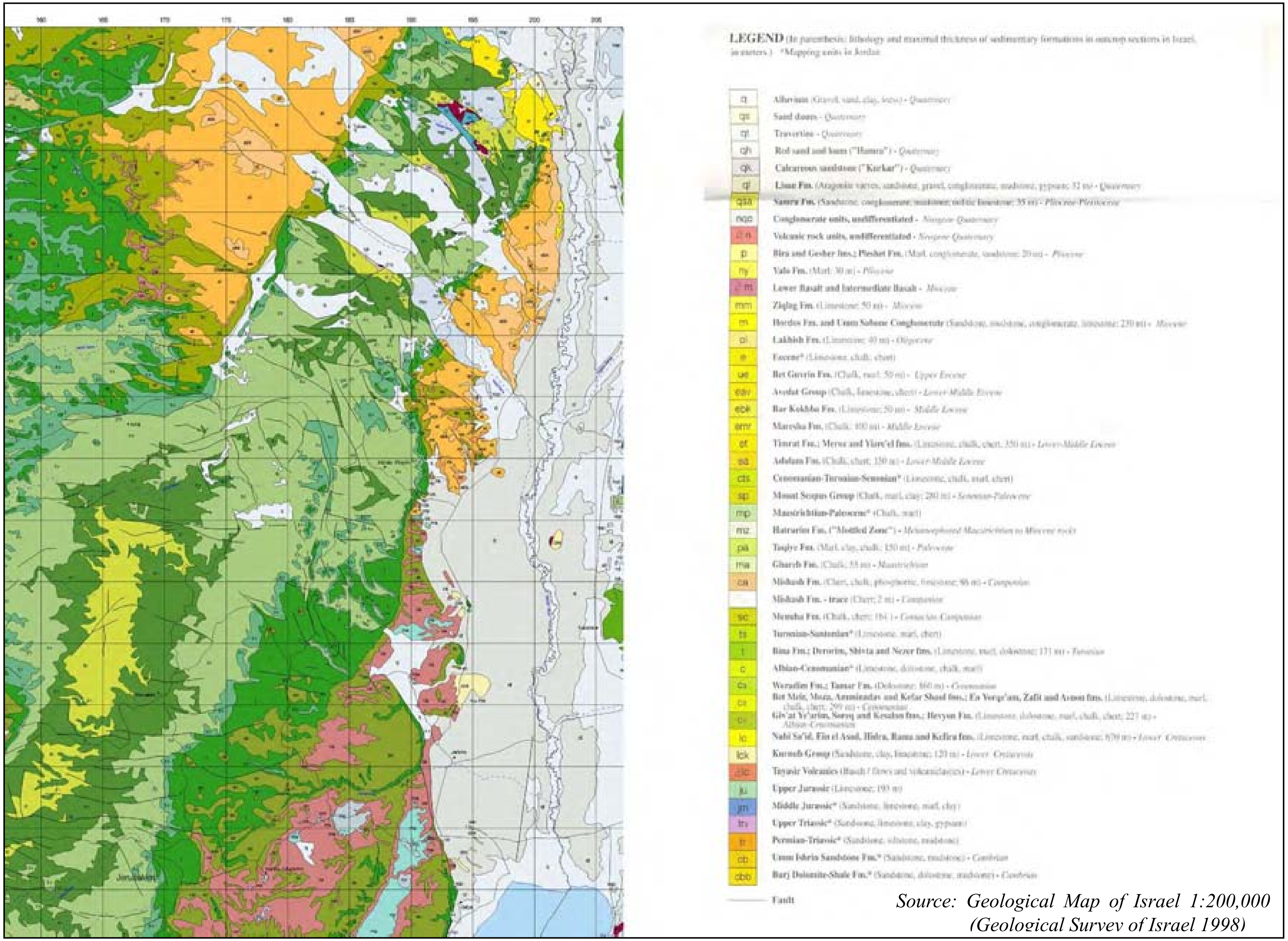
Table 4.3.1 Geological Stratigraphy

Period	Age	Graphic Log	Typical Lithology	Formation (Palestine terminology)	Sub-Formation	Group	Formation and Group (Israeli Terminology)	Hydro-stratigraphy	Typical Thickness (m)
Quaternary	Holocene		Nari (surface crust) and alluvium gravels and fan deposits	Alluvium		Dead Sea	Alluvium	Local Aquifer	0 - 100
	Pleistocene		Thinly laminated marl with gypsum bands and poorly sorted gravel and pebbles	Lisan			Kurkar Group (W.A. Basin) / Samra and Lisan formations (E.A. Basin)	"Aquitard"	10 - 200
Tertiary – Neogene	Pliocene - Miocene		Conglomerates, marl, chalk clay and limestone	Beida		Neogene Conglomerates	Saqiye Group	Saqiye (Aquitard) Israel / Beida (Local Aquifer) Palestine	20 - 200
Tertiary – Paleogene	Eocene (Lower - Middle)		Reefal limestone	Jenin	Jenin 4	Jenin	'Avedat Group	Aquifer	90 - 670
			Nummulitic bedded limestone		Jenin 3				
			Nummulitic limestone, chalk		Jenin 2				
			Chalk, nummulitic limestone		Jenin 1				
	Paleocene		Marl, chalk	Khan Al-Ahmar		Nablus	Mt. Scopus Group	Aquitard (Local Aquifer)	40 - 150
Cretaceous – Upper – Senonian	Maastrichtian - Danian		Chalk, marl						
	Campanian		Main chert, phosphate	Wadi Al-Qilt				Aquiclude	10 - 120
	Coniancian-Santonian		Chalk and chert	Abu Dis					0 - 450
	Turonian		White limestone, stilolithes dolomite and thin bedded limestone	Jerusalem		Ramallah (West Bank)	Bina	Mountain Aquifer System	40 - 190
	Cenomanian – Upper		Dolomite, soft	Bethlehem	Upper		Weradim	Upper Aquifer	50 - 210
			Chalky limestone, chalk		Lower		Kefar Sha'ul		
			Karstic dolomite	Hebron			Amminadav		65 - 160
	Cenomanian – Lower		Yellow marl	Yatta	Upper / Middle		Moza	"Aquitard"	50 - 125
			Limestone & dolostone, chalk, (clay)		Lower		Beit Meir		
Cretaceous – Lower	Albian		Reefal limestone	Upper Beit Kahil	UBK2		Kesalon	Lower Aquifer	10 - 20
			Dolomite limestone, interbedded with marl		UBK1		Soreq		60 - 130
			Dolomite	Lower Beit Kahil	LBK2		Giv'at Ye'arim		40 - 90
			Karstic limestone		LBK1		Kefira		100 - 160
			Marl, marly nodular limestone	Qatana		Kobar	Qatana	Aquitard	42
			Marly limestone and limestone	Ein Qinya			Ein Qinya	Aquitard (Local Aquifer)	55
	Aptian		Shale	Tammun			Tammun	Aquiclude (Local Aquifer)	300+
			Shale and limestone	Ein Al-Assad					20+
			Marly limestone, sandy	Nabi Sa'id		Kurnub	Hatira		20+
	Neocomian		Sandstone	Ramali				Aquifer	70+
			Volcanics	Tayasir					35
Jurassic	Oxfordian		Marl interbedded with chalky limestone	Maleh	Upper Maleh	-	'Arad Group	Aquitard	100 - 200
			Dolomitic limestone, jointed and karstic		Lower Maleh	-		Aquifer	50 - 100

LEGEND

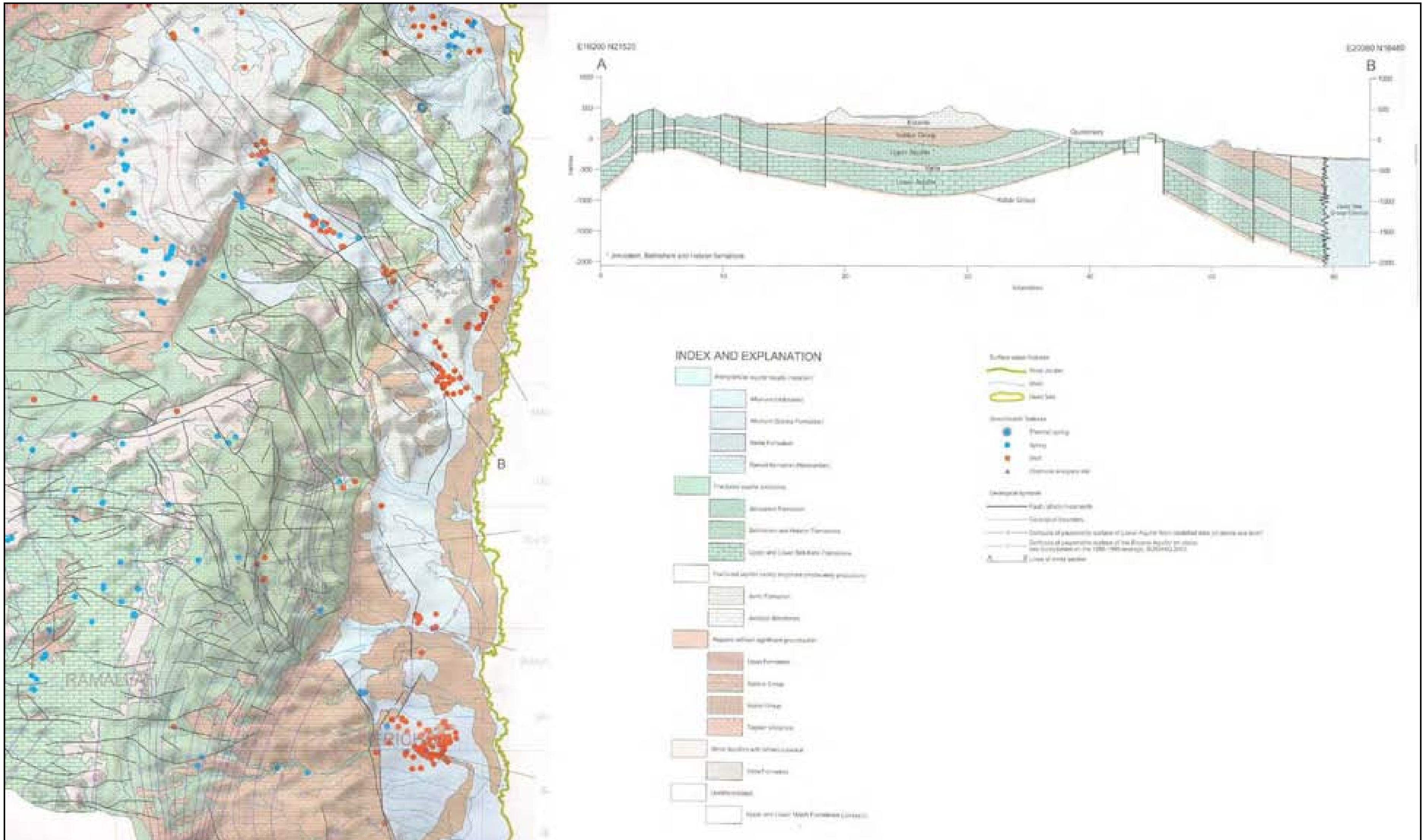
- Dolomite
- Limestone
- Marl
- Conglomerate
- Megafauna
- Flint concretions
- Chalk
- Nari
- Sandstone
- Volcanics

Source: Hydrogeological Map of the West Bank (PWA 2004)



Source: Geological Map of Israel 1:200,000 (Geological Survey of Israel 1998)

Figure 4.3.1 Geological Map of the Study Area



Source: Hydrogeological Map of the West Bank (PWA 2004)

Figure 4.3.2 Hydrogeological Map and Cross Section of the Study Area

The Study Area is divided into the lowland part of sea level, -200 m to -300 m along Jordan River, and the mountainous regions, 600 m - 900 m above sea level. The Quaternary deposits are mainly distributed in the lowland area along Jordan River. Miocene - Pliocene conglomerate is distributed in some parts of this region. The mountainous region consists mainly of limestone and partly chalks, dolomite, and charts, deposited during the Jurassic to Eocene geological age.

The aquifer of the Study Area is roughly divided into the following five layers.

(1) Quaternary Aquifer

In Quaternary aquifer, Samra formation of Pleistocene, which consists mainly of gravel and sand, has interred relation with Lisan formation mainly consisting of marl. The Samra formation is formed from confined aquifer, whereas the Lisan formation is formed from confined beds in the lowland area of JRRV. Local Holocene gravel aquifer is distributed along the fan and Wadi,.

(2) Neogene Aquifer

Neogene aquifer is composed of Beida Formation between Miocene to Pliocene, which consists mainly of conglomerates and partly marl and chalk. This aquifer is distributed in the northern part of the Study Area.

(3) Eocene Aquifer

Eocene aquifer consists mainly of limestone and partly chalk. This aquifer is widely distributed in northern part of the Study Area. A lot of springs originate from this aquifer and are scattered around Wadi Far'a and Nablus.

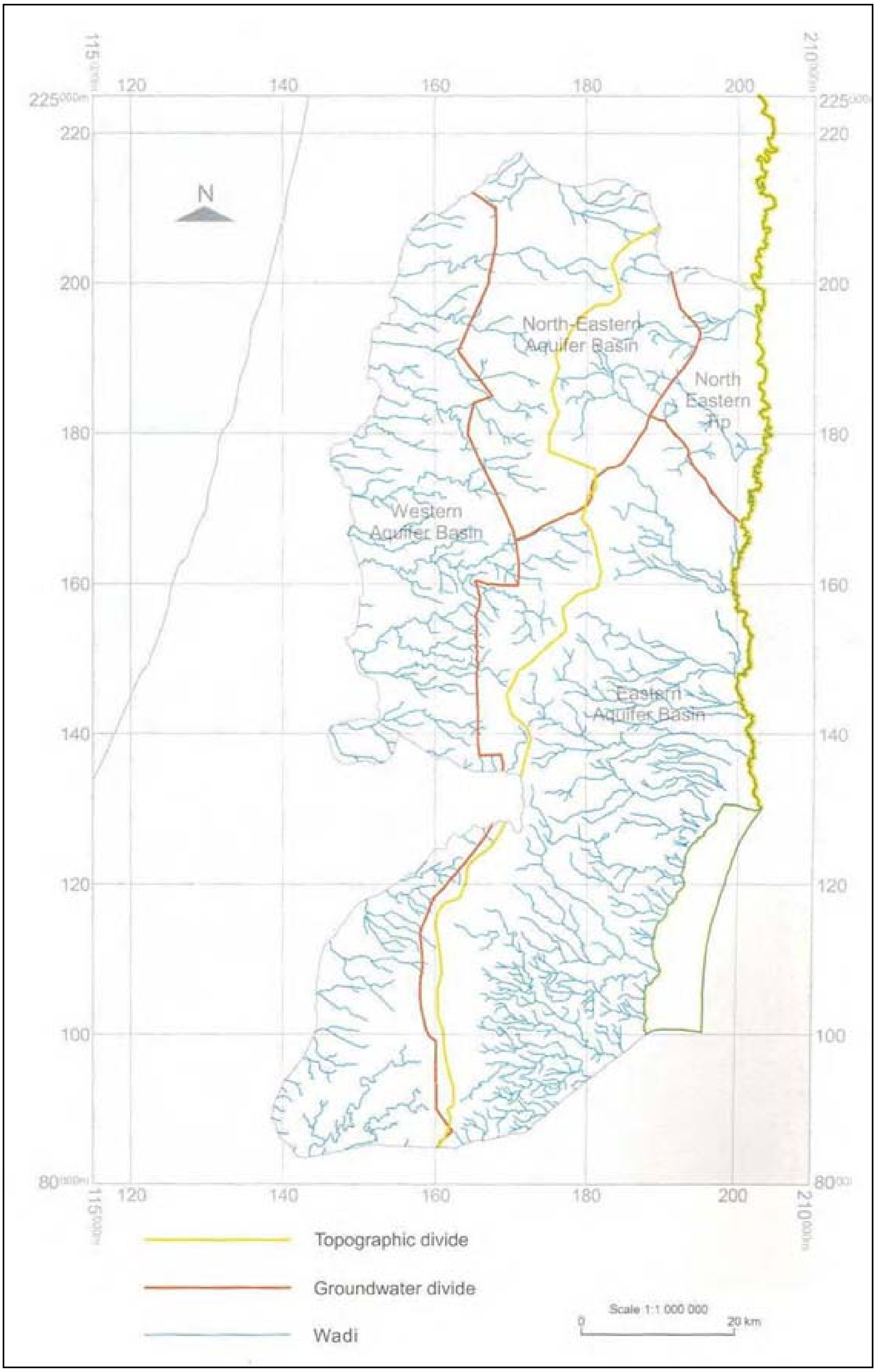
(4) Upper Cretaceous Aquifer

Upper Cretaceous aquifer constitutes the Jerusalem formation, Bethlehem formation, and Hebron formation. This was accumulated during the late stage of Cretaceous, and consists mainly of limestone, chalk and dolomite. This aquifer is widely distributed in the Study Area, and is also a major groundwater source of the Quaternary aquifer.

(5) Lower Cretaceous Aquifer

Upper and lower Beit Kahil formation accumulated in the early stage of Cretaceous, which forms the Lower Cretaceous Aquifer consisting mainly of limestone and partly dolomite and marl. This aquifer appears in the northern part of the Study Area.

Groundwater basin in the study is divided into Eastern Basin and North Eastern Basin, with anticline syncline structure. It means that the basin of surface water and groundwater are differed each other. The watershed of surface water and groundwater is shown in Figure 4.3.3.



Source: Hydrogeological Map of the West Bank (PWA 2004)

Figure 4.3.3 Watershed Division of Surface Water and Groundwater

4.3.2 Hydraulic Parameter of Aquifer

The hydraulic parameters of the eastern aquifer in and around Jericho are shown in Table 4.3.2. The pumping test data and the hydraulic parameter, which was analyzed based upon the Jacob method, are shown in Table 4.3.3.

Table 4.3.2 Hydraulic Parameters of Eastern Aquifer

Well Name	Coordinate		Static Water Level	Pumping Rate		Hydraulic Parameter	
	X	Y		m^3/hr	m^3/day	T (m^2/day)	S
19-13/012T	196	138				232	10^{-2}
19-13/015	196.10	139.51	42.105	76.2	1828.8	24.5	$2.46x10^{-2}$
19-14/008	195.19	140.33				60-193	10^{-1}
19-14/010	195.22	140.61	56.6	27.6	662.4	332	$5.05x10^{-5}$
						21.5	$5.41x10^{-3}$
19-14/052	195.68	140.98	60.81	36.0	864.0	502.4	$6.24x10^{-5}$
19-14/071	196.87	140.08				339	$0.9x10^{-4}$
						308	$0.9x10^{-4}$
						2030	$0.8x10^{-2}$
						1629	$1.1x10^{-2}$
19-14/081	197.06	142.31	26.96	43.2	1036.8	167.1	$1.02x10^{-1}$
19-14	196.87	140.09				143	10^{-3}
19-14	197.06	142.31				315-452	10^{-5}

Data Source: PWA, Analysis: JICA Study Team

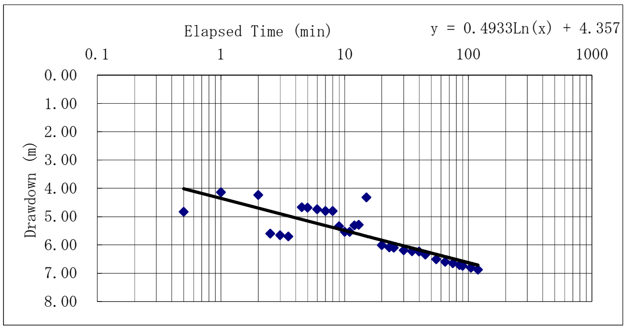
The pumping tests are executed with considering a pumping rate of approximately 1,000 m^3/day. The coefficients of transmissibility indicate that there are very wide values due to the interred relation between Samra formation and Lisan Formation and also many variations of gravel aquifer's thickness.

The hydraulic parameters of Mesozoic - Tertiary aquifer have not been obtained. The pumping amounts of each well are significant. This aquifer consists mainly of limestone, and the groundwater flows through the crack and cave of the limestone. Therefore, it is imaginable that the wells with limestone cave or crack would contain a large amount of groundwater.

Table 4.3.3 (1) Pumping Test Data and the Result of Analysis – (19-14/081)

Well Name	19-14/081
Coodinate(x)	197.06
Coodinate(y)	142.31
Date	6/4/99
Static Water Level	25.96

Elapsed Time (min)	Water Level (m)	Drawdown (m)	Pumping Rate (m^3/hr)
0.5	30.79	4.83	
1	30.10	4.14	
2	30.20	4.24	
2.5	31.56	5.60	
3	31.62	5.66	
3.5	31.66	5.70	
4.5	30.63	4.67	
5	30.64	4.68	
6	30.70	4.74	
7	30.76	4.80	
8	30.76	4.80	
9	31.30	5.34	
10	31.50	5.54	
11	31.50	5.54	
12	31.27	5.31	
13	31.25	5.29	
15	30.28	4.32	
20	31.97	6.01	
23	32.05	6.09	
25	32.06	6.10	
30	32.15	6.19	43.2
35	32.18	6.22	
40	32.20	6.24	
45	32.30	6.34	43.2
55	32.47	6.51	
65	32.56	6.60	
75	32.61	6.65	
85	32.67	6.71	
90	32.70	6.74	
105	32.77	6.81	
120	32.84	6.88	

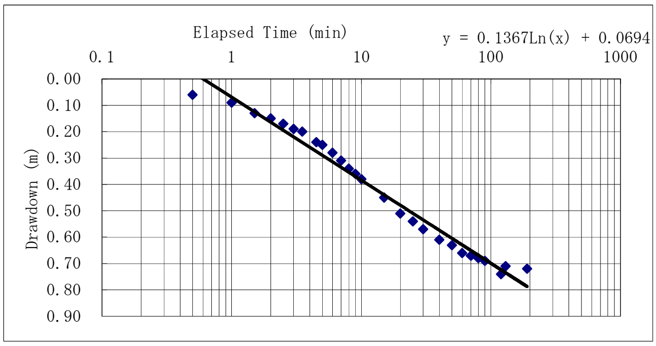


T=2.3Q/4$\pi\Delta$s
=6.96 m2/hr =167.1m2/day
S=2.25Tt/r_0^2
=1.02x10^{-1}

Table 4.3.3 (2) Pumping Test Data and the Result of Analysis – (19-14/052)

Well Name	19-14/052
Coodinate (x)	195.68
Coodinate (y)	140.98
Observation Well	19-14/054
Distance (m)	674
Date	24/3/99
Static Water Level	60.81

Elapsed Time (min)	Water Level (m)	Drawdown (m)	Pumping Rate (m^3/hr)
0.5	60.87	0.06	36
1	60.90	0.09	
1.5	60.94	0.13	
2	60.96	0.15	
2.5	60.98	0.17	
3	61.00	0.19	
3.5	61.01	0.20	
4.5	61.05	0.24	
5	61.06	0.25	
6	61.09	0.28	
7	61.12	0.31	
8	61.15	0.34	
9	61.17	0.36	
10	61.19	0.38	
15	61.26	0.45	
20	61.32	0.51	
25	61.35	0.54	
30	61.38	0.57	
40	61.42	0.61	
50	61.44	0.63	
60	61.47	0.66	
70	61.48	0.67	
80	61.49	0.68	
90	61.50	0.69	
120	61.55	0.74	
130	61.52	0.71	
190	61.53	0.72	



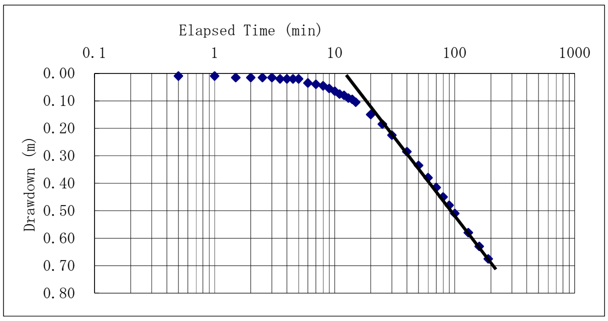
T=2.3Q/4$\pi\Delta$s
=20.93 m2/hr =502.4m2/day
S=2.25Tt/r_0^2
=6.24x10^{-5}

Data Source: PWA Database Analyzed by JICA Study Team

Table 4.3.3 (3) Pumping Test Data and the Result of Analysis – (19-13/015)

Well Name	19-13/015
Coodinate (x)	196.10
Coodinate (y)	139.51
Observation Well	19-13/055
Distance (m)	164
Date	14/4/99
Static Water Level	42.105

Elapsed Time (min)	Water Level (m)	Drawdown (m)	Pumping Rate (m^3/hr)
0.5	42.12	0.01	76.8
1	42.12	0.01	
1.5	42.12	0.02	
2	42.12	0.02	
2.5	42.12	0.02	
3	42.12	0.02	
3.5	42.13	0.02	
4	42.13	0.02	
4.5	42.13	0.02	
5	42.13	0.02	
6	42.14	0.04	
7	42.15	0.04	
8	42.15	0.05	76.6
9	42.16	0.05	
10	42.17	0.07	
11	42.18	0.08	
12	42.19	0.08	
13	42.20	0.09	
14	42.20	0.10	
15	42.21	0.11	
20	42.26	0.15	76.2
25	42.29	0.19	
30	42.33	0.23	
40	42.39	0.29	76.2
50	42.44	0.34	
60	42.49	0.38	74.4
70	42.52	0.42	
80	42.56	0.45	70.2
90	42.59	0.48	73.8
100	42.62	0.51	75.0
130	42.69	0.58	72.0
160	42.74	0.63	72.0
190	42.78	0.68	75.0



$T=2.3Q/4\pi\Delta s$
$=24.5$ m2/hr $=587.2$m2/day
$S=2.25Tt/r_0^2$
$=2.46\times10^{-2}$

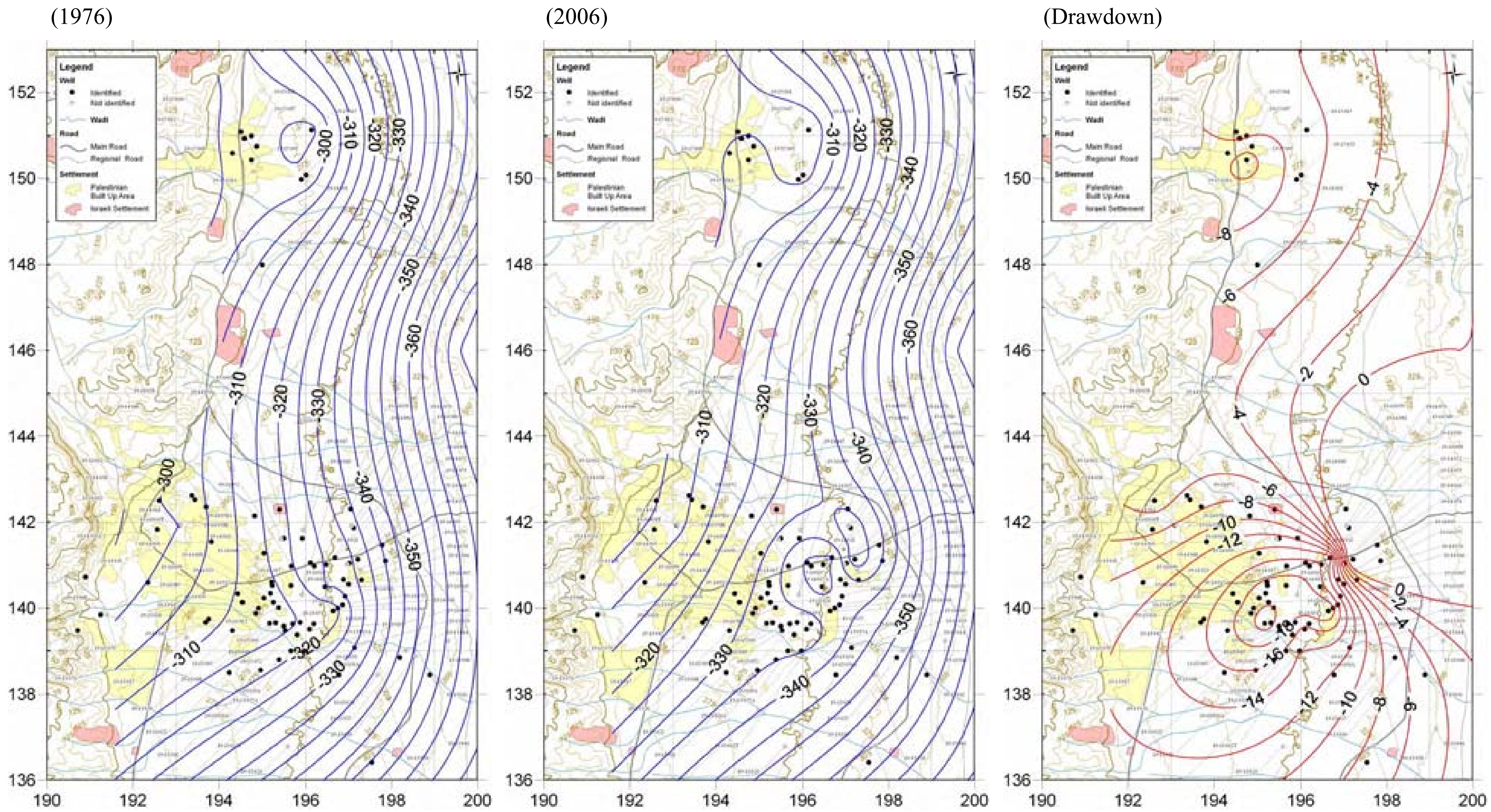
Data Source: PWA Database Analyzed by JICA Study Team

4.3.3 Groundwater Flow

(1) Groundwater Distribution and Flow Direction

Figure 4.3.4 shows a contour map of the groundwater level in and around Jericho.

The groundwater level around Jericho is about GL-50 m. The groundwater of Quaternary aquifer flows from the mountainous areas towards the Jordan River. The groundwater level in 2006 has decreased by about 20 m, or less from that in 1976.



Data Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.4 Groundwater Level Contour Map around Jericho City

(2) Annual and Seasonal Changes of Groundwater Level

The annual and seasonal changes of groundwater level are summarized below.

1) Eastern Basin

<u>Quaternary Aquifer</u>

The annual and seasonal changes of groundwater level are shown in Figure 4.3.5. The groundwater level shows a decrease tendency. An increase tendency is observed during the 1990's due to large amount of rainfall in 1992. The rainfall affects the groundwater level with a time lag of about one year in and around Wadi Qilt, and about two to three years in the northern part of Jericho. It is presumed that the groundwater recharge source in this region is at considerable distance. On the other hand, there is a slight time delay in the northern part of this region, and precipitation recharges rapidly to the groundwater.

<u>Neogene Aquifer</u>

A decrease tendency of groundwater level is not observed in this aquifer. Indication of excessive pumping is also not recognized so far. The precipitation rapidly recharges to the groundwater.

<u>Eocene Aquifer</u>

The groundwater level shows a decrease tendency. An increase tendency is found during the 1990's due to the large amount of rainfall in 1992. However, the groundwater level changes back to a decrease tendency after 2000. Because the response from precipitation to groundwater level is not considerable, the recharge speed is presumed to be slow. Excessive pumping from the groundwater will be a future concern.

<u>Upper Cretaceous Aquifer</u>

The groundwater level of this aquifer shows a similar tendency change as the Quaternary aquifer. This layer is a major recharge source of the groundwater of Quaternary aquifer distributed in JRRV. This is also closely related to Quaternary aquifer, and indication of excessive pumping is evident.

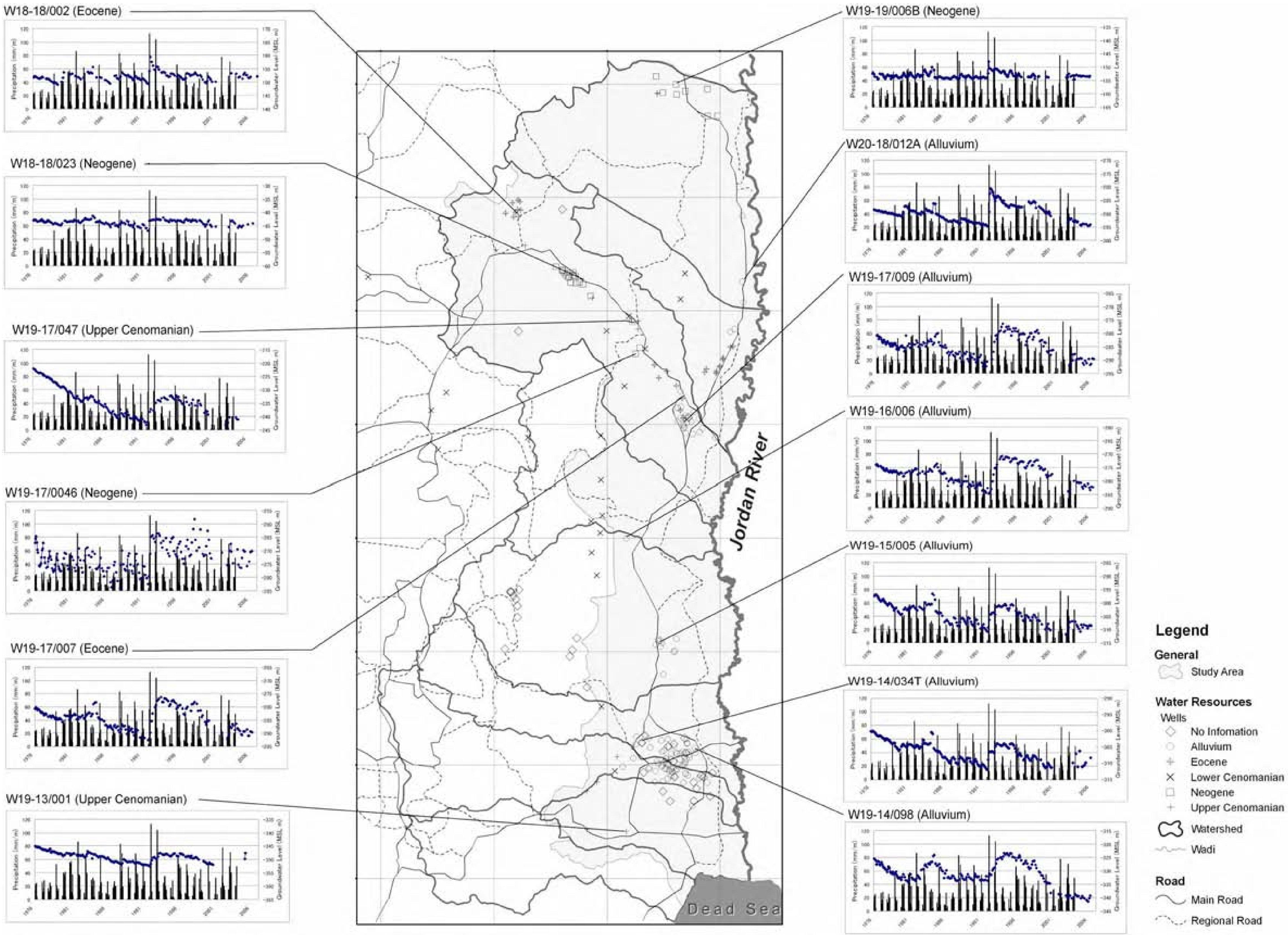
2) North Eastern Basin

<u>Neogene Aquifer</u>

A decrease tendency of groundwater level is not recognized. There is no indication of excessive pumping at present. The response from precipitation to groundwater level is also relatively swift. Thus, precipitation rapidly recharges to the groundwater.

<u>Eocene Aquifer</u>

A decrease tendency of the groundwater has not been found, because the groundwater level in this layer is similar to Neogene aquifer. The response with precipitation and groundwater level is also comparatively swift. Thus, precipitation rapidly recharges to the groundwater.



Source: PWA Database Analyzed by JICA Study Team

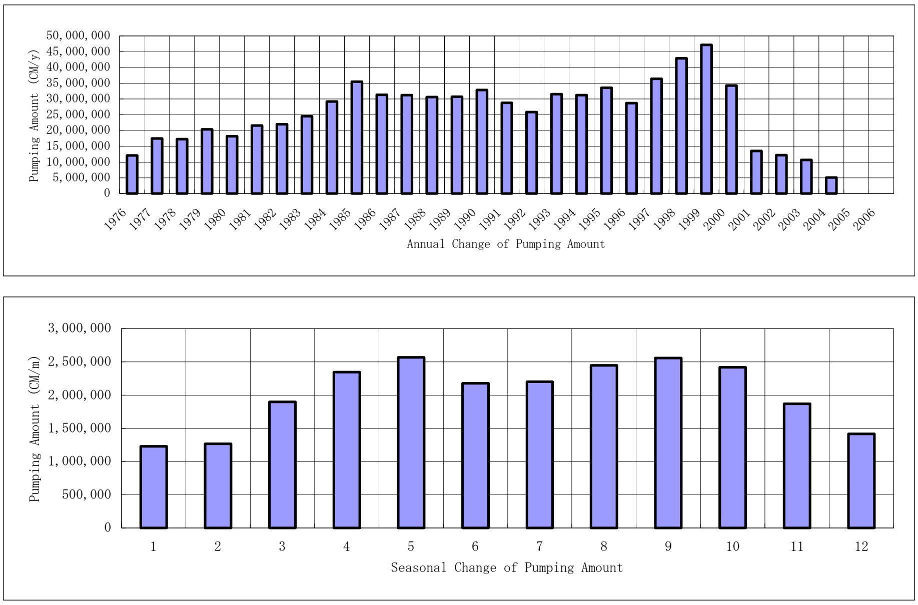
Figure 4.3.5 Annual and Seasonal Change of Groundwater Level

4.3.4 Groundwater Use

The groundwater uses of the Eastern Basin and the North Eastern Basin are summarized as follows.

(1) Eastern Basin

The annual and seasonal changes of groundwater use of the Eastern Basin are shown in Figure 4.3.6.

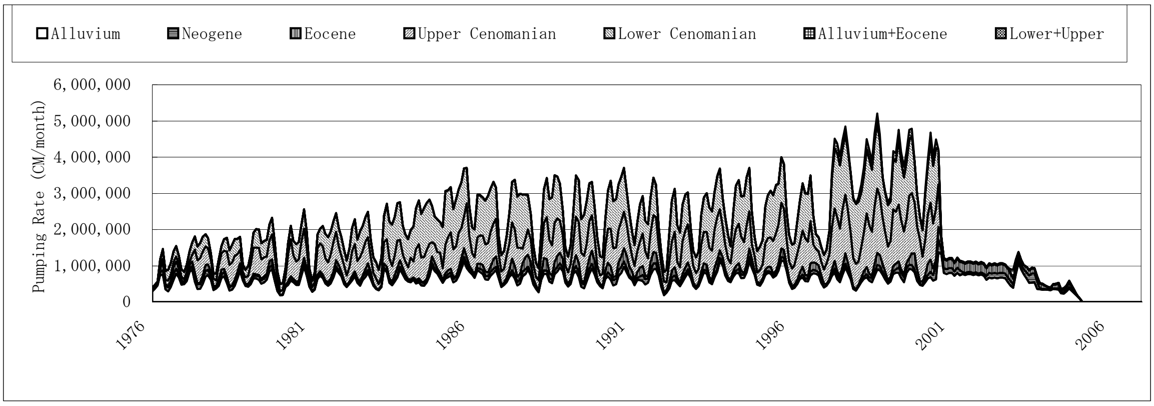


Source:PWA Database Analyzed by JICA Study Team

Figure 4.3.6 Annual and Seasonal Changes of Groundwater Use（Eastern Basin）

The pumping amount of the Eastern Basin shows the increase tendency from 1970's to the middle of 1980's, and has leveled-off briefly during the year afterwards. The pumping amount rose again in the latter half of 1990's and the peak of groundwater use reached about 50 MCM/year in 1999. The pumping amount decreased sharply after 2000 which is expected on incomplete recording. Considering seasonal change, the pumping amount decreased in the rainy season of December to February and the fallow period of June and July, and increased in April to May and in August to October.

The seasonal change of the groundwater use in each aquifer is shown in Figure 4.3.7. Pumping from Upper Cretaceous, Lower Cretaceous and Quaternary Aquifer appeared significant. The peak pumping amount exceeded 5,000,000 m^3/month. The groundwater level of this aquifer indicates a long-term decrease tendency, where excessive pumping is a concern.

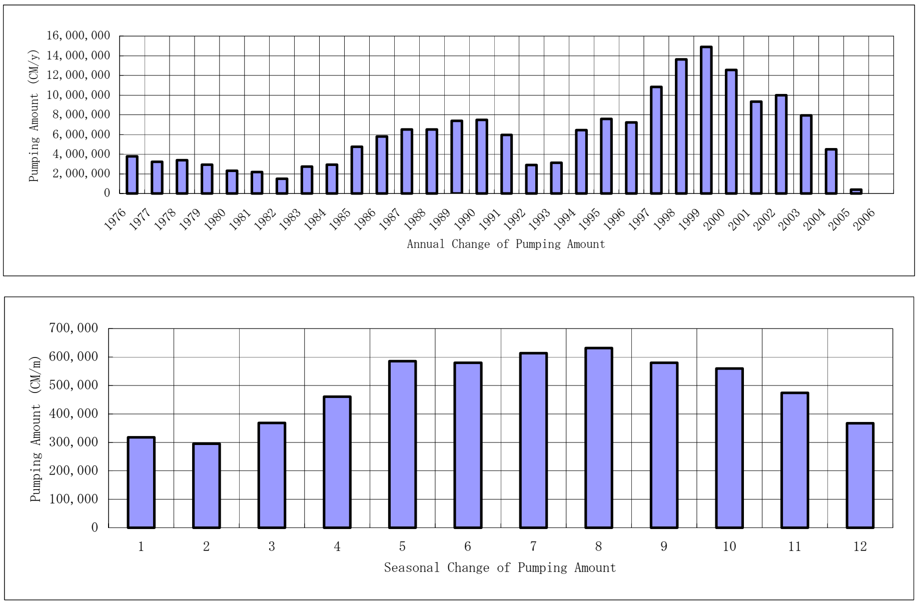


Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.7 Annual and Seasonal Change of Groundwater Use (Eastern Basin)

2) North Eastern Basin

The annual and seasonal changes of groundwater use of the North Eastern Basin are shown in Figure 4.3.8.

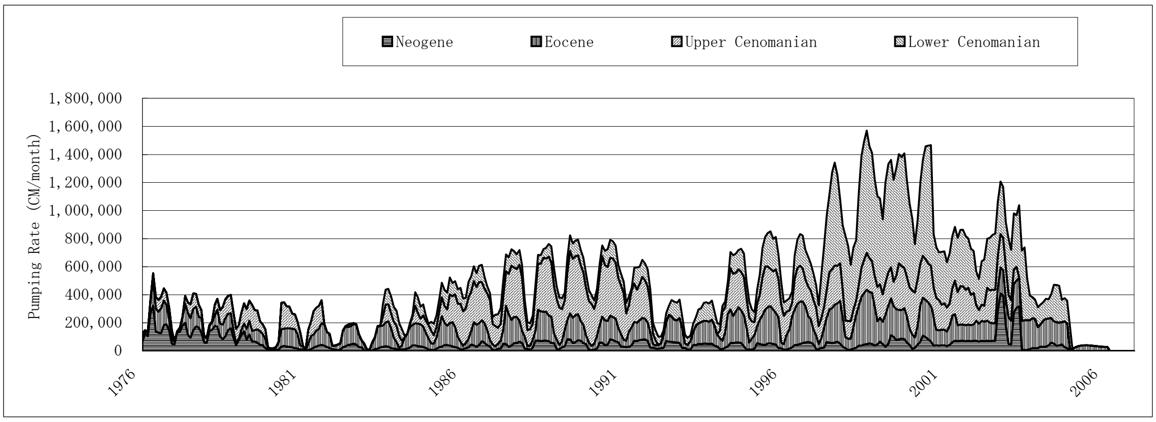


Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.8 Annual and Seasonal Changes of Groundwater Use (North Eastern Basin)

The pumping amount of the North Eastern Basin shows the increase tendency since 1980's, except for a specific period. The pumping amount rises again in the latter half of 1990's with about 15,000,000 m^3/year of peak groundwater use obtained in 1999. The pumping amount has then decreased sharply after 2000. This indicates that the record seems incomplete.

The annual changes of groundwater use in each aquifer are shown in Figure 4.3.9.



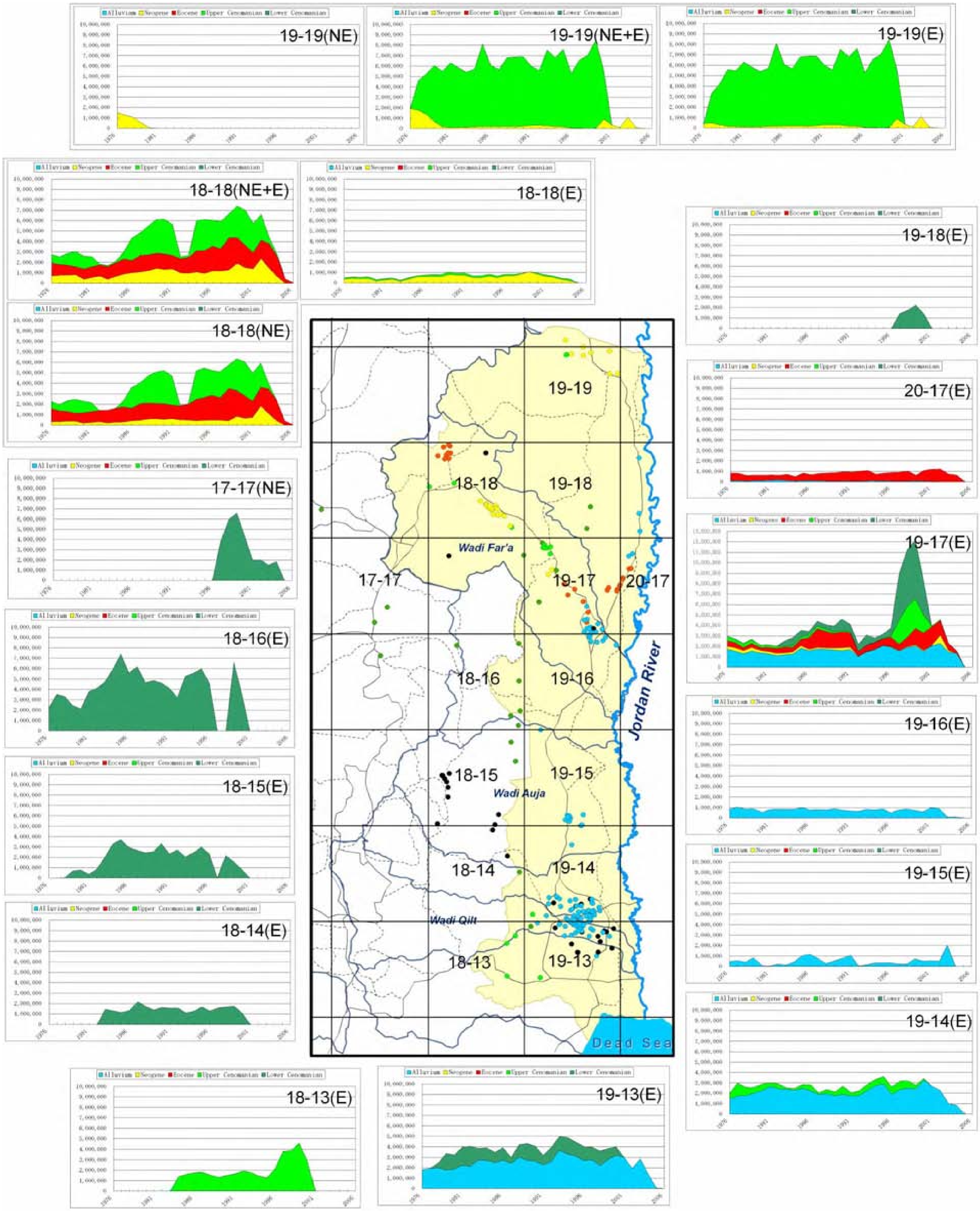
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.9 Annual Changes of Groundwater Use（North Eastern Basin）

Previously, the main aquifers for groundwater use include Upper Cretaceous and Eocene. However, pumping from Lower Cretaceous aquifer increased recently. The peak pumping amount reaches about 1,600,000 m^3/month.

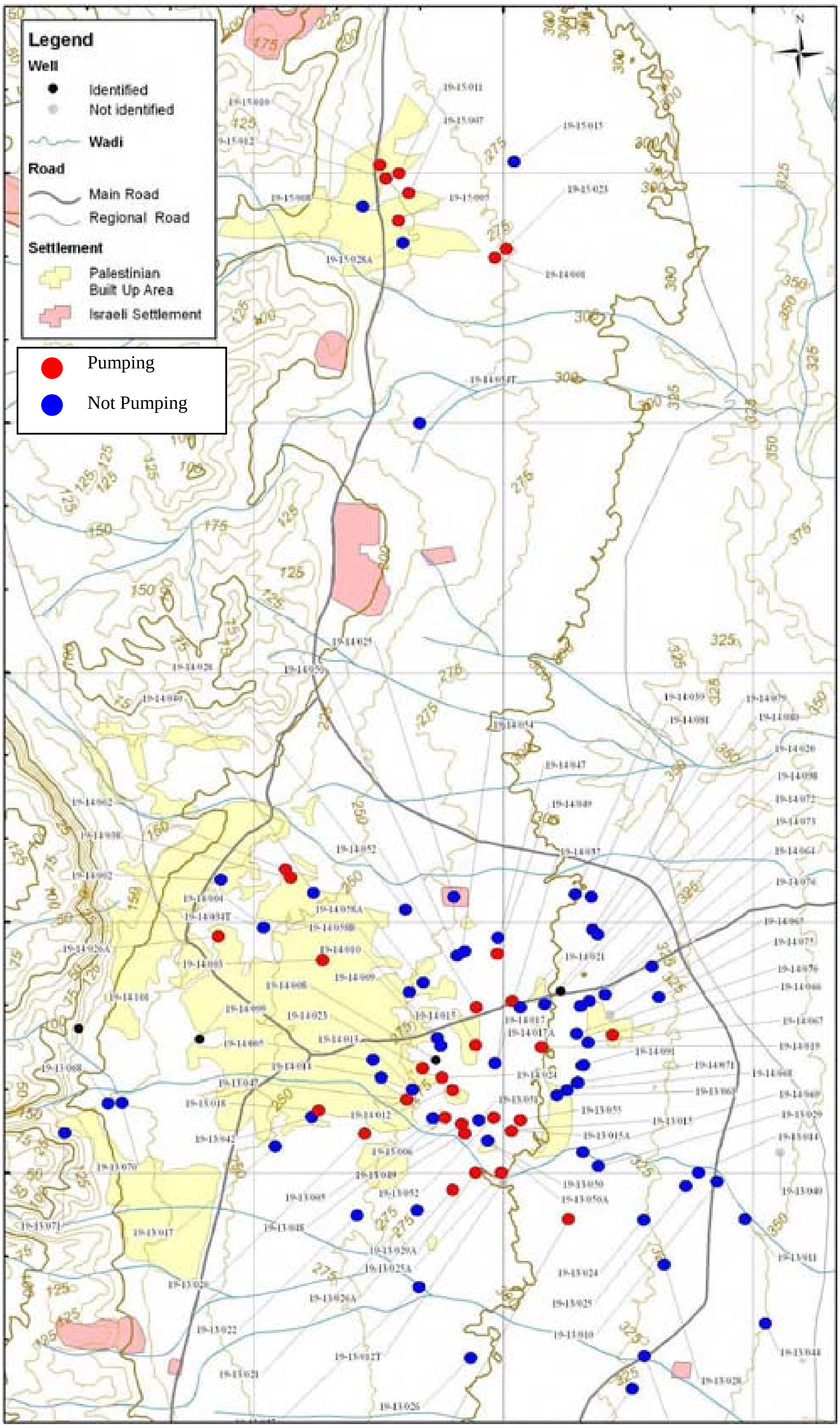
The distribution map of the existing wells and the annual change of the groundwater use in each mesh and aquifer are shown in Figure 4.3.10. The existing wells are mainly located at Jericho and Jiftlik area along Jordan Rift Valley. However, there are a lot of groundwater uses in the limestone region in the mountainous regions. The discharge of the well located at the limestone area is very large compared with that of the well located at Quaternary deposits area.

The operation of wells in Jericho, Jiftlik and Far'a area is shown in Figure 4.3.11. More than a half of the wells in Jericho area are not operational due to excessive pumping and increase in salinity.



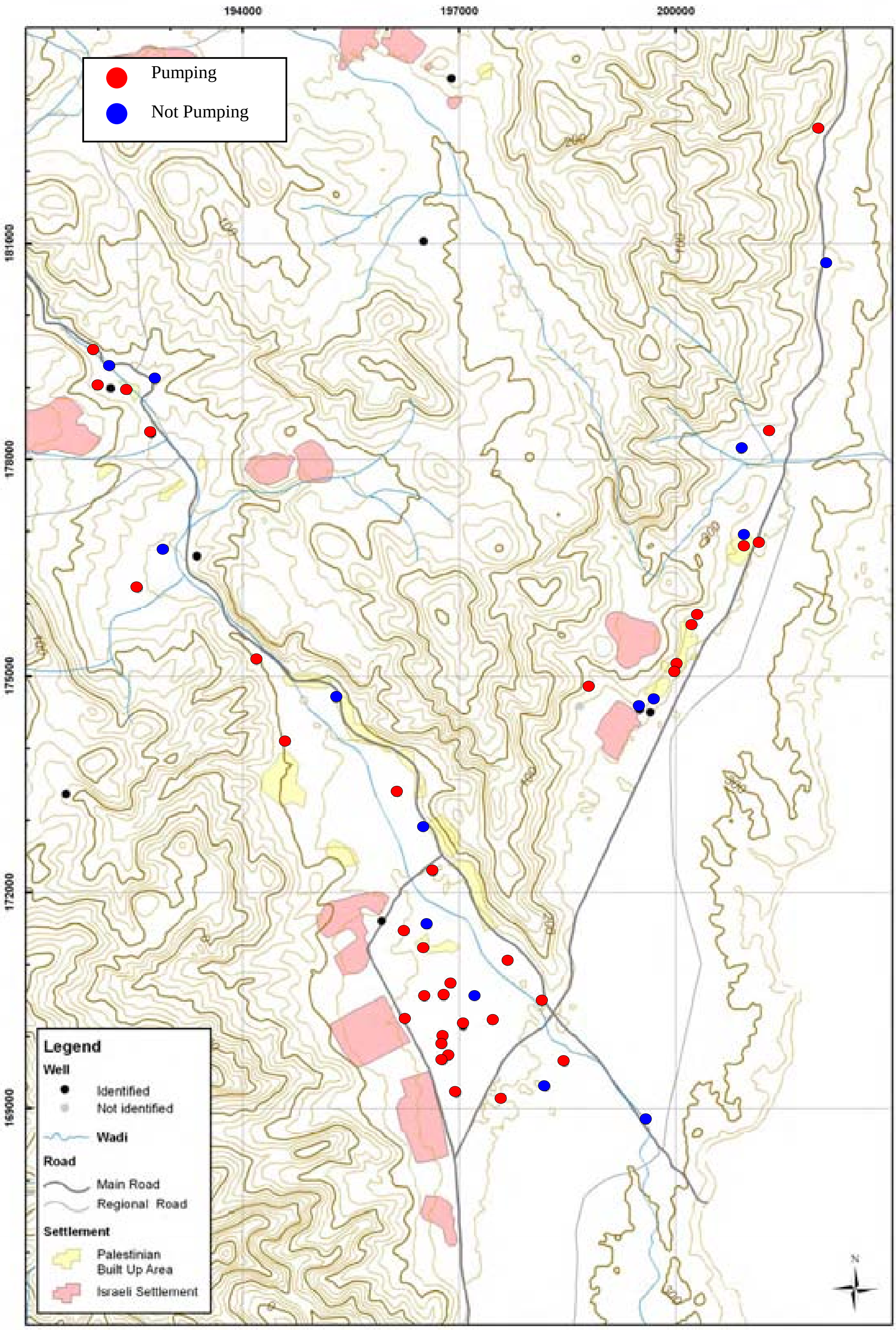
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.10 Annual and Seasonal Change of Groundwater Use (Mesh Data)



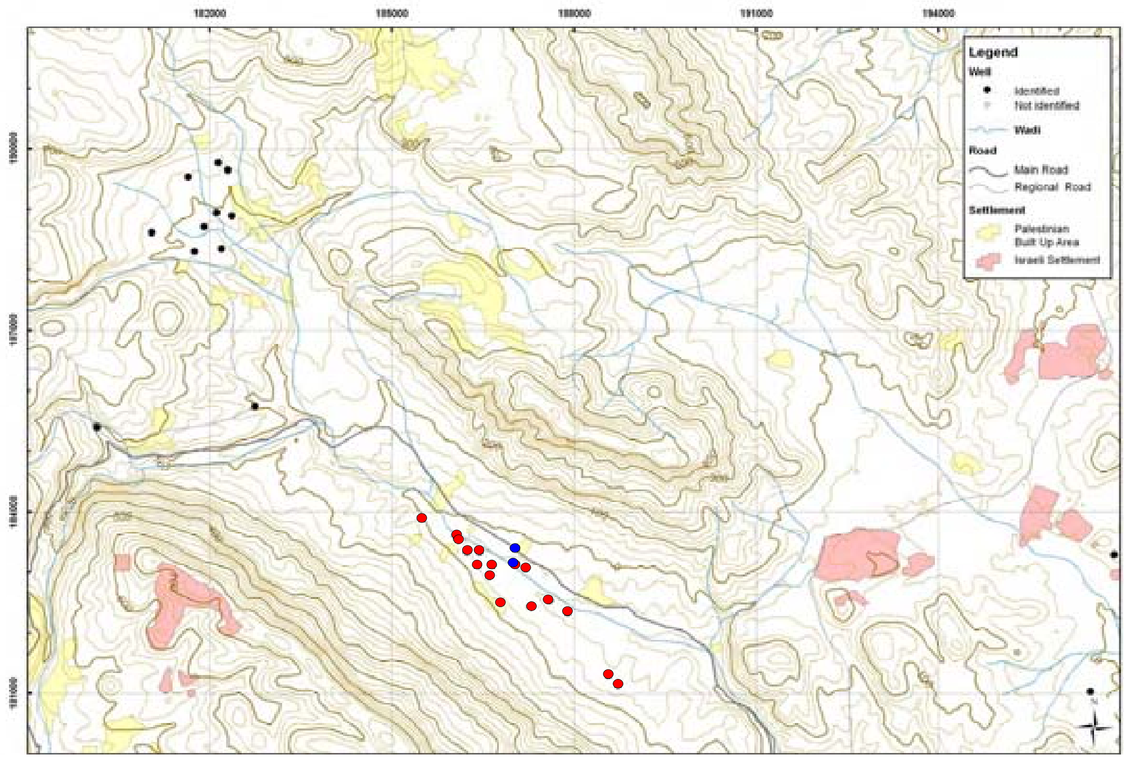
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.11 (1) Operation of the Agriculture Wells – Jericho Area



Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.11 (2) Operation of the Agriculture Wells – Jiftlik Area



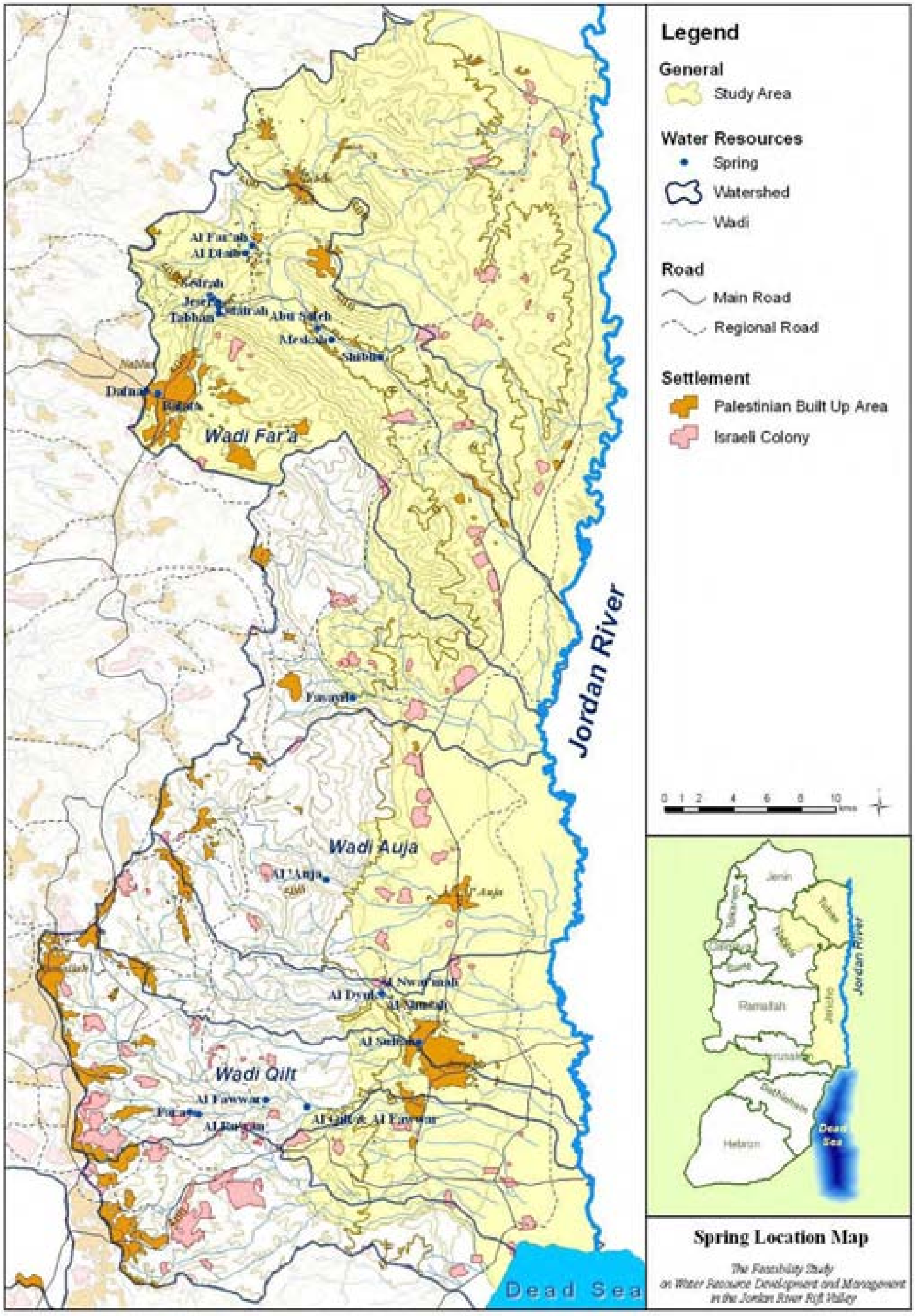
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.11 (3) Operation of the Agriculture Wells – Far'a Area

4.3.5 Spring Water

All the springs in the Study Area are shown in Figure 4.3.12 and listed in Table 4.3.4.

The origin of springs in Wadi Qilt watershed and around Jericho is the Upper Cretaceous aquifer, while those in Wadi Auja and Fasayil originated from the Lower Cretaceous aquifer. The origin of springs in the upstream of Wadi Far'a is an Eocene aquifer, while its middle stream is the Neogene aquifer.



Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.12 Location Map of Springs in the Study Area

Table 4.3.4 Springs in the Study Area

No.	Name	Code	Basin	Geology	Location	Average Discharge (Mcm/yr)
1	Fasayil	AC/054	Eastern	Lower Cenomanian	Al Jiftlik	0.66
2	Al Dyuk	AC/060	Eastern	Upper Cenomanian	Jericho (Ariha)	4.98
3	Al Nwai'mah	AC/060A	Eastern	Upper Cenomanian	Jericho (Ariha)	2.60
4	Al Shusah	AC/060B	Eastern	Upper Cenomanian	Jericho (Ariha)	0.61
5	Al Sultan	AC/061	Eastern	Upper Cenomanian	Jericho (Ariha)	5.57
6	Shibli	AQ/022	Eastern	Mio-Pliocene	An Nassariya	0.89
7	Abu Saleh	AQ/024	Eastern	Mio-Pliocene	Al'Aqrabaniya	0.16
8	Meskah	AQ/025	Eastern	Mio-Pliocene	Al'Aqrabaniya	1.39
9	Al Far'ah	AQ/030	North Eastern	Eocene	Ras Al-Far'a	5.56
10	Al Dlaib	AQ/032	North Eastern	Eocene	Ras Al-Far'a	1.26
11	Sedrah	AQ/036	North Eastern	Eocene	Al Badhan	1.46
12	Hamad & Baidah	AQ/037A	North Eastern	Eocene	Al Badhan	0.92
13	Qdairah	AQ/037B	North Eastern	Eocene	Al Badhan	1.26
14	Jeser	AQ/038	North Eastern	Eocene	Al Badhan	0.14
15	Tabban	AQ/039	North Eastern	Eocene	Al Badhan	1.30
16	Al Subyan	AQ/040	North Eastern	Eocene	Al Badhan	0.19
17	Balata	AQ/043	North Eastern	Eocene	Balatah	0.18
18	Dafna	AQ/044	North Eastern	Eocene	Nablus	0.13
19	Al 'Auja	AR/020	Eastern	Lower Cenomanian	Al 'Auja	9.45
20	Al Qilt & Al Fawwar	AS/020	Eastern	Upper Cenomanian	Wadi Al Qilt	6.75
21	Al Fawwar	AS/021	Eastern	Upper Cenomanian	Wadi Al Qilt	4.56
22	Fara	AS/022	Eastern	Upper Cenomanian	Ein Fara	0.76
23	Al Jummaizah	AS/022A	Eastern	Upper Cenomanian	Wadi Al Qilt	0.33
24	Al Ru'yan	AS/022B	Eastern	Upper Cenomanian	Wadi Al Qilt	0.39

Source: PWA Database

The annual and seasonal changes of the spring discharge are shown in Figure 4.3.13.

1) Wadi Qilt Watershed (Upper Cretaceous Aquifer)

The largest discharge spring in the watershed is Al Qilt & Al Fawwar springs. Relation between annual and monthly mean discharge of Al Qilt & Al Fawwar spring, as well as the rainfall and discharge, are comparatively clear. A decrease tendency of spring discharge is not evident. The seasonal peak of spring discharge is appeared in March, during the last stage of the rainy season, where exceeding a discharge of 600 l/sec. The spring discharge decreased to about 100 l/sec in November, the initial stage of the rainy season.

2) Northern Part of Jericho City (Upper Cretaceous Aquifer)

A decrease tendency from 1980’s to 1990’ is observed in the Al Dyuk spring discharge, although, it has recovered in 2000. The decrease tendency of discharge as well as seasonal fluctuation is also not found in the other springs.

3) Wadi Auja and Fasayil Area (Lower Cretaceous Aquifer)

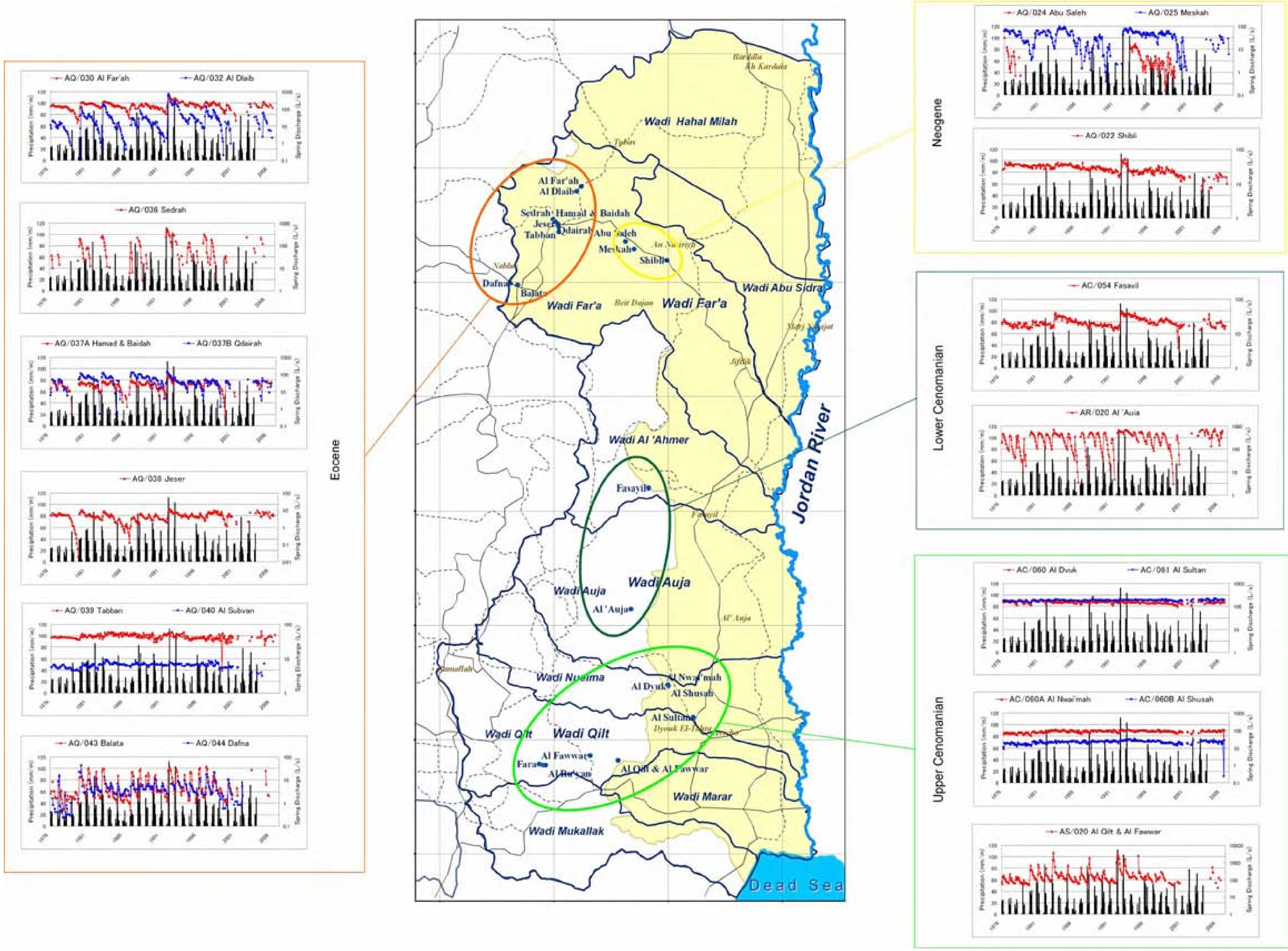
The seasonal fluctuation of Al 'Auja spring is very large. The discharge of Al ‘Auja spring is more than 500 l/sec during the rainy season, and less than 10 l/sec during the dry season. Al ‘Auja spring is the most unstable spring in the Study Area. Fasayil spring meanwhile has sufficient discharge for several years, when large amount of rainfall occurs continuously.

4) Upstream of Wadi Far’a (Eocene Aquifer)

Many springs are located in the upstream of Wadi Far’a. At a certain portion of the springs, seasonal fl Geological stratigraphy of the Study Area is shown in Table 4.3.1. uctuation is significant.

5) Midstream of Wadi Far’a (Neogene Aquifer)

The discharge of Shibli spring exhibits a decrease tendency. It is suspected that decrease of the spring discharge is due to excessive groundwater use in the surrounding area.



Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.13 Annual and Seasonal Change of Spring Discharge

4.3.6 Groundwater Quality

(1) Secular Change of Groundwater Quality

The secular change of concentration of chloride (Cl) ion and nitrate (NO3) ion since 1976, which is shown in Figure 4.3.14, is summarized as followings.

1) Eastern Basin

<u>Quaternary Aquifer</u>

Concentration of Cl ion: Exceeding 1,000 mg/l in Jericho city. Higher concentration observed in the northern area of Jericho.

Concentration of NO3 ion: Approximately 40 mg/l and constant in Jericho city. In turn, an increased tendency shown in the northern area of Jericho city.

<u>Neogene Aquifer</u>

Concentration of Cl ion: Showing significantly higher figure than the Quaternary aquifer. An increase tendency has also been confirmed.

Concentration of NO3 ion: Exceeding 100 mg/l in some wells. This groundwater pollution is due mainly to waste water.

<u>Eocene Aquifer</u>

Concentration of the Cl ion: Considerably high

Concentration of NO3 ion: Low; much less than 50 mg/l.

<u>Upper Cretaceous Aquifer</u>

Concentration of the Cl ion: Low; approximately 100 mg/l.

Concentration of the NO3 ion: Low but an increase tendency confirmed even slightly.

2) North Eastern Basin

<u>Neogene Aquifer</u>

Concentration of the Cl ion: Showing an increase tendency even slightly.

Concentration of the NO3 ion: Showing an increase tendency even slightly.

Both the increase tendencies would be caused by waste water pollution such as saline intrusion.

<u>Eocene Aquifer</u>

Concentration of the Cl ion: Showing an increase tendency even slightly.

Concentration of the NO3 ion: Showing an increase tendency even slightly.

Both the increase tendencies would be caused by waste water pollution such as saline intrusion.

<u>Upper Cretaceous Aquifer</u>

Concentration of the Cl ion: Low; generally 50 mg/l (or lesser).

Concentration of the NO3 ion: Low.

Observed water quality was excellent.

3) Spring

Wadi Qilt Watershed (Upper Cretaceous Aquifer)

Concentration of Cl ion: Not so high, but slightly reveals increase tendency.

Concentration of NO3 ion: Not so high, but slightly reveals increase tendency.

Northern Part of Jericho City (Upper Cretaceous Aquifer)

Concentration of Cl ion: Low, but reveals increase tendency after 2000.

Concentration of NO3 ion: Increase tendency is found after the 1980's.

Wadi Auja and Fasayil Watershed (Lower cretaceous Aquifer)

Concentration of Cl ion: Low, but demonstrates increase tendency after the middle of 1990's.

Concentration of NO3 ion: An increase tendency appeared after 1980's.

Upstream of Wadi Far'a (Eocene Aquifer)

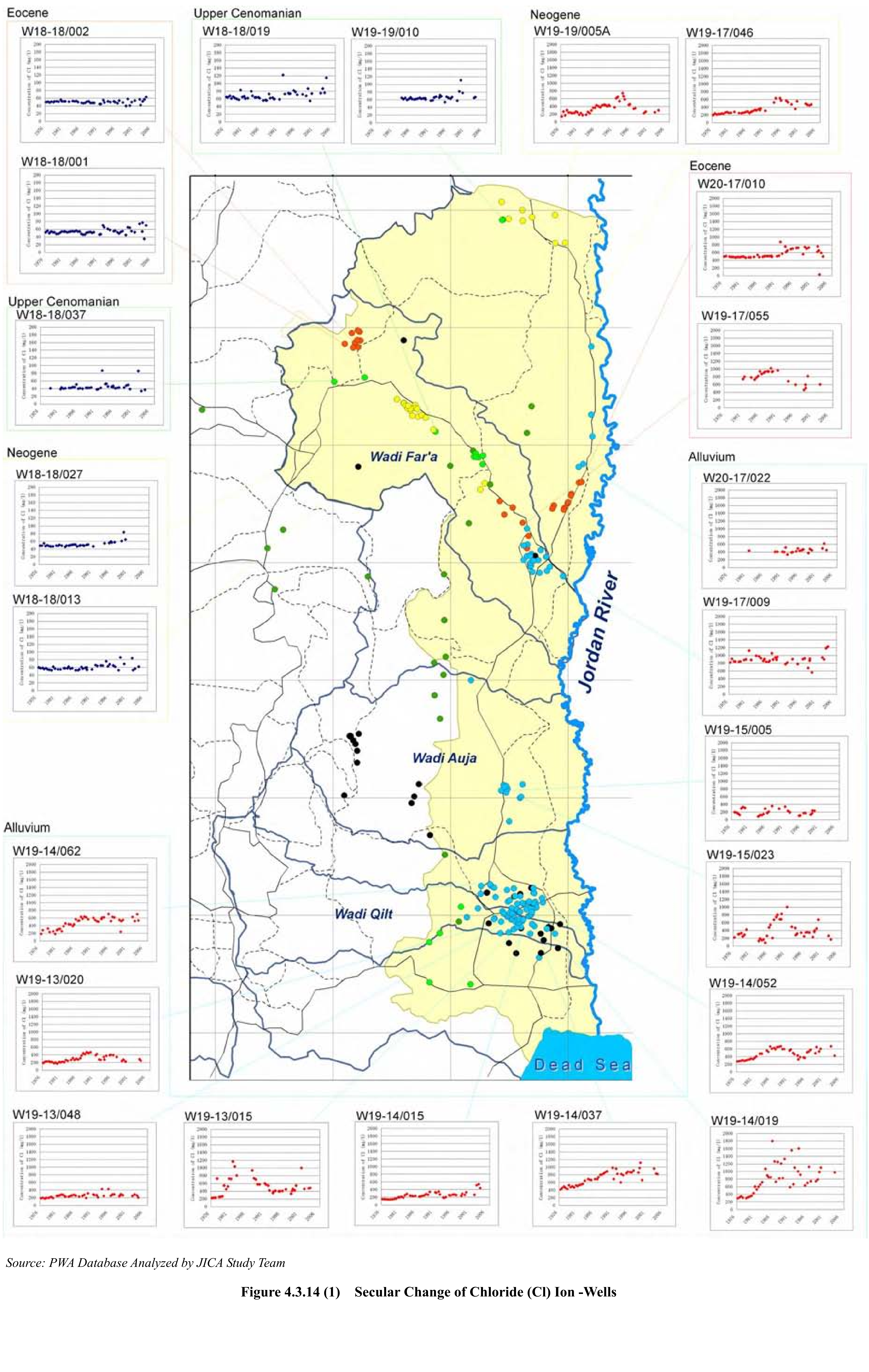
Concentration of Cl ion: Low, but exhibits increase tendency after the middle of 2000, particularly significant in Al Far'a spring.

Concentration of NO3 ion: High; especially identified in Balata spring.

Midstream of Wadi Far'a (Neogene Aquifer)

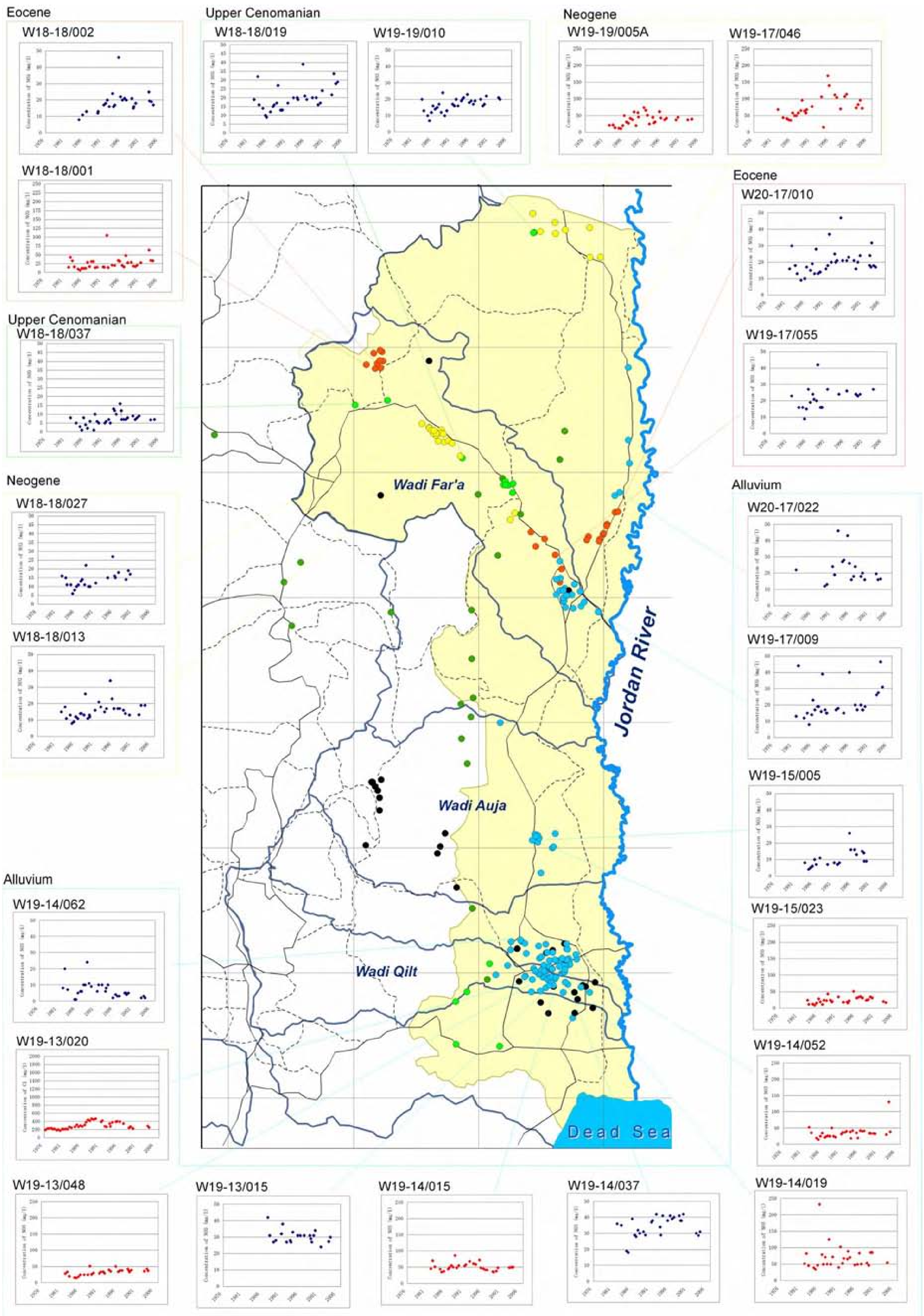
Concentration of Cl ion: Showing an increase tendency in Mesakah spring from the middle of 1990's. The similar tendency is demonstrated at Shibli spring, from the end of 1990's.

Concentration of NO3 ion: Showing an increase tendency.



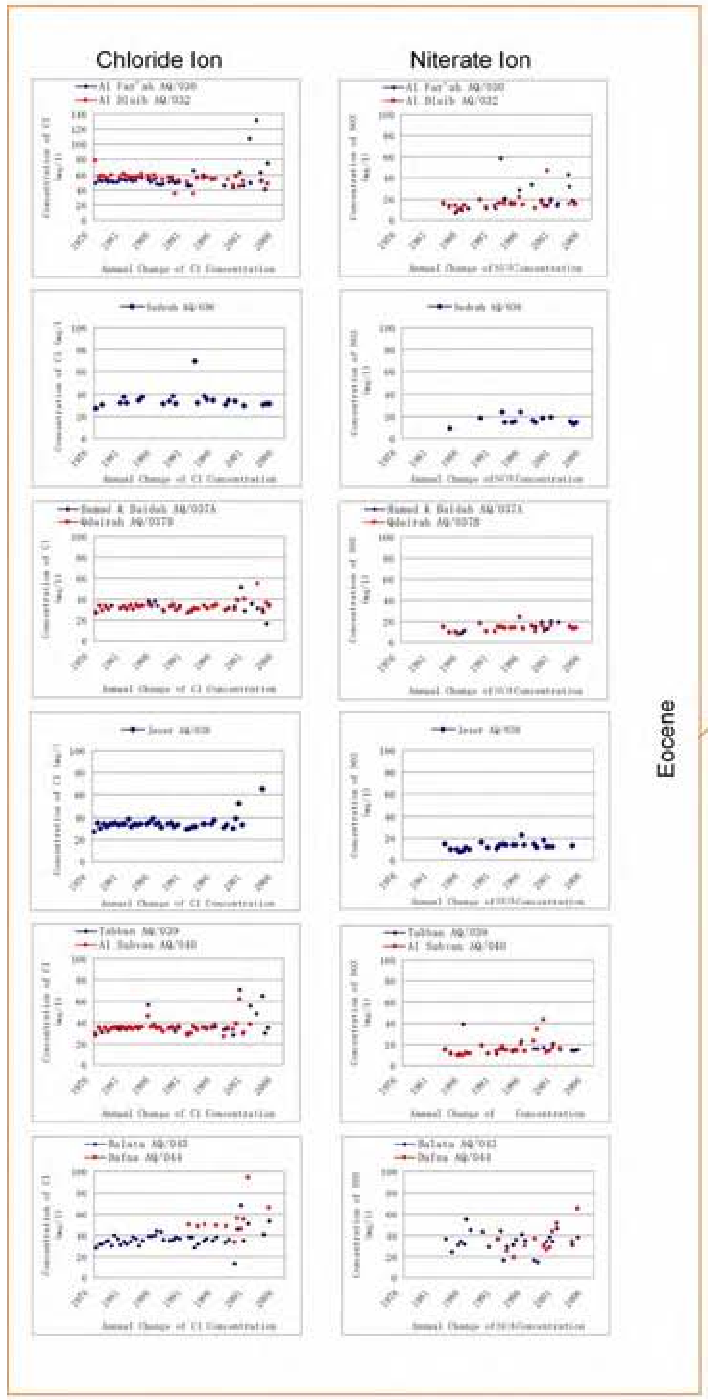
Source: PWA Database Analyzed by JICA Study Team

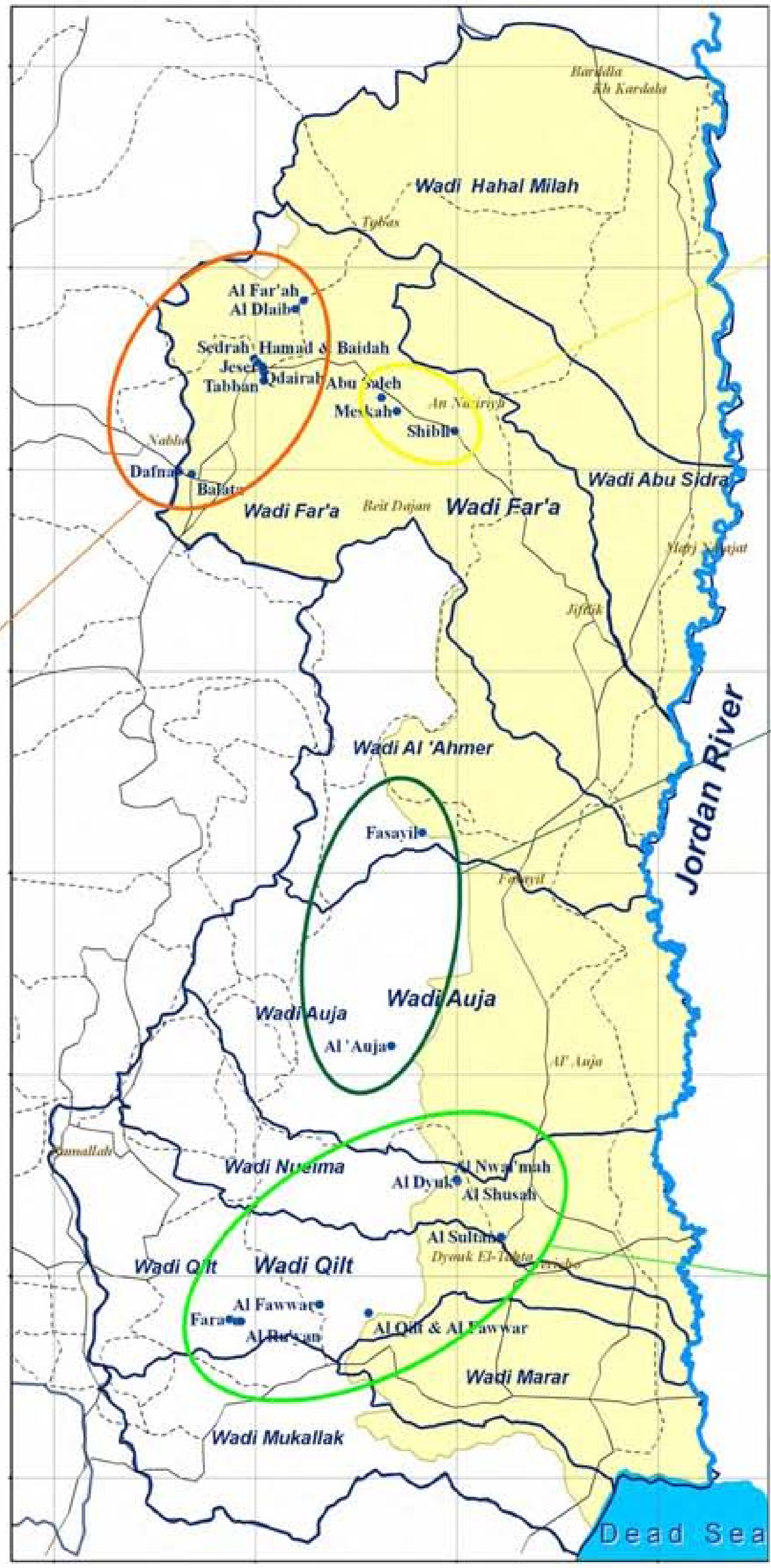
Figure 4.3.14 (1) Secular Change of Chloride (Cl) Ion -Wells

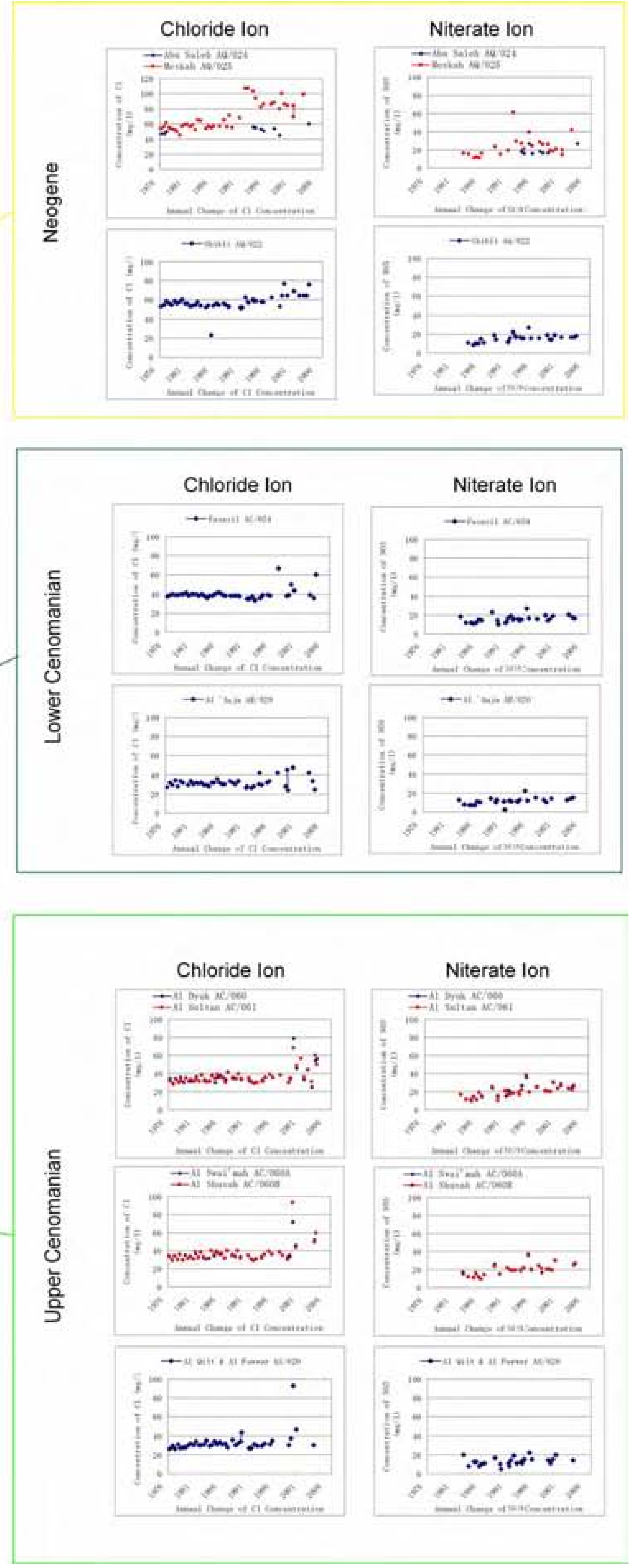


Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.14 (2) Secular Change of Nitrate (NO3) Ion -Wells







Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.14 (3) Secular Change of Chloride (Cl) and Nitrate (NO3) Ion -Springs

(2) Geo-Chemical Items

Tri-linier Diagram and Hexa Diagram of wells and springs are shown in Figure 4.3.15. These were prepared based on the water quality analysis considering the most numbers of obtained samples in 1999. The characteristic of groundwater quality is summarized as follows:

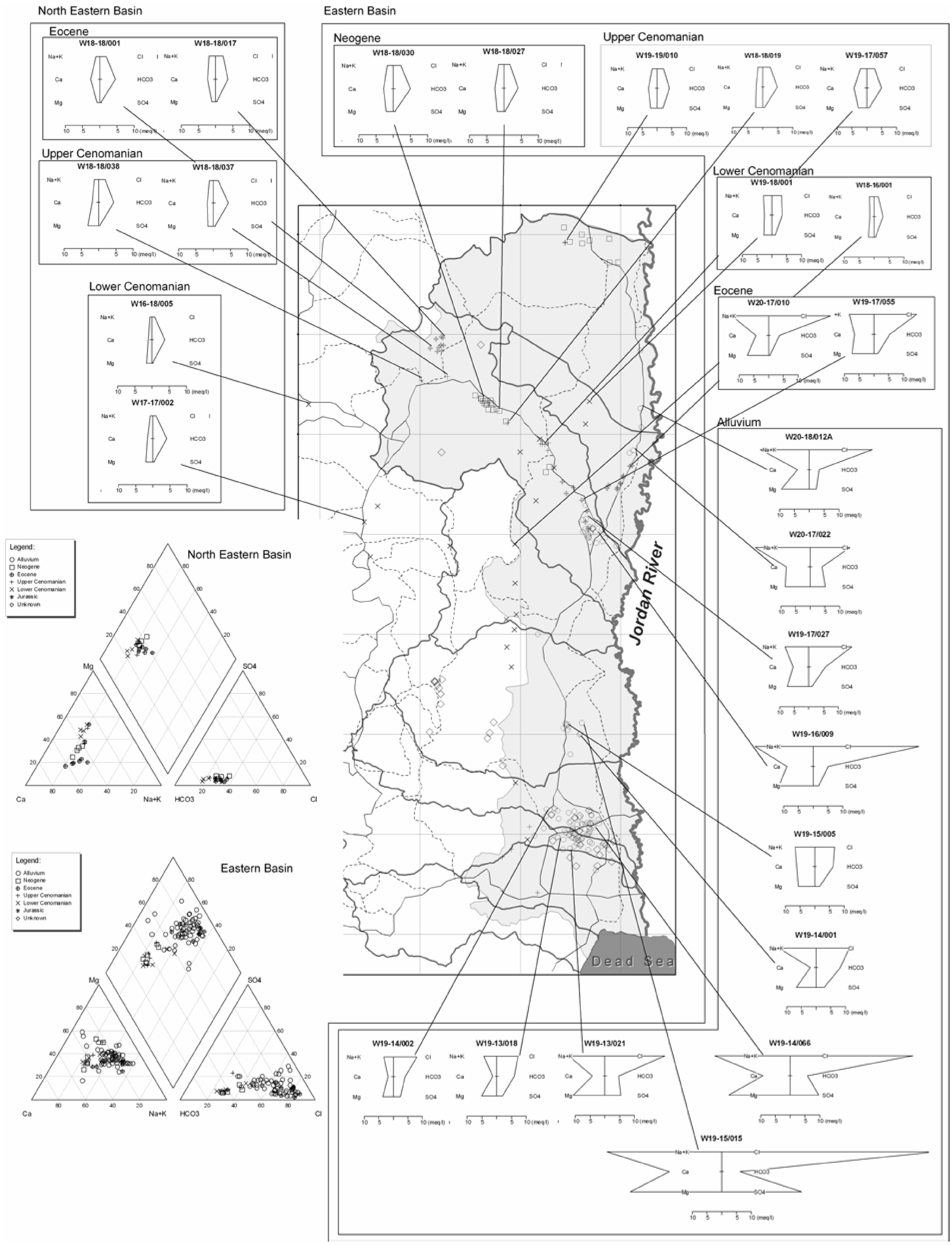
Eastern Basin

As for the groundwater of Quaternary aquifer, majority are classified as NaCl type. The groundwater of this aquifer is influenced by the Dead Sea Formation. Upper Cretaceous, Lower Cretaceous and Neogene aquifers indicate a $Ca(HCO_3)_2$ type, originated from limestone.

The springs of Upper and Lower Cretaceous also indicate a $Ca(HCO_3)_2$ type originated from limestone. A part of the springs of Neogene aquifer shows NaCl type due to waste water pollution.

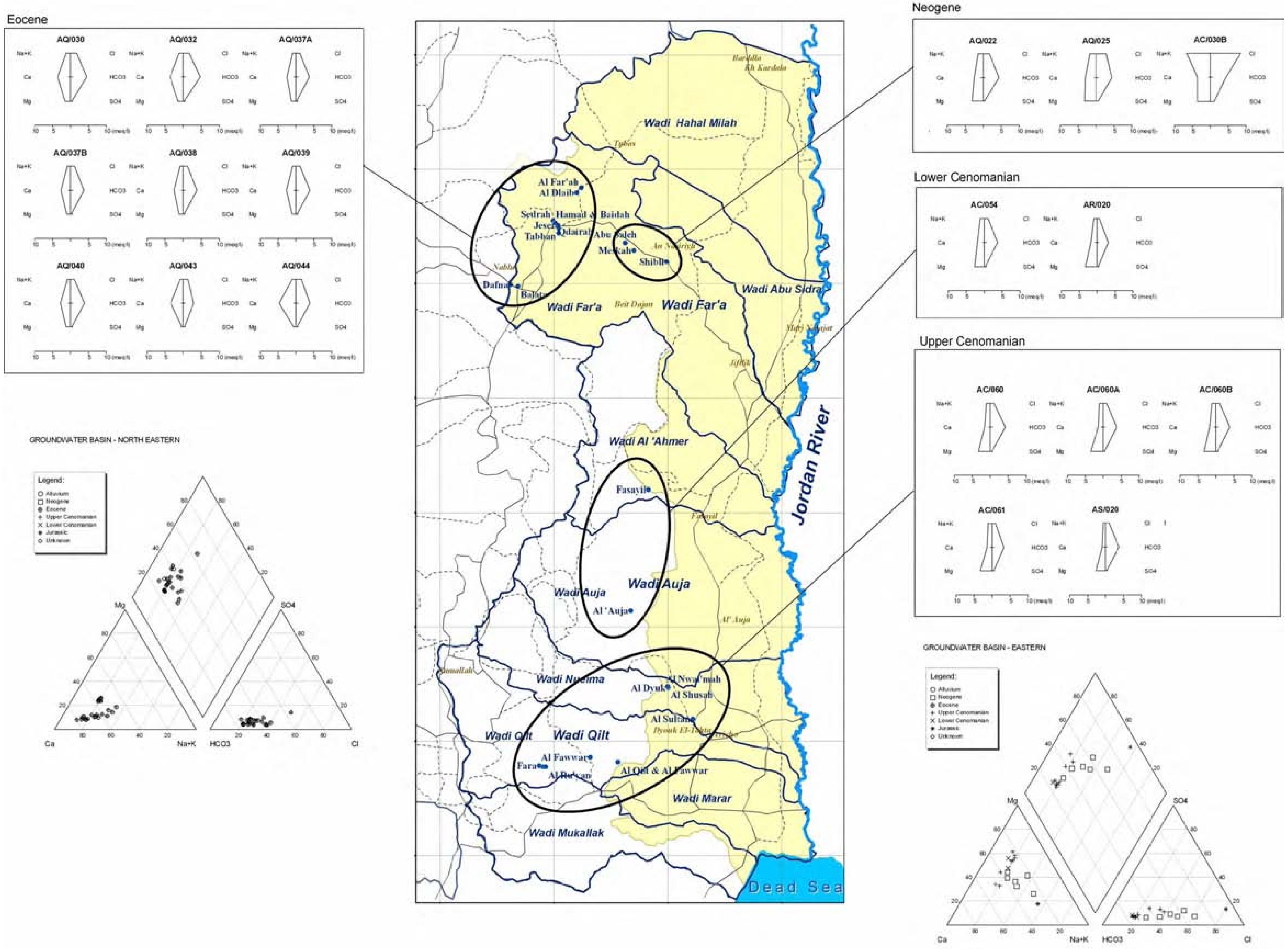
North Eastern Basin

All aquifers, except the Quaternary aquifer, are distributed in the North Eastern Basin. The water quality of all groundwater and that of springs are classified by $Ca(HCO_3)_2$.



Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.15 (1) Tri-linear Diagram and Hexa Diagram -Wells

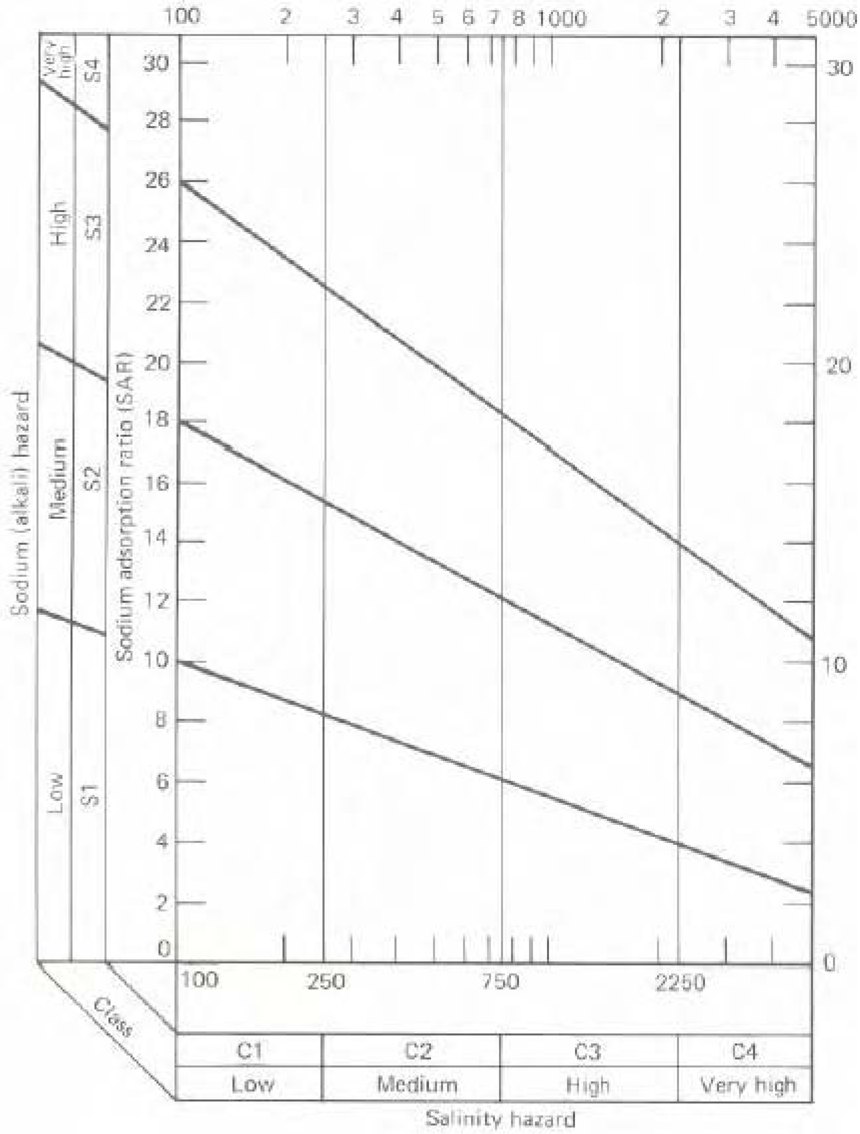


Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.15 (2) Tri-linear Diagram and Hexa Diagram -Springs

(3) Suitability for Irrigation Water

The diagram based on sodium absorption ratio (SAR) and electric conductivity is widely used for the classification of irrigation water (refer to Figure 4.3.16).

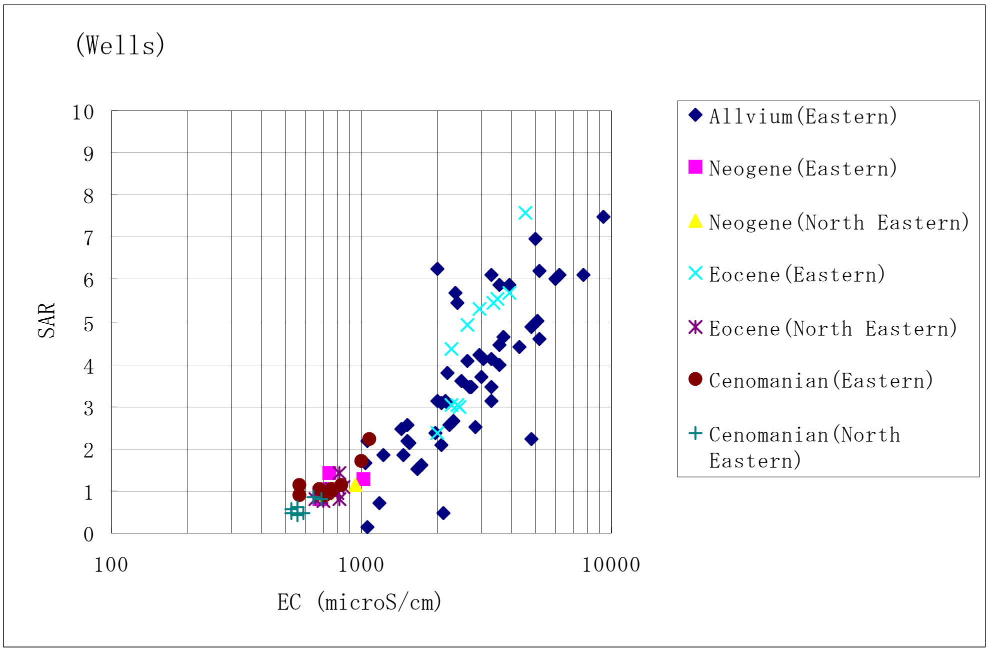


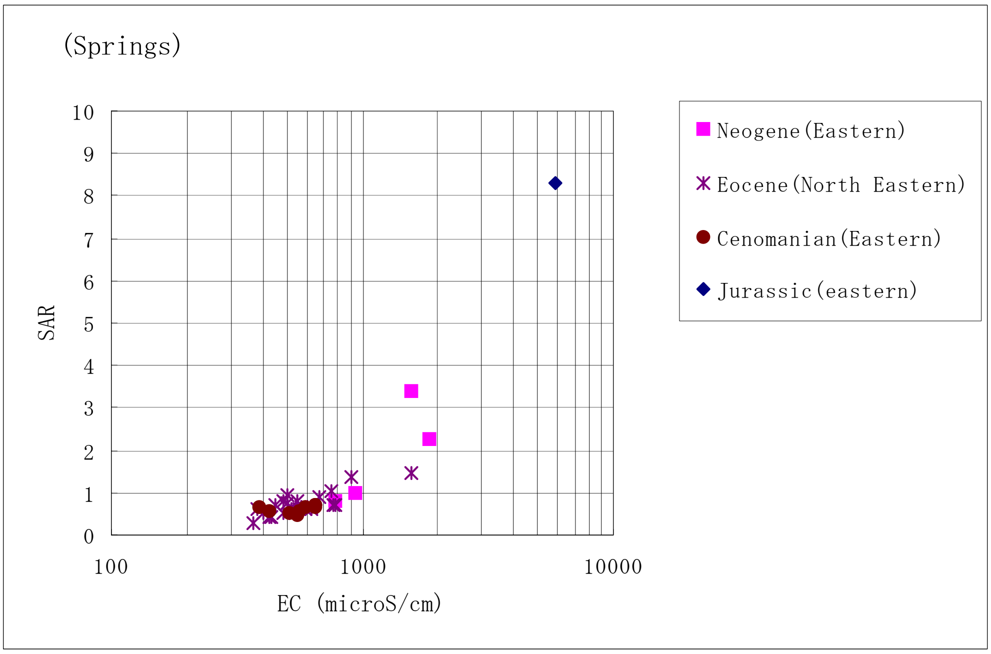
Source: Groundwater and Wells

Figure 4.3.16 Diagram for Classification of Irrigation Water

Electric conductivity - SAR correlation of groundwater and spring in the Study Area is shown in Figure 4.3.17

SAR is not so high since the groundwater and spring water within the Study Area contain large amount of calcium and magnesium. However, due to very high electric conductivity of the groundwater of Quaternary and Eocene Aquifer, salinity hazard were classified as either “Very High” or “High” in many wells. On the other hand, the remaining spring water is classified as “Medium”, which is suitable for irrigation.





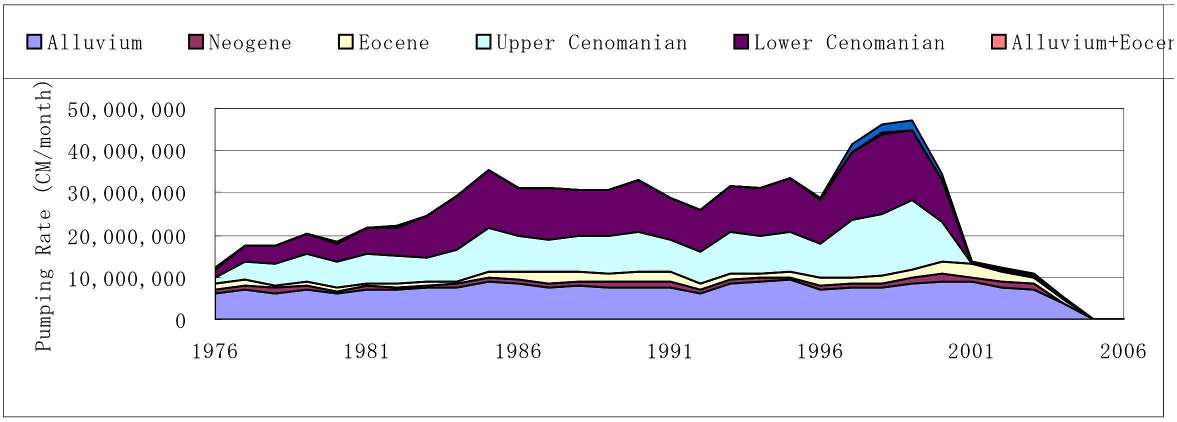
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.17 Suitability for Irrigation Water

4.3.7 Evaluation of Groundwater Resources

(1) Eastern Basin

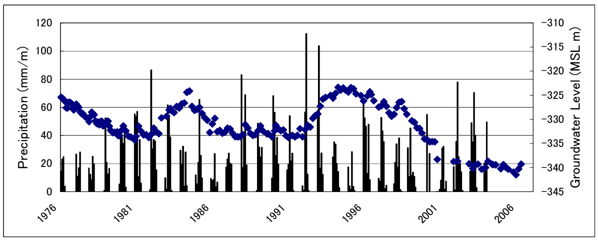
The annual changes of groundwater use of Eastern Basin are shown in Figure 4.3.18 while the annual and seasonal changes of groundwater level are shown in Figure 4.3.19. Meanwhile, the annual changes of Cl ion are also presented in figure 4.3.20.



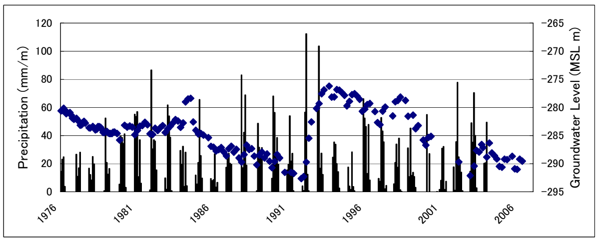
Source: JICA Study Team

Figure 4.3.18 Annual and Seasonal Change of Groundwater Use（Eastern Basin）

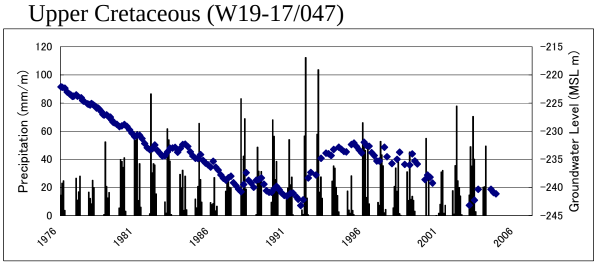
Alluvium (W19-14/098)



Eocene (W19-17/007)



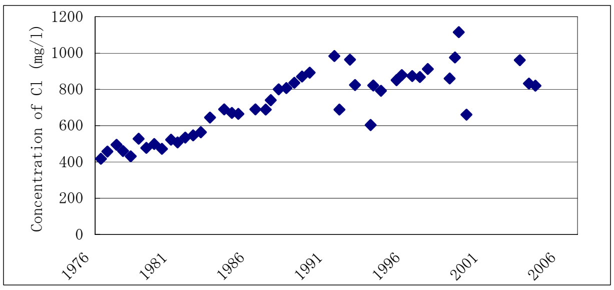
Upper Cretaceous (W19-17/047)



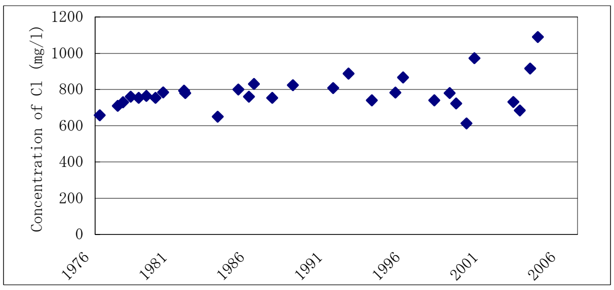
Source: JICA Study Team

Figure 4.3.19 Annual Change of Groundwater Level (Eastern Basin)

Alluvium (W19-14/037) - Jericho



Alluvium (W19-17/010) - Jiftlik



Source: PWA Database Analyzed by JICA Study Team

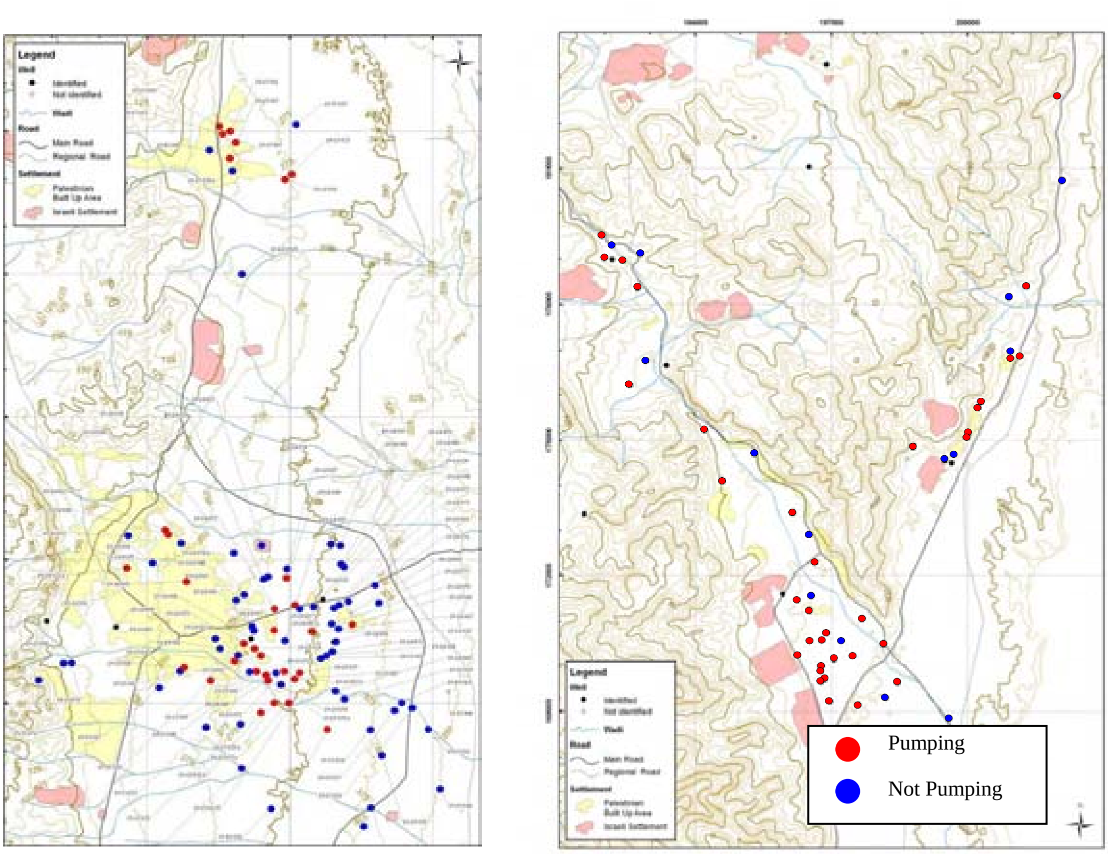
Figure 4.3.20 Annual Change of Chloride Ion (Eastern Basin - Wells)

The monthly pumping rate increases in the latter half of 1990's. This was mainly caused by Lower Cenomanian aquifer in the northern part of the Eastern Basin. The pumping amount from Alluvial aquifer remains unchanged. On the other hand, the groundwater level shows a decrease tendency, while the Cl ion exhibits an increase tendency.

The increase tendency of Cl ion is significant in Jericho and Al 'Auja area. Therefore, more than half the number of wells have been abandoned due to water quality deterioration (refer to Figure 4.3.21). The causes include excessive pumping from Alluvium Aquifer and the decrease in groundwater inflow due to pumping from limestone aquifer at the west side, which eventually becomes the groundwater source of Alluvium Aquifer.

Since development of new groundwater is not possible, it is necessary to decrease the pumping amount of limestone aquifer. The pumping from lime stone aquifer is mainly carried out by Israeli users and thereby, it is highly encouraged to develop groundwater conservation measures incorporate with Israeli authorities.

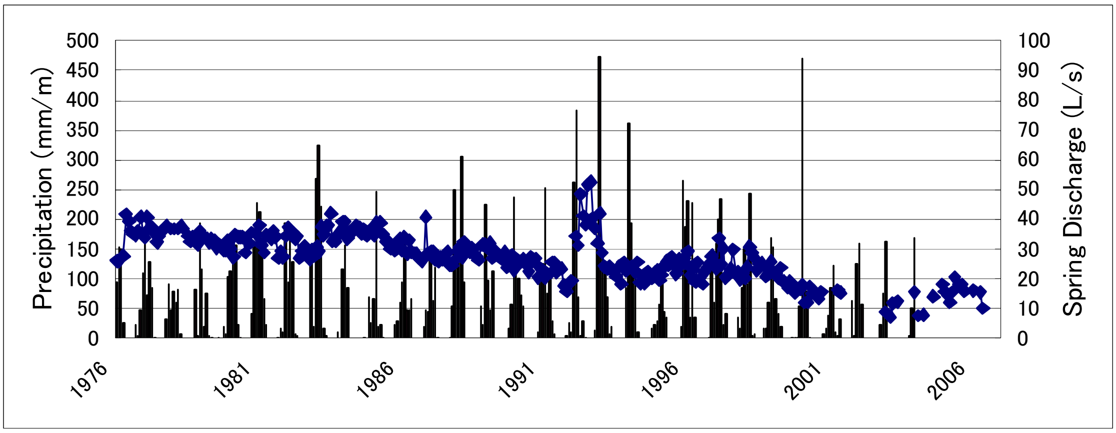
A similar phenomenon is observed in the north Jiftlik area, with a new groundwater development for Alluvial aquifer. The decrease tendency of discharge is observed at a certain portion of the springs, originating from Eocene aquifer (refer to Figure 4.3.22). This phenomenon indicates that with an unbalanced budget allotted for groundwater, new groundwater development would be difficult.



a) Jericho Area *b) Jiftlik Area*

Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.21 Operation of the Agricultural Wells



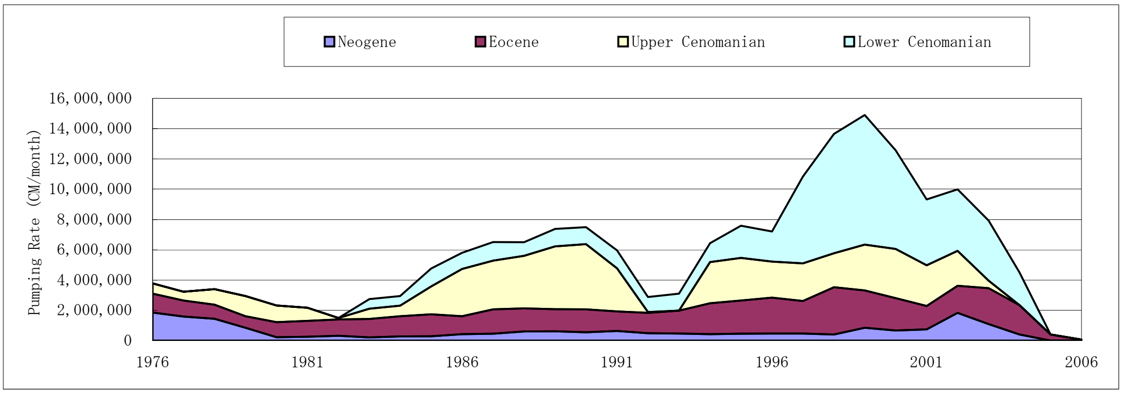
PMD_Code	AQ/022	PN_Name_E	Shibli
GWB_Name_E	Eastern	LOC_Name_E	An Nassariya
GR_Governate_E	Nablus	Precipitation	Nablus Meteorological Station

Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.22 Annual Change of Spring Discharge – Shbli Spring (Eocene Aquifer)

(2) North Eastern Basin

The annual changes of groundwater use of North Eastern Basin are shown in Figure 4.3.23 while the annual and seasonal changes of groundwater level are shown in Figure 4.3.24. The annual changes meanwhile of Cl and NO3 ions are shown in Figure 4.3.25.

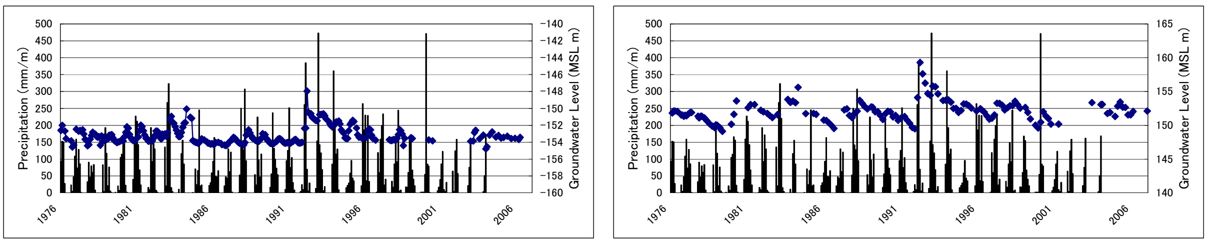


Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.23 Annual Change of Groundwater Use (North Eastern Basin)

Neogene (W19-19/006B)

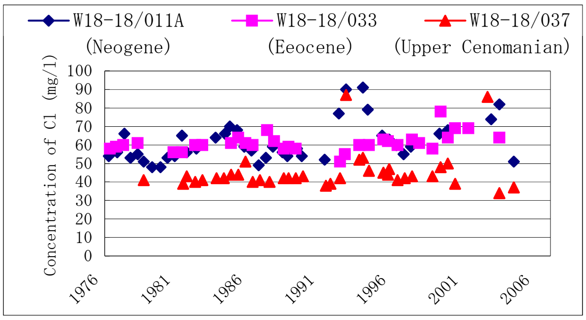
Eocene (W18-18/002)



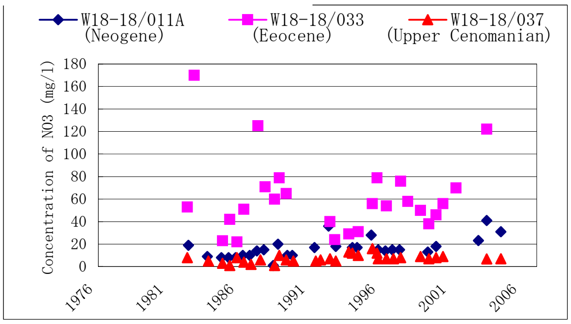
Source: PWA Database Analyzed by JICA Study Team

Figure 4.3.24 Annual Change of Groundwater Level (North Eastern Basin)

Chloride Ion (Cl)



Nitrate Ion (NO3)



Source:PWA Database Analyzed by JICA Study Team

Figure 4.3.25 Annual Change of Chloride and Nitrate Ion (North Eastern Basin - Wells)

The pumping amount increases in the latter half of 1990's, and is particularly significant in the Lower Cenomanian aquifer. This decrease tendency of the groundwater level of Neogene and Eocene aquifers is not evident. Since the observation data of groundwater level of Lower Cenomanian aquifer is insufficient, the tendency is still unknown. Concentration of the Cl ion is lower than that of Eastern Basin, and its water quality seem more excellent. The decreasing tendency of spring discharge is not observed.

Therefore, new groundwater development in North Eastern Basin is encouraged. The aquifer consisting of limestone, exhibits excellent well capacity. The groundwater development plan should however consider the influence on existing wells and springs. The increase tendency of both Cl and NO3 ions is found due to its contamination with waste water. It is, therefore, necessary to examine the conservation measures of the groundwater quality.

4.3.8 Analysis of Effective Use of Seasonal Variation of Spring by Groundwater Simulation

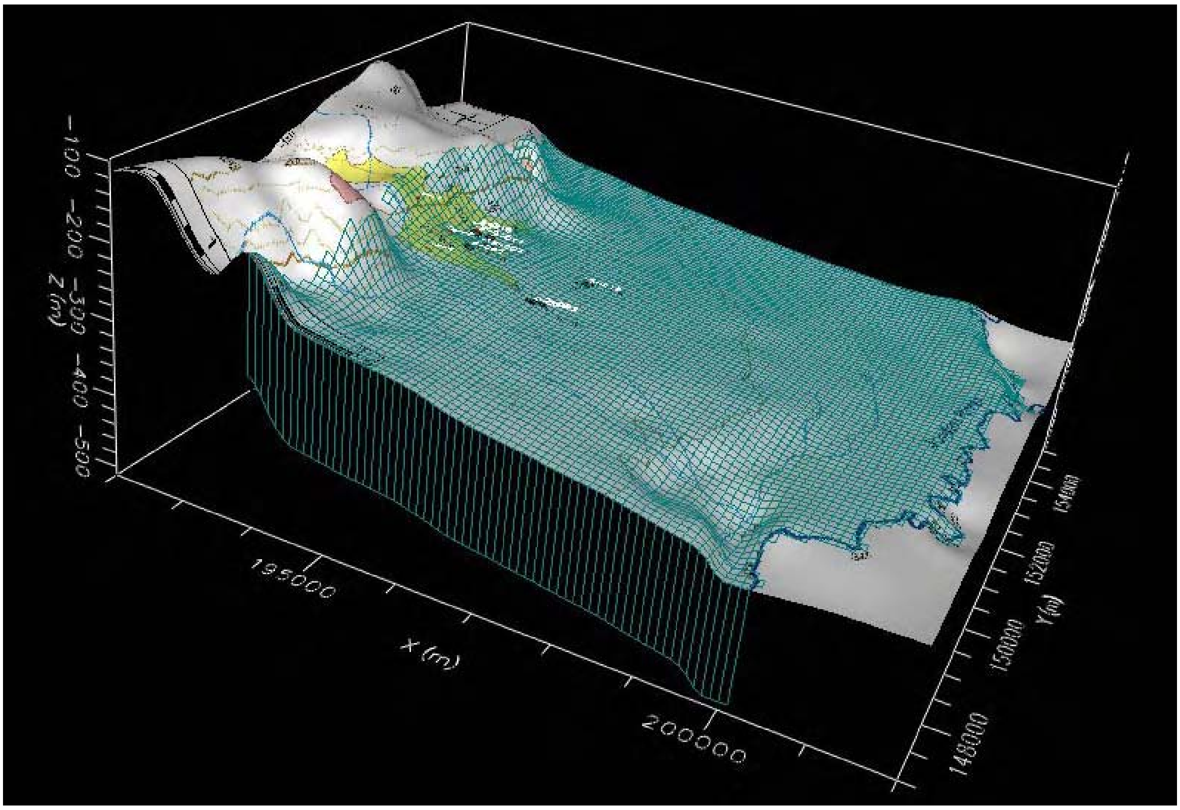
(1) Background and Purpose of Analysis

The seasonal variation of Al 'Auja spring discharge is significant. During the rainy season, excess water from Al 'Auja spring flows out wasted, and not utilized for irrigation. On the other hand, with the considerable decrease in spring discharge during the dry season, irrigation water becomes insufficient. In the future, existing transmission channel is planned to replace the pipe line. The design discharge is planned at 70% of the monthly maximum spring discharge. Spring water which exceeds the design discharge will be released into the existing channel.

The excess water of Al 'Auja spring penetrates into the Alluvial aquifer as artificial recharge water source. The groundwater simulation is conducted to evaluate the effect of artificial recharge for the groundwater environment in the Al 'Auja area.

(2) Objective Area for Simulation

The objective area for simulation is illustrated in Figure 4.3.26, of which range are about 7 km east and west, and 8 km north and south.



Source: JICA Study Team Analysis Based on PWA Database

Figure 4.3.26 Analytical Area of Groundwater Simulation

(3) Change of Groundwater Balance by Simulation

Table 4.3.5 shows the summary of change of annual groundwater balance by artificial recharge.

Table 4.3.5 Summary of Change of Annual Groundwater Balance by Artificial Recharge (1976 – 1999)

Unit: m^3/day

	Inflow		Outflow		Change of Storage
	Groundwater Inflow	Artificial Recharge	Pumping	Groundwater Outflow	
Injection-0	13,761	0	1,527	12,385	-151
Injection-1	13,699	237	1,527	12,535	-126
Injection-2	13,657	403	1,527	12,641	-108
Injection-3	13,627	522	1,527	12,717	-95
Injection-4	13,606	608	1,527	12,773	-86

Source: JICA Study Team

(4) Evaluation

Based on the ground water simulation results, the current situation and improvement plan of the water environment of Al ‘Auja are summarized as follows:

(i) The average ground water balance records from 1976 to 1999 are shown as negative due to excessive pumping;

(ii) The ground water becomes imbalanced during the dry years. This is due to less pumping volume during the wet years, and higher pumping volume during the dry years;

(iii) Since 1996, the water levels recorded based on actual measurement is consistently below the estimated levels. Meanwhile, it was noted that from 1976 to 1991, both actual and estimated levels appeared equal. This implies that at the upstream area, pumping of groundwater by Israel, affects the fall of influent quantity of groundwater over the Al ‘Auja areas. Therefore, the current situation seemed to have worsened as compared to the estimates obtained during the simulation period. In this context, reduction of Israel’s pumping volume would be considered in order to rectify the groundwater imbalance;

(iv) Although the simulation records of 1992 and 1993 indicate more preferred figures, continuous unexceptional precipitations are apparent. Therefore, the declining trend of groundwater level remains unchanged;

(v) Artificial recharge provides minimal contribution to the improvement of groundwater balance, since it is only effective during the wet years; and

(vi) The artificial recharge benefits during dry years are apparent when the groundwater balance becomes seriously negative. Therefore, it is expected that the redundant water of springs will be utilized or a multi-year reservoir will be constructed to take running water of Wadi-river. The upper stream of Al ‘Auja aquifer has suitable terrains and hydrogeologic conditions for constructing an underground dam. Hence, a technical study concerning the groundwater dam construction could be conducted.

The details of simulation are given in Annex 2.

4.4 Potential Water Resources

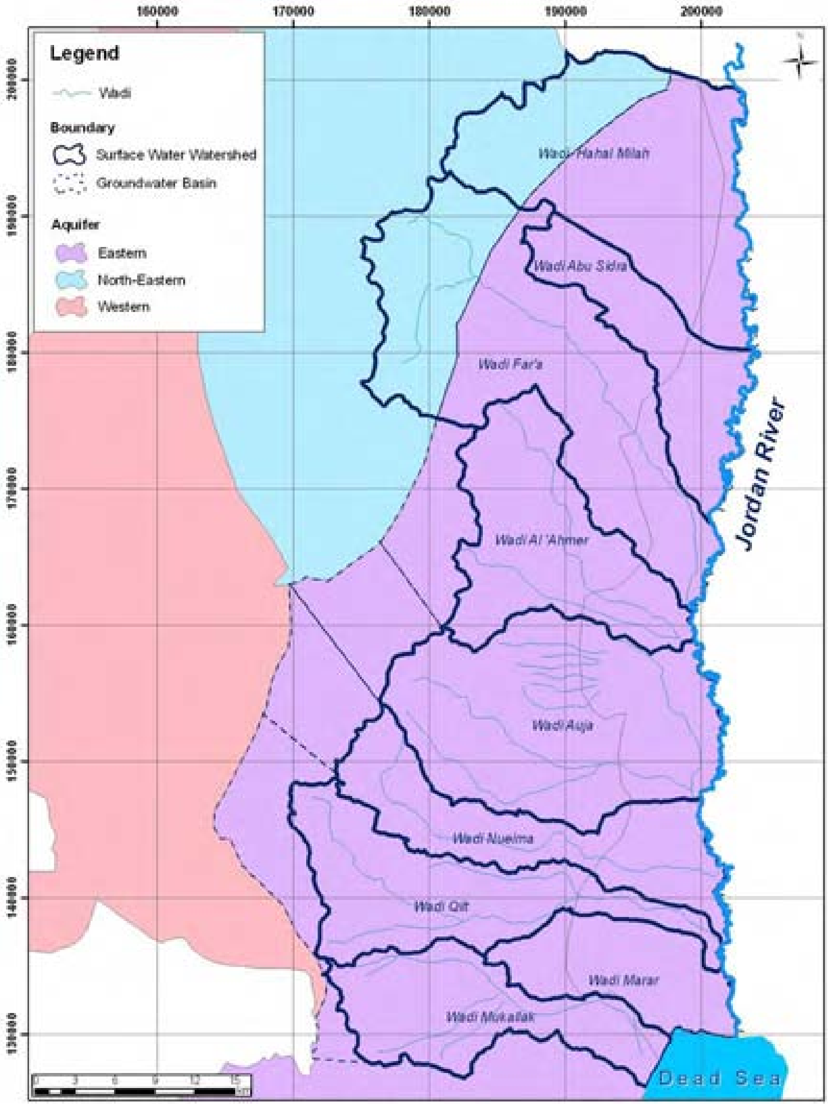
4.4.1 General

Water resources amount in each of the major catchments are initially estimated based on a quite limited available hydro-meteorological and topographic data regarding the Study Area. Thereby, the estimated results on water resources potentials presented herein should be regarded still preliminary ones.

In general, the runoff condition in the Study Area is characterized by the high permeability of the ground, as well as significantly less rainfall and high evaporation during the summer season. During the summer seasons, there is no possibility of increasing the water resources. While a large amount of evapotranspiration of rainfall is lost, still a considerable amount of the remaining rain water penetrates underground due to high permeability, unless said amount exceeds the primary moisture content of the surface and sub-surface soil layers. As a result, runoff rarely takes places in the wadi channel except during occurrence of heavy rainstorm. Thus, the water resources in the Study Area are mainly groundwater and spring water, which is also sourced from groundwater.

The other characteristic of water resources in the Study Area is that the main sources, obtained from heavy rainfalls and less evapotranspiration (rainfall loss), lie in the western mountainous regions with ground elevations of more than around 500 m. Moreover, rainfall in the eastern low-land areas hardly contribute to supply of water resources, since it barely exceeds the evapotranspiration amount. It eventually forms a desert or dry land. As mentioned above, a considerable amount of rainfall exceeding the evapotranspiration still penetrates underground to recharge groundwater. Then, rainfall in the high mountainous area gradually moves eastward, recharging groundwater in low-land areas, where Jericho is located. For the time being however, it is too hard to quantitatively analyze the groundwater movement in the Study Area due to a very complex phenomenon. For instance, groundwater in the basins covering at the south of Wadi Al 'Ahmer and to the north of Wadi Mukallak, is augmented by groundwater from other basins adjacent to the east. Meanwhile, groundwater in the upstream catchments of Wadi hahal Milah and Wadi Far'a, which are located in northernmost part of the Study Area, flows in the northern direction. The groundwater is subsequently streams through the territory of Israel. Thus, in the Study Area, the boundary of surface water area does not coincide with that of the groundwater area.

The amount of water resources in the Study Area are estimated for each of the nine wadi basins. The catchment areas of the surface water and groundwater areas in these wadi basins are derived from the existing geological map shown as follows:



Source: PWA, JICA Study Team

Figure 4.4.1 Boundaries of Surface Water and Groundwater of 9 Wadi Basins

Table 4.4.1 Surface Water (SW) and Groundwater (GW) Areas of 9 Wadi Basins

	Name of Wadi	Area (km^2)		
		SW Area (Catchment Area)	Additional GW Area	GW Area of the Study Area
1	Wadi Hahal Milah	270.9	0*	270.9
2	Wadi Abu Sidra	117.8	0*	117.8
3	Wadi Far'a	335.7	0*	335.7
4	Wadi Al 'Ahmer	179.9	58.7	238.6
5	Wadi Auja	291.1	59.1	350.2
6	Wadi Nwai'mah	152.2	57.2	209.4
7	Wadi Qilt	172.4	72.8	245.2
8	Wadi Marar	100.8	0.0	100.8
9	Wadi Mukallak	139.9	12.2	152.1
Total		1,760.7	260.0	2,020.7

<u>*Notes*</u>

**: A part of northeastern aquifer is included.*

Source: PWA, JICA Study Team

4.4.2 Effective Rainfall and Effective Catchment in Each Catchment

In the Study Area, rainfall in the low-land areas does not contribute to the yield or recharge of water resources, as it hardly exceeds the evapotranspiration amount which is dependent on various meteorological values. The Wadi Far'a basin situated in the northern part of the Study Area is relatively rich in vegetation even in its low elevation areas, while desert areas are spread over the low-land areas of the Wadi Qilt basin. This means that the rainfall amount at the northern part up to its areas with lower elevations exceeds evapotranspiration, as compared to the southern wadi basins like Wadi Qilt.

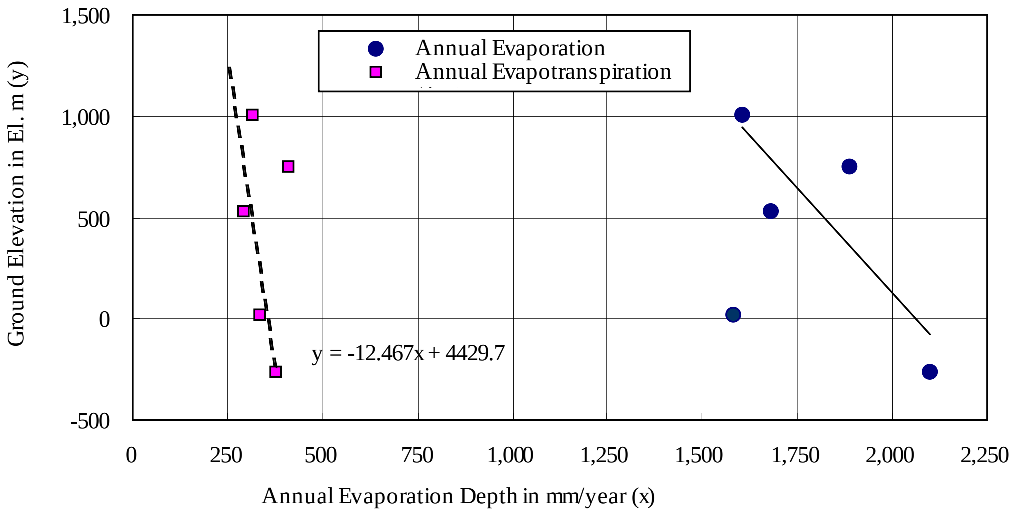
To estimate the effective catchments in each major wadi that contribute to yield of water resources, the marginal ground elevation (where annual rainfall is almost equivalent to annual evapotranspiration) is determined based on evaporation and topographic data of the Study Area.

The Tank Model analysis discussed in Section 4.2 shows that the evaporation from the uppermost tank is equivalent to about 55% of the sum of evaporations in November to April. Considering the Study Area, assuming that the evapotranspiration at certain elevation is 55 % of the total evaporation for six months, a relationship between ground elevation and evapotranspiration (evapotranspiration line) is formulated based on the evaporation records observed, as shown in Figure 4.4.2 and below:

$$y = -12.467x + 4429.7$$

Where, y : Ground elevation (El. m)

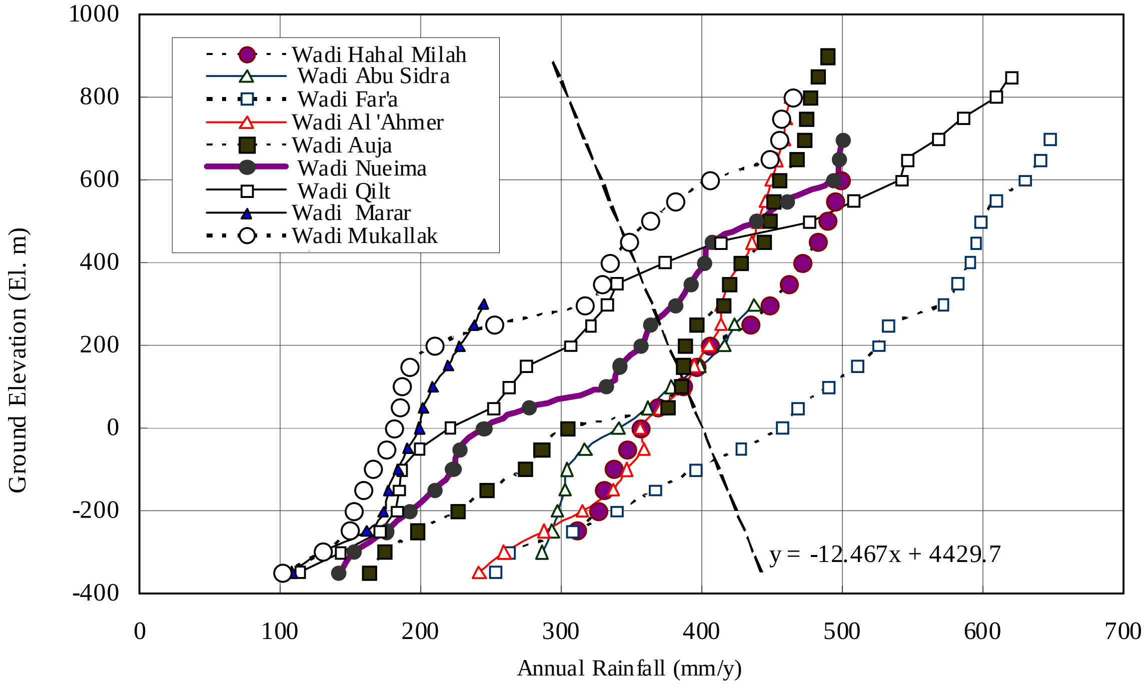
x : Annual evapotranspiration (mm/year)



Source: JICA Study Team

Figure 4.4.2 Relation between Ground Elevation and Annual Evaporation Depth

Figure 4.4.3 depicts the relationship between ground elevation and annual rainfall in each of the nine wadi basins, as well as the aforesaid evapotranspiration line. The marginal ground elevation in each wadi basin, at which the annual rainfall balances with annual evapotranspiration, as well as the marginal annual rainfall corresponding to the marginal ground elevation, is derived as shown in the table below:



Source: JICA Study Team

Figure 4.4.3 Relation between Annual Rainfall and Ground Elevation

Table 4.4.2 Marginal Ground Elevation and Annual Rainfall

No.	Name of Wadi	Ground Elevation (El. m)	Annual Rainfall (mm/year)
1	Wadi Hahal Milah	0	343
2	Wadi Abu Sidra	-50	368
3	Wadi Far'a	-50	367
4	Wadi Al 'Ahmer	28	353
5	Wadi Auja	32	353
6	Wadi Nueima	153	343
7	Wadi Qilt	290	366
8	Wadi Marar	-	-
9	Wadi Mukallak	340	328

Source: JICA Study Team

Applying the GIS techniques, the following data in each wadi basin were obtained from the topographic map and isohyetal map of the Study Area, provided by PWA:

(i) Catchment areas at 50 m intervals of ground elevations in each wadi basin, which were derived from the topographic map, are shown in Table 4.4.3; and

(ii) Catchment areas at 50 mm intervals of isohyetal lines in each wadi basin, which are derived from the isohyetal map, are shown in Table 4.4.4.

For each of Surface Water (SW) area and Additional Groundwater (AG) area in the nine wadi basins, the effective catchment area (ECA) which has ground elevations higher than the marginal ground elevation, was first estimated by interpolating the ground elevation data in Table 4.4.3. As a second step, the basin average rainfall of the ECA is derived from the annual rainfall data in Table 4.4.4.

Table 4.4.3 Catchment Area at 50 m Intervals of Contour Lines in Each Wadi Basin

(1) Catchment Area Intervened by 2 Neighboring Contour Lines in Surface Water (SW) Area

No.	Name of Wadi Basin	Catchment Area in Each Ground Elevation Range (km^2) / Range of Ground Elevation at 50m Intervals (El. m): Less than -400	-400 to -350	-350 to -300	-300 to -250	-250 to -200	-200 to -150	-150 to -100	-100 to -50	-50 to 0	0 to 50	50 to 100	100 to 150	150 to 200	200 to 250	250 to 300	300 to 350	350 to 400	400 to 450	450 to 500	500 to 550	550 to 600	600 to 650	650 to 700	700 to 750	750 to 800	750 to 800	800 to 850	850 to 900	Over 900
	(Average El	-400	-375	-325	-275	-225	-175	-125	-75	-25	25	75	125	175	225	275	325	375	425	475	525	575	625	675	725	775	825	875	925	900
1.	Wadi Hahal Milah		0.4	4.0	10.8	16.5	16.9	15.1	15.8	22.4	26.5	22.6	17.3	13.3	11.5	14.3	14.3	12.3	14.6	9.5	5.6	3.4	2.5	1.3						
2.	Wadi Abu Sidra		1.2	11.6	18.8	3.7	3.8	2.7	3.5	7.2	16.6	16.6	9.2	7.1	3.9	3.3	3.6	2.2	1.2	0.6	0.3	0.2	0.2							
3.	Wadi Far'a		1.7	9.0	19.2	11.6	8.1	10.8	14.7	20.0	18.3	19.3	18.3	15.7	13.7	14.7	15.5	14.9	16.8	28.3	24.5	15.7	10.6	7.1	5.1	1.4	0.6	0.1		
4.	Wadi Al 'Ahmer		1.1	7.9	16.8	5.8	4.3	4.8	4.5	5.4	5.5	8.8	8.6	8.4	7.9	9.2	9.2	11.3	6.6	6.6	7.7	9.7	11.8	6.8	5.2	3.8	2.0			
5.	Wadi Auja		1.6	38.2	39.7	16.3	11.8	23.2	12.9	9.3	6.8	5.2	4.1	4.0	5.3	6.2	6.6	7.1	9.6	10.3	11.9	8.7	11.2	14.7	8.9	7.8	3.1	1.6	3.4	1.5
6.	Wadi Nueima		7.3	22.4	17.9	7.7	4.7	5.2	2.9	1.2	2.6	4.2	4.2	4.7	3.6	3.8	2.7	1.8	2.1	3.9	6.0	5.3	4.2	3.7	4.7	7.2	8.7	6.6	1.9	0.9
7.	Wadi Qilt		4.2	6.4	7.2	3.4	1.2	0.8	1.1	2.6	5.2	5.8	5.1	6.2	9.0	11.1	5.1	4.8	3.7	5.5	11.2	13.4	13.6	9.9	10.5	8.6	7.2	9.4	0.2	
8.	Wadi Marar	1.3	24.1	14.5	21.3	5.3	2.5	5.9	4.6	5.7	3.0	2.6	2.9	2.6	2.5	2.1														
9.	Wadi Mukallak	4.1	5.2	3.8	3.0	1.1	0.8	1.9	6.4	6.1	3.9	2.2	2.2	6.9	11.8	16.4	10.0	11.9	9.6	7.3	7.0	6.6	4.7	3.2	2.0	1.5	0.3			
	Total	5.4	46.8	117.8	154.7	71.4	54.1	70.4	66.4	79.9	88.4	87.3	71.9	68.9	69.2	81.1	67.0	66.3	64.2	72.0	74.2	63.0	58.8	46.7	36.4	30.3	21.9	17.7	5.5	2.4

Abbreviations: EL; Ground elevation

(2) Catchment Area Intervened by 2 Neighboring Contour Lines in Groundwater (GW) Area

No.	Name of Wadi Basin	Catchment Area in Each Ground Elevation Range (km^2) / Range of Ground Elevation at 50m Intervals (El. m): Less than -400	-400 to -350	-350 to -300	-300 to -250	-250 to -200	-200 to -150	-150 to -100	-100 to -50	-50 to 0	0 to 50	50 to 100	100 to 150	150 to 200	200 to 250	250 to 300	300 to 350	350 to 400	400 to 450	450 to 500	500 to 550	550 to 600	600 to 650	650 to 700	700 to 750	750 to 800	750 to 800	800 to 850	850 to 900	Over 900
	(Average El	-400	-375	-325	-275	-225	-175	-125	-75	-25	25	75	125	175	225	275	325	375	425	475	525	575	625	675	725	775	825	875	925	900
1.	Wadi Hahal Milah			0.1	0.1	0.1	0.1	2.6	3.5	5.5	3.8	2.5	2.4	2.4	3.7	8.8	11.7	10.3	13.2	8.4	4.8	2.7	1.6	0.8						
2.	Wadi Abu Sidra																													
3.	Wadi Far'a								0.1	0.0	0.0	1.2	4.7	6.7	6.3	7.3	8.5	8.4	12.4	19.1	16.1	9.1	5.2	3.0	1.7	1.0	0.3	0.1		
4.	Wadi Al 'Ahmer																				0.2	3.1	9.6	11.3	11.1	13.1	8.9	1.4		
5.	Wadi Auja																			0.3	1.7	3.4	4.7	14.3	13.3	10.0	4.4	2.8	4.2	
6.	Wadi Nueima																			0.6	2.1	3.1	4.7	7.8	10.7	11.6	9.2	4.6	2.4	0.4
7.	Wadi Qilt								0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.0	1.9	4.3	13.1	26.9	18.1	7.2	0.3	
8.	Wadi Marar																													
9.	Wadi Mukallak																					1.1	2.4	3.2	3.2	1.5	0.8			
	Total	0.0	0.0	0.1	0.1	0.1	0.1	2.6	3.7	5.5	3.8	3.7	7.1	9.1	10.0	16.1	20.3	18.7	25.6	28.4	24.9	23.5	30.1	44.7	53.1	64.1	41.7	16.1	6.9	0.4

Abbreviations: EL; Ground elevation

Source: JICA Study Team

Table 4.4.4 Catchment Area at 50 mm Interval of Annual Rainfall in Each Wadi Basin

(1) Catchment Area Intervened by 2 Neighboring Isohyetal Lines in Surface Water (SW) Area

No.	Name of Wadi Basin	Catchment Area in Each Rainfall Range of Annual Rainfall (km^2) — Range of Annual Rainfall at 50mm Intervals (mm)													
		Less than 100	100 - 150	150 - 200	200 - 250	250 - 300	300 - 350	350 - 400	400 - 450	450 - 500	500 - 550	550 - 600	600 - 700	700 - 800	Over 800
	(Average Rain)	(100.0)	(125.0)	(175.0)	(225.0)	(275.0)	(325.0)	(375.0)	(425.0)	(475.0)	(525.0)	(575.0)	(650.0)	(700.0)	(700.0)
1.	Wadi Hahal Milah					5.4	119.6	72.1	46.8	26.5	0.6				
2.	Wadi Abu Sidra					41.0	33.6	29.4	13.7						
3.	Wadi Far'a				0.1	41.0	43.3	58.5	40.6	71.2	29.2	36.3	14.7	1.0	
4.	Wadi Al 'Ahmer				4.0	36.9	15.3	52.8	64.7	6.2					
5.	Wadi Auja			40.0	62.1	54.1	24.3	33.7	54.1	22.2	0.5				
6.	Wadi Nueima	0.3	21.3	42.8	12.8	11.5	4.3	8.0	14.3	20.7	8.5	7.3	0.6		
7.	Wadi Qilt	2.0	10.2	16.4	22.1	22.0	10.7	8.8	16.6	19.4	19.5	9.4	15.5		
8.	Wadi Marar	22.5	30.2	38.6	9.5										
9.	Wadi Mukallak	8.1	10.9	23.8	22.5	33.5	14.9	13.9	7.6	4.2	0.5				
	Total	35.1	72.8	161.8	132.9	251.1	269.2	277.7	257.7	171.3	58.8	53.1	30.8	1.0	

(2) Catchment Area Intervened by 2 Neighboring Isohyetal Lines in Groundwater (GW) Area

No.	Name of Wadi Basin	Catchment Area in Each Rainfall Range of Annual Rainfall (km^2) — Range of Annual Rainfall at 50mm Intervals (mm)													
		Less than 100	100 - 150	150 - 200	200 - 250	250 - 300	300 - 350	350 - 400	400 - 450	450 - 500	500 - 550	550 - 600	600 - 700	700 - 800	Over 800
	(Average Rain)	(100.0)	(125.0)	(175.0)	(225.0)	(275.0)	(325.0)	(375.0)	(425.0)	(475.0)	(525.0)	(575.0)	(650.0)	(700.0)	(800.0)
1.	Wadi Hahal Milah						1.3*	24.0*	36.7*	26.5*	0.6*				
2.	Wadi Abu Sidra														
3.	Wadi Far'a								0.5*	33.9*	25.0*	36.3*	14.7*	1.0*	
4.	Wadi Al 'Ahmer								4.2**	38.5**	14.4**	1.8**			
5.	Wadi Auja									10.4**	11.5**	15.9**	21.1**		
6.	Wadi Nueima										1.1**	6.7**	29.5**	19.9**	
7.	Wadi Qilt										14.2**	26.0**	27.8**	4.7**	
8.	Wadi Marar														
9.	Wadi Mukallak								1.5**	8.1**	2.6**				
	Total	35.1	72.8	161.8	132.9	251.1	269.2	277.7	257.7	171.3	58.8	53.1	30.8	1.0	

Notes

***** : Decremental catchmnet area of underground water out of surface runoff area

** : Incremental catchment area in addition to surface runoff area

Source: JICA Study Team

Consequently, the total potential water resources amount in each Surface Water (SW) and Additional Groundwater (AG) areas were estimated using the following formula:

$$WR_t = ECA \times (R_{ECA} - R_{MAR})/10^{3}$$

Where, WR_t: total water resources amount (MCM/year)

ECA: Effective catchment area (km^2)

R_{ECA}: Basin average rainfall of ECA (mm/year)

R_{MAR} Marginal annual rainfall (mm/year)

Table 4.4.5 shows the water resources amount in each of the nine wadis that were estimated considering the procedures mentioned above. As shown in said table, the total water resources amount in the Study Area is estimated to be 141.5 MCM/year.

4.4.3 Water Resources Amount by Water Source

To assess the possibility of groundwater resources development in the Study Area, the following categories were set as present source of groundwater:

(i) Abstraction wells, including the Palestinian Well and Mekorot Well;

(ii) Spring;

Above information was obtained from PWA database during 1995-1999. Based on this, the annual average abstraction and discharge were calculated.

(iii) Storm water harvesting; and

In addition, storm water harvesting was considered although storm water resource is yet to be developed.

(iv) Unidentifiable water resources.

Finally, the difference between the total water resources supplied as groundwater and the total water usage from this was regarded as the groundwater balance. It should be realized that this balance include unidentifiable water resources, such as unidentified spring discharge and well abstraction, uncertainty of surface runoff rate and groundwater boundaries, and unreported Israeli well abstraction.

The amounts of water resources for the above four categories are estimated based on the existing data collected from PWA.

4.4.4 Overall Assessment of Results of Estimated Water Resources Amount in the Study Area

The estimated water resources amounts from each source are tabulated in Table 4.4.5. Said table shows that recharged amount of groundwater exceed the amount of present water use by only 1.0 MCM. In fact, water quality and quantity from wells located in Jericho and Auja area are deteriorating due to present over-pumping. Therefore, PWA is required to monitor and regulate the pumping amount from wells to avoid the depletion of groundwater resource, in parallel with continuous negotiation with Israel towards integrated groundwater management.

Table 4.4.5 Estimated Potential Water Resources in the Study Area

I. Potential Water Resources in Surface Water (SW) Area

No	Name of Wadi Basin	Marginal Conditions of Effective Catchment (EC)		Water Resources in Effective Catchment of SW Area					
		Annual Rainfall	Ground Elevation	Total Catchment Area (TCA)	Effective Catchment Area (ECA)	Ratio of ECA to TCA	Average Rainfall in EC	Average Evapo-transpiration	Recharged Water from SW Area (Surface Runoff to Inside of Study Area + Groundwater of Study Area)
		(mm)	(m)	(km^2)	(km^2)	(%)	(mm/year)	(mm/year)	(MCM/year)
		(1)		(2)	(3)	=(3)/(2)x100	(4)	(5)	(6)=((4)-(5))x(3)/1000
1	Wadi Hahal Milah	343	0	270.9	169.0	62.4	398.9	343.6	9.3
2	Wadi Abu Sidra	368	-50	117.8	55.7	47.3	380.0	346.7	1.9
3	Wadi Far'a	367	-50	335.7	286.1	85.2	457.4	357.4	28.6
4	Wadi Al' Ahmer	353	28	179.9	126.0	70.1	368.4	360.6	1.0
5	Wadi Auja	353	32	291.1	133.6	45.9	404.0	335.4	9.2
6	Wadi Nwai'mah	343	153	152.2	71.7	47.1	440.7	311.6	9.3
7	Wadi Qilt	366	290	172.4	103.1	59.8	482.3	310.7	17.7
8	Wadi Marar*	-	-	100.8	0.0	0.0	-	-	0.0
9	Wadi Mulkallak	328	340	139.9	64.1	45.8	346.5	320.7	1.6
	Total			1,760.7	1,009.4	57.3			78.6

Note

* There was no effective catchment area in Wadi Marar due to smaller amount of annual rainfall compared with estimated evapotranspiration. Therefore, the amount of water recharge is nil.

II. Potential Water Resources in Additional Groundwater (AG) Area

No	Name of Wadi Basin	Marginal Conditions of Effective Catchment (EC)		Total Catchment Area (TCA)	Additional Water Resources in AG Area				
		Annual Rainfall	Ground Elevation		AG Catchment Area	Ratio of ECA to TCA	Average Rainfall in AG	Average Evapo-transpiration	Recharged Water from AG Area (Surface Runoff to Outside of Study Area + Groundwater of Study Area)
		(mm)	(m)	(km^2)	(km^2)	(%)	(mm/year)	(mm/year)	(MCM/year)
		(1)		(2)	(7)	=(7)/(2)x100	(8)	(9)	(10)=((8)-(9))x(7)/1000
1	Wadi Hahal Milah*	-	-	270.9	0.0	0.0	-	-	0.0
2	Wadi Abu Sidra*	-	-	117.8	0.0	0.0	-	-	0.0
3	Wadi Far'a*	-	-	335.7	0.0	0.0	-	-	0.0

4	Wadi Al' Ahmer	353	28	179.9	58.7	32.6	486.9	316.3	10.0
5	Wadi Auja	353	32	291.1	59.1	20.3	574.4	309.2	15.7
6	Wadi Nwai'mah	343	153	152.2	57.2	37.6	656.2	302.7	20.2
7	Wadi Qilt	366	290	172.4	72.8	42.2	601.9	307.0	21.5
8	Wadi Marar**	-	-	100.8	0.0	0.0	-	-	0.0
9	Wadi Mulkallak	328	340	139.9	12.2	8.7	479.8	316.8	2.0
	Total			1,760.7	260.0	14.8		1,552.0	69.4

Note

* There were no additional catchment areas in Wadi Milah, Wadi Abu Sidra, Wadi Far'a.

** There was no effective catchment area in Wadi Marar due to smaller amount of annual rainfall compared with estimated evapotranspiration. Therefore, the amount of water recharge is nil.

III. Balance of Water Resources by Source

No	Name of Wadi Basin	Water Resources as			Water Resources used as				Balance of Groundwater (including Unidentifiable Water Resources Volume**)
		Surface Runoff*	Groundwater**	Total**	Well Abstraction	Spring	Storm Water Harvesting	Total	
		(MCM/y)	(MCM/y)	(MCM/y^2)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)	(MCM/y)
		(11)	(12)	(13)=(11)+(12)	(14)	(15)	(16)	(17)=(14)+(15)+(16)	(18)=(12)-((14)+(15))
1	Wadi Hahal Milah	6.5	-	-	7.0	0.0	0.0	7.0	-
2	Wadi Abu Sidra	1.9	-	-	3.3	1.3	0.0	4.6	-
3	Wadi Far'a	8.6	-	-	17.6	13.8	0.0	31.4	-
4	Wadi Al' Ahmer	4.4	-	-	5.1	0.7	0.0	5.8	-
5	Wadi Auja	7.2	-	-	11.1	8.1	0.0	19.2	-
6	Wadi Nwai'mah	3.7	-	-	3.3	12.6	0.0	15.9	-
7	Wadi Qilt	4.4	-	-	5.4	6.8	0.0	12.2	-
8	Wadi Marar	0.0	-	-	3.9	0.0	0.0	3.9	-
9	Wadi Mulkallak	3.2	-	-	0.0	0.6	0.0	0.6	-
	Total	39.9	101.6	141.5	56.7	34.9	0.0	100.6	1.0

Note

* Rate of surface runoff rate reported by "The Potential for Storm Water Harvesting in the Eastern Surface Catchment of the West Bank" (USAID, 1998) was applied to the calculation. In case of Wadi Abu Sidra, estimated runoff based on the above USAID report exceeded the total amount of water resources in effective catchment in SW. Therefore, the total amount in this table was based on surface runoff.

** Catchment area of the groundwater could not be classified clearly. Therefore, only the total amount of groundwater was shown in the above table.