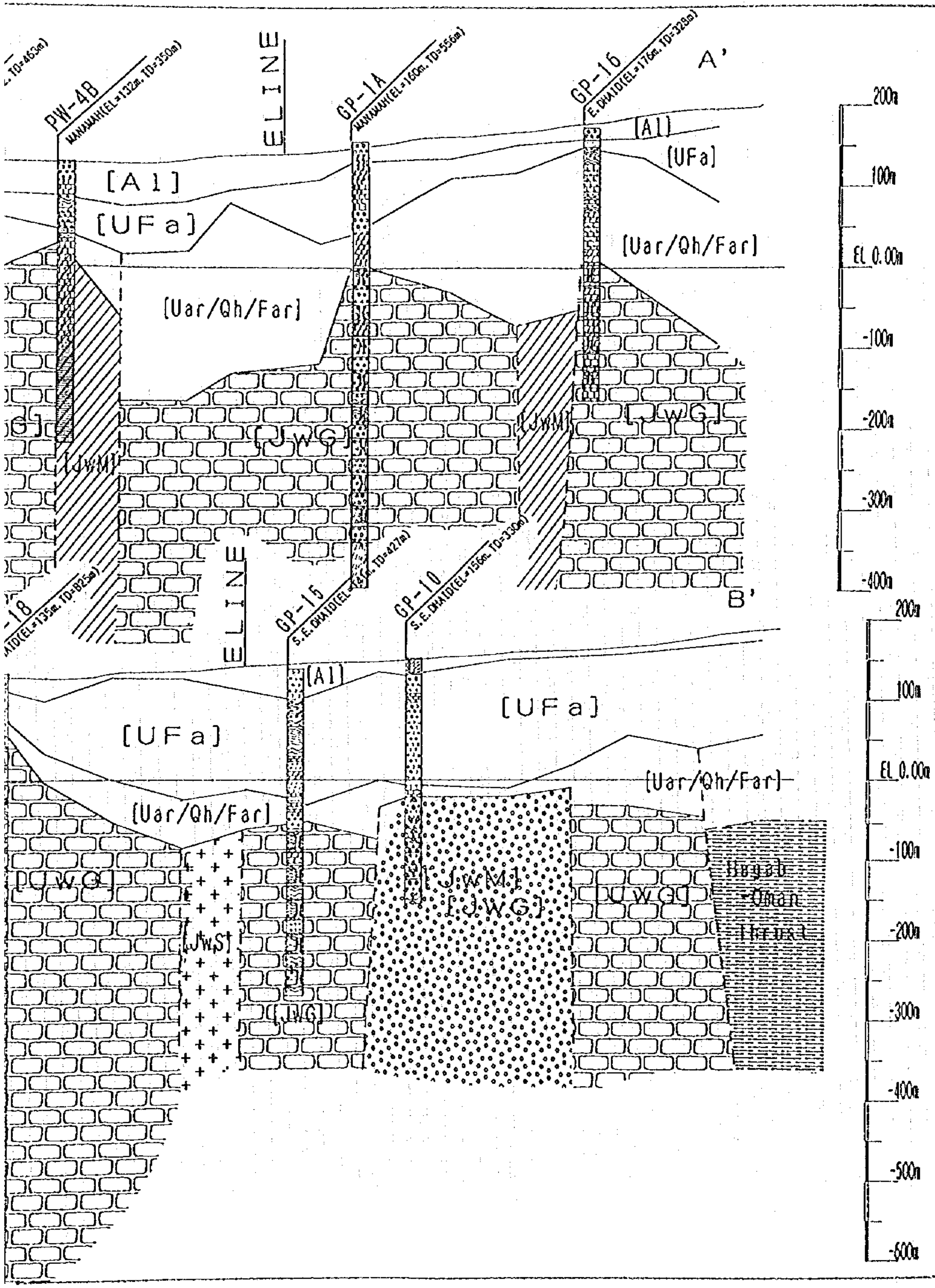
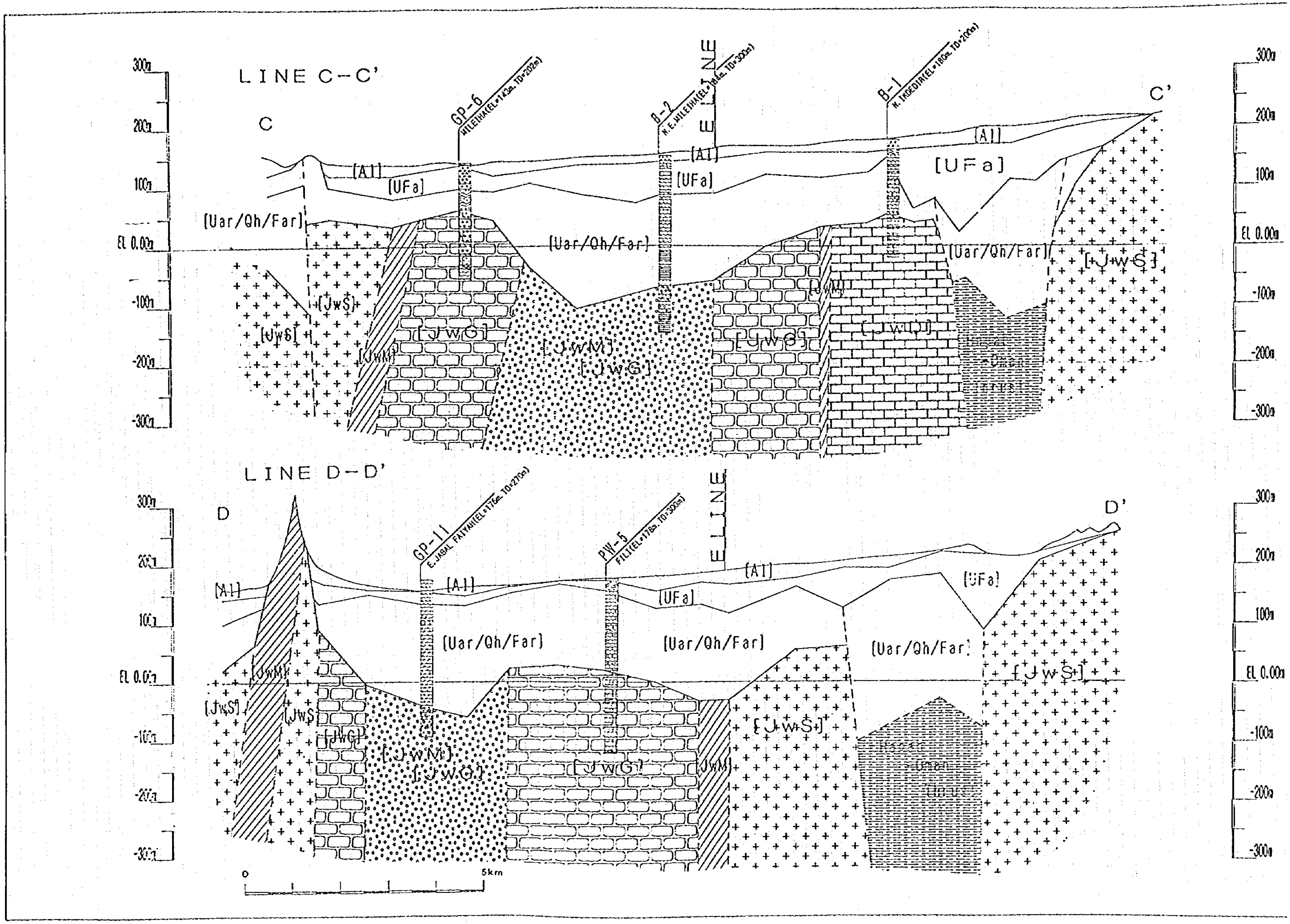


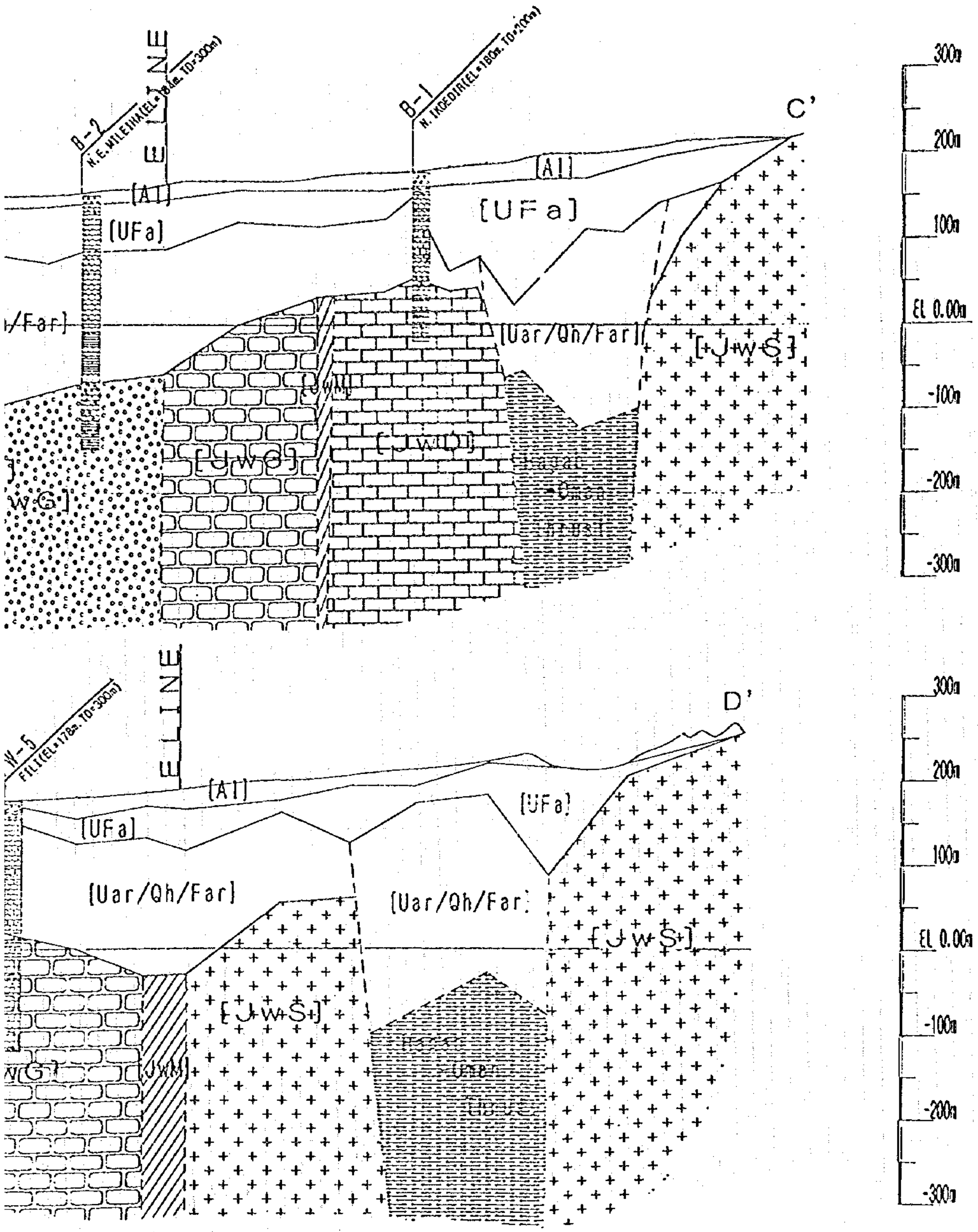
Geologic Member in the Study Area

STRATIGRAPHIC UNITS	GEOLOGIC SYMBLOS	FORMATION CORRELATED	LITHOLOGY	RESISTIVE LAYER CORRELATED
HOLOCENE	Al	[Al]Superficial Deposit(Recent alluvial gravel, sands and screen)	Gravel, Gravel with sand and silt, partly cemented.	LAYER I (AVG. 100 ohm-m)
PLEISTOCENE-NEOGENE	UFa	[UFa]Post-Upper Far or Razzak Formation (Cemented sand and gravel)	Clay hard, Limestone,Marl, Gravel, Limestone Gravely and Sandy.	LAYER II (AVG. 50 ohm-m)
PALEOGENE	Uar/Qh/Far	[Uar/Qh/Far] Umm al Radhuma, Qahlah , Far Formation	Shale, Limestone, Marl, Sandstone, Dolomite, Magnesite.	LAYER III (AVG. < 10 ohm-m)
	Esh/Far	[Esh/Far]Eocene shale, Far Formation		
MAASTRICHTIAN to Pre-PERMIAN	Os	[Os]Semail Ophiolite Sequence	Semail Ophiolite,	LAYER IV (AVG. 20 ohm-m)
	Jw	[Jw]Juweiza Formation		
	JwS		[JwS]Limestone with Melange Serpentinite,	
	JwG		[JwG]Gravely Facies,	
	JwM		[JwM]Marly & shalely Facies,	
	JwD		[JwD]Dolomitic Facies.	

Note : Map shows the litho-facies of the surface of Lower Aquifer

Figure 1.4.9 Geologic Cross-section along A-A' and B-B'


LINE C–C'
C
C'
GP-6
MILEIHA(EL=143m, TD=202m)
B-2
N.E. MILEIHA(EL=184m, TD=300m)
E LINE
B-1
N. IKOEDIR(EL=180m, TD=200m)
300m
200m
100m
EL 0.00m
-100m
-200m
-300m
[Al]
[UFa]
[Uar/Qh/Far]
[JwS]
[JwM]
[JwG]
[JwD]
LINE D–D'
D
D'
GP-11
E.JABAL FAIYAH(EL=176m, TD=270m)
PW-5
FILI(EL=178m, TD=300m)
E LINE
[Al]
[UFa]
[Uar/Qh/Far]
[JwM]
[JwS]
[JwG]
0
5km



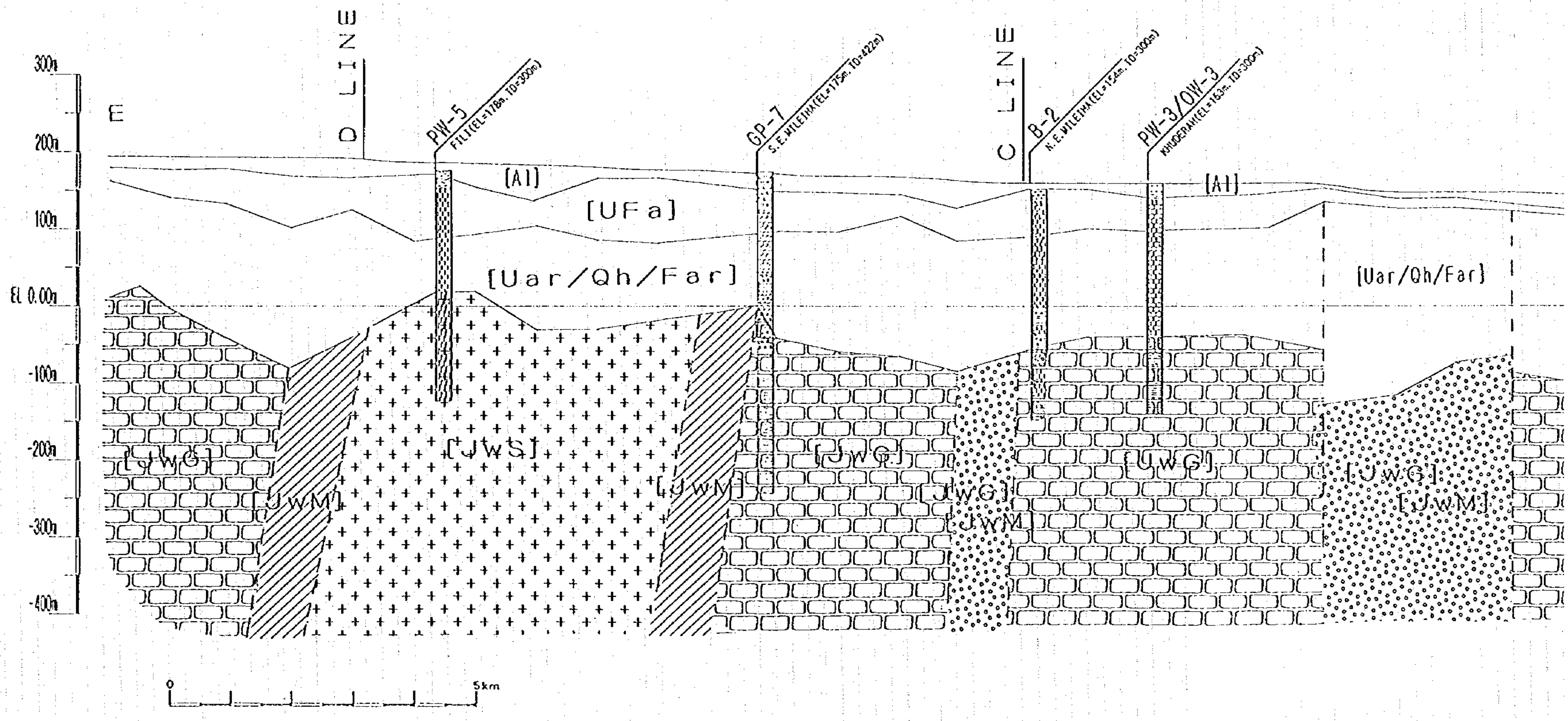
Geologic Member In the Study Area

STRATIGRAPHIC UNITS	GEOLOGIC SYMBLOS	FORMATION CORRELATED	LITHOLOGY	RESISTIVE LAYER CORRELATED
HOLOCENE	Al	[Al]Superficial Deposit(Recent alluvial gravel, sands and screen)	Gravel, Gravel with sand and silt, partly cemented.	LAYER I (AVG. 100 ohm-m)
PLEISTOCENE-NEOGENE	UFa	[UFa]Post-Upper Far or Razzak Formation (Cemented sand and gravel)	Clay hard, Limestone,Marl, Gravel, Limestone Gravely and Sandy.	LAYER II (AVG. 50 ohm-m)
PALEOGENE	Uar/Qh/Far	[Uar/Qh/Far] Umm al Radhuma, Qahlah , Far Formation	Shale, Limestone, Marl, Sandstone, Dolomite, Magnesite.	LAYER III (AVG. < 10 ohm-m)
	Esh/Far	[Esh/Far]Eocene shale, Far Formation		
MAASTRICHTIAN to Pre-PERMIAN	Os	[Os]Semail Ophiolite Sequence	Semail Ophiolite,	LAYER IV (AVG. 20 ohm-m)
	Jw	[Jw]Juweiza Formation		
	JwS		[JwS]Limestone with Melange Serpentinite,	
	JwG		[JwG]Gravely Facies,	
	JwM		[JwM]Marly & shalely Facies,	
	JwD		[JwD]Dolomitic Facies.	

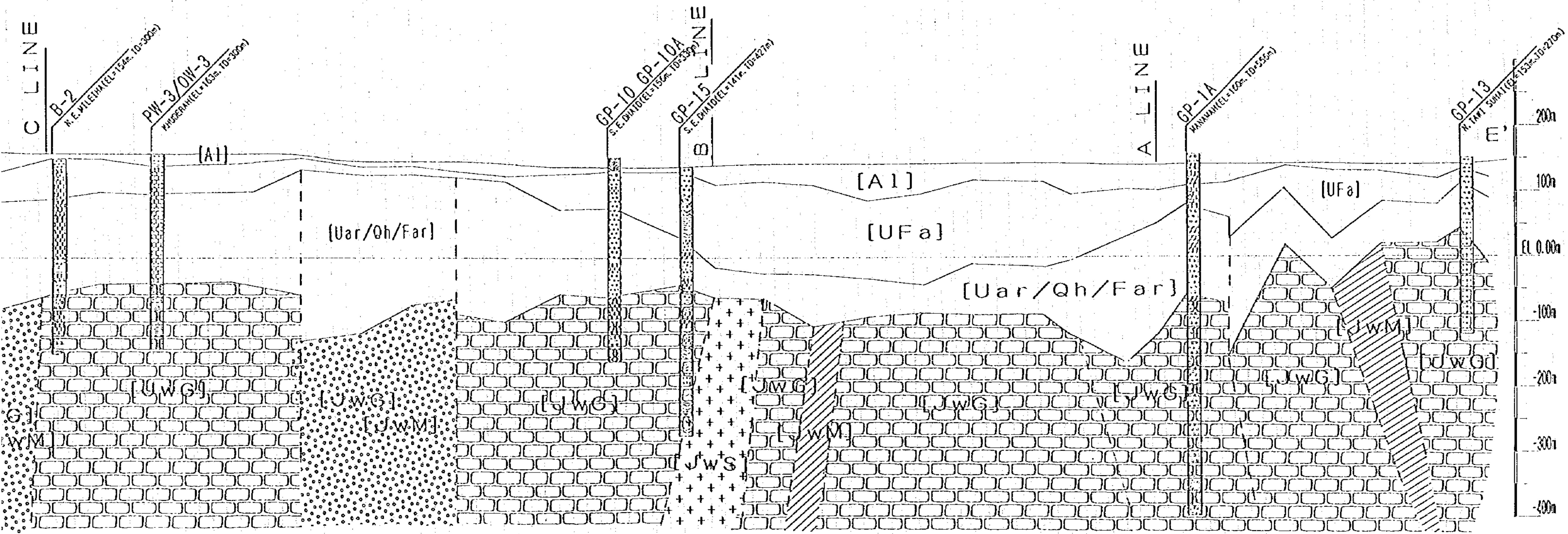
Note : Map shows the litho-facies of the surface of Lower Aquifer

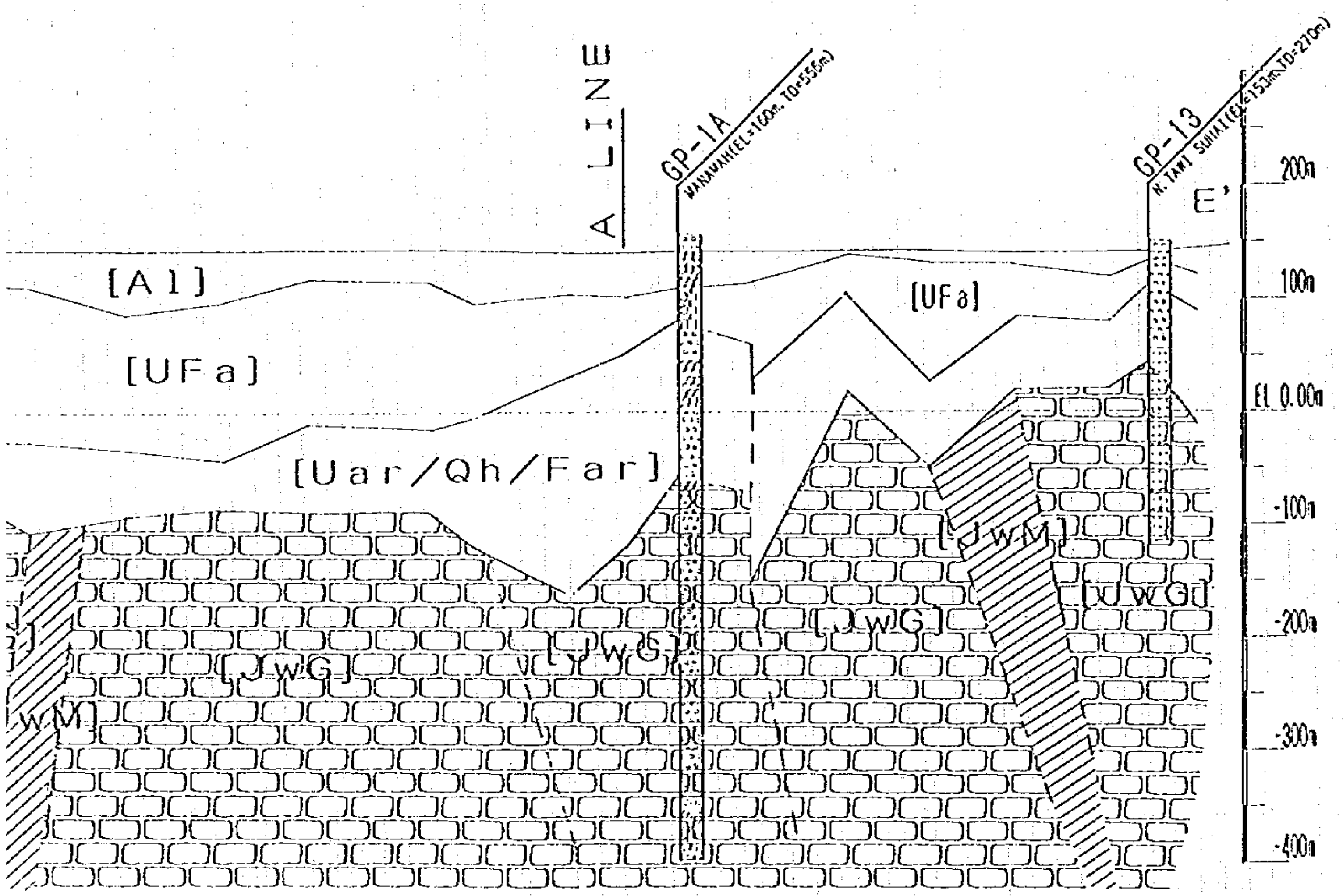
Figure 1.4.10 Geologic Cross-section along C-C' and D-D'

LINE E-E'



D LINE
C LINE
E
PW-5
FILI(EL=178m, TD=300m)
GP-7
S.E.MILEIHA(EL=175m, TD=422m)
B-2
N.E.MILEIHA(EL=154m, TD=300m)
PW-3/OW-3
KHUDERAH(EL=163m, TD=300m)
300m
200m
100m
EL 0.00m
-100m
-200m
-300m
-400m
[Al]
[UFa]
[Uar/Qh/Far]
[JWS]
[JwG]
[JwM]
[UwG]
[UwM]
0
5km


C LINE
B-2
N.E.MILEIHA(EL=154m, TD=300m)
PW-3/OW-3
KHUDERAH(EL=163m, TD=300m)
GP-10 GP-10A
S.E.DHAID(EL=156m, TD=330m)
GP-15
S.E.DHAID(EL=141m, TD=427m)
B LINE
A LINE
GP-1A
GP-13
E'
[Al]
[Uar/Qh/Far]
[UFa]
[Uar/Qh/Far]
[UFa]
[JwG]
[JwM]
[JwS]
[JwGd]
200m
100m
EL 0.00m
-100m
-200m
-300m
-400m



Geologic Member in the Study Area

STRATIGRAPHIC UNITS	GEOLOGIC SYMBLOS	FORMATION CORRELATED	LITHOLOGY	RESISTIVE LAYER CORRELATED
HOLOCENE	Al	[Al]Superficial Deposit(Recent alluvial gravel, sands and screen)	Gravel, Gravel with sand and silt, partly cemented.	LAYER I (AVG. 100 ohm-m)
PLEISTOCENE-NEOGENE	UFa	[UFa]Post-Upper Far or Razzak Formation (Cemented sand and gravel)	Clay hard, Limestone,Marl, Gravel, Limestone Gravely and Sandy.	LAYER II (AVG. 50 ohm-m)
PALEOGENE	Uar/Qh/Far	[Uar/Qh/Far] Umm al Radhuma, Qahlah , Far Formation	Shale, Limestone, Marl, Sandstone, Dolomite, Magnesite.	LAYER III (AVG. < 10 ohm-m)
	Esh/Far	[Esh/Far]Eocene shale, Far Formation		
MAASTRICHTIAN to Pre-PERMIAN	Os	[Os]Semail Ophiolite Sequence	Semail Ophiolite,	LAYER IV (AVG. 20 ohm-m)
	Jw	[Jw]Juwelza Formation		
	JwS		[JwS]Limestone with Melange Serpentinite,	
	JwG		[JwG]Gravely Facies,	
	JwM		[JwM]Marly & shalely Facies,	
	JwD		[JwD]Dolomitic Facies.	

Note : Map shows the litho-facies of the surface of Lower Aquifer

Figure 1.4.11 Geologic Cross-section along E-E'

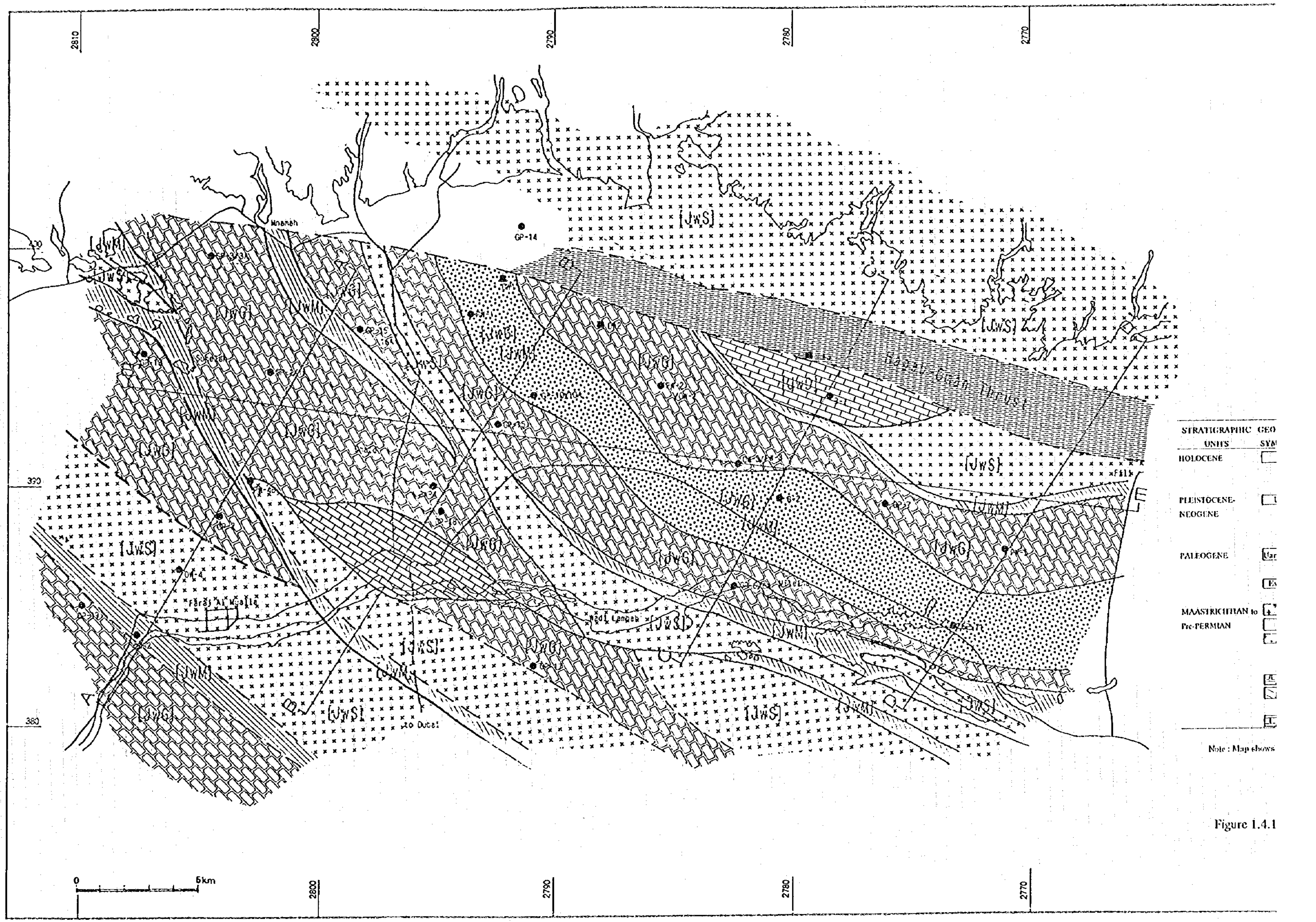
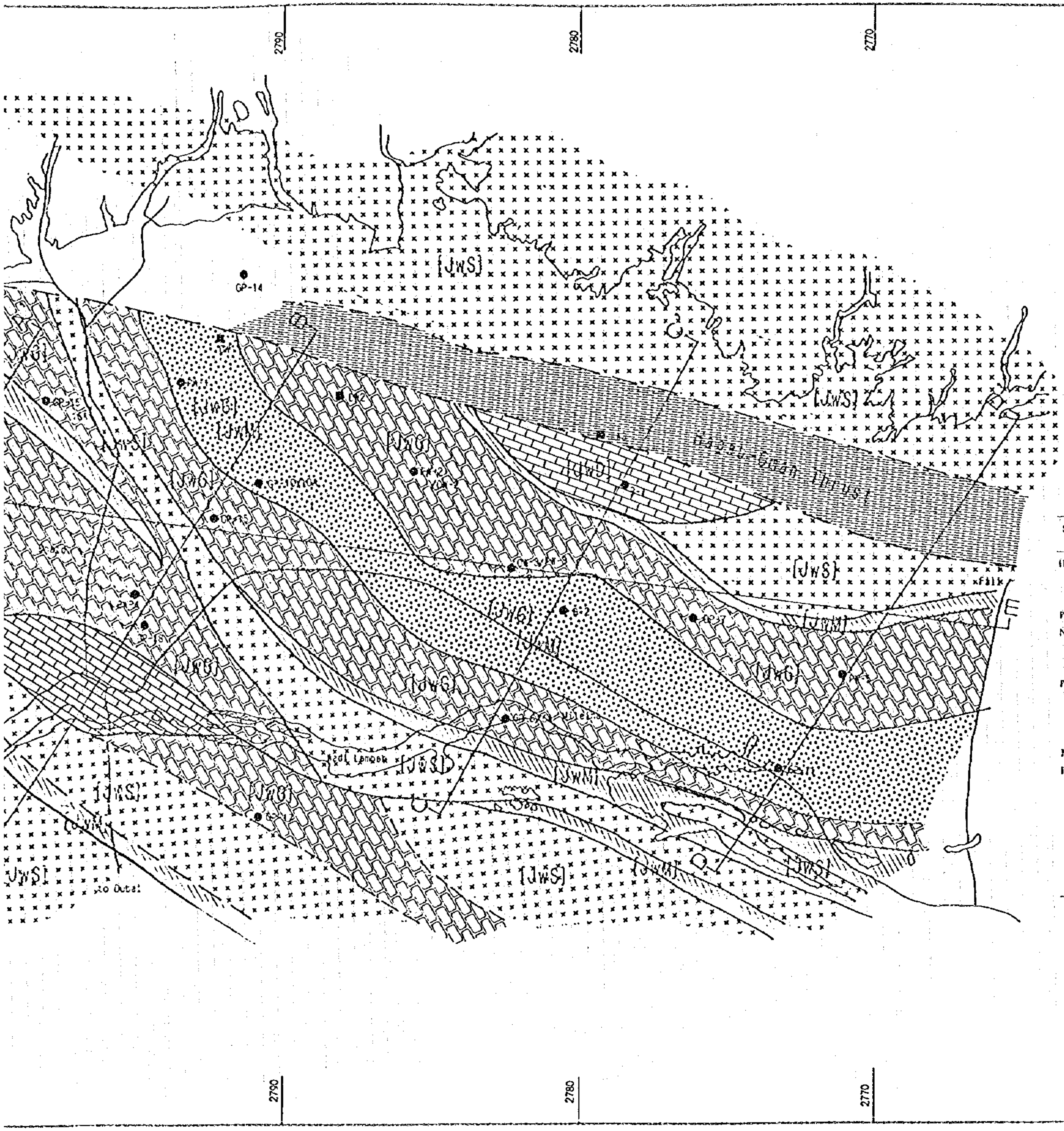

2810
2800
2790
2780
2770
390
380
[JwS]
[JwG]
[JwM]
GP-14
to Dubai
0
5km
STRATIGRAPHIC UNITS
GEO SYM
HOLOCENE
PLEISTOCENE-NEOGENE
PALEOGENE
MAASTRICHTIAN to Pre-PERMIAN
Note : Map shows

Figure 1.4.1



Geologic Member In the Study Area

STRATIGRAPHIC UNITS	GEOLOGIC SYMBLOS	FORMATION CORRELATED	LITHOLOGY	RESISTIVE LAYER CORRELATED
HOLOCENE	Al	[Al]Superficial Deposit(Recent alluvial gravel, sands and screen)	Gravel, Gravel with sand and silt, partly cemented.	LAYER I (AVG. 100 ohm-m)
PLEISTOCENE-NEOGENE	UFa	[UFa]Post-Upper Far or Razzak Formation (Cemented sand and gravel)	Clay hard, Limestone,Marl, Gravel, Limestone Gravely and Sandy.	LAYER II (AVG. 50 ohm-m)
PALEOGENE	Uar/QhFar	[Uar/QhFar] Umm al Radhuma, Qahlah , Far Formation	Shale, Limestone, Marl, Sandstone, Dolomite, Magnesite.	LAYER III (AVG. < 10 ohm-m)
	Esh/Far	[Esh/Far]Eocene shale, Far Formation		
MAASTRICHTIAN to Pre-PERMIAN	Os	[Os]Semail Ophiolite Sequence	Semail Ophiolite,	LAYER IV (AVG. 20 ohm-m)
	Jw	[Jw]Juweiza Formation		
	JwS		[JwS]Limestone with Melange Serpentinite,	
	JwG		[JwG]Gravely Facies,	
	JwM		[JwM]Marly & shalely Facies,	
	JwD		[JwD]Dolomitic Facies.	

Note : Map shows the litho-facies of the surface of Lower Aquifer

Figure 1.4.12 Sub-surface Geologic Map of the Study Area

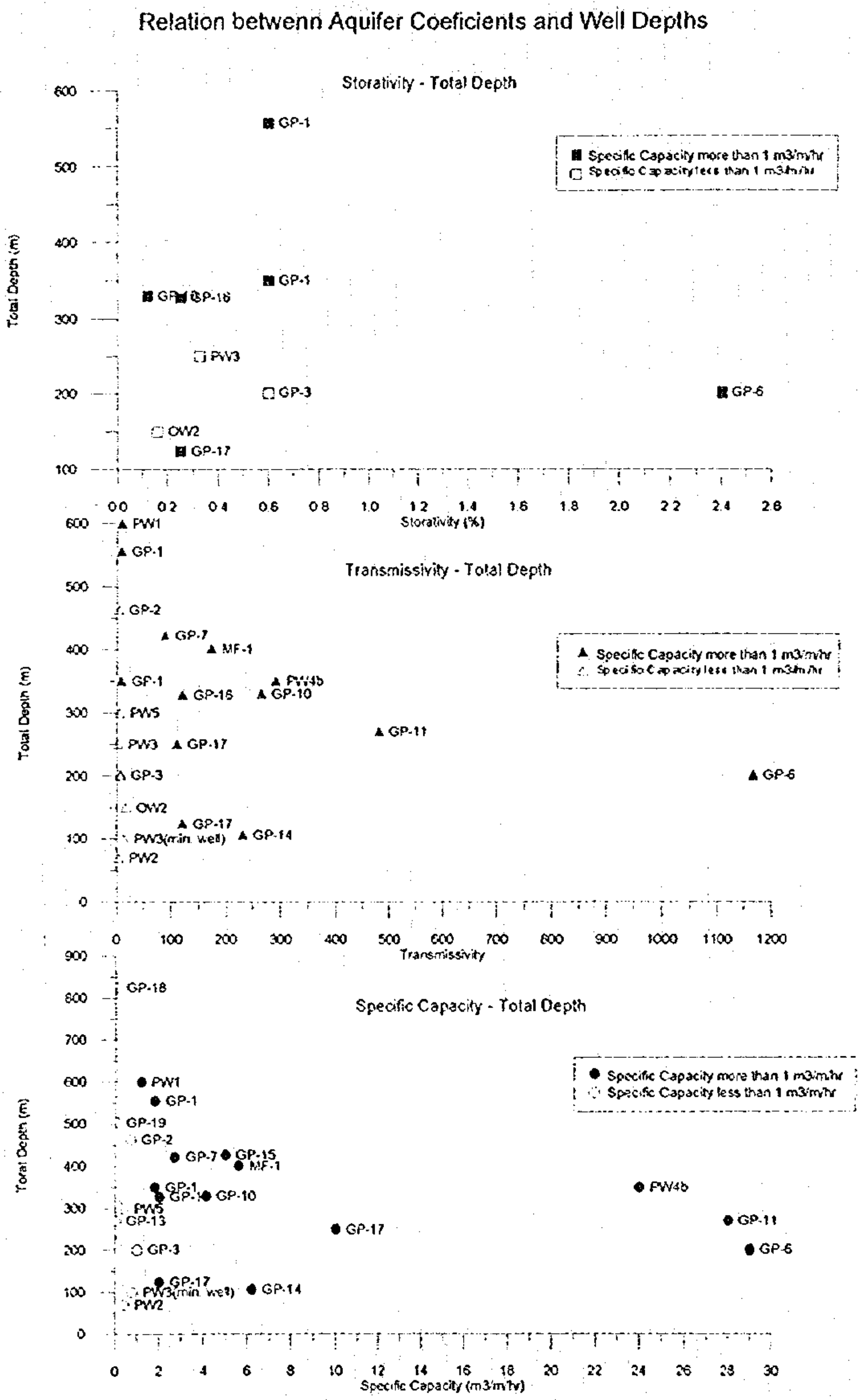


Figure 1.4.13 Relation between Aquifer Coefficient and Well Depths

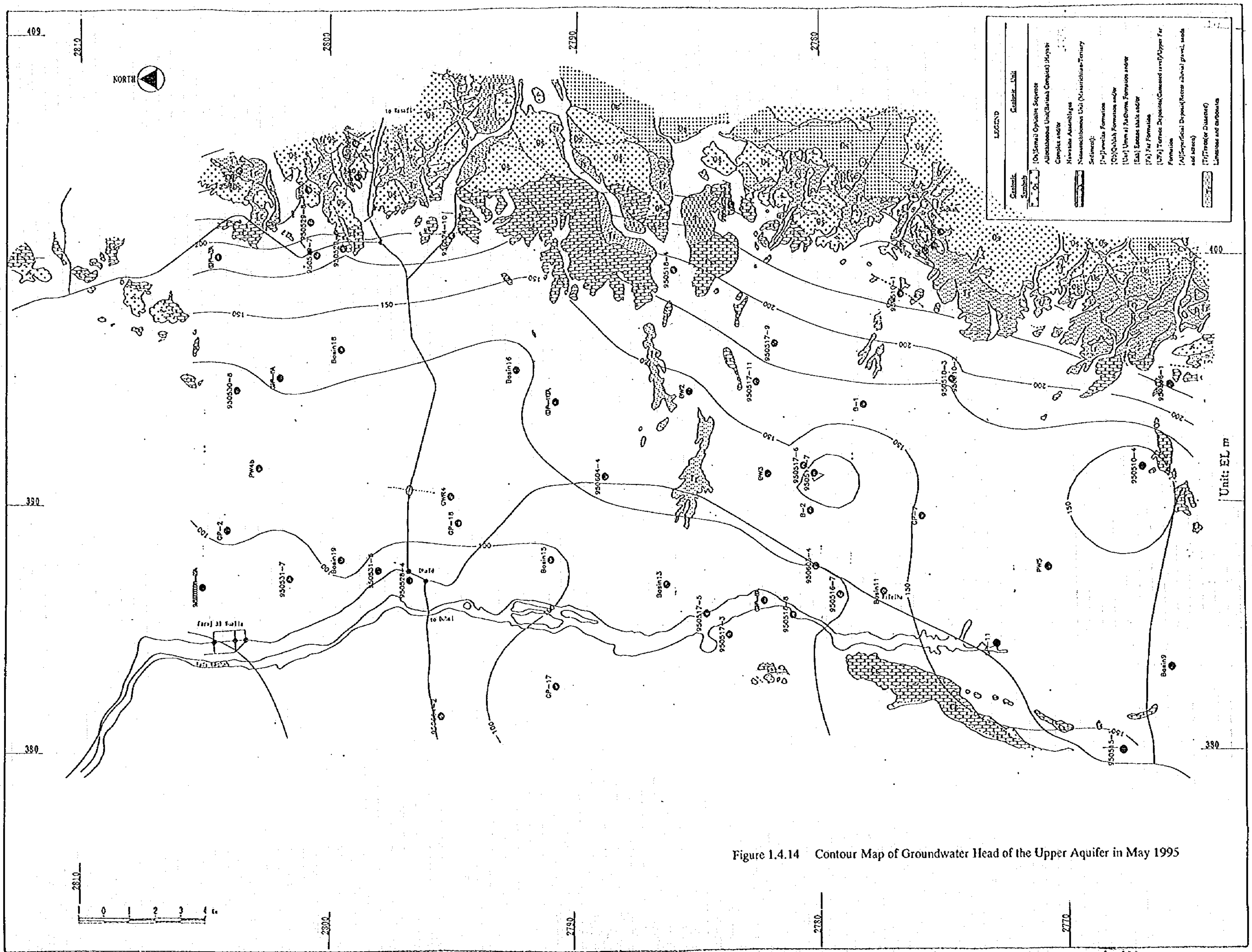


Figure 1.4.14 Contour Map of Groundwater Head of the Upper Aquifer in May 1995

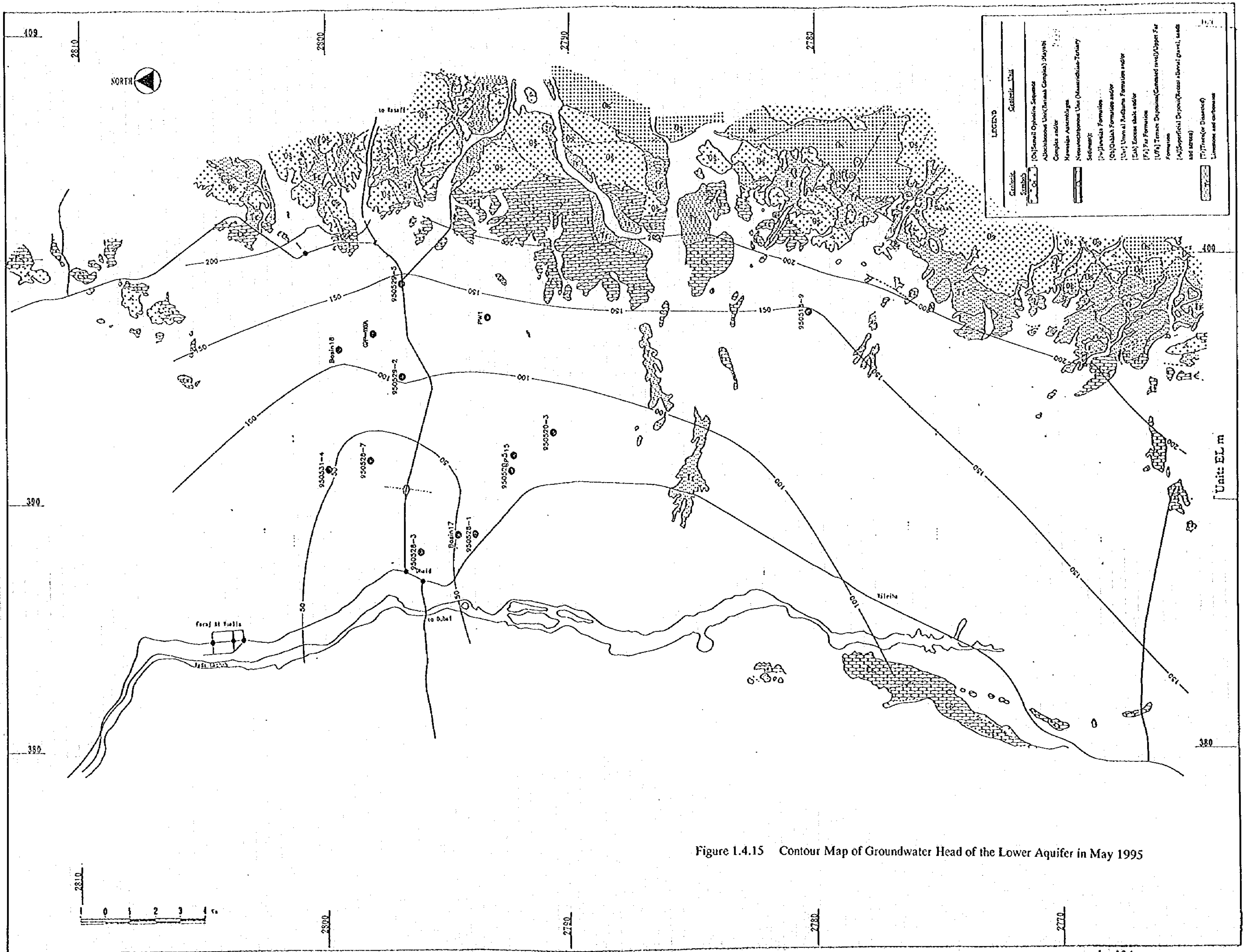


Figure 1.4.15 Contour Map of Groundwater Head of the Lower Aquifer in May 1995

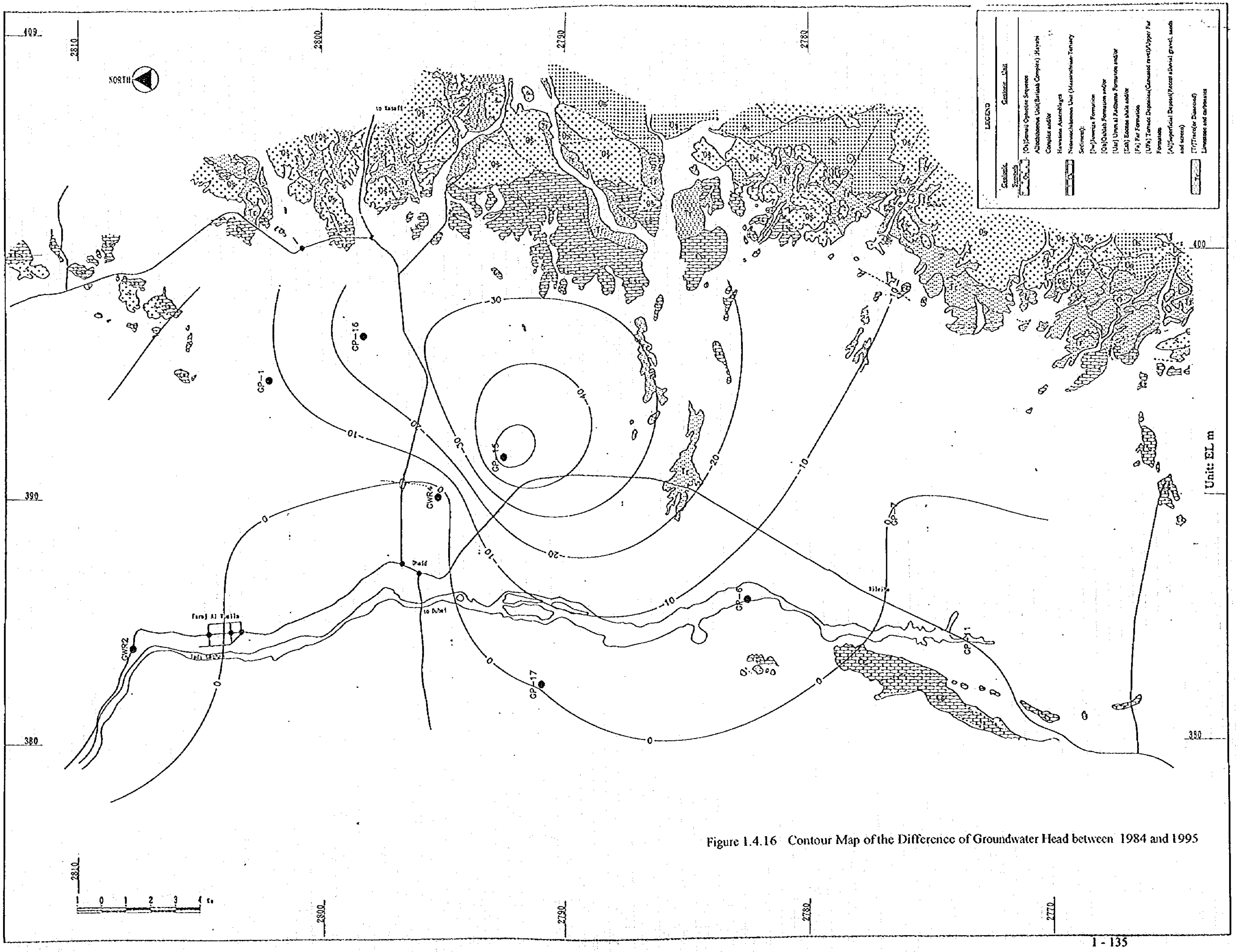
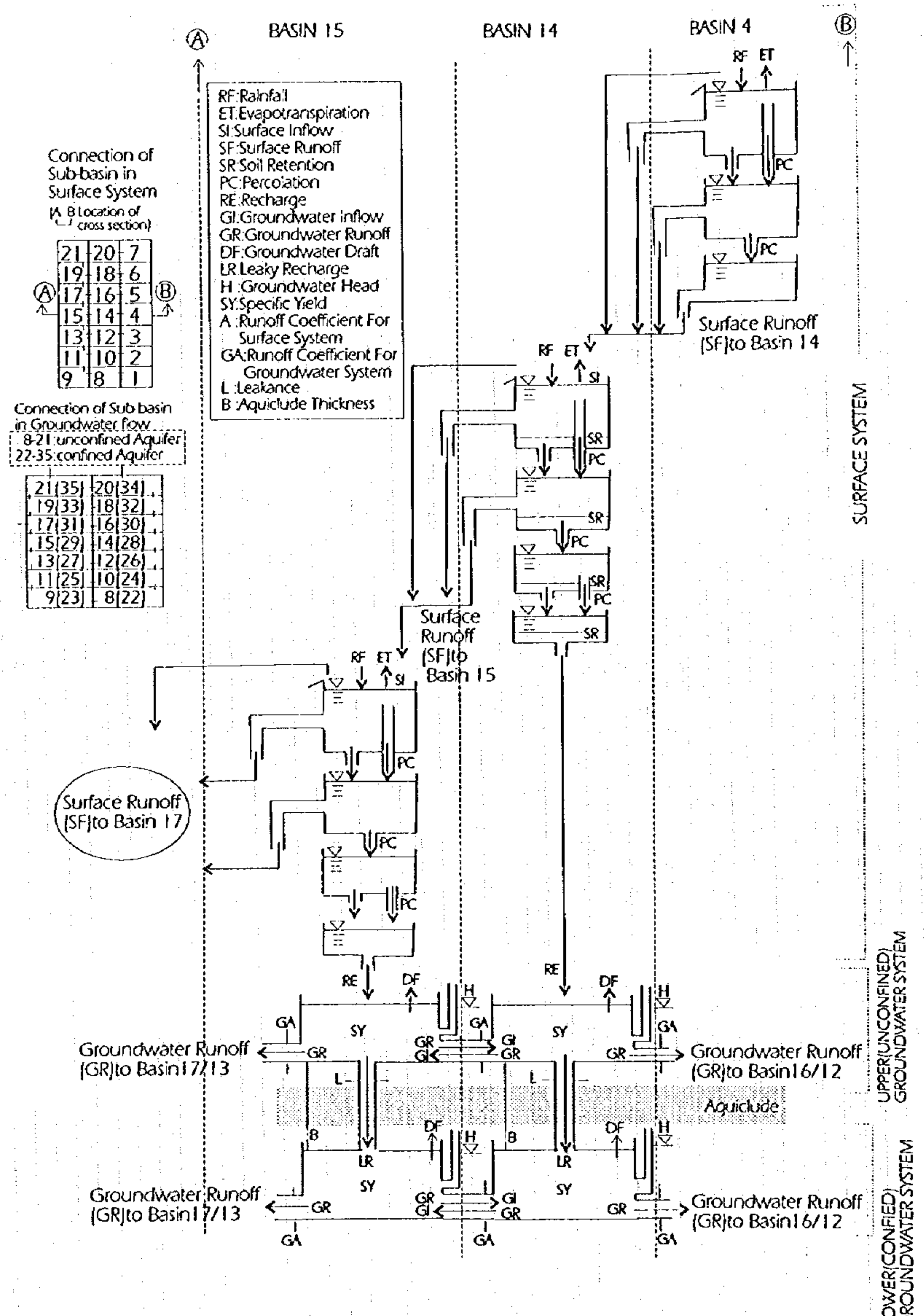
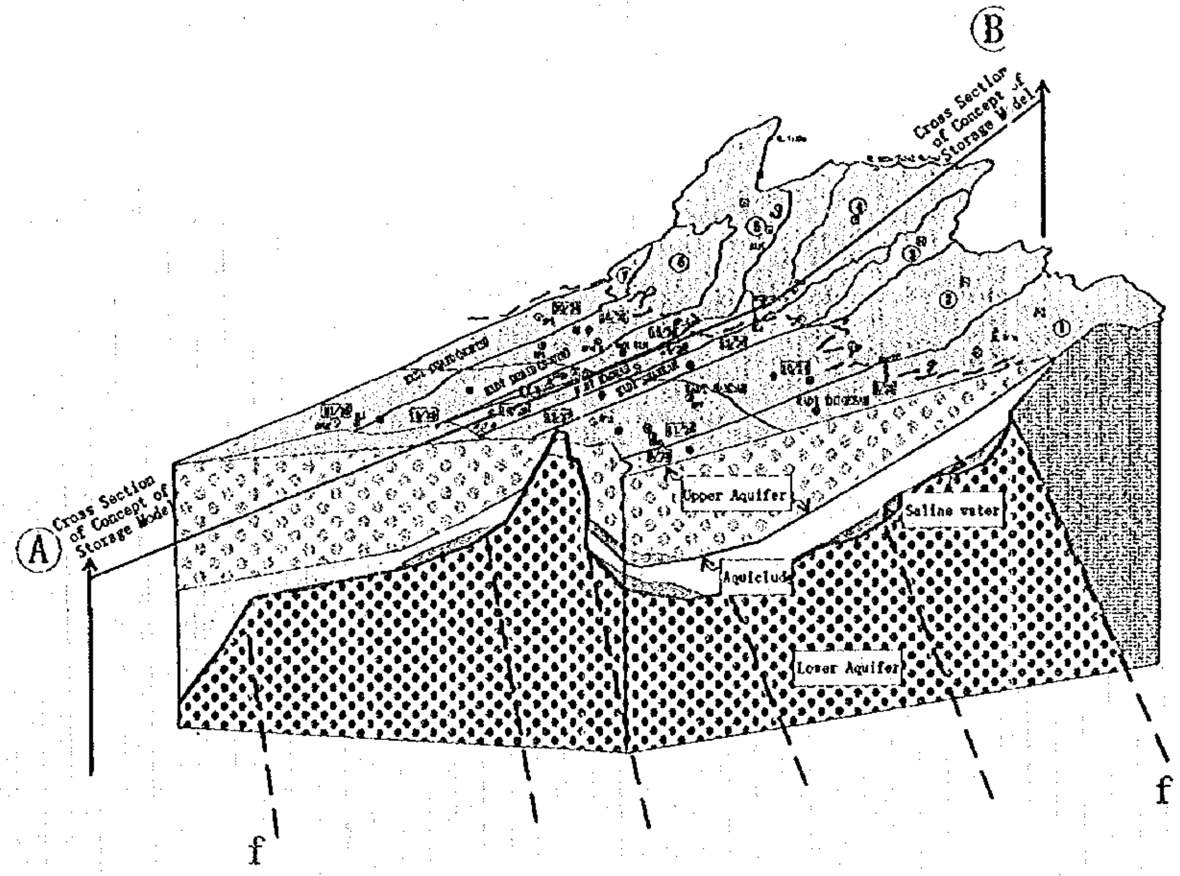


Figure 1.4.16 Contour Map of the Difference of Groundwater Head between 1984 and 1995



Concept of Storage Model



Conceptual Model for Hydrogeologic Structure of Study Area

Figure 1.5.1 Concept of Storage Model

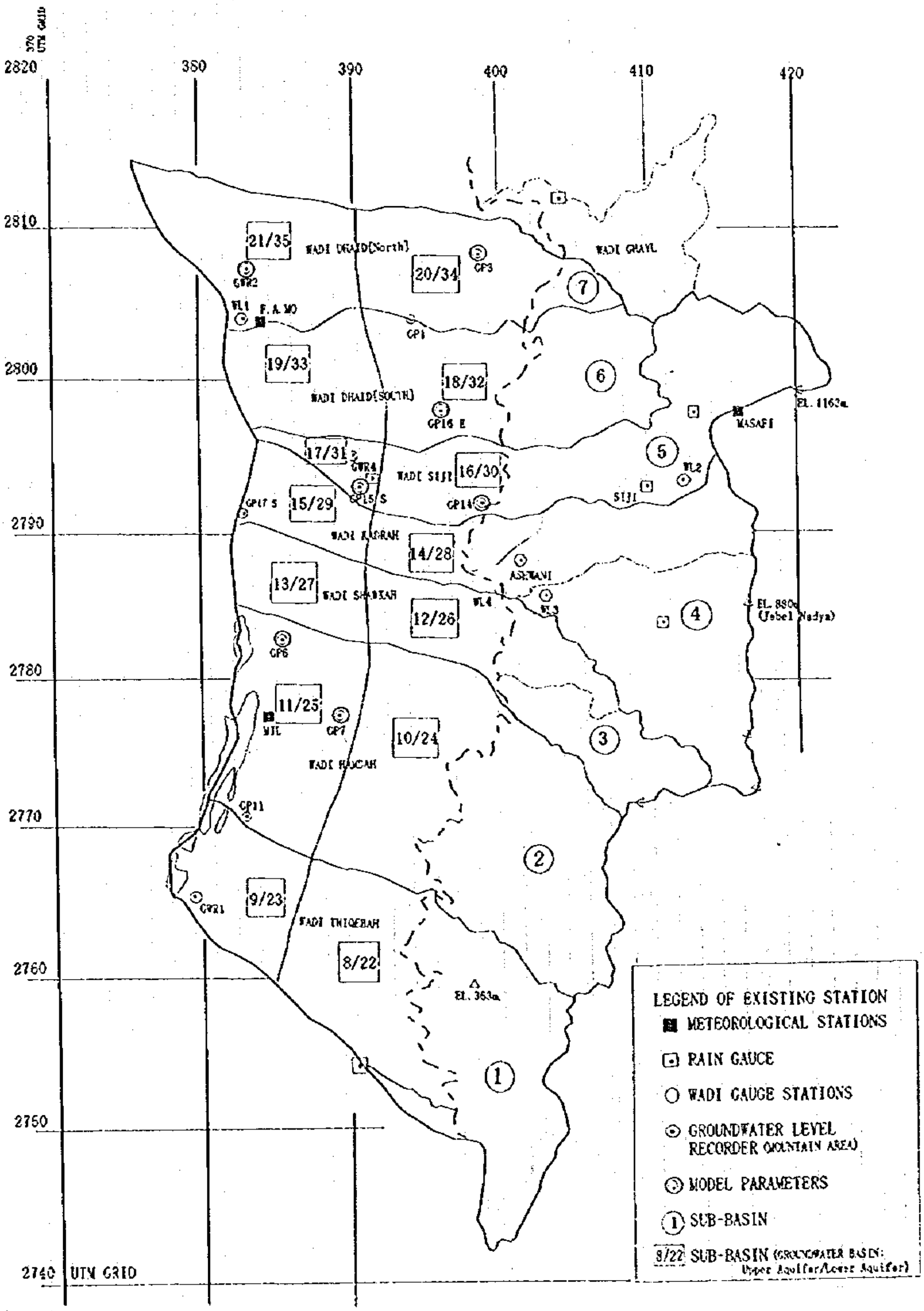


Figure 1.5.2 Sub-basin Division of the Study Area

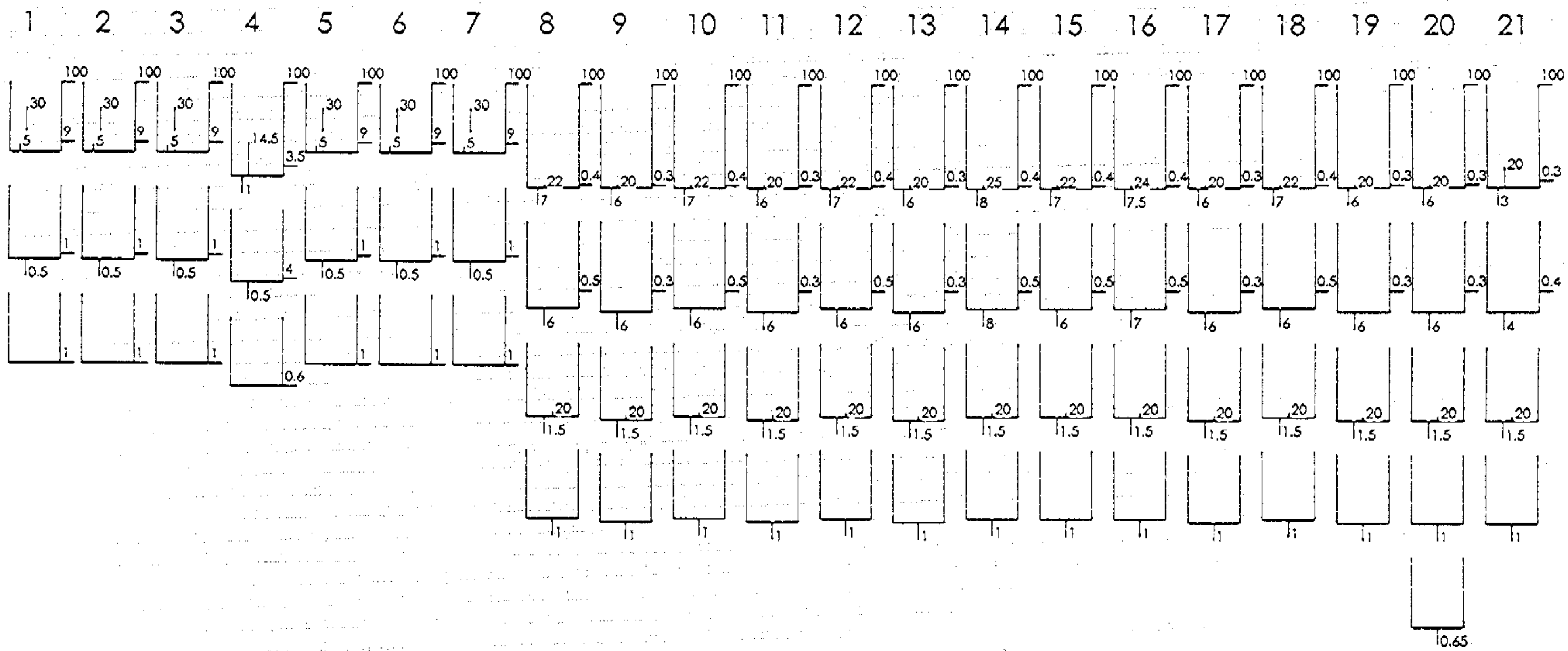


Figure 1.5.3 Verified Parameter of Surface System

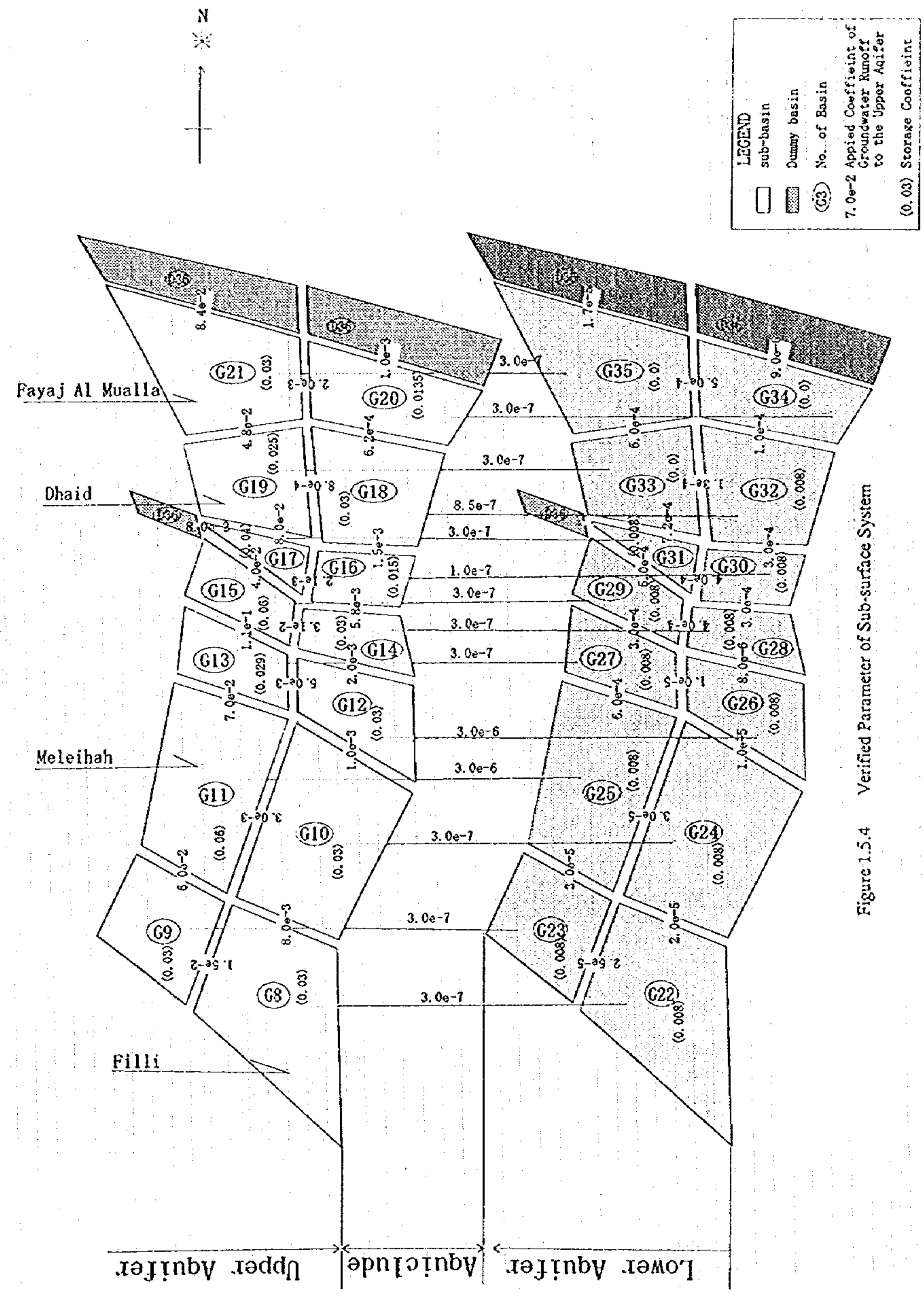


Figure 1.5.4 Verified Parameter of Sub-surface System

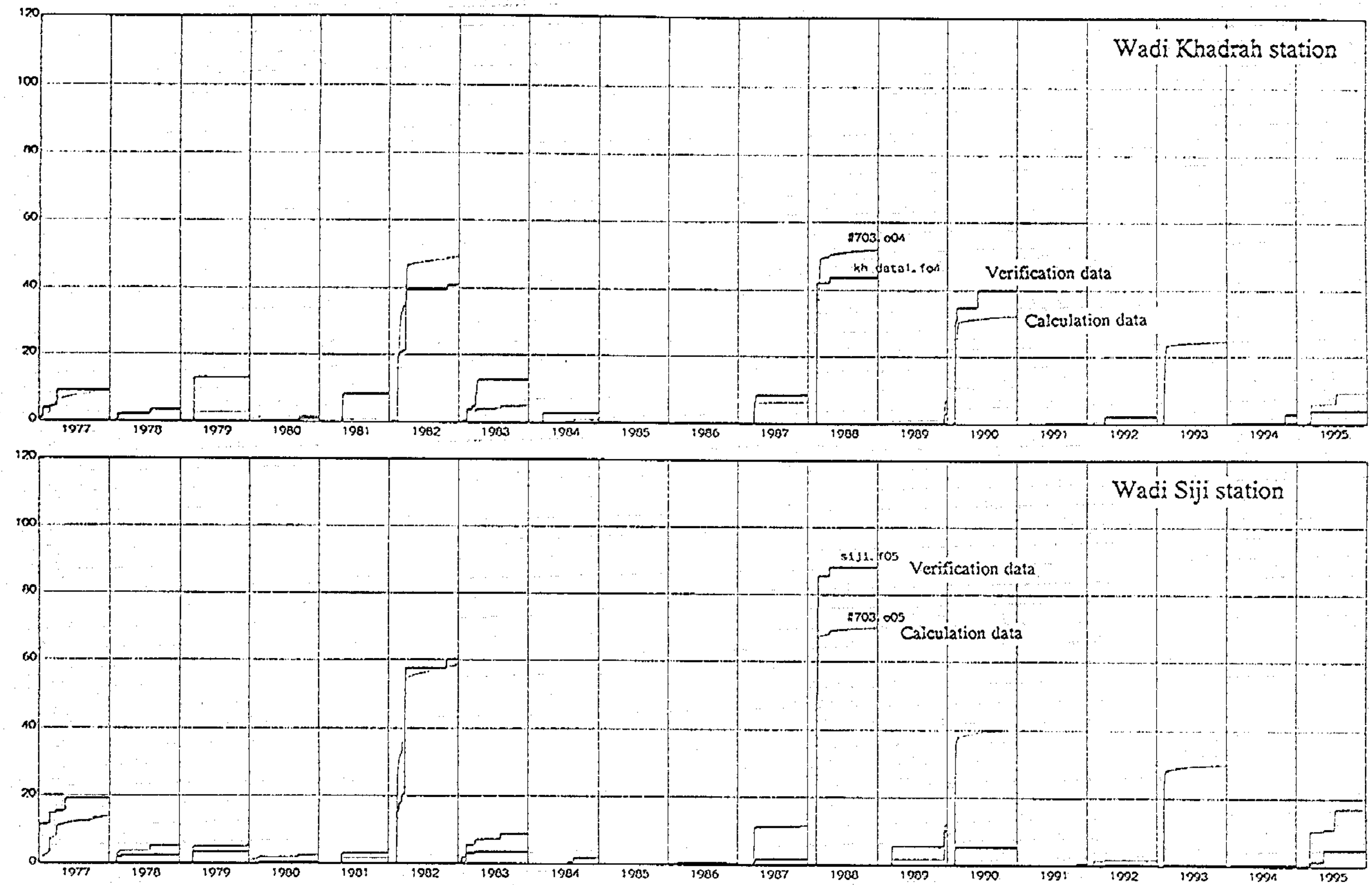


Figure 1.5.5　Result of the Verification of Surface Runoff

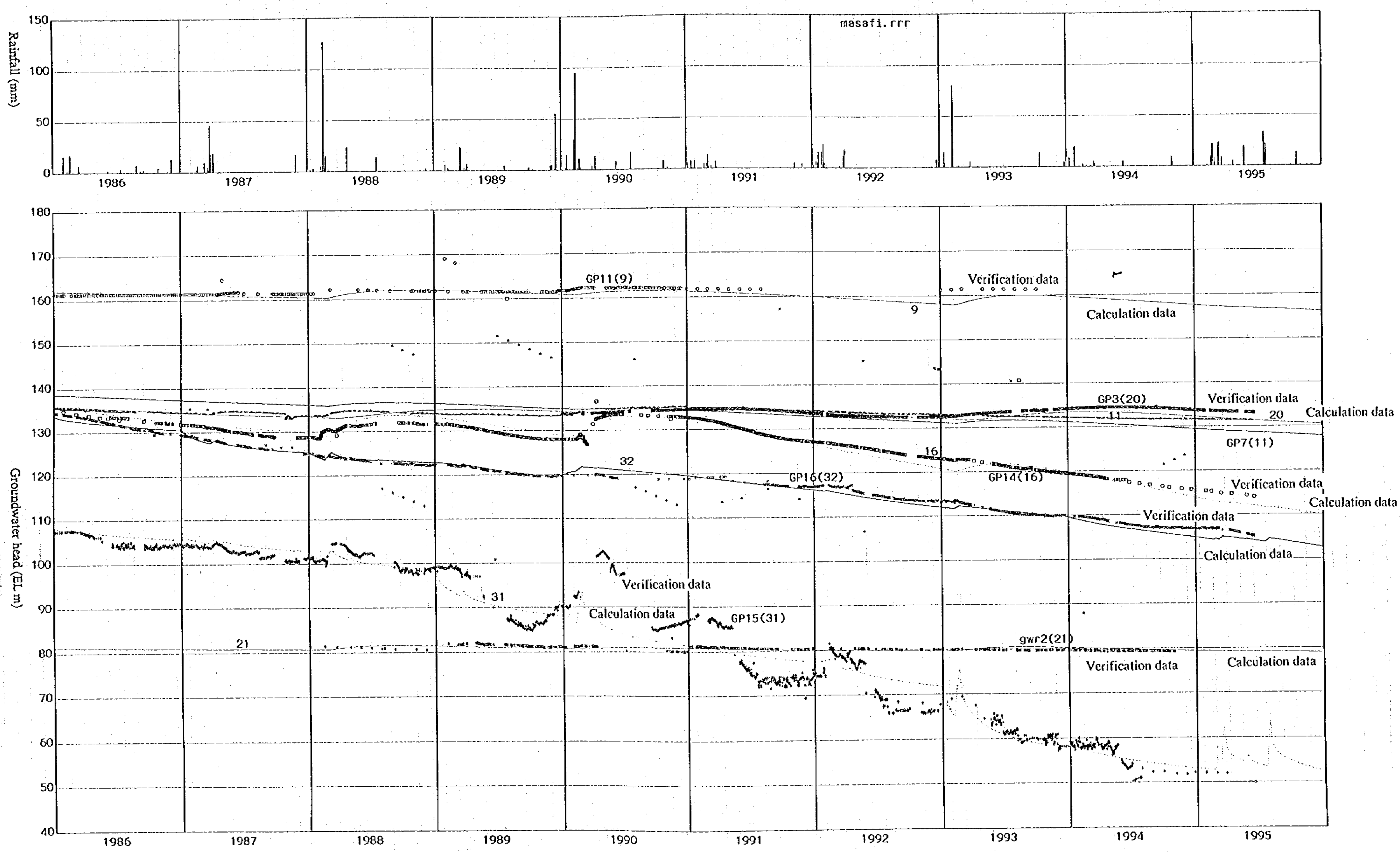


Figure 1.5.6 Result of the Verification of Groundwater Head

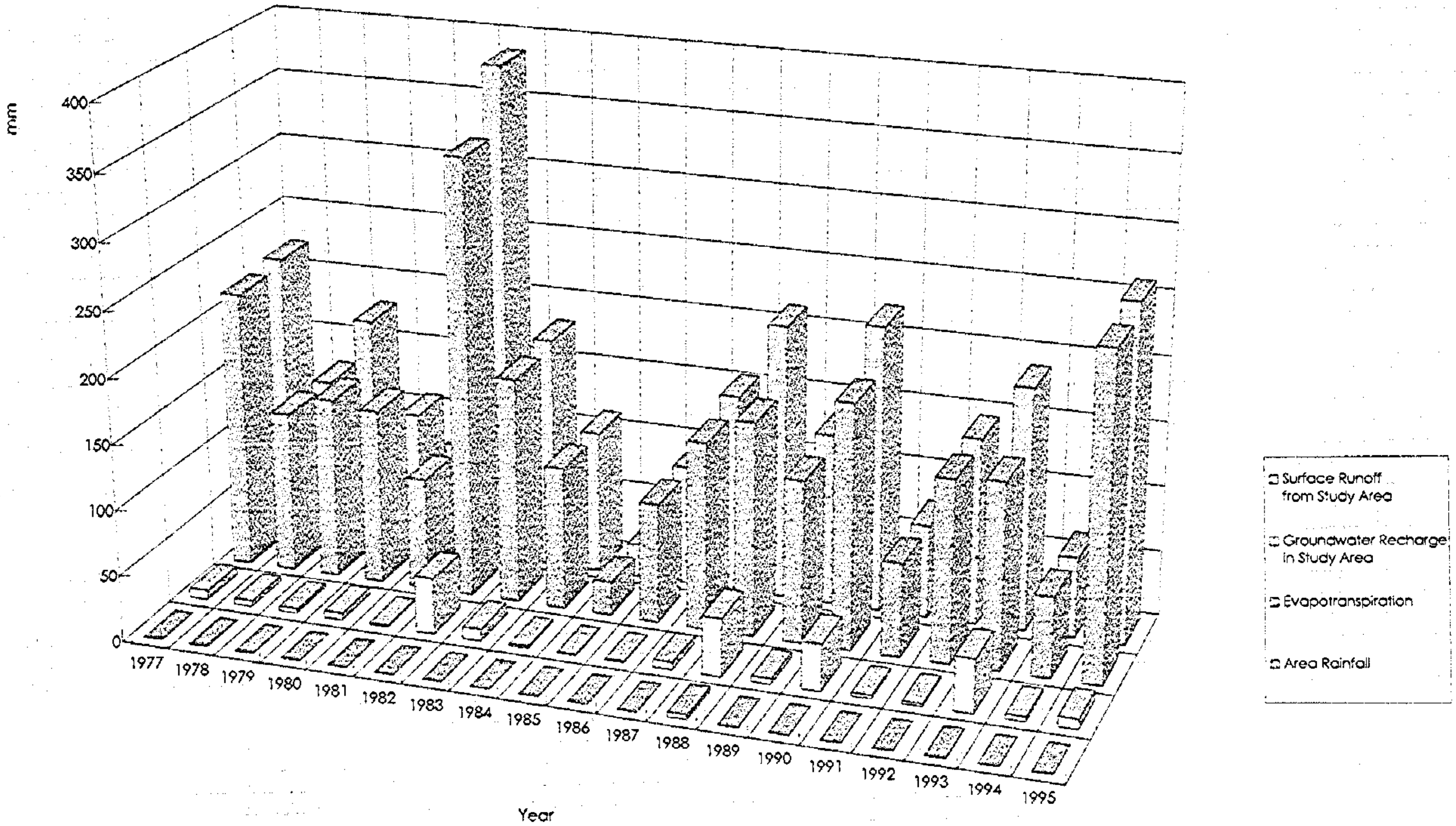
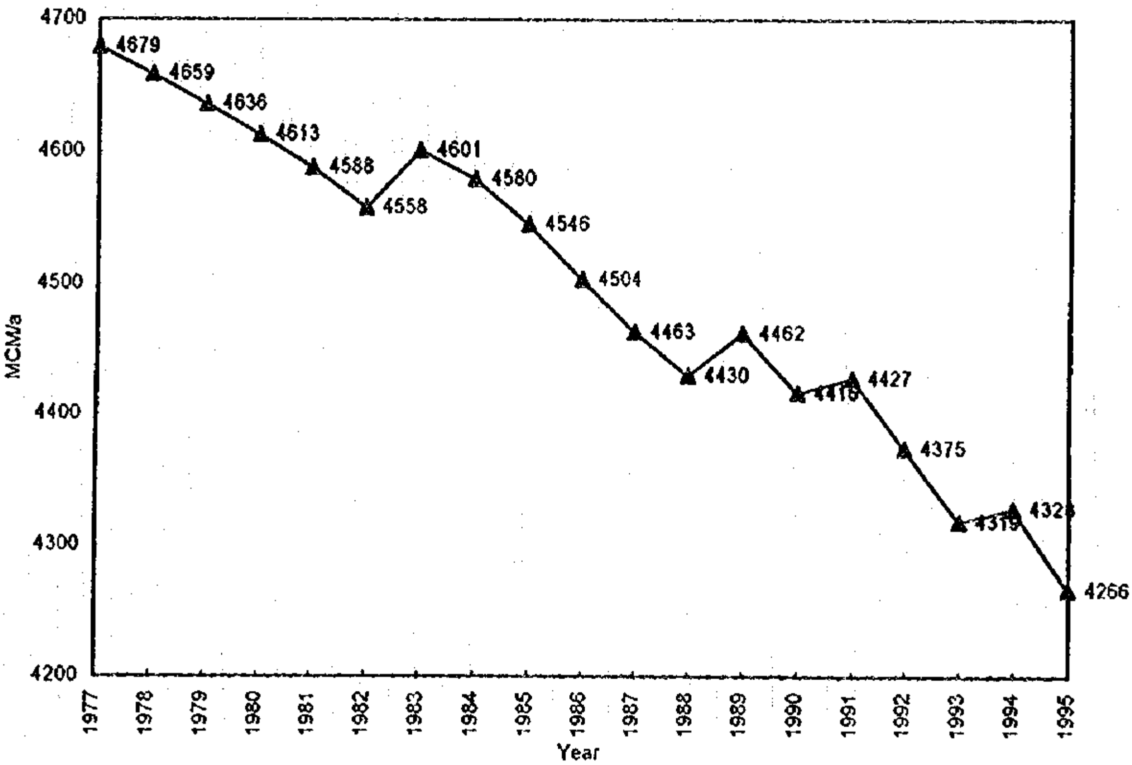


Figure 1.5.7 Hydrologic Balance in Current Condition (1977 - 1995)

Figure 1.5.7.(2)

Groundwater Storage in the Study Area during 1977-1995



Hydrologic Balance In Current Condition (1977-1995)

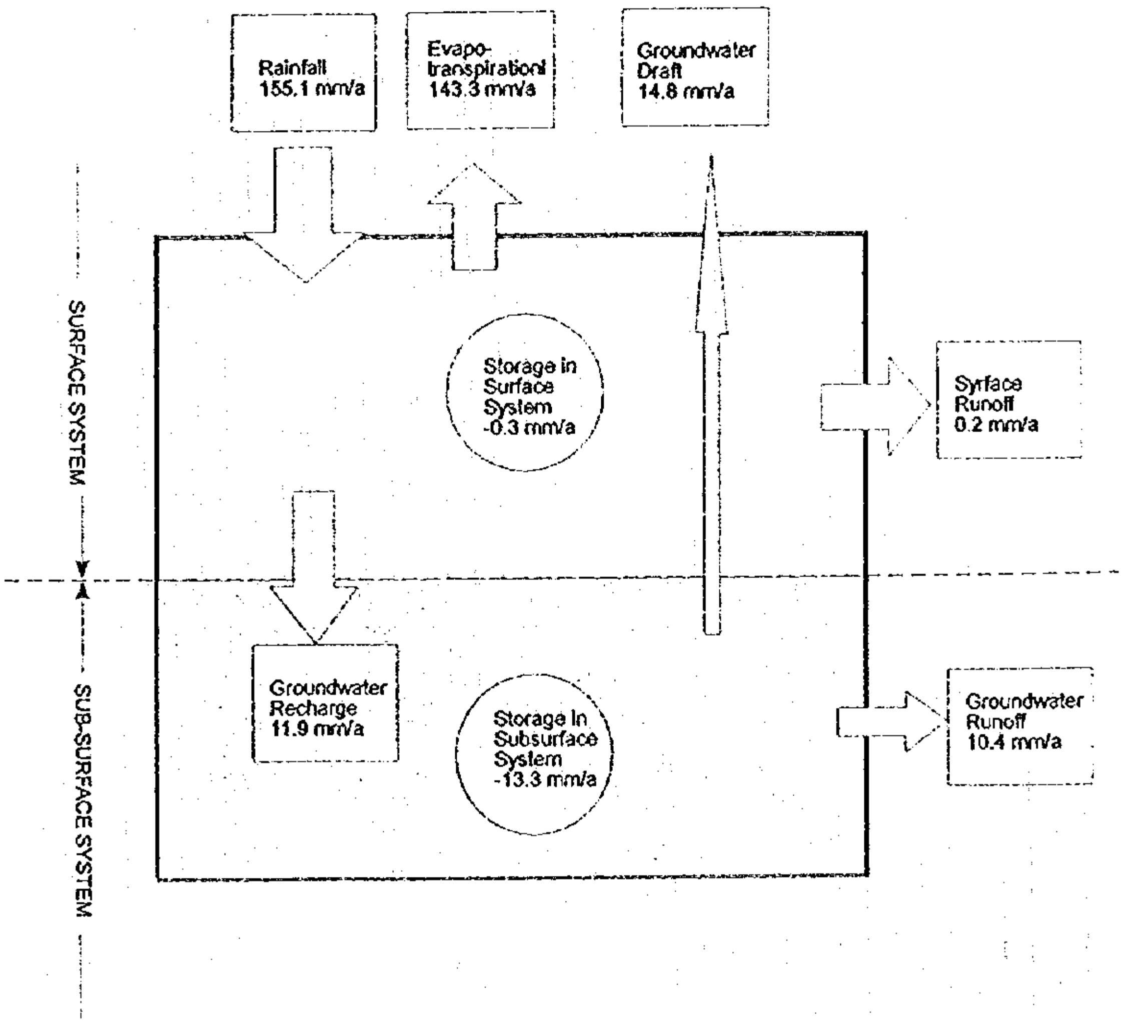


Figure 1.5.8 Hydrologic Balance in Current Condition (average of 1977 - 1995)

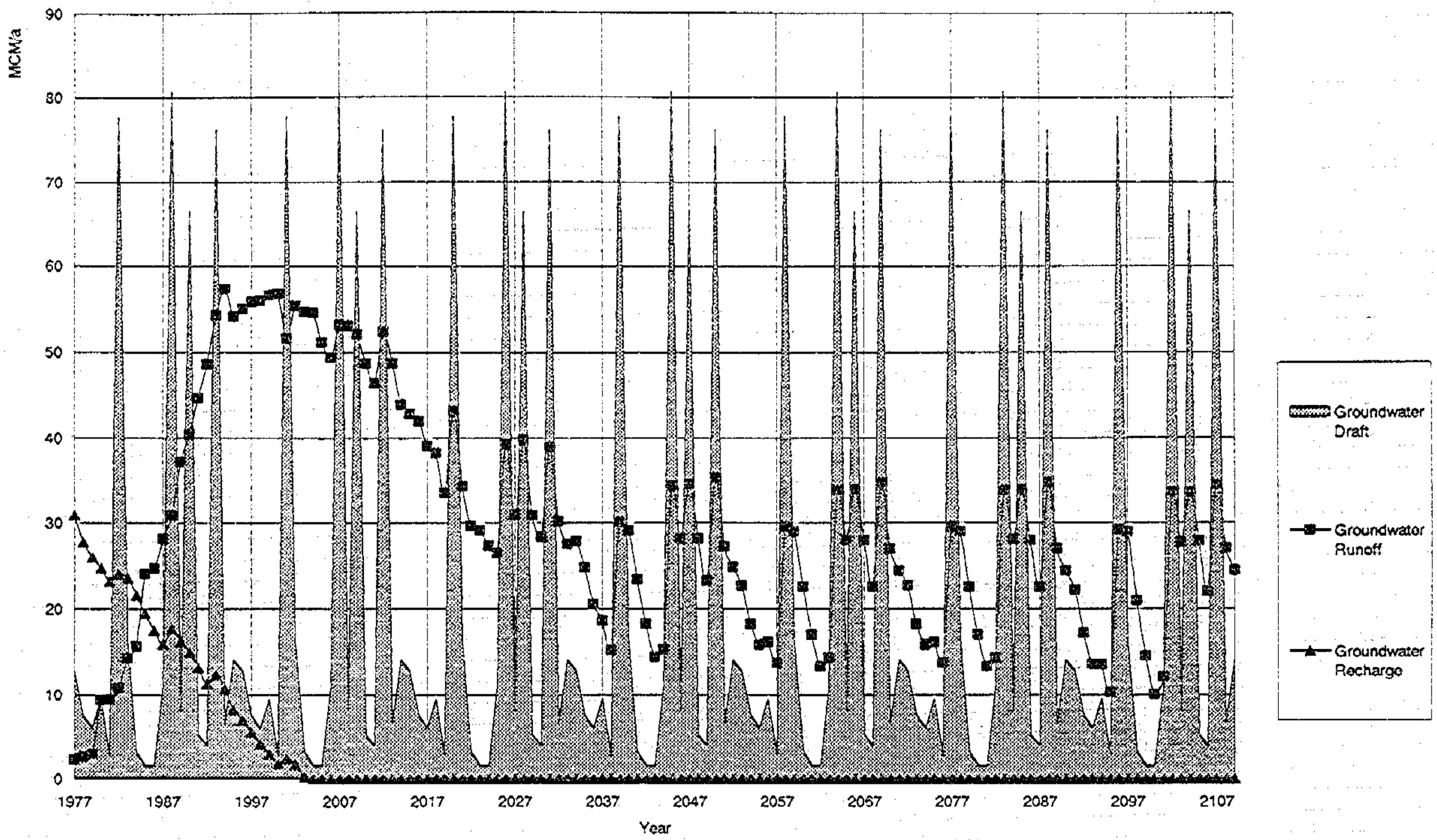


Figure 1.5.9 Result of Case1 (Groundwater Balance of the Study Area)

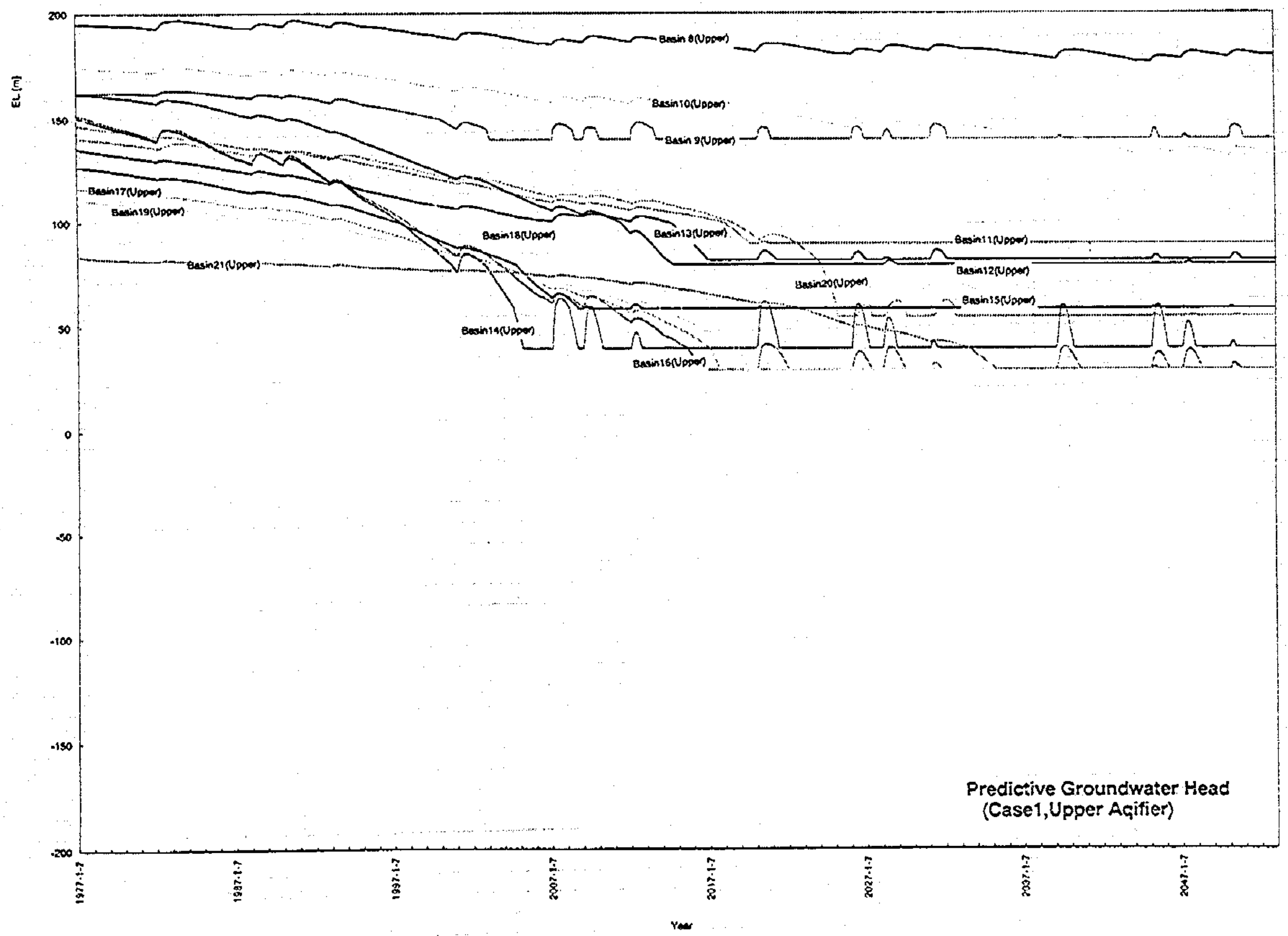


Figure 1.5.10 Result of Case1 (Predictive Groundwater Head, Upper Aquifer)

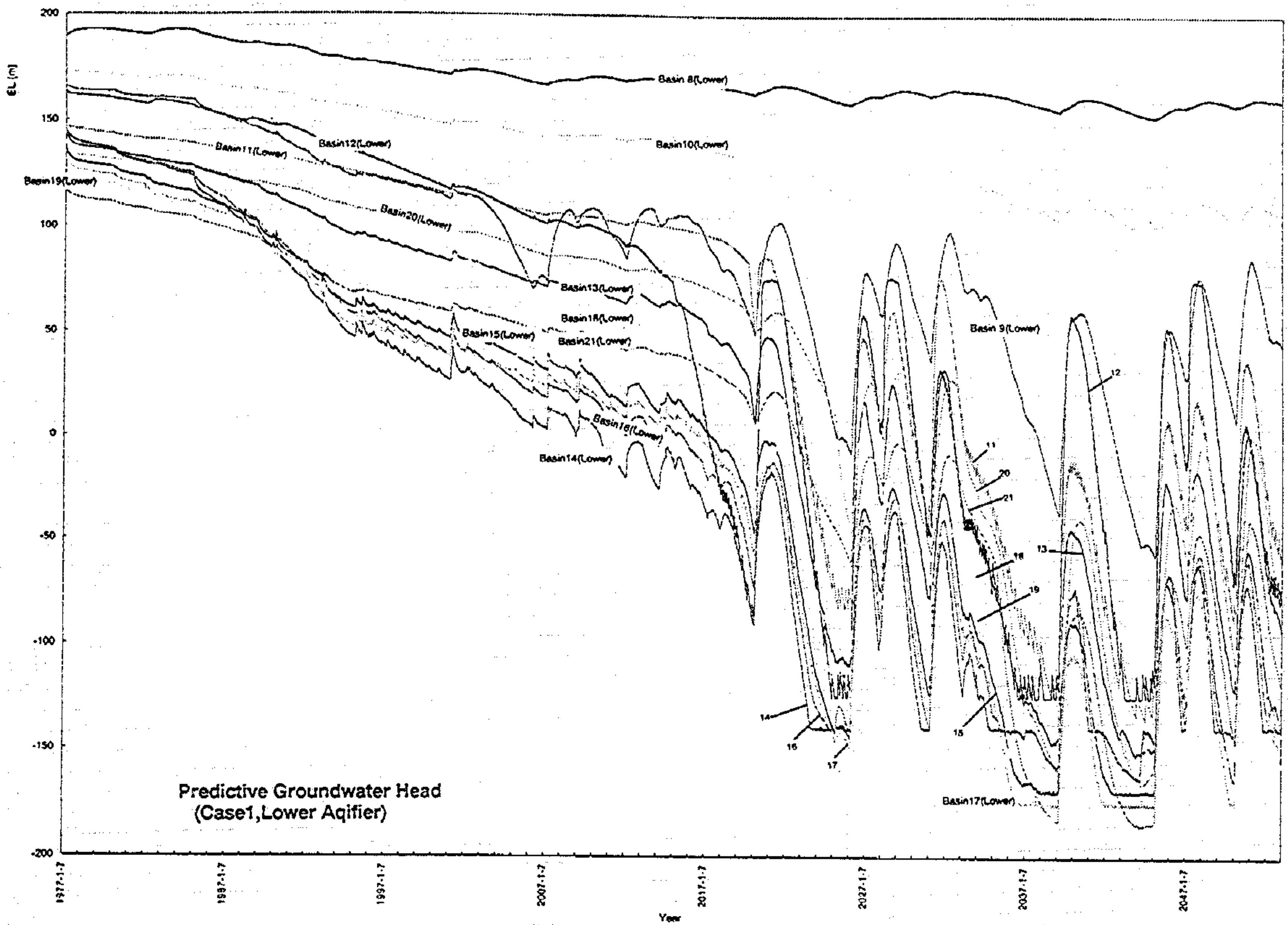


Figure 1.5.11 Result of Case1 (Predictive Groundwater Head, Lower Aquifer)

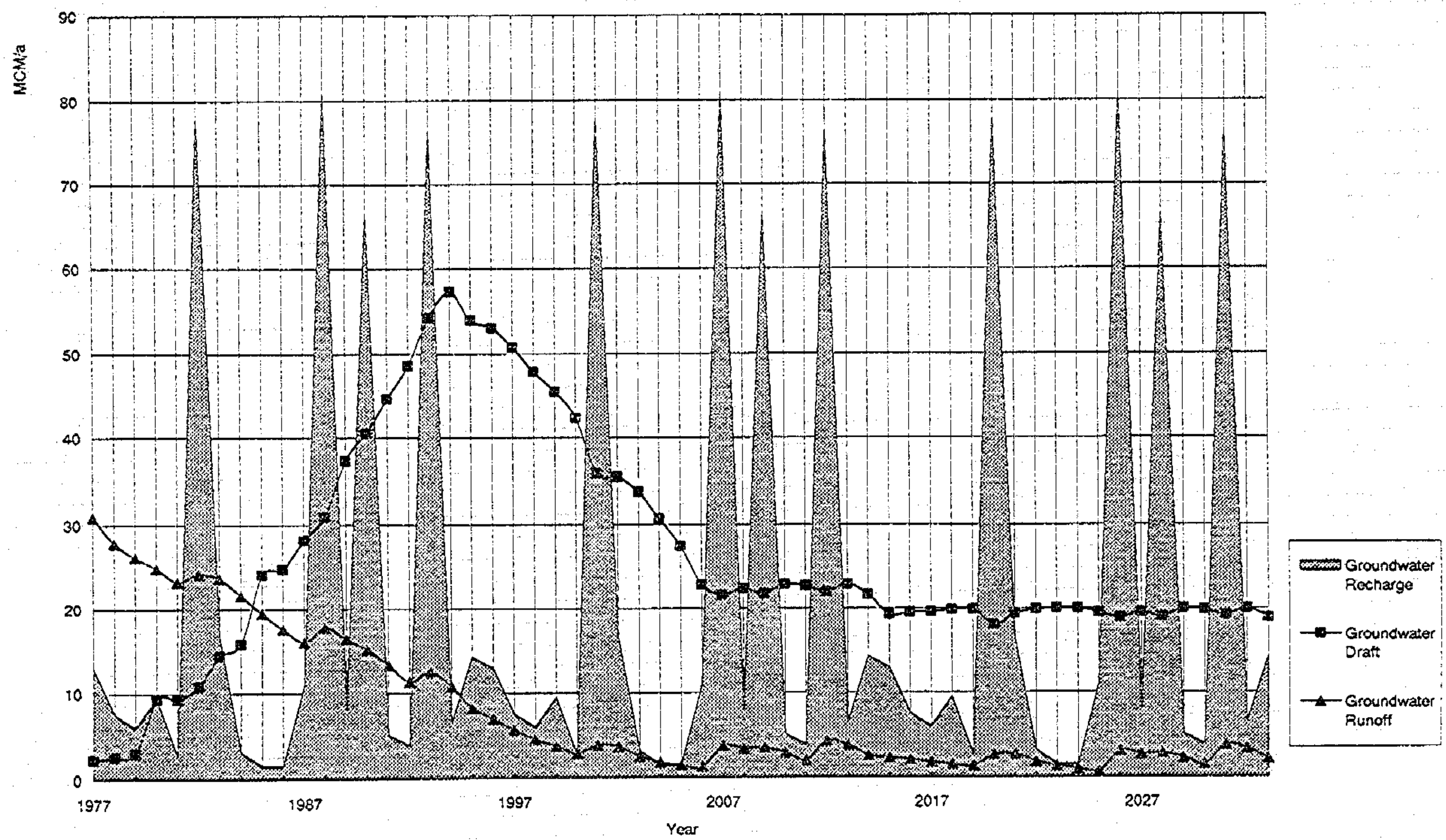


Figure 1.5.12 Result of Case2 (Groundwater Balance of the Study Area)

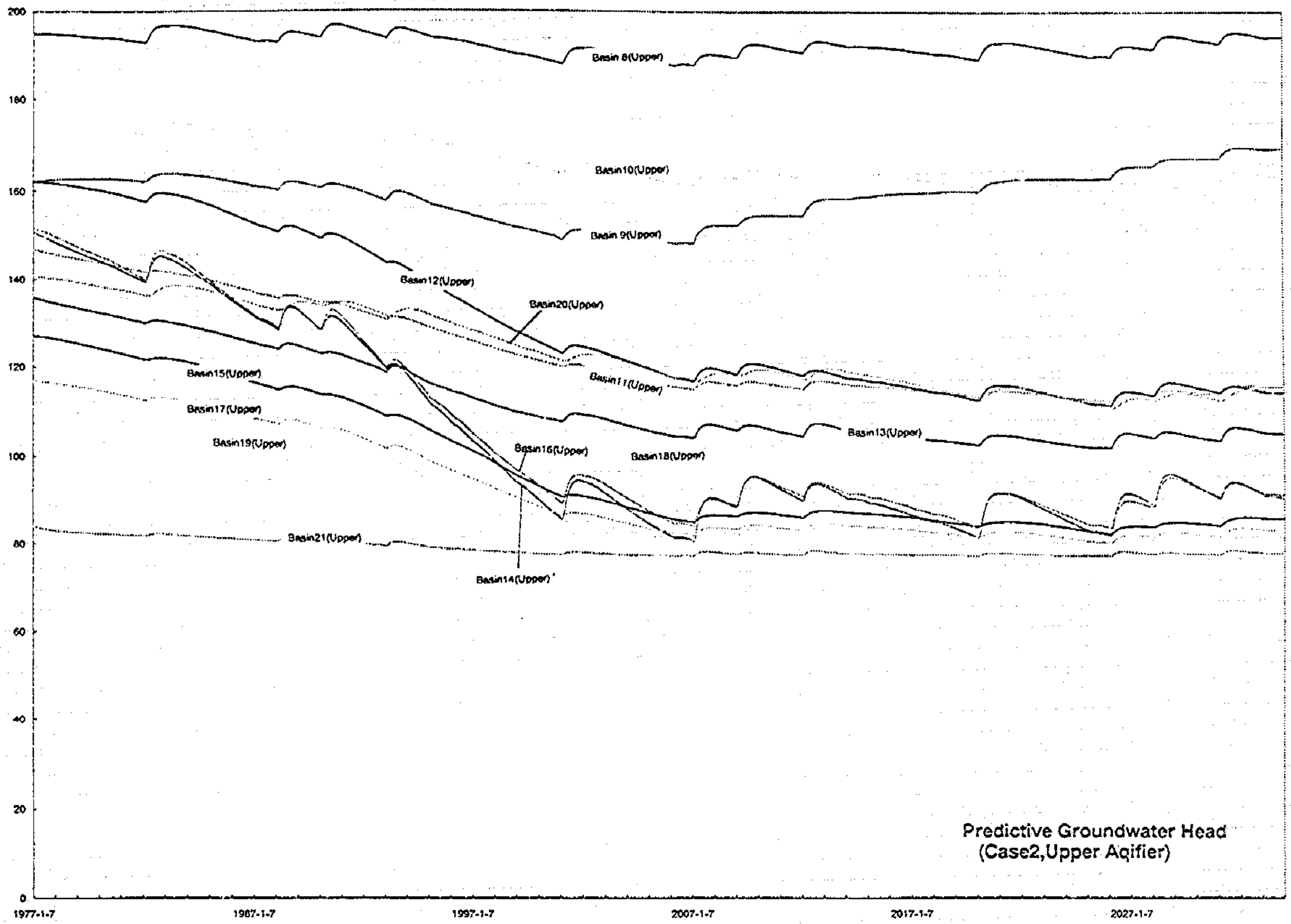


Figure 1.5.13 Result of Case2 (Predictive Groundwater Head, Upper Aquifer)

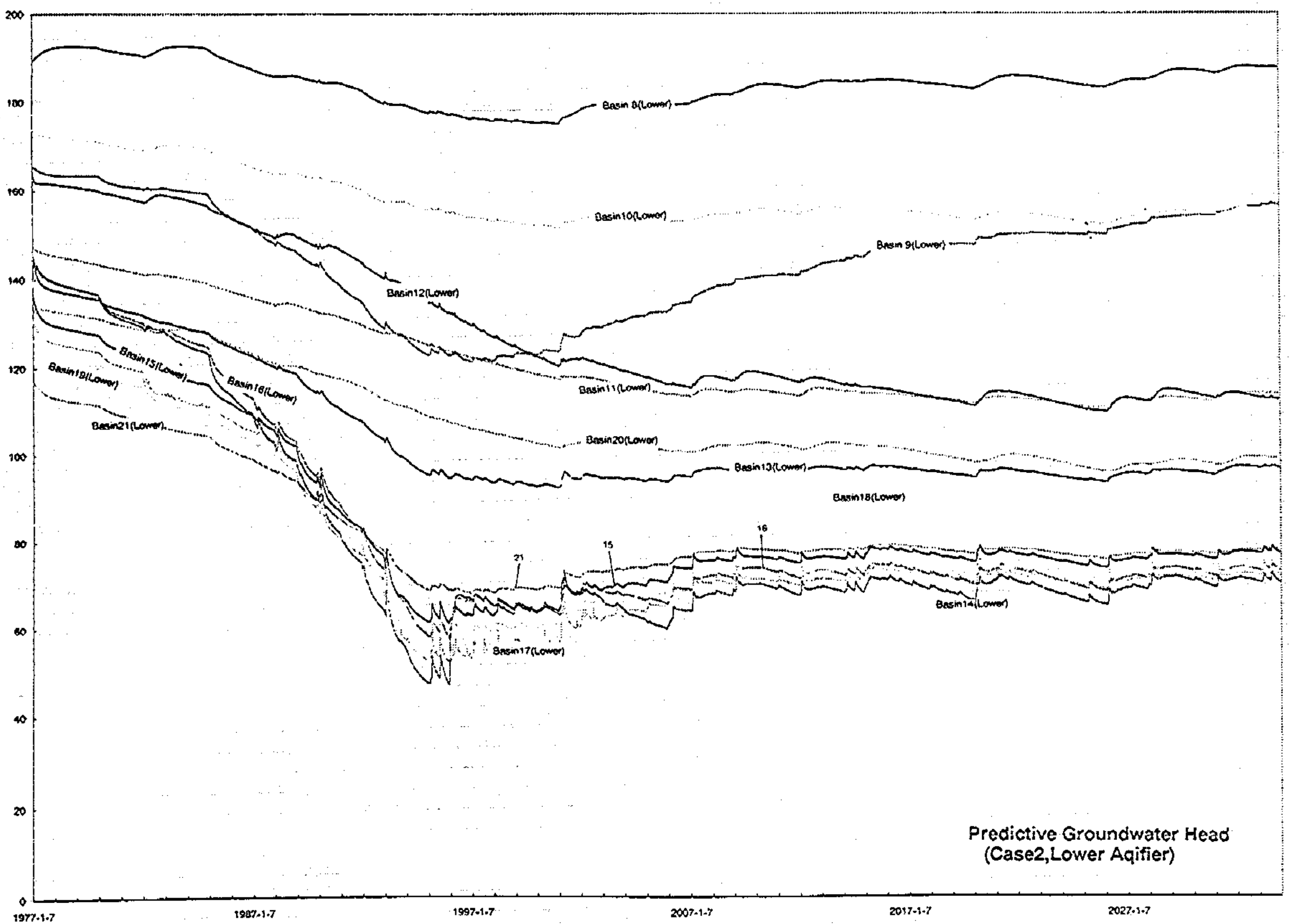


Figure 1.5.14 Result of Case2 (Predictive Groundwater Head, Lower Aquifer)

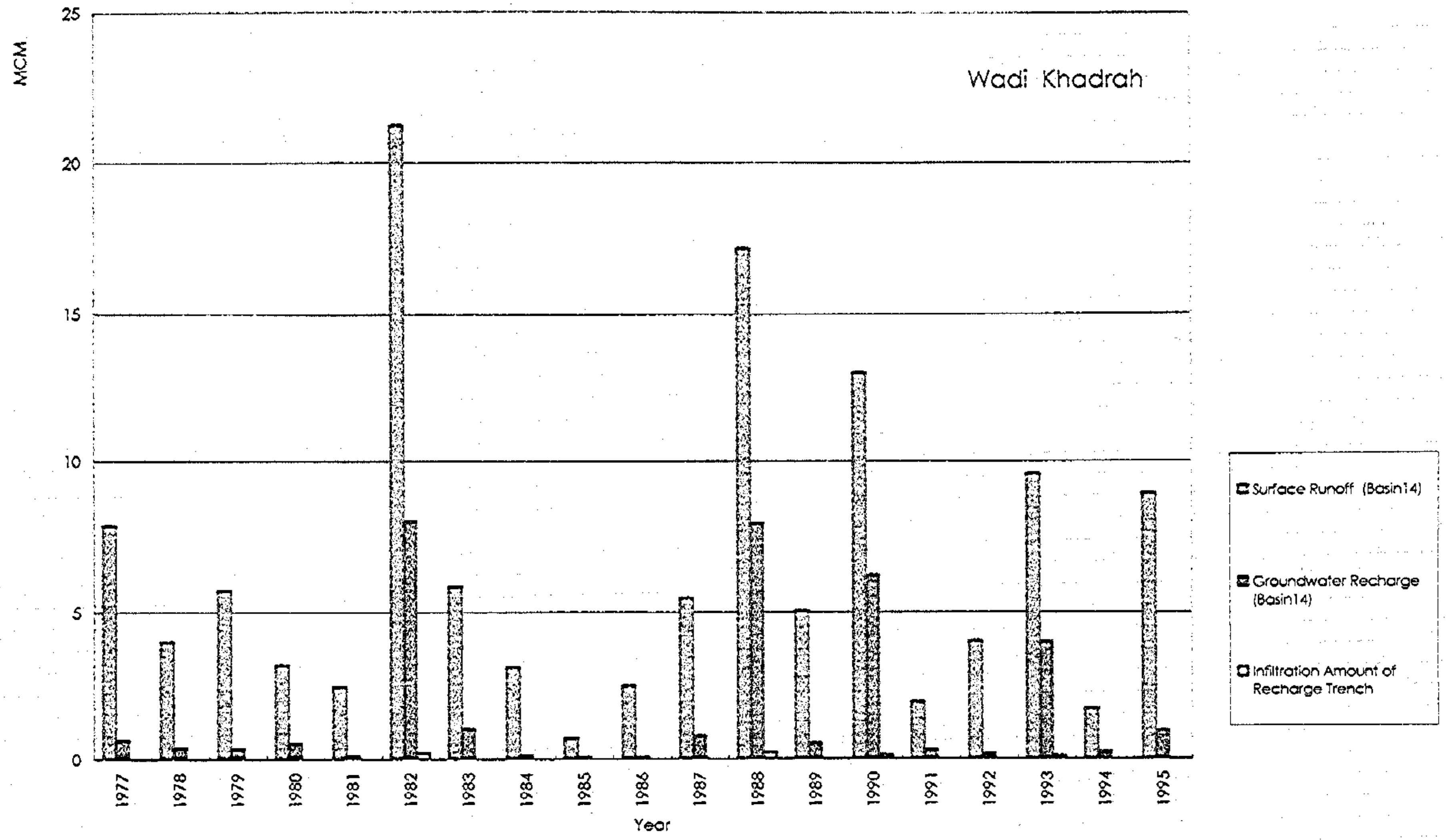


Figure 1.5.15 Result of Case3 (1000 m Trench, Wadi Khadrah)

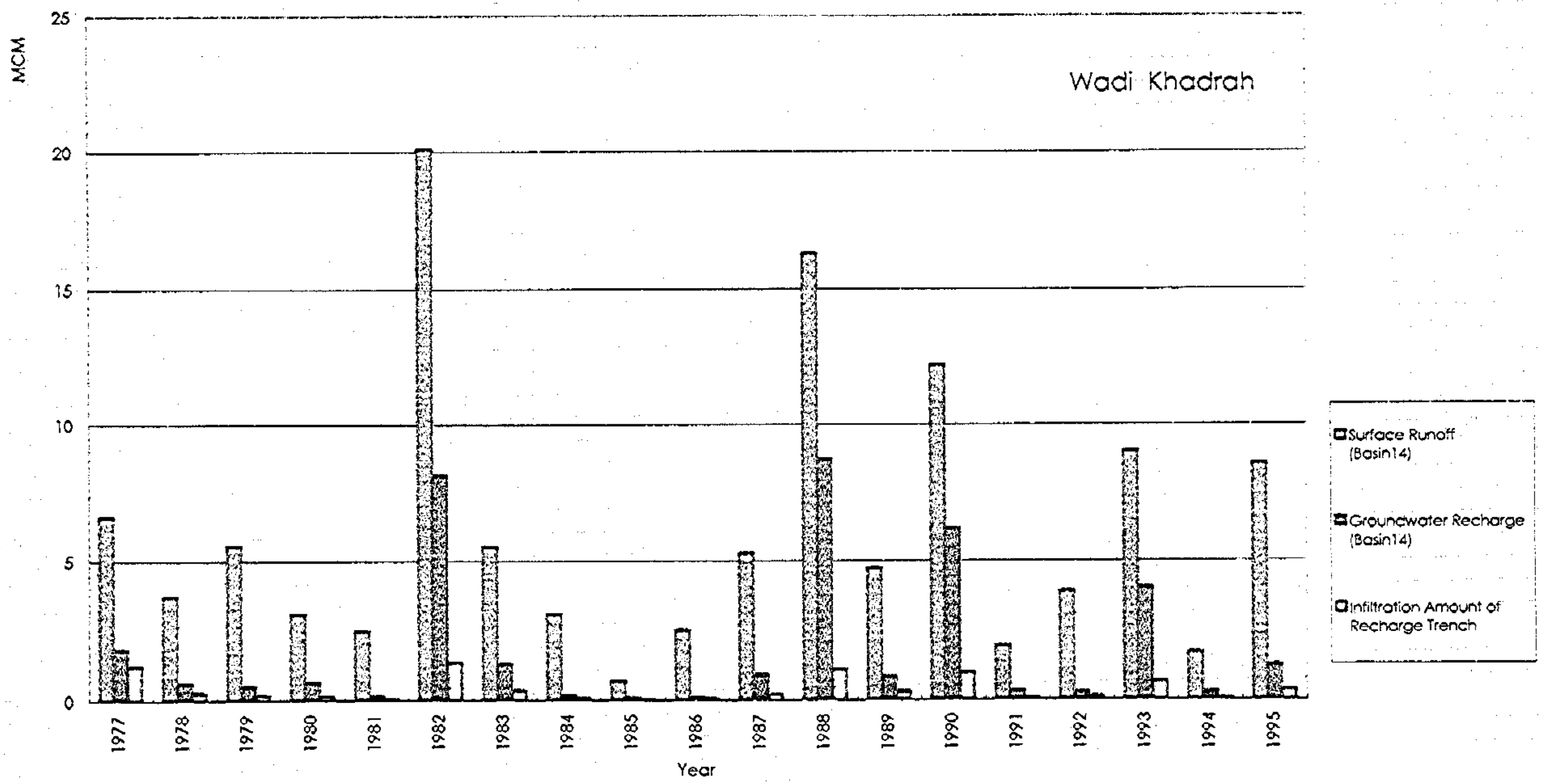


Figure 1.5.16 Result of Case4 (1000 m Trench + Detention Dam, Wadi Khadrah)

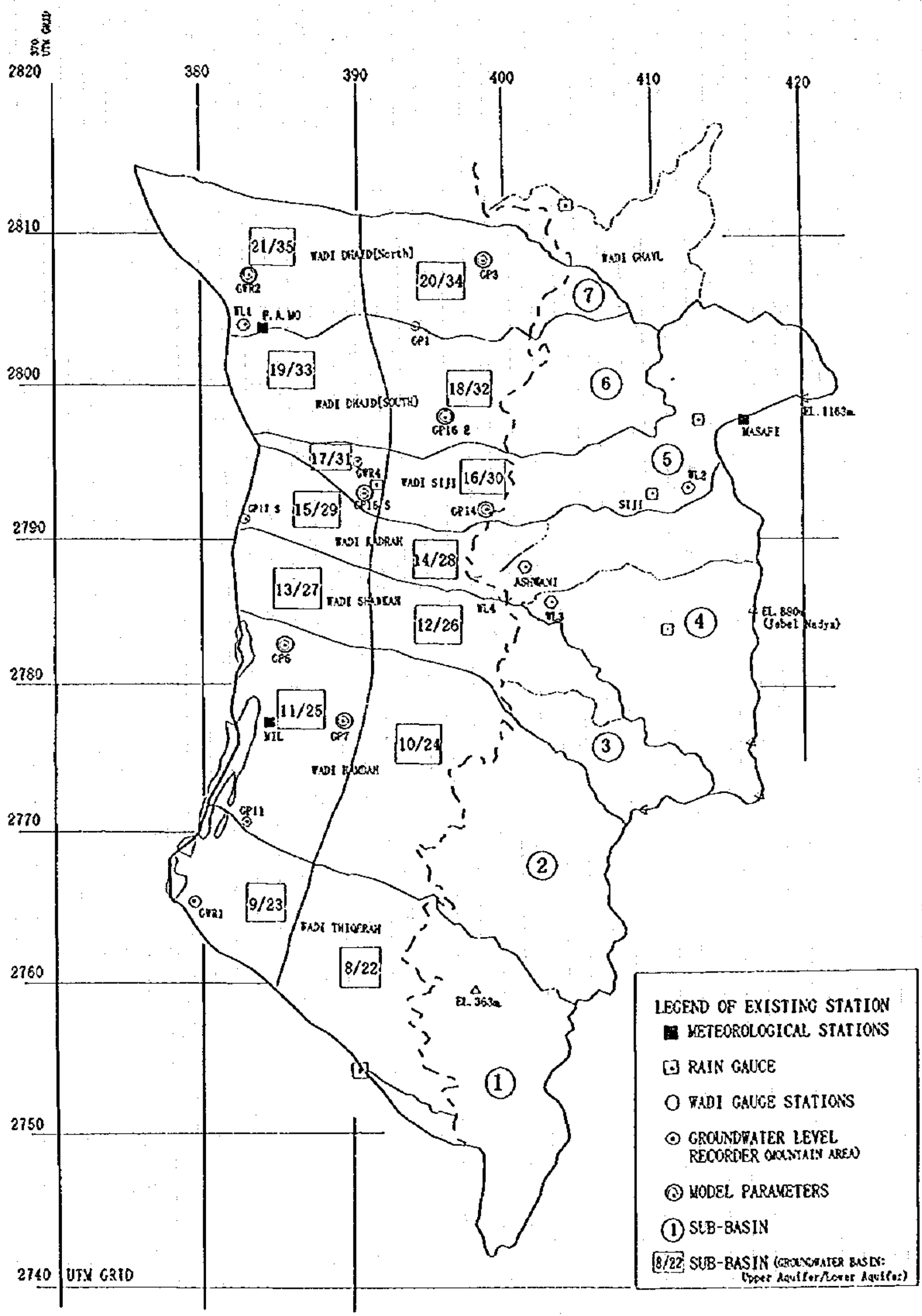
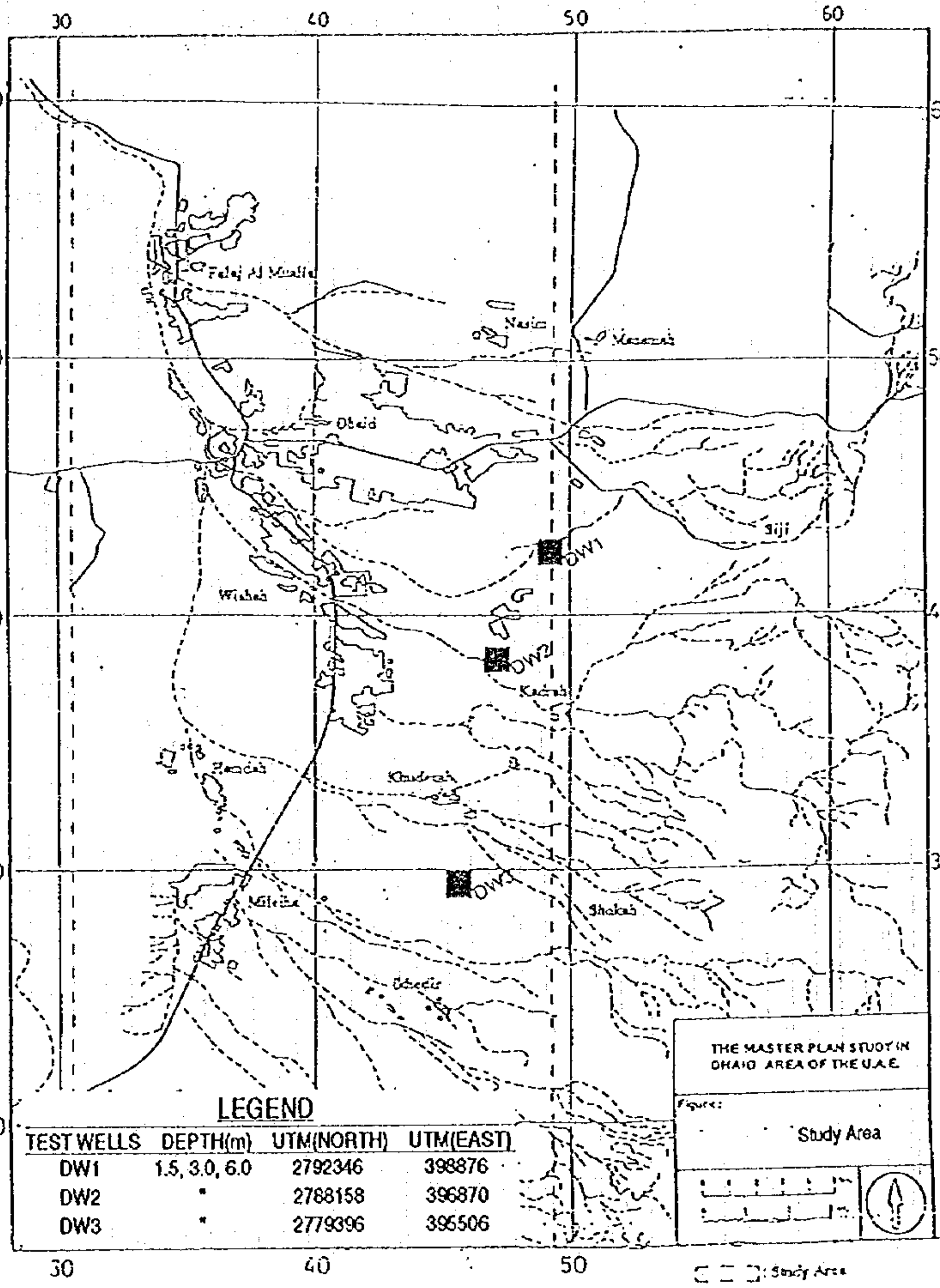


Figure 1.6.1 Proposed Stations of Groundwater Monitoring System



LEGEND

TEST WELLS	DEPTH(m)	UTM(NORTH)	UTM(EAST)
DW1	1.5, 3.0, 6.0	2792346	398876
DW2	"	2788158	396870
DW3	"	2779396	395506

Figure 1.7.1.

INFILTRATION EXPERIMENTS
LOCATION PLAN

Figure 1.7.2. INFILTRATION EXPERIMENT SET UP

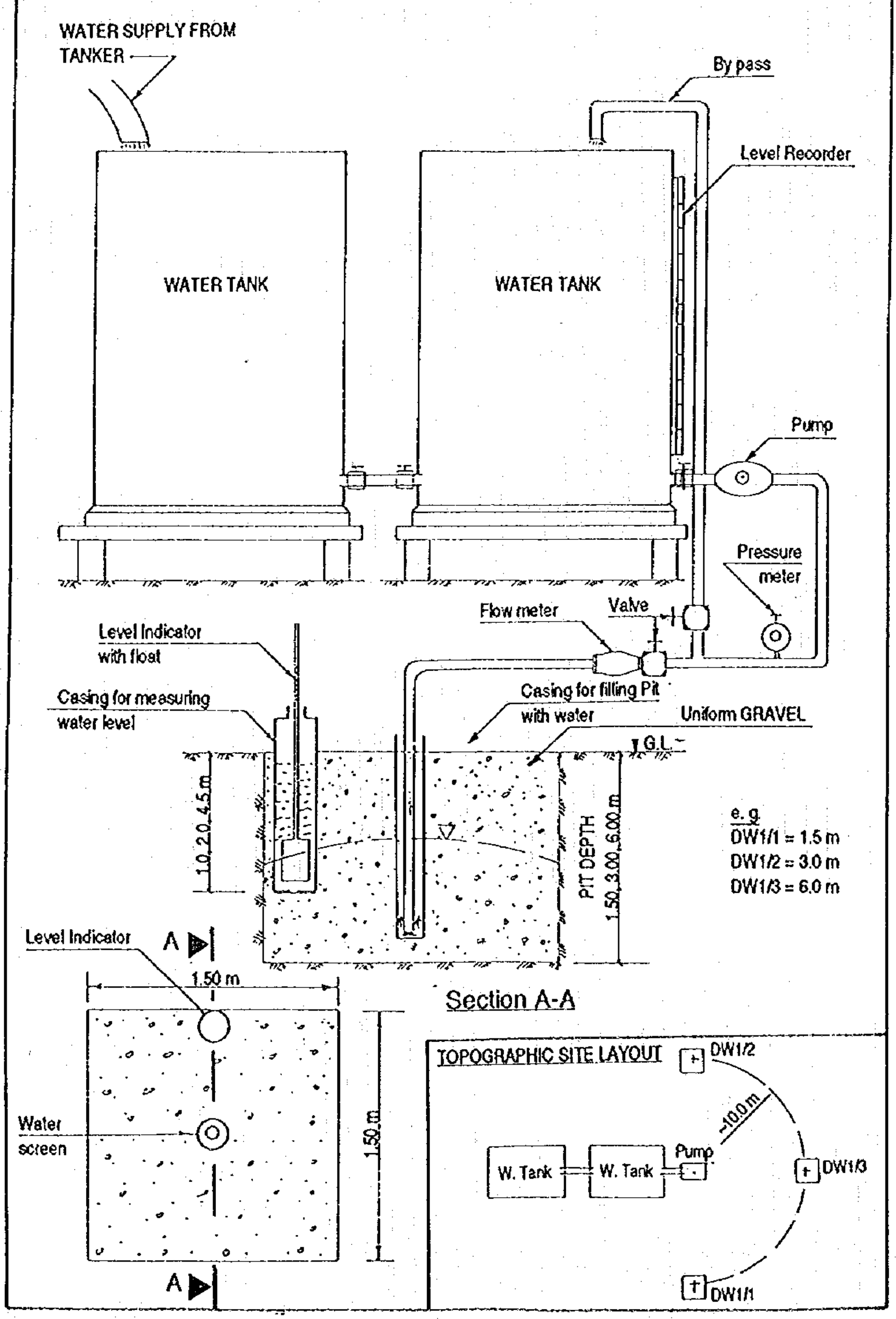


Figure 1.7.3. Infiltration Test DW1-1 (1.5m Pit)
Constant Head Test Analysis by Gibson's Method.

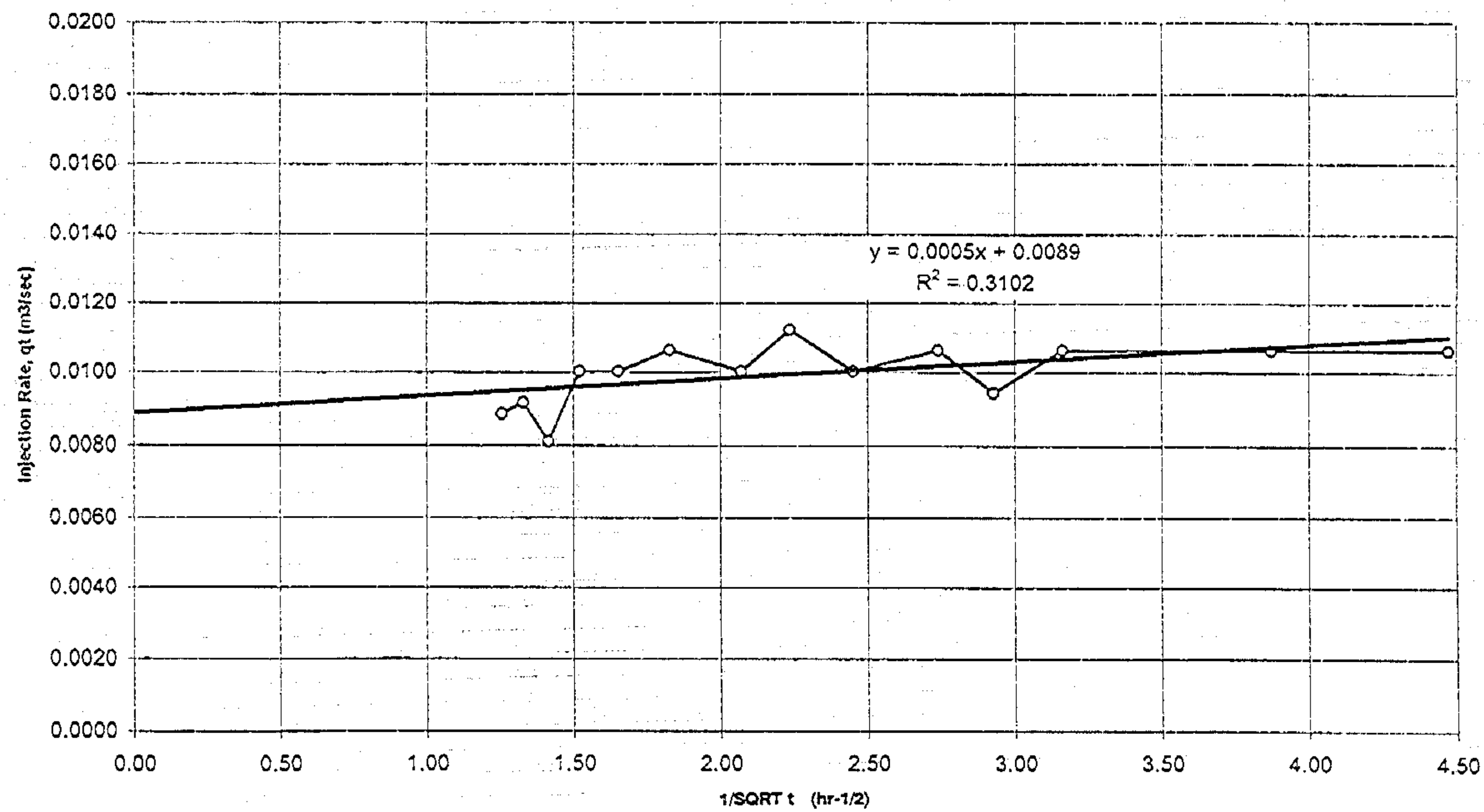
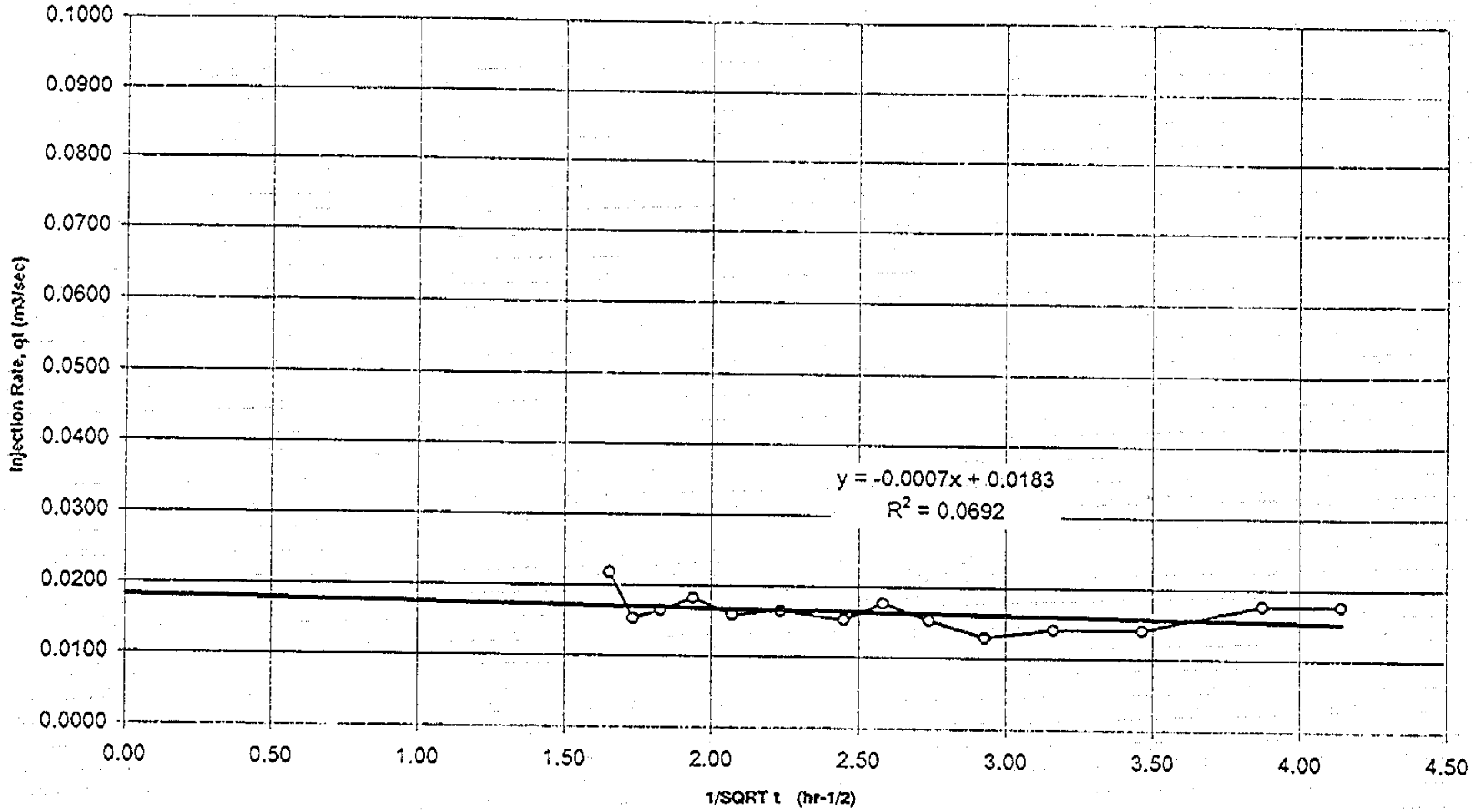


Figure 1.7.4. Infiltration Test DW1-2 (3m Pit)
Constant Head Test Analysis by Gibson's Method.



DHDW12.XLS
05/02/96
13:59

SWISSBORING

A. de Jong

Figure 1.7.5. Infiltration Test DW1-3 (6m Pit)
Constant Head Test Analysis by Gibson's Method.

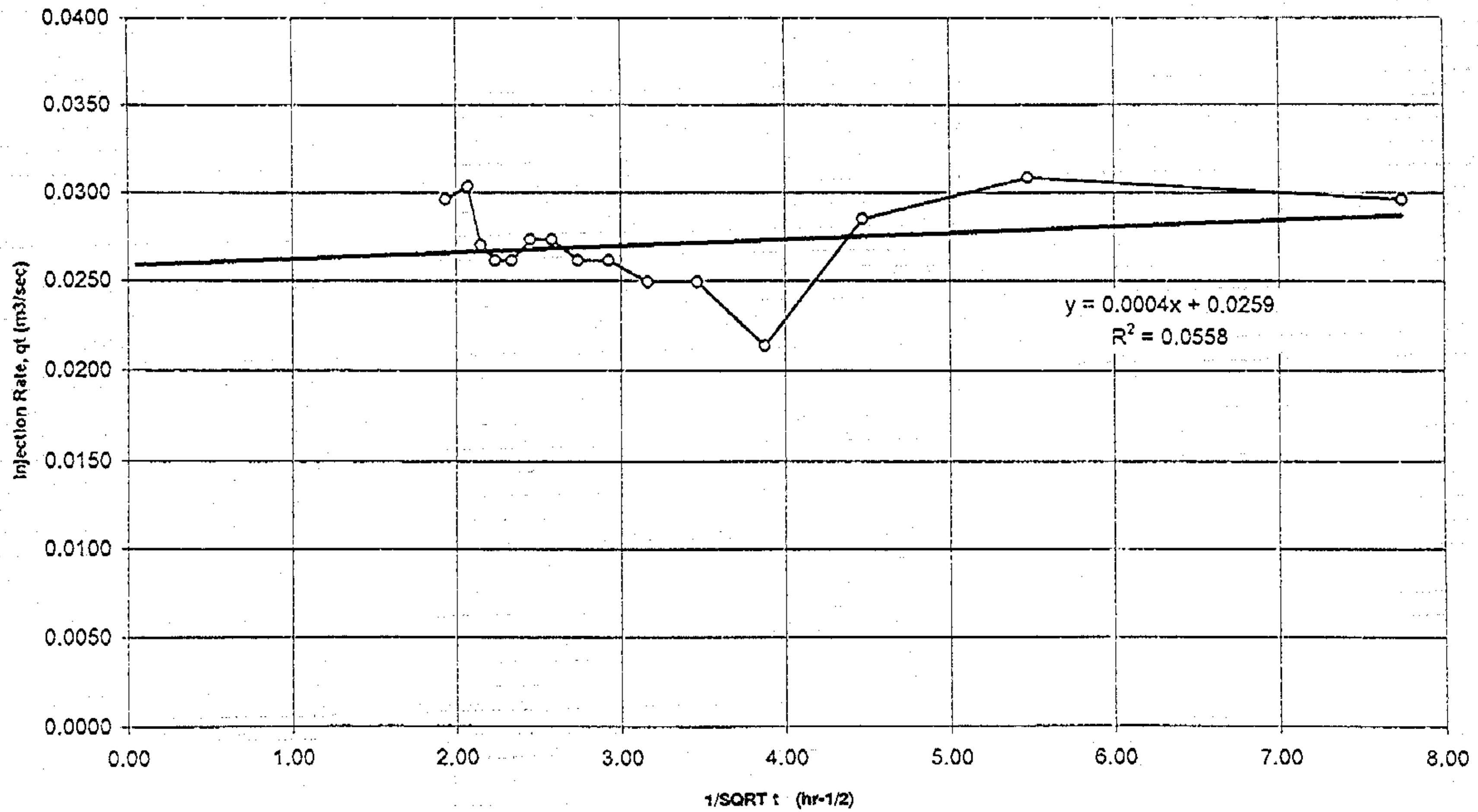
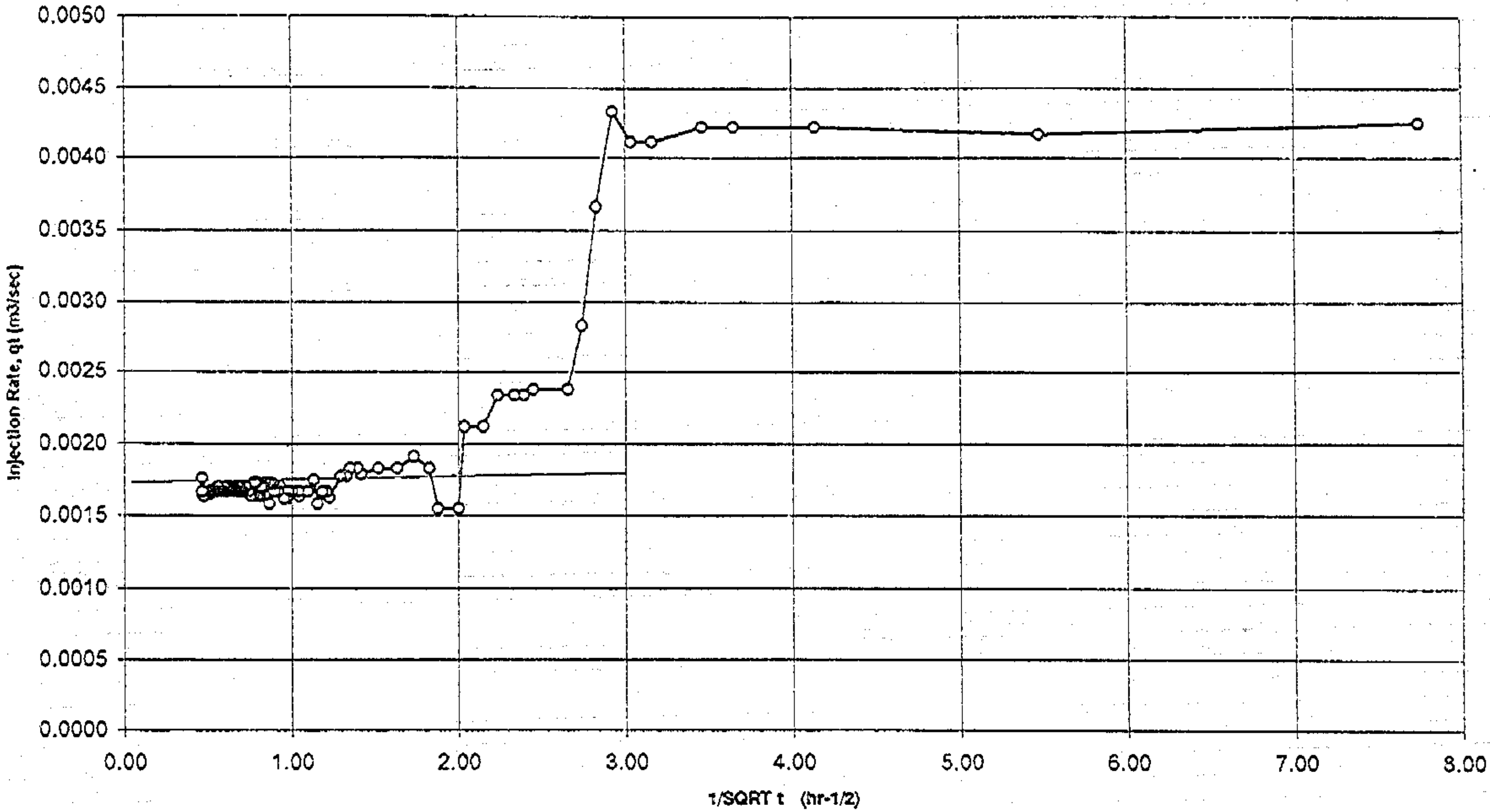


Figure 1.7.6. Infiltration Test DW2-1 (1.5m Pit)
Constant Head Test Analysis by Gibson's Method.

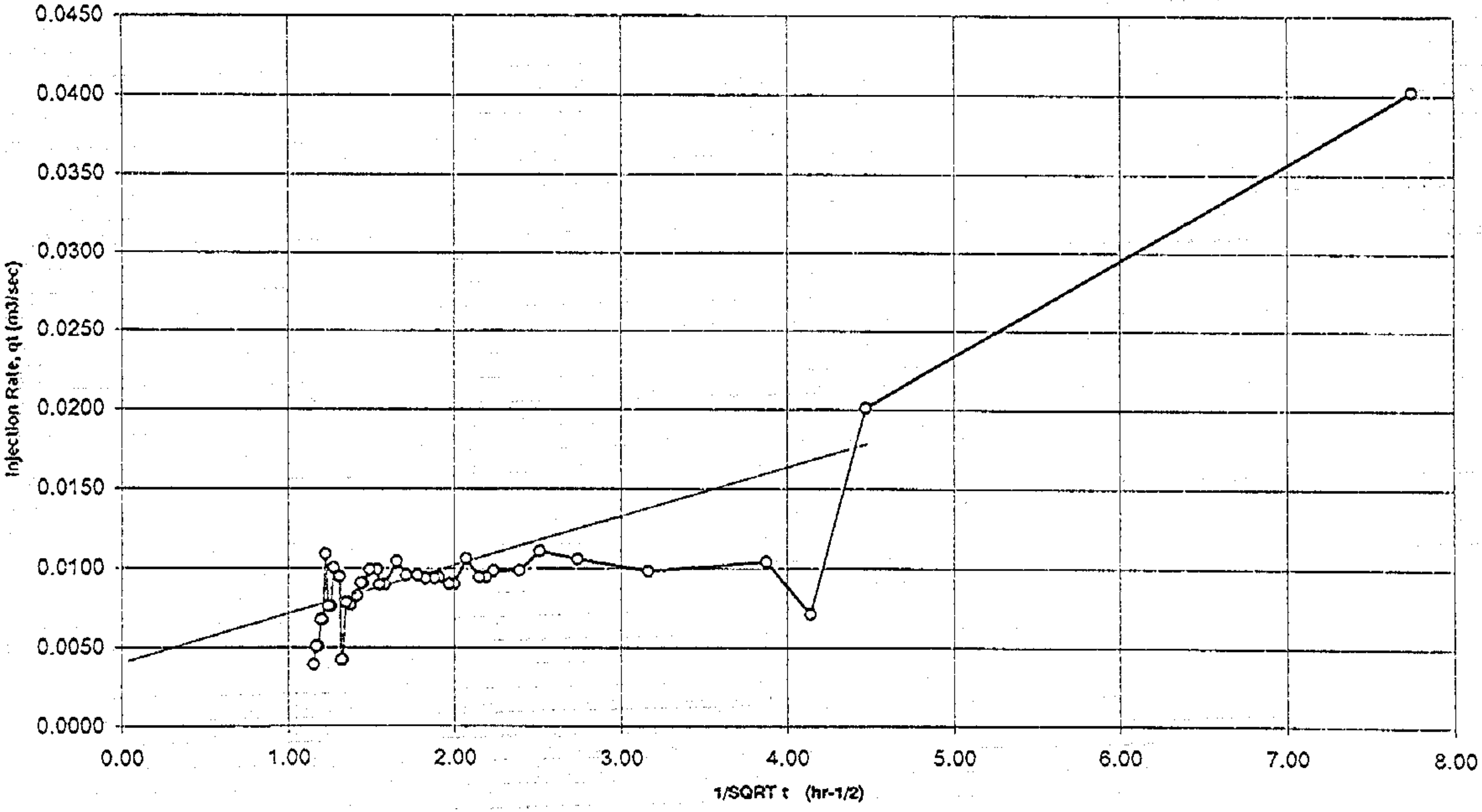


DHDW21.XLS
05/02/96
14:37

SWISSBORING

A. de Jong

Figure 1.7.7. Infiltration Test DW2-2 (3m Pit)
Constant Head Test Analysis by Gibson's Method.

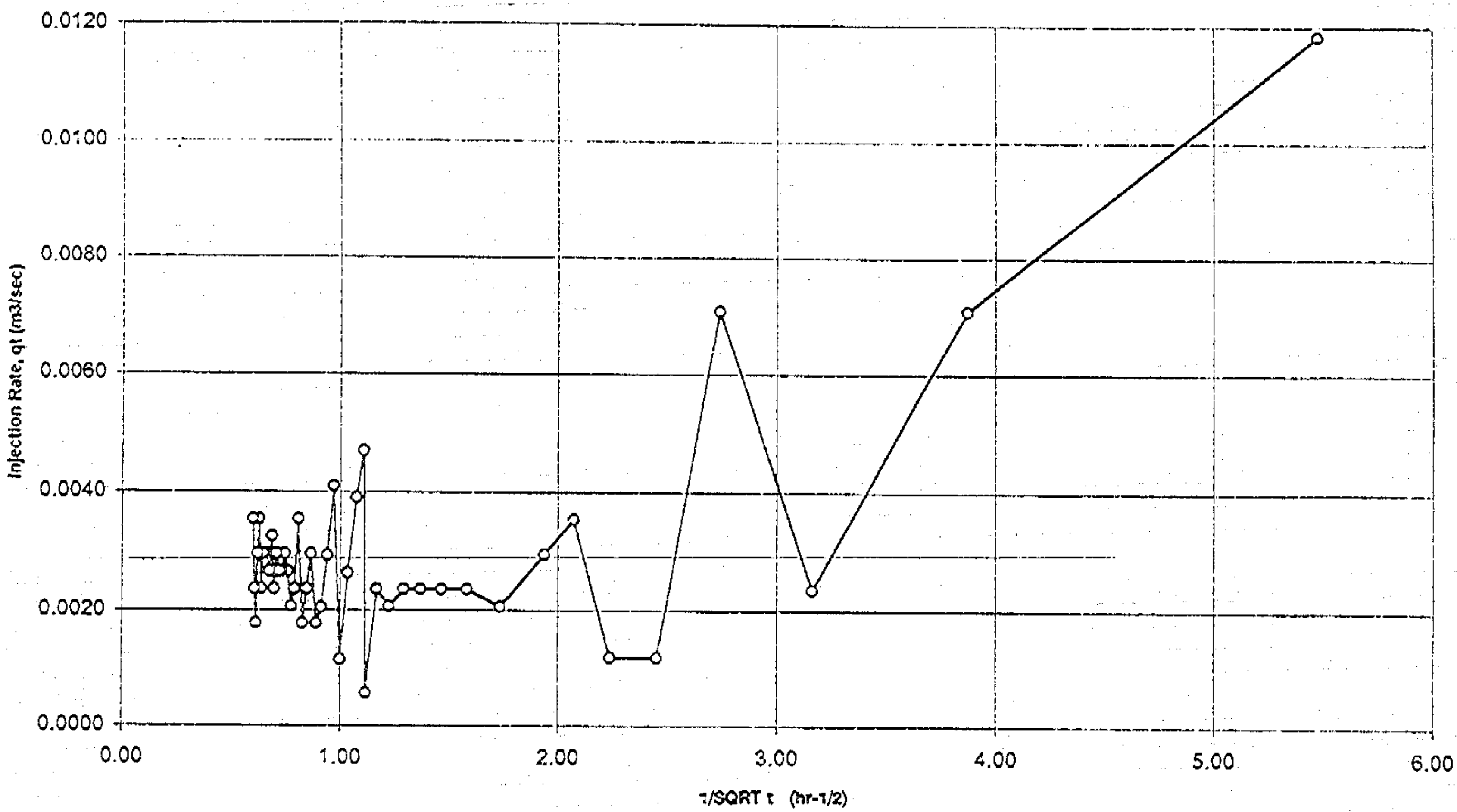


DHDW22.XLS
06/02/96
22:32

SWISSBORING

A. de Jong

Figure 1.7.8. Infiltration Test DW2-3 (6m Pit)
Constant Head Test Analysis by Gibson's Method.

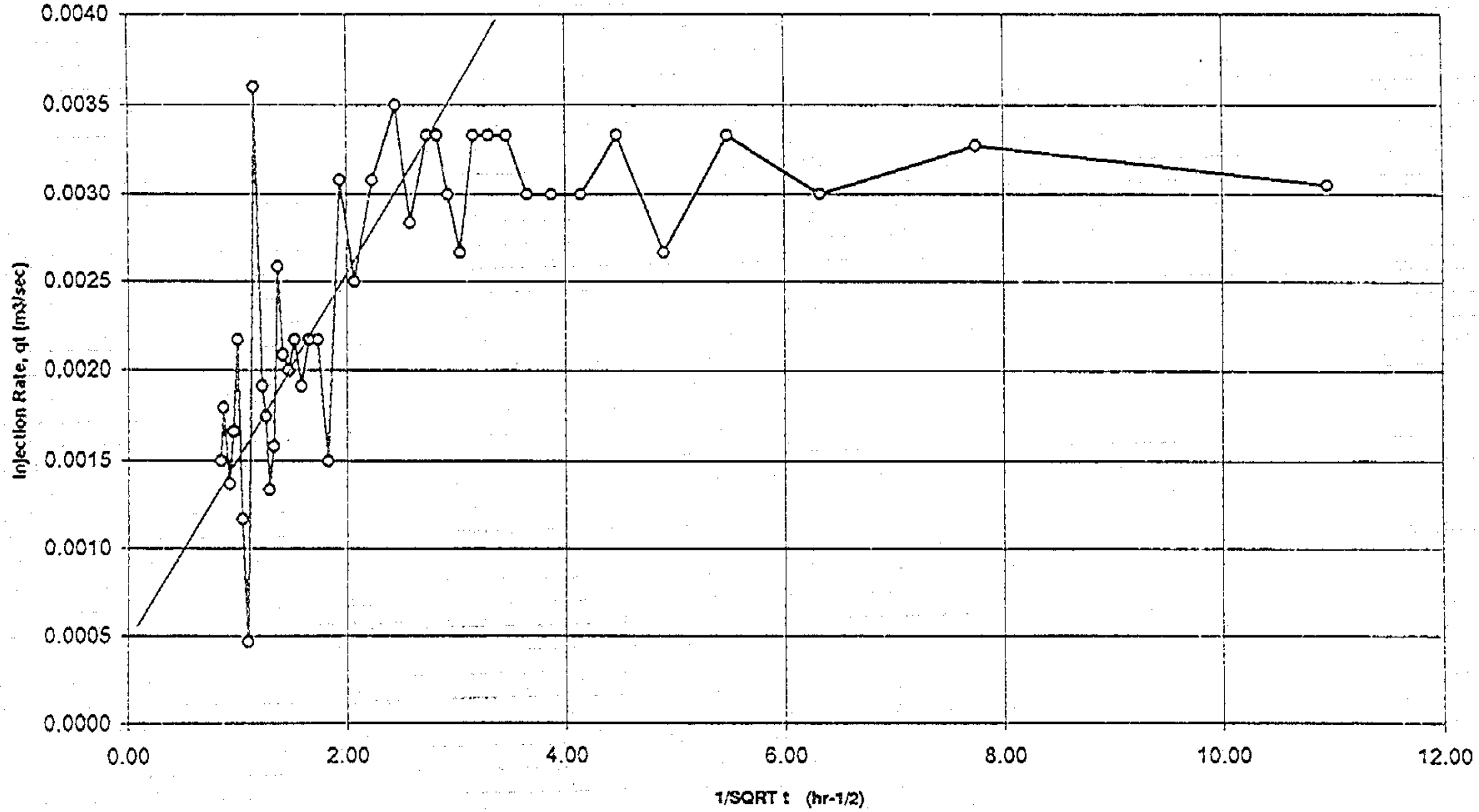


DHDW23.XLS
06/02/96
22:33

SWISSBORING

A. de Jong

Figure 1.7.9. Infiltration Test DW3-1 (1.5m Pit)
Constant Head Test Analysis by Gibson's Method.

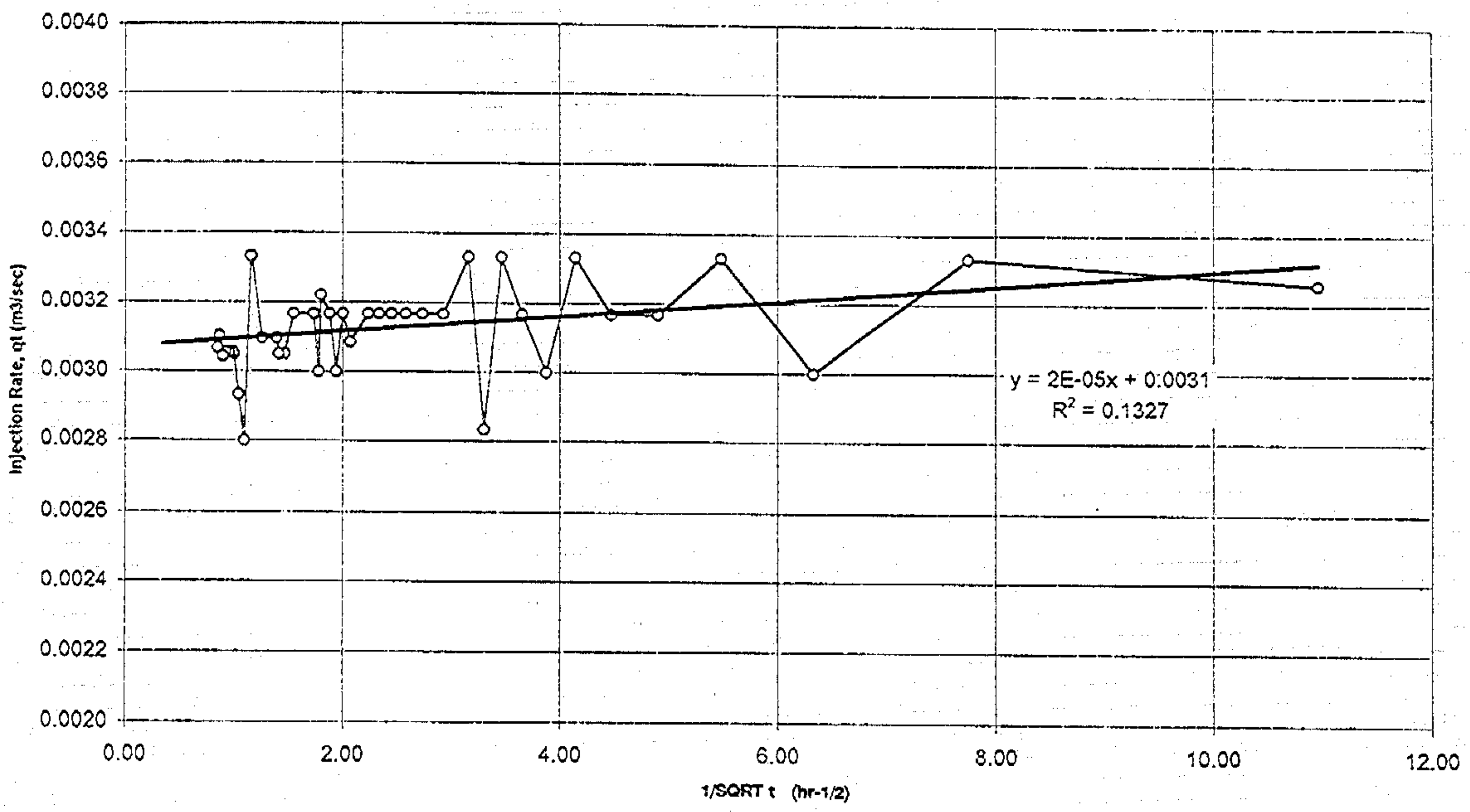


DHDW31.XLS
03/02/96
15:18

SWISSBORING

A. de Jong

Figure 1.7.10. Infiltration Test DW3-2A (3m Pit) : TEST 3
Constant Head Test Analysis by Gibson's Method.

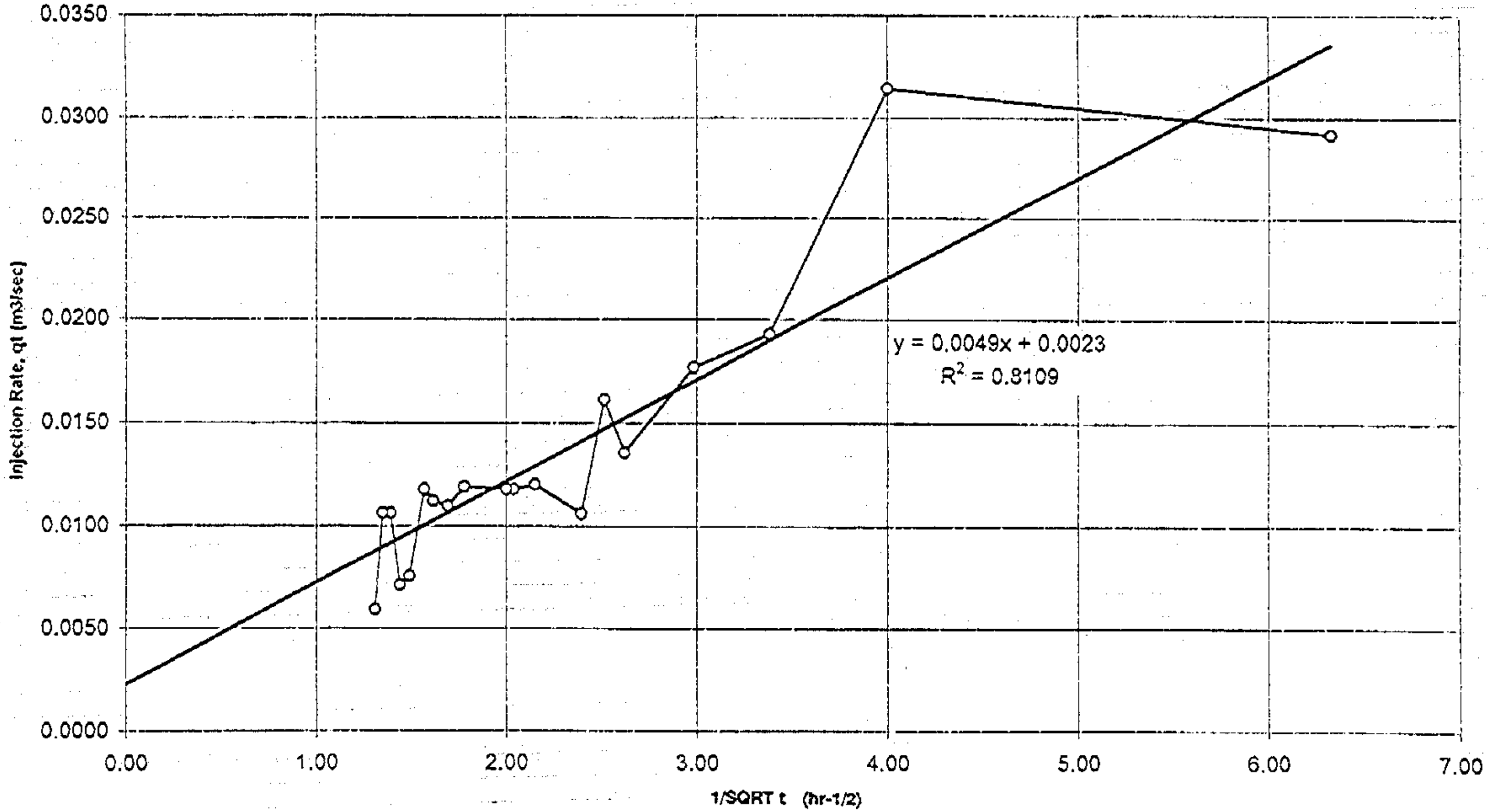


DHCW32A.XLS
06/02/96
11:34

SWISSBORING

A. de Jong

Figure 1.7.11. Infiltration Test DW3-2B (3m Pit) : TEST 2
Constant Head Test Analysis by Gibson's Method.

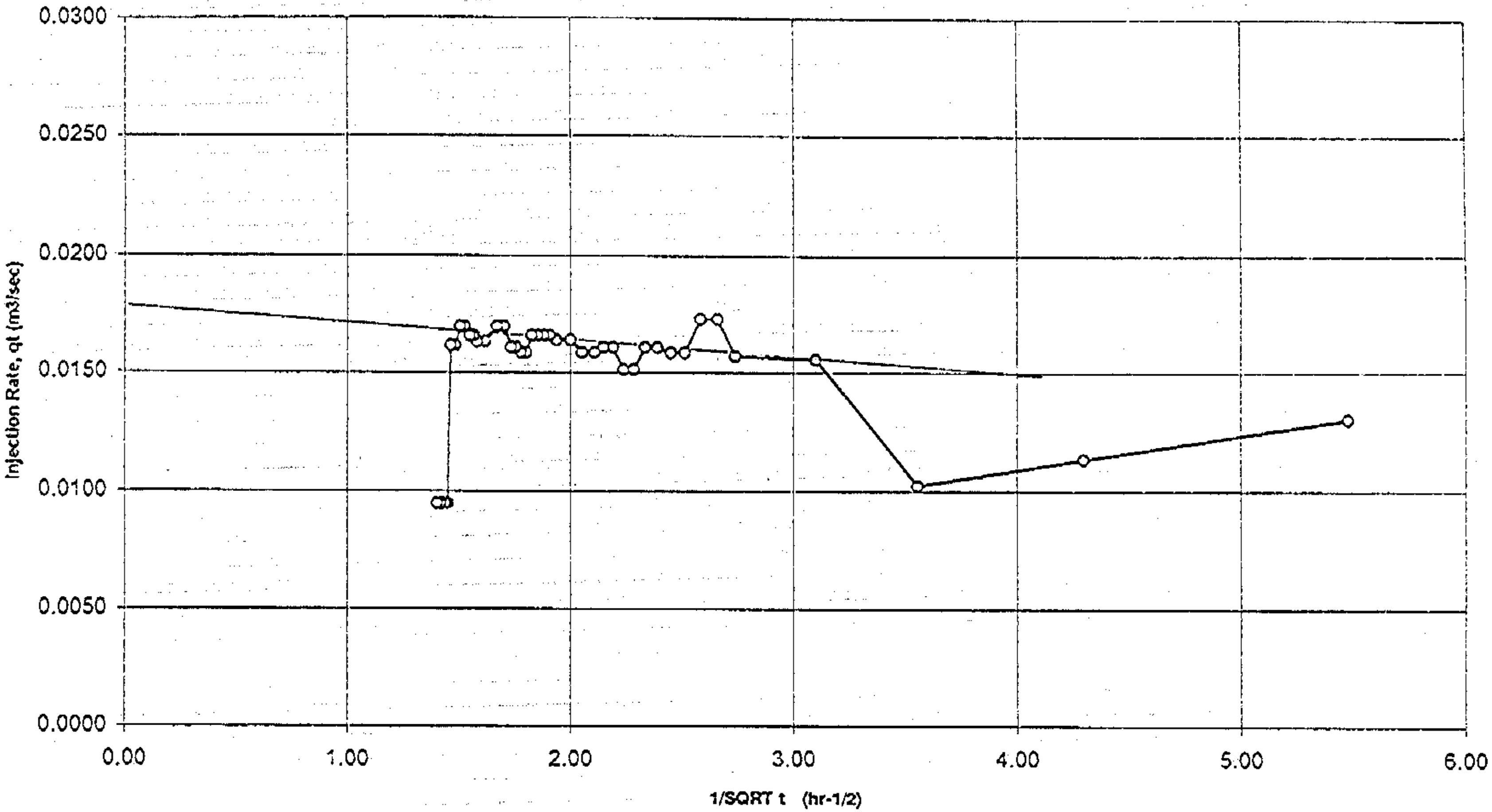


DHDW32B.XLS
03/02/96
15:32

SWISSBORING

A. de Jong

Figure 1.7.12. Infiltration Test DW3-3 (6m Pit)
Constant Head Test Analysis by Gibson's Method.



DHDW33.XLS
06/02/96
22:48

SWISSBORING

A. de Jong

VOLUME TWO : SECTOR REPORT

CHAPTER TWO : SOIL AND IRRIGATION

VOLUME TWO : SECTOR REPORT
CHAPTER TWO : SOIL AND IRRIGATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER TWO : SOIL AND IRRIGATION

2.1. Soils

2.1.1. Soils in UAE

The classification of soil types varies depending on the system adopted; as yet, there is no unified or detailed soil map of UAE available.

(1) Soil Classification of FAO

According to "World Soil Resources" [FAO, 1991], the soil in UAE is classified into the following five main soil groups, with the distributions as shown in Figure 2.1.1:

- Calcisols, Combisols, Luvisols (CL)–soils with lime accumulation mainly in arid and semi-arid areas;
- Leptosols (LP)–shallow soils with outcrops of rock that predominantly occur in desert and mountain regions;
- Solonchaks, Solonetz (SC)–saline and sodic soils;
- Arensols (AR)–deep sandy soils, mainly windblown sands newly fixed by vegetation;
- Shifting Sands–moving sand dunes.

(2) Soil Classification in the Atlas of UAE

The United Arab Emirates University prepared the soil association map shown in the "National Atlas of the United Arab Emirates", which was drawn using different sources, such as images from LANDSAT-5, geological and geomorphologic maps, and measured soil sections taken from several parts of the country [UAE University (1993)]. It is classified into the following three soil associations:

Soil Association	Soil Group	Sub-soil Group
Entisols	Torripsamments	Torripsamments-1
		Torripsamments-2
		Torripsamments-3
		Torripsamments-4
	Torrifluvents	
	Torriorthents	
Inceptisols	Haplaquepts	
	Eutrochrepts	
Aridisols	Calciorthids	
	Gypsiorthids	
	Salorthids	

- **Entisols**

Entisols display little or no evidence of soil development. They occur on steep, actively eroding slopes and have none of the diagnostic soil horizons.

- **Torripsamments**

Entisols that have formed in the poorly graded sands of dunes and in other sandy deposits. Areas of shallow or moderately deep torripsamments have also been recognized in places where there is a thin sand cover over bedrock. They are mostly non-saline or slightly saline. Torripsamments in UAE are divided into four sub-groups based on the geomorphic features and nature of sand accumulation.

- **Torrifluvents**

Entisols formed in the alluvial sediments of intermittent streams. They are subject to flooding. Most of them are stratified with each layer reflecting a period of flooding. Other torrifluvents, mainly those found in or near wadi channels, are stratified with contrasting textures ranging from silt loam to very gravelly sand. They are mostly deep, non-saline to moderately saline soils. Some are sandy or gravelly although most are loamy. They are not extensive but occur all along the mountainous and Bahada areas of UAE.

- **Torriorthents**

Entisols formed mostly in residuum or in colluvium, on actively eroding slopes, and in materials which are resistant to weathering. In some areas they have formed in alluvium on stream terraces. They tend to be shallow soils but occasionally reach considerable depths. Their texture is of loamy sand, fine sandy loam, loam, or clay loam with gravelly counterparts. Salinity ranges from non-saline to strongly saline.

- **Inceptisols**

These soils show a relatively minor alteration of the parent material by soil forming processes. These soils do not occur extensively throughout the country. They make up only one map unit, the haplaquepts-eutrochrepts which are deep, loamy, wet soils with slopes of between 0 and 1%. They are found in low, inter-dunal areas where they are associated with the occurrence of natural springs. These soils are often under cultivation.

- **Haplaquepts**

Haplaquepts are poorly drained inceptisols. They are formed in deep, loamy deposits on the lower parts of the landscape and have a water table at or near the surface, unless they are drained. Their texture is mainly loamy, ranging from slightly saline to strongly saline.

- **Eutrochrepts**

Eutrochrepts are inceptisols that are better drained than the haplaquepts. They have a water table at a depth of 75 cm or more, unless they are drained. They form in deep loamy deposits and are mainly sandy loam or loam, ranging from slightly saline to strongly saline.

- Aridisols

These are soils which are dry and do not have moisture available over long periods of time for plants requiring moderate amounts of water. All of the aridisols in UAE have an aridic moisture regime except for the salothids, which occasionally have a high water table in addition to a salic horizon. Aridisols are extensively found throughout the country. The aridisols are divided into three groups:

- Calciorthids

Calciorthid aridisols in which secondary carbonates have accumulated from a calcic horizon that has its upper boundary within 1 m of the soil surface. Rainfall has not been sufficient to leach carbonates from the upper part of the soil. Thus, these soils are mostly calcareous from the surface down to the calcic horizon and, in many places, below it. Their salinity ranges from non-saline to strongly saline. They are the most extensive subgroup of the aridisols in UAE. They occur throughout the sedimentary succession where limestone and calcareous sandstone are common sources of calcium carbonate.

- Gypsiorthids

Gypsiorthids aridisols that have a gypsic or petrogypsic horizon within 1 m of the soil surface. Their texture is mostly loam with gravelly counterparts and show from slightly saline to strongly saline. Although gypsiorthids are scattered throughout UAE, they occur most extensively in the south-eastern part of the country.

- Salorthids

Salorthids aridisols that have a salic horizon. They are wet and strongly saline when they occur in basins where capillary rise and evapotranspiration concentrate salts into a salic horizon. In most places, the surface layer when dry has a salt crust. Salorthids are deep soils. Their texture is one of silt to clay. They are extensive in the coastal zone and the western part of UAE.

Their distribution of these soils is shown in Figure 2.1.2.

2.1.2. Previous Soil Studies in the Study Area

(1) 1967 Survey

The major source of the soil survey data for the Study Area is "Survey of Soils and Agricultural Potential in the Trucial State" [University of Durham, UK, 1967].

The survey concentrated on the gravel plains in the west of the mountain zone but also included some selected areas in the mountain and east coast zones. Soil series and land capability maps were drawn for the gravel plain zone.

Soils on the gravel plains have been formed from outwash deposits derived from wadi discharges from the mountains. The texture of these soils becomes increasingly fine away from the mountains as the thickness of outwash sands and silt deposits increase. Aeolian sands encroaching from the west have covered most of the fine-textured soils, consequently, few of these soils are exposed. Soils in the gravel plain exhibit a high carbonate content because of the limestone parent material which is found to the north of the Dibba line. Parent material is the dominant factor for all the soils in the Study Area and all are poorly-structured and immature. N, K and P levels are low and deficiencies of trace elements have been observed, especially in the tree crops.

Major soil types recognized by the survey were sierozems, non-saline alkali, and saline alkali soils. These types were sub-divided into series on the basis of texture and carbonate content. The gravel occurring within 50 cm of the soil surface was indicated on the soil survey map by suffix (g).The gravel content of the soil has a great effect on its land capability classification.

(2) 1982 Study

In a study, "Dams and Recharge Facilities in the UAE" [Halcrow (1982)], a soil survey was prepared covering the Study Area. The study recognized two further soil types of relevance, namely saline non-alkali soils and wadi gravel soils.

(3) Atlas of UAE

The Soil map was prepared by the University of UAE in 1992 based on LANDSAT images and some field observation. The land in the Study Area is covered by fluvial deposits and sand deposit, and soils are classified into; 1) Torrifluvents, torriorthents and outcrops, 2) Torripsamments-2 and calciorthids, and 3) Rock outcrops torripsamments and calciorthids

2.1.3. Soil Investigation

(1) Test Pit Investigation

The main purposes of the soil survey are to size up the soil conditions of existing farms and to identify the future development potential of agricultural development in the Study Area. Consequently, the survey points were selected not only in existing farms but also virgin land in the Study Area. Areas which have no possibility of agricultural

development such as outcrops of the base rock, gravel quarries and moving sand dunes were not surveyed in the Study.
The location of 131 surveyed points are shown in Figure 2.1.3.
Soil survey fieldwork in the Study Area was conducted in the following two stages;

1) Reconnaissance survey to size up the type of soils and their distribution in the Area;
2) Detailed observation and sampling for laboratory analysis from test pits.

The laboratory analysis was undertaken by local consultants.

(2) Reconnaissance Soil Survey

After the collection and review of existing data , such as aerial photographs, topographic maps, and previous investigation reports, a reconnaissance soil survey was conducted at 65 test pits. Originally the survey planned to use augers, but because of the soil conditions (most of the soils contain gravel and were dry in the survey period), the survey method was changed to observation made of the soil profiles, including the characteristics of each layer with regard to factors such as thickness, texture, color, gravel contents, size of gravel, moisture conditions, hardness, and the depth of crop or vegetation root penetration.

As a result of the reconnaissance survey the following points became apparent:

- Morphologically, the Study Area can be divided in to 3 zones--1) Moving sand dunes or rather stable desert zone spreading along the western and northern edges of the Study Area; 2) A zone of rocky outcrops mainly distributed along the foot of the eastern mountain area; and 3) Gravel plains between the above two zones.
- Soils in the gravel plains can be classified according to the gravel contents
- Some gravel plain soils are deposited as a shallow layer on calcareous basement, or occasionally the hard pan, and salt accumulation caused by rainfall or irrigation water appears in these gravelly layers.
- Except for the area near to sand dunes, gravel plain soil covers the fluvial gravel layer which usually appears within 70 cm of the surface.
- Gravel plain cultivation : There are many farms/gardens on the gravel plain in the Study Area. It is not normally used for cultivation, but these have cultivated tree crops on thin topsoils. Cobbles and gravel on the grand surface were removed, and the farms are bound by a flood dike, and sometimes silty sand from the sand dunes has been spread on the gravel layer. Consequently, it was difficult for the survey to distinguish the original

soil conditions. These are located sometimes in the wadi flood courses, and could be detected where water was available.

- Salt accumulating in the coarse sand and gravel layers : In the cultivation area, on citrus farms in An Nasim and forage farms in Suhelah, where high salinity groundwater is extracted for irrigation and excess water is applied for irrigation, salt accumulations were uncovered. Also non-cultivated areas had salt crystals in the gravel/coarse sand layers especially in the eastern toe of Jabal Al Fayah. Most of the salt crystal accumulation is $CaCo_3$ or Ca SO_4 and the longest crystals were about 2 cm long. Sodium chloride accumulation was found in the Wishah gravel plain area, where there is high electric conductivity of extracted groundwater (EC 8,000 μS/cm).

(3) Test Pit Survey and Soil Sampling

Based on the reconnaissance survey, detailed survey and soil samplings were made at 66 pits to get more detailed information of each soil type and area that was outlined by the reconnaissance survey.

The location of test pits and sampling sites were selected in the following places:

- Sand dunes including inland sabkha occupying the north and east area of the Study Area where little land is under cultivation;
- The fluvial plain wadis which are covered by the dune sands that extensively cover the Study Area,
- Gravel plains underlain by weathered limestone, which are located near the foot of mountains and rocky outcrops in the Study Area
- Gravel plain covered by silty sand in the Study Area.

In addition to the above classification, the area not covered by salt accumulation during the reconnaissance survey period was also subject to a detailed soil survey to identify the extent of the area.

2.1.4. Laboratory Analysis of Soil

(1) Soil Samples and Analysis

The location of test pits from which samples for laboratory analysis were collected are shown in Figure 2.1.3.

(2) Laboratory Analysis

In order to assess the chemical and physical properties of the soils according to soil type, 65 collected samples were sent to the laboratory. Laboratory analysis is being conducted during the reporting period on the following items:

Physical properties:	apparent/specific gravity (bulk density), specific gravity, grain size distribution, pF - moisture contents, and clay mineral structure
Chemical properties:	pH (1:5 water and 1:5 KCl extracted), conductivity (Ece), cation exchange capacity (Ca, Mg, K and Na), cation (Ca, Mg, K and Na), anion (Cl, SO_4, HCO_3, CO_3), phosphoric acid, nitrogen, carbon, contents, and rear metals (Cu, Zn, Mn).

Laboratory analysis of soils was conducted in the UK after the Study Team collected samples from survey pits. They are summarized as follows:

(3) Results of Chemical Analysis

Initial analysis of laboratory tests are shown can be summarized as follows:

- Average sand content is 87%, while clay accounts of 4.2% of the soil;
- The clay mineralogy analysis shows that most clay is composed of palygorskite or illaite;
- Soil pH (1:5 water and 1:5 KCl extracted) ranges between 7.6 and 9.3;
- Electric conductivity (1:5 water) averaged 650 μS/cm and the maximum value was 4,400 μS/cm, which was sampled where salt had accumulated;
- Contents of exchangeable Ca^{++} shows high with an average of 61.6 meq/100g
- Contents of SO_4^{++} (1:5 in water) shows high with an average of 888 mg/kg
- Contents of organic carbon is very small with an average of 0.29%.

The results of the chemical analysis of the soils is summarized in Table 2.1.1. Some important items are explained below:

Cation exchange capacity (CEC) (sometimes erroneously called base exchange capacity)
The total sum of exchangeable cations that a soil can absorb, expressed in centimoles, per kg of soil, clay or organic colloid.

Exchangeable sodium percentage (ESP)
The percentage of the cation exchange capacity of soil occupied by sodium.
$ESP = (Na^{+}_{exchangeable} / CEC)$

Exchangeable cation percentage (ECP)
The extent to which the cation adsorption complex of a soil is occupied by particular

cation. This is expressed as follows:

$$ECP = \left[\frac{\text{exchangeable cation}_{(cmole/kg\ soil)}}{\text{cation-exchange capacity}_{(cmole/kg\ soil)}} \right] X\ 100$$

Sodium absorption ratio (SAR)

A value representing the relative hazard of irrigation water because of a high sodium content relative to its calcium plus magnesium content as shown follows:

$$SAR = \left[\frac{Na+}{((Ca^{++} + Mg^{++})/2)^{1/2}} \right] X\ 100$$

The ions are in millimoles per liter.

(4) Results of Physical Analysis

a) Soil Texture

Soil in the Study Area is gravelly sand. Sand is the dominant constituent, averaging 87% while clay accounts for 4.55%, with a range of between 0.73% and 13.62%. Soil textures with particles under 2 mm are classified as sand to loamy sand according to the US system and coarse according to the FAO system. Soils with finer texture usually show high ESP or SAR.

b) Particle Density and Bulk Density

As shown in Table 2.1.2., particle (specific) density of the soil ranges from between 2.61 to 2.97 g/cm^3. Bulk densities of undisturbed samples measured at between 1.33 to 1.79 g/cm^3.

c) Soil Clays (X-Ray analysis)

25 soil samples were analyzed by X-ray for their soil minerals. As shown in Table 2.1.2., Palygoskite is dominant in all soils, especially sand dune soils, followed by Kaolinite and Smectite (Montmorillonites).

e) Soil Moisture Retention and Available Moisture

Soil water holding characteristics were analyzed and they gave the pF scale classification results as shown in Table 2.1.3. and Figure 2.1.4.

2.1.5. Soil Classification

(1) General

The Study Area was divided into three main morphological categories--sand dunes or shifting sand dunes (about 25,000 ha or 30% of the Study Area), gravel plains or fluvial plains (about 60,000 ha of the Study Area) and rocky outcrops (about 1,500 ha of the Study Area). They are generally distributed from the western to eastern portion of the Study Area. The soil survey was implemented mainly in the gravel plain where the existing agriculture land is distributed and there is some area under cultivation among the sand dunes. The survey was carried out during the summer of 1995.

(2) Soil Classification

a) Previous Classification in the Study Area

Three major soil types were recognized in the 1977/67 survey by the University of Durham. These are sierozems (xerosols), non saline alkali and saline alkali soils. These types were subdivided into series on the basis of texture and carbonate content. After these types, the study of "Dams and Recharge Facilities in the UAE, 1982" added two further soil types of relevance, namely saline non-alkali soils and wadi gravel soils.

- Sierozem : (C2, C3, C4 and C6 based on the carbonate content and texture)
- Non-saline Alkali : (NS2, NS3, NS4)
- Saline Alkali (SA3 and SA6)
- Saline Non Alkali
- Wadi Gravel

(In recent terminology, alkali is replaced with sodic.)

b) Saline and Sodic Classification in the Gravel Plain

Classification of salt-affected soils is made according to the following definitions:

Saline soil has a saturation extract conductivity of 4.0 decisiemens per meter (4.0 mS/cm) or greater and has low SAR. These soils were formerly called white alkali.

Sodic soil has an SAR of the saturation extract of 13 or more but has low salt content. These soils were formerly called black alkali.

Saline-sodic soil has both the salt concentration to qualify as saline and SAR of 13 or more needed to qualify as sodic. These soils were formerly known as either white alkali or black alkali.

These are summarized as follows:

Name for Soil	Ece $_{saturation\ extract}$ (mS/cm)	SAR
Normal soils	less than 4.0	less than 13
Saline soils	more than 4.0	less than 13
Sodic soils	less than 4.0	more than 13
Saline-sodic soils	more than 4.0	more than 13

c) Soil Classification

Based on the Soil pit survey and the laboratory analysis, the soil classifications in the Study Area have been divided into the following groups:

Order	Sub-group	Great Group	Subgroup
Entisols	Fluvents	Torrifluvents	
	Orthents	Torriorthents	
	Psamments	Torripsaments	Torripsaments-2
Aridsols	Orthids	Calciothids	
		Gypsiorthids	
Wadi Riverbed			
Rock Outcrop			

(3) Soil Maps

Based on the soil classifications mentioned above, a soil map of the Study Area was prepared in this Sector Report referring to test pit data and the result of physical and chemical analysis in the laboratory.

(4) Soil Map Units

a) Calciorthids

Soils are aridisols in which secondary carbonates have accumulated from a calcic horizon that has its upper boundary within one meter of soil surface. Rainfall has not been sufficient to leach carbonates from the upper part of soil. As a result, these soils are mostly calcareous from the surface down to the calcic horizon and, many places, below to it. Calciorthids range from shallow to deep and are sandy and loamy. In many places, calcirothids have formed in residuum and are loamy-skeletal. In terms of salinity they range from non-saline to strongly saline. They occur throughout the sedimentary succession where limestone and calcareous sandstone are common sources of calcium carbonate. These soils are mainly distributed in the northern part of the Study Area, Dhaid and Mileiha Area

b) Gypsiorthids

Soils are aridisols that have a gypsic or petrogypsic horizon within one meter of the soil surface. These orthids range from very shallow to deep. They are loamy or loamy-skeletal, and their texture is mostly one of loam, fine or sandy loam, or loam with gravelly counterparts. The soils range from slightly saline to strongly saline. These soils are mainly located in the southern area of the Study Area.

c) Torripsaments

Soils are entisols. This map unit consists of nearly level and gently sloping soils on plains, and nearly level to strongly sloping soils on dunes. The dunes are less than two meters in height. Some are shifting sand dune. Soils have a calcareous composition and loamy in small areas. The soils are saline or moderately saline, and there is evidence of a drainage pattern. Small area has thin argillic layer. These soils are located in the east and north part of the Study Area. Also they located at the central part of the Study Area which are separated by wadi channels and rock outcrops.

d) Torriorthents

Soil are entisols that have formed mostly in residuum or in colluvium, on active eroding slopes, and in materials which are resistant to weathering. In some areas, they have formed in alluvium on stream terraces. Torriorthents tend to be shallow soils although occasionally they reach to considerable depths. Their texture is of loamy sand, fine sandy loam, loam, or clay loam with gravelly counterparts. They range from non-saline to strongly saline.

e) Wadi Bed

The map unit consists of nearly level soils on wadis, mainly meandering braided streams. These streams often cut deeply into surrounding terrain. Topographically, they are the base level and drainage outlets subject to frequent and serve flooding. These units are calcareous; very gravelly and extremely gravelly sandy, shallow to deep soils. Slopes range 0 to 1 percent. The surface is generally rugged and irregular.

f) Rock Outcrops - Torriorthents

The map unit consists of rock outcrop on highly dissected mountains, low hills and steep soils on hillslope, slope range 0 to 10 percent. The torriorthents and similar soils are on piedmont slopes, footslopes and channels. Slope ranging from 0 to 15 percent. The torriothents are calcareous, very gravelly loamy to sandy, shallow to deep soils. They are mainly located on the eastern and south-western corner of the Study Area.

2.2. Land Use and Vegetation

2.2.1. Present Land Use in the Study Area

(1) Present Land Use by the Orthophoto Map Interpretation

The orthophoto map was prepared by the Study Team during Field Survey (I) period of the Study. The map presents the latest land use information compared with other maps. The present land use in the Study Area is prepared based on the orthophoto map as shown below:

Category	Area (ha)	Weight (%)
Cultivation Land	5,800	6.6
Non-cultivated Land	2,300	2.6
Residential and Public Facilities	600	0.7
Quarry	6,200	7.1
Sand Dune	65,600	75.0
Rock Outcrop	5,800	6.6
Others such as road	1,200	1.4
Total	87,500	100.0

The non-cultivated land area is estimated at about 30% of the total agricultural land. Based on the Atlas of UAE, which presents the land use map of the Dhaid Area shown in Figure 2.2.1., abandoned farms occupy 10% of the agricultural land. This evidence indicates that groundwater deterioration has recently been accelerating and has caused an increase in abandoned farms, especially in the Dhaid Area.

(2) Classification of Land Suitability for Agricultural Development

The existing farm land occupies the most suitable agricultural land. Some of the farms been developed in the gravel plain after transporting in 5 to 20 cm of artificial sandy silt topsoil. These farms have high intake rates, such as 212 mm/hr in Ikhedir, because of the high permeability of the gravelly base layer.

Based on 1) the topographical conditions mainly slope of the land 2) the thickness of topsoil on the gravelly base layer; 3) soil characteristics of the area, and 4) drainage conditions, it is possible to say that most suitable land for agriculture has been mostly developed in the Study Area. The virgin land in southern part of the Study Area has potential for agricultural development, but it needs careful irrigation for salinity control because of affects of gypsum.

2.2.2. Land Use Planning

Considering the present over-extraction of groundwater for irrigation against the rechargeable amount in the Study Area, no additional land should be opened up to agriculture. Basically, gravel plains such as exist in the Study Area are not suitable for agricultural development with scant water resources. The gravel plains which have been covered with silt washed out by wadi floods and loamy sand coverage blown from sand dunes, and which are suitable for agricultural land development, have already been developed as farm land.

2.2.3. Vegetation

(1) Vegetation in UAE

A complete botanical survey of UAE has not yet carried out. Vegetation zones are therefore difficult to define and boundaries are indistinct, especially considering that rapid changes in vegetation patterns can occur with erratic rainfall.

The shifting sand dunes of the western dune plains are unable to support hardly any vegetation apart from clumps of species such as *Cyperus congromeratus* and *Calligonum comosum*, which may survive even when almost buried by shifting sand. The coastal areas and sabkhah of the west also support little vegetation, which is mainly halophytic.

In the central desert, as rainfall increases plant cover increases towards the north-east. Trees become more common, and *Acacia* forest remnants, witnesses of a wetter past, survive between Ash Shiweb and Al Hiyar, and inland of Jabal Ali. The fertile alluvial plains are capable of supporting quite a dense cover. Jiri plain with their sands and silts and high water table are particularly well covered. The permeability of Dhaid, Madam and Al Ain plains is, however, affected by a caliche horizon below the gravel.

The northern emirates, with their increased rainfall, are the most thickly vegetated and support the greater diversity of species. Summer showers, which can occur in the mountains, are important for the germination of many species, such as *Tribulus*. Generally, biological activity in UAE soils is low, but mountain soils may be quite well populated with soil organisms.

(2) Vegetation in the Study Area

The Study Area lies in a dry but semi-humid climate, and consequently, vegetation density is relatively higher than in other areas. The nature of vegetation is sparse shrub including species such as, *Ornulaca leucacantha, Hammada elegans, Leptadenia protechnica,* and *Orchradenus aucher.* with scattered *Acacia tortilis* and *Prosopis* tree species. The average height of acacia observed was 3 to 5 m. These trees rely on erratic rainfall and runoff from the mountain areas.

2.3. Present Conditions of Irrigation

2.3.1. Irrigation in UAE

Because of the dry climate, with high evaporation losses and low supply of rainfall, agriculture in UAE is highly dependent on irrigation. The water source for the irrigation is groundwater, but the traditional falajes are mostly dried-up and abandoned.

(1) Water Sources

In 1993, there were a total of 32,376 wells in UAE; of which 3,887 wells were almost dry or capable of providing only negligible amounts of groundwater; 28,489 wells were productive enough to be suitable for agricultural activities.

From Table 2.3.2. it is clear that Abu Dhabi has the highest proportion of low-production wells; the Northern and Eastern Regions have the lowest proportion of low production wells.

(2) Traditional Irrigation

The two mainly used traditional irrigation systems in UAE are described below.

Furrow irrigation. This system uses furrows and ridges placed alternately parallel to water supply channels. Furrows are divided transversely into convenient lengths of three to five meters by earth cross-ridges. Water is diverted into these sections up to about 3/4 of the furrow height and is then released to the section. This system is used for Tomato, Water Melon, Squash, Onion, Pepper, Cabbage, Cauliflower and Cucumber.

Basin irrigation. This system consist of flat beds, bordered by small dikes which are filled with water, the water is then allowed to permeate into the soil. Water is usually conveyed to these basins by an earth furrow from a central channel. Basins vary in area from 6-10 m^2 and are used for Onions, Pepper, Alfalfa, cereals, and fruit trees.

(3) Modern Irrigation

MAF are aware of the clear advantages of using modern irrigation systems compared to the high levels of water consumption of traditional irrigation systems. Studies conducted at the Hamraniyah research station showed that the use of a trickle irrigation system could result in saving 82% of the water compared with open earth furrow systems and a 45% saving on improved (lined and covered) furrow systems; labor savings of 75%-88% could also be expected.

At present, MAF is successfully trying to modernize agriculture by encouraging the utilization of modern irrigation systems which are more suitable from the point of view of the rationalization of water usage for agricultural purposes.

In the 1980s MAF started an irrigation modernization plan which has given the following results for 1993: out of total cultivated area in UAE of 66,682 ha, 40,453 ha (more than 60% of total cultivated area) uses modern irrigation methods. Within the area using modern irrigation systems, the drip system is the most used with 71% of total area under modern irrigation system; sprinkler and bubbler systems occupy 23% and 6%, respectively (Table 2.3.1.).

2.3.2. Irrigation Water in the Study Area

(1) Irrigation Water Sources

In the Central Region of MAF, there were 843 dry wells and 8,187 productive wells in 1993. With the exception of Abu Dhabi, the Central Region has a relatively higher number of dry wells compared with the Northern and Eastern Regions; while in the Northern Region the figure is only 6% of the wells existing in that region are poor, in the Central Region the proportion is 9%. It is likely that the number of poor wells in the Central Region will have already increased since 1995, due to the drop in the groundwater table, especially in the Study Area.

On the other hand, the Central Region had the second largest number of generators (6,585) and pumps (3,956) in UAE.

In the Study Area, most farms have one to four tubewells drilled on their own land. Especially in the northern Dhaid area the extracted water is sometimes conveyed by pipes for more than two km in places where the wells have dried up. Where it is not possible to bring in an outside water supply, the farms are abandoned.

There were three falajes in the Study Area: Falaj Al Mualla, Dhaid and Siji. They had no water flow during the Study.

(2) Water Quality for Irrigation

The water source for irrigation is groundwater in the Study Area. Groundwater quality was measured by the Study Team using portable EC and pH meters during the Well Inventory Survey, and sampling for laboratory analysis at MAF Central Laboratory was done during previous fieldwork.

a) Result of Existing Wells Inventory Survey

Groundwater quality of 1,250 was measured using the EC, pH and temperature meters in summer 1995 during the Well Inventory Survey. The sample locations are shown in Figure 2.3.1. The measurements are summarized in Table 2.3.3.

The highest EC value, of 3,500 μS/cm, was in the Dhaid-2 area and the lowest, 1,900 μS/cm was in the Dhaid-1 area, especially the Wishah area.

b) Water Sampling and Laboratory Analysis

In parallel with the measurement of EC and pH of groundwater as a part of the Well Inventory Survey, groundwater sampling was conducted by the Study Team for laboratory analysis in the Central Laboratory of MAF in the summer of 1995. Groundwater sampling and field measurements of EC were made at 171 wells in the Study Area as shown in Figure 2.3.2., and 125 samples were sent to the laboratory.

The results of the EC field measurement are plotted as shown in Figure 2.3.3.

According to the results of laboratory analysis of groundwater quality, the groundwater in the Study Area shows an EC between 700 and 9,000 μS/cm with an average 2,800 S/cm, 7.8 average pH, and about 10 as an average SAR. As shown in Figure 2.3.4., the waters are classified as irrigation water classes C3-S1, C3-S2 and C4-S3.

c) Previous Water Quality during 1977–1980

According to "Water and Soil Yearbook No. 2, MAF", several groundwaters in the Study Area were analyzed. They are shown in Table 2.3.4. and summarized as follows:

Area	EC (μS/cm)	SAR
Dhaid	700	3.0
Hammada	840 - 2,000	1.4 - 7.2
Fili	600	1.2 - 2.0

These data are plotted in Figure 2.3.4. together with the present readings. They are classified as irrigation water C2-S1, C3-S1 and C3-S2. Compared with the present condition as mentioned above, it is possible to say that groundwater in the Study Area has become worse.

d) Irrigation Water Criteria and Crop -Salinity Response

Irrigation water is usually classified by a combination of the electric conductivity and sodium absorption ratio (SAR). A typical irrigation water classification diagram is shown in Figure 2.3.4. According to this classification, half of the irrigation water in the Study Area is classified as saline water of fair quality. Only three wells indicate good quality water. Also through the analysis, a SAR increase with electric conductivity with ranges of no alkaline water was noticed. Consequently, it is possible to say electric conductivity can be an indicator of the irrigation water in the Study Area.

Together with the saline characteristics of soil, saline irrigation water accelerates the degradation of the land productivity in the Study Area through careless irrigation. Consequently, irrigation must be carefully managed in the Study Area.

Soil salinity and saline irrigation water reduce agricultural production. Their sensitivities are summarized in Table 2.3.5.

(3) Groundwater Extraction for Irrigation

According to the irrigation water survey conducted in 1977 by UNDP/FAO/MAF, the average annual groundwater extraction per unit irrigation area is 49,000 m^3/ha (Table 2.3.6.).

The Study Team also conducted a groundwater extraction survey in the of summer 1995 (Table 2.3.7.). In the season of the survey, farmers were only irrigating Date palms and fodder. The annual groundwater extracted per unit of irrigation area varied from between 62,000 to 320,000 m^3/ha with an average of 237,500 m^3/ha for perennial crops. Based on these results, applying the average crop coefficient of Date palm and fodder, the present irrigation water extraction amount in the Study Area is from 4 to 25 times more than the net irrigation water requirement.

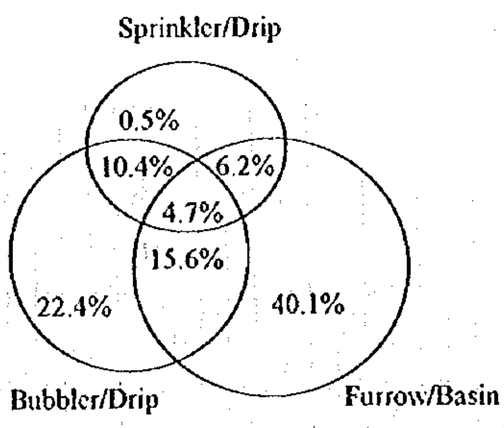
Monitoring the actual groundwater extraction by water meter at the outlet of water tank of typical farms is therefore recommended.

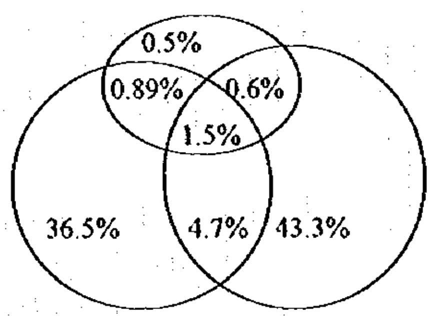
2.3.3. Irrigation Practices

(1) Farm Inventory Survey Results

According to the Farm Inventory Survey, farmers are irrigating their fields by basin/furrow, sprinkler/drip and bubblers. The weights of each category of irrigation method are as follows:

[Installed] (192 farms) [in Use] (180 farms)





- The main water source for irrigation is tube wells, existing open wells are not used for irrigation due to the depletion of the groundwater table. Water in falaj is no longer used for irrigation.
- An average of 6 tube wells are dug in the farm land, but only 555 of them are used in the surveyed farms. 22 open wells exist mainly in the Mileiha area, but only 33% are used at present.
- Modern irrigation methods have been introduced in the surveyed farms: bubblers for tree crops and other crops sprinklers or drip irrigation systems, which have been extended respectively to 50% and 20% of surveyed farms, especially in the Dhaid Area. However, associated equipment, such as sand filters, liquid injectors, sand traps and so on, have not been not completely installed.
- All farms that face water problems, such as only being able to use half of their existing wells, (half of an average of six), can extract groundwater. Salinity problems are serious in the region except for the Dhaid area.
- The survey was conducted during the hot season, so therefore only fodder crops or tree crops were irrigated. Usually farmers start irrigation from early in the morning until noon and from evening to night in order to apply irrigation water more efficiently. However, some farms irrigated their fodder crop in the hot day time by sprinkler.

(2) Irrigation System

MAF and individual farmers are trying to minimize the amount of irrigation water through the introduction of modern irrigation methods with the help of agricultural extension services and government subsidies, both in the Study Area, and elsewhere.

Around 60% of the farms in the Study Area already use one or more modern type of irrigation. Sprinklers account for 33% of modern irrigation methods, bubblers for 35% and drip irrigation for 29%.

a) Drip Irrigation System

The drip irrigation method was introduced through the efforts of MAF in the Study Area. According to the Farm Inventory Survey in summer 1995, 37 farms (22%) installed the drip irrigation method, and 28 farms (15%) have it in operation mainly for vegetable irrigation. Some 80% of farms have water filters and only 30% of farms have a chemical injection system. Most farmers are facing emitter clogging by salts in the water and only 10% of farmers consider operating the system to be expensive.

The drip system introduced in the Study Area comes with various type of emitter. Most emitters have a capacity of 4 lit./hr under 1 bar. Drip irrigation system is the irrigation applied in all greenhouses. Some trees on the farms are also irrigated using the drip irrigation system though it is not effective for the tree crops. The interval of the emitters and micro tubes from the lateral irrigation pipes are mostly 50 cm and 80-200 cm, respectively. Most of the farmers irrigate twice a day for 15 minutes.

Also, irrigation efficient studies using the drip system at Hamraniyah Station (1979-81) show that a high efficiency of water use can be obtained with lateral spacing of 1.5 - 2.0 m and double row cropping per lateral (Table 2.3.8.).

b) Bubbler Irrigation System

The bubbler irrigation method has been introduced to the tree crops in the Study Area. According to the Farm Inventory Survey made in summer 1995, 102 farms (53%) have installed the bubbler irrigation method, and 99 farms (52%) have it in operation. Some 80% of farms have water filters and only 30% of farms have chemical injection systems. Some farmers have removed the stakes. Traditional basin irrigation of Date palms through concrete lined lateral canals is the most common traditional method in the Study Area. The basin area varies depending on the growth of trees and fodder crops that may be growing in the basin. This traditional basin irrigation shows low efficiency of irrigation water and sometimes salt accumulation appears in the root zone of gravelly soils in the Study Area.

Experimental studies on the efficiency of Lemon tree irrigation by UNDP/FAO at Hamraniyah and Dibba Station (1981-1983) showed that drip, bubbler and microsprinkler systems can save 65–70% of the water which would applied under the improved basin method. And drip irrigation system caused a high concentration of salts in the soils and affected severe leaf burns and defoliation had occurred (Table 2.3.9.).

c) Sprinkler Irrigation System

The fixed type sprinkler irrigation method has been introduced to the fodder crops in the Study Area. Also, a center pivot type irrigation system has been installed in the northeastern area of the Study Area. However, it is not functioning and has been abandoned because of the water shortage. Most Alfalfa cultivation does not use sprinkler irrigation because of leaf burns during the summer season, and traditional or improved (water conveyance by buried pipes) basin irrigation is used instead.

Potatoes and Onions responded to sprinkler irrigation with a significant increase in yield of between 25% and 77% compared with improved furrow irrigation. (Table 2.3.10.: UNDP/FAO at MAF Hamraniyah Station, 1979-1980)

(3) Irrigation Facilities

a) General

Figure 2.3.5. and 2.3.6. show typical farm specifications. Farm A irrigates three quarters of its area with bubblers and a quarter by basin. Farm B irrigates most of its area with sprinklers, less than 10% by basin. The means of water distribution is PVC piping, and pipes with a diameter of between 110 mm and 25 mm are popular. Non-built-in type drip tubes are commonly used along with emitters; these are the most popular and are sold in agricultural retail stores in the area, though it seems that the non-built-in type is more popular than the built-in type. Both high and low pressure sprinklers are used in the Study area. Many different types and makers of sprinkler were found.

Estimated facility costs are 122,000 and 148,000 Dh./ha, with well construction and submersible pumps taking the majority share of 75% of the estimated cost, so selection of irrigation types is not a major factor in the cost structure.

b) Greenhouse

The Agricultural Research Center of the Northern Agricultural Region initially introduced greenhouses into the UAE. Recently, greenhouses with drip irrigation were installed in the Study Area, some of them with cooling systems, for the following reasons:

1) Effective management of crop production, including irrigation, fertilizer and pesticides,

2) Possible reductions in manpower, and

3) Keeping air moist in the house, thus saving water.

According to observations by JICA experts from UAE University, the cooling system of the greenhouses using the water filter pad method reduces the internal temperature at the middle of the greenhouse by a minimum 2°C in winter and maximum 15°C in summer [Dr. Miyoshi, 1995 unpublished].

Normal green houses are covered with plastic sheets with internal dimensions of 8 m width and 36 - 40 m length, without cooling system, and cost Dh. 3,000 to Dh. 8,500. The installation cost of standard greenhouses with a cooling system costs about Dh. 23,000 to Dh. 45,000.

(4) Irrigation Efficiency at Present

As shown in Table 2.3.7., the irrigation efficiencies for perennial crops (Date palm and Alfalfa) are estimated based on the field investigation results of the Study. Gross irrigation amount per cultivation area varies from 12 to 314 m³/ha/day. Based on the data gathered at Mileiha-east and Mileiha, which show nearly the average of the surveyed farms, the irrigation efficiency is estimated at 47% and 67%, respectively. Referring to these data and to previous studies, the irrigation efficiency in the Study Area at present is estimated. Also the net irrigation area which is estimated by reducing the area of working passes, open canal area, and other area with consideration of shaded area of crop, spacing of trees, lateral spacing and wetted width drip irrigation from gross cultivation area. They are estimated based on the field survey in the Study Area as shown in the following table:

Irrigation Method	Net Irrigation Area Ratio	Irrigation Efficiency
Vegetables by Drip	0.4	0.75
Tree Crops by Bubbler	0.3	0.60
Field Crops by Basin	0.7	0.60

Based on the irrigation water requirement of each crop and cropping pattern in the present Study Area, the gross irrigation water requirement including vegetables, tree crops and field crops is estimated at 11,500 m^3/ha/year, as shown in the table below.

Present Irrigation in the Study Area (Cropping Area based on MAF statistic), 1994

Crops	Gross Cultivation Area (ha)	Water Consumption (m^3/year)	Net Water Consumption (m^3/year)	Rate of net Irrigation Area	Net Irrigation Area (ha)	Irrigation Efficiency	Gross Water Consumption* (m^3/year)	Water Consumption (m^3/ha/year)	Water Consumption (m^3/ha/day)
Vegetable	1,157.8	3,099,918	3,874,898	0.40	463.1	0.75	2,066,612	1,785	4.9
Tree Crops	1,825.3	23,622,695	29,528,369	0.30	547.6	0.60	14,764,184	8,089	22.2
Forage Crops	1,601.1	24,675,322	30,844,153	0.70	1,120.8	0.60	35,984,845	22,475	61.6
Total	4,584.2	51,397,935	64,247,119		2,131.5		52,815,641	11,521	31.6

2.3.4. Intake Rate Test Results

In order to determine the irrigation water application discharge, the basic intake rate is required. The basic intake rate is measured by the furrow intake rate test for the furrow irrigation method, and the cylinder intake rate test by cylinder infiltrometer for the border and sprinkler irrigation method.

The cylinder intake rate is used to measure the vertical intake rate of soil in the cylinder. The measurement apparatus consists of internal and outer cylinders. The internal cylinder is a 300 mm dia. and 400 mm height steel pipe, which penetrates the soil vertically to a depth of about 200 mm. The water depth in the cylinder is read on a scale at 1, 2, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 100 and 120 minutes after starting the observation. The outer cylinder with a diameter of 600 mm and length of 3,000 mm is driven into the soil to a depth of about 150 mm. The space between the two cylinders is filled with water to the same level as the water level in the inner cylinder to avoid the soil boiling in the inner cylinder and reduce the horizontal infiltration of water in the inner cylinder.

The intake rate tests were made at 19 points, as shown in Figure 2.3.7. in the Study Area. They are selected based on the type of soil which was identified by the initial soil investigation of the Study Team in summer 1995. The locations of the intake rate test were selected in an uncultivated area.

Results of the intake rate investigation are shown in Table 2.3.11. According to the test results, intake rates of soils in sand dunes or deep dune sands are in the region of 50 to 75 mm/hr and shallow sandy soil on the gravelly soil show results of around 120 to 210 mm/hr, while saline-sodic and saline soils, especially in the southern portion of the Study Area have intake rates of 8 to 20 mm/hr. The basic intake rate in the gravel plain depends on the thickness of the top soils, because most of the Study Area lies on the gravel plain and topsoil is transported from the sand dune for the agriculture. The investigation results at No. 15-A and 15-B show the importance of the thickness of top layers. As shown by the result of No. 8, even gravel soil filled with fine particle has a low basic intake rate.

Generally, the irrigation methods applicable to basic intakes rate are shown in the table below.

Irrigation Method	Land Slope	Basic Intake Rate (mm/hr)	Applicable Crop
Sprinkler	not influenced	more tan 5	all
Perforated Pipe	not influenced	more than 15	all
Furrow	less 5%	5 to 100	all includes tree crop
Border	less 5%	less 75	fodder crop
Counter Ditch	14 to 50%	not influenced	fodder crop
Basin	less 0.2%	less 75	
Drip	flat	not influenced	vegetables & tree crops

Source : FAO Soil Bulletin No.42 "Soil Survey Investigations for Irrigation", 1979

2.4. Irrigation Plan

2.4.1. Basic Strategy for Agricultural Development

(1) General

As already stated in the previous paragraph, annual groundwater use in the Study Area is estimated at about 54 million m^3 which is far in excess of the sustainable development potential of the groundwater basin which is estimated at about 22 million m^3. This over-extraction has been continuing since the 1970s and has resulted in the symptomatic deterioration of groundwater, such as a depletion of the groundwater table by nearly 40 m and degradation of groundwater quality in the Study Area. According to the simulation results, the groundwater table in the Study Area will drop to more than 100 m after 20 years (by 2015) and exhausted altogether within 40 years (by 2035). In this case, an alternative water source (possibly desalinated water) will need to be imported to allow agricultural production to continue in the Study Area.

Currently, the sustainable development of natural water resources is the prevailing common sense in the world. The UAE, however, has no clear policies or guidelines on this issue.

Given the above-mentioned condition, two basic alternative strategies for agriculture and water development are recommended in the two (2) policy options set out below:

Option -1 : The agricultural development plan is to be kept within the limits of the sustainable development potential of groundwater in the Study Area.

Option -2 : The agricultural development plan will maintain the current extent of cultivation with a supplementary alternative water source .

The agricultural development plans in both options aim a type of agriculture that is sustainable, water-saving, high-income and market-oriented. Feasibility shall take into account not only economic but also sociological and environmental aspects. In consideration of a shift in agricultural scale or new water resources both short- and long-term measures should be taken into account, for either option.

(2) Target Year

The Study aims to solve the degradation of regional agriculture caused by the deterioration of groundwater quality, quantity and water table, and in addition, if possible to promote the development of agriculture.

According to the Existing Well Inventory Survey, the average depth of submersible pumps in the wells varies from 74 m in Mileiha to 206m in Dhaid. It can be said that their average depth is about 140m. Generally, the limitation for normal lift of prototype submersible pumps with a capacity of 5 to 15 lit./sec. is 100m. Hence, it is necessary to take action to stop the groundwater deterioration before the present pumps become unable to supply water .

Results of groundwater balance analysis conducted by the Study through mathematical simulation show that the water level in the Study Area will go down to 100m below ground level by 2015 if the present pumping rate continues.

Therefore, the target year of the Study is set at 2015, about 20 years from the reporting period.

(3) Basic Strategy of Water Sources Development

a) Groundwater Development

The amount of potential groundwater for development in the Study Area will be 21.5 million m^3/year, adding the expected amount of groundwater strengthened by recharge dams and recharge trenches at 2.0 million m^3/year to the natural sustainable recharge amount at 19.5 million m^3/year.

b) Alternative Water Sources

Supplemental water to the sustainable groundwater sources for the agricultural development of the Study Area in Option 2, shall be desalinated water. Desalinated sea water will be produced in Sharjah City and transported to the Study Area by pipeline.

(4) Basic Strategy for Agricultural Development

Speaking in general terms, one of the top priorities for agricultural development is self-sufficiency in foodstuffs from the viewpoint of national food security; however, for a country where agricultural production depends on limited groundwater resources, it is difficult to attain self-sufficiency in foodstuffs, which is the main aim of agricultural development. With this in mind one of the most important items concerning UAE agriculture is how to implement a manageable, stabilized, sustainable agriculture together with efficient utilization of limited groundwater resources. The two main points in setting the development aims for the present Study were sustainable agriculture and high-income agriculture. To achieve these aims the following problems must be addressed:

i) Grasp of Optimum Irrigated Area and Restriction of Irrigated Area
ii) Effective Utilization of Irrigation Water

iii) Development of High-Income Agriculture
iv) Access to Markets and Production of Commercial-Quality Products
v) Socio-economic Considerations

(5) Land Use and Water Sources

It has been confirmed by the groundwater balance analysis that the deterioration of groundwater is caused by the over-development of farm land and over-extraction for irrigation. Recently developed farm lands are located on the outskirts of the fertile lands, which have cultivated since olden times in the Dhaid area. The land is basically gravelly, and consequently, the surface is covered to a certain depth by silty sand transported for cultivation, even though it cannot improve irrigation efficiency.

In Option 1, it is planned to reduce the cultivation area to reduce the irrigation water requirements down to the sustainable recharge amount after the maximization of recharge capacity. How to reduce the cultivation area or close existing farms is beyond the scope of this present Study due to social background, and no measures for this are proposed in this Study. If farmland must be closed, those farms practicing inefficient irrigation methods, such as farms in gravelly areas, would be closed first.

In Option 2, the whole cultivation area as of 1994 would be supplied with irrigation water under a water-saving irrigation system. In that case there would be insufficient water, and demand would be met by supplying desalinated sea water.

In both options, new farm development or the expansion of existing cultivation is not proposed.

(6) Sustainable Agricultural Development

The cropping area with a consideration for sustainable agricultural development was determined as follows:

Sustainable agriculture in the Study Area is defined as agriculture which can be managed with irrigation water supplied regularly from several water sources.

In the study, the following options are analyzed:

Option 1:	Use of groundwater only Agriculture is planned to use 21.5 million m^3/year of irrigation water. (Based on the results of the groundwater analysis, available groundwater is 19.5 million m^3/year and 2 million m^3/year is the expected potential)
Option 2:	Use of groundwater and desalinated sea water Agriculture with high profit crops and water saving irrigation methods

will be introduced to the entire present cultivated area of vegetables, tree crops and pastures. The resultant water shortfall will met by a supply of desalinated sea water.

2.4.2. Irrigation Method

The Study Area is facing a serious water shortage problem. Consequently, it is necessary to make rational use of water for sustainable agriculture together with recharging the groundwater with rainfall. For rational irrigation water usage, it is necessary not only to irrigate with the right amount at right time but also to irrigate highly efficiently.
The main factors for determining an irrigation method in the Study Area are as follows:

- Salinity of gravelly soil
- Salinity of water
- Hot and dry weather especially in summer
- Reduction in manpower required for cultivation
- Vegetable, forage and tree crop cultivation in small plots

(1) Drip Irrigation for Vegetables

A well-operated drip irrigation system allowing frequent application of small quantities of water can provide a nearly constant low tension soil water condition in the major portion of the root zone. The high water use efficiency can be attributed to improved water conveyancing and water distribution to the root zone. As clarified by lysimetric study at Hamraniyah Research Station in 1980-83, crop water requirements can be reduced during the low ground coverage (less than 33%) stage, because the limited wetting area of the drip irrigation system can reduce non-beneficial transpiration and evaporation losses from the ground.

(2) Bubbler for Tree Crops

The bubbler irrigation system is a drip irrigation system in which emitters supply water at a rate of about 330 lit./hr under 1.4 kg/cm^2 to tree crops.

(3) Sprinkler for Fodder Crops

Sprinkler irrigation is widely used for all types of crop in the world. It is considered to be an artificial precipitation for the crops, and the quantity and time of water supplied for irrigation can be controlled, and it was one of the first modern irrigation methods to be developed.