

GROUNDWATER FLOW MODELING OF BANDUNG AQUIFER

(A CASE STUDY)

BY

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ABSTRACT.

Due to the increasing demand of fresh water in Bandung, the capital city of the West Java Province, The Republic of Indonesia, since 1980's, the municipal government and private firms have started to use deep groundwater through deep wells.

This project report investigates the impact of this development on the pattern of deep groundwater flows and the environment by means of a two dimensional computer model. A computer program called AQUIFEM-1 is used.

The conceptual model, consisting of a triangular finite element grid with 164 nodes and 289 elements, which represents the study area of about 325 km². The results are shown either on printing outputs or on graphs that show the changes of the groundwater flow pattern.

It is concluded that, the total existing well discharge of about 666 m³/day does change the groundwater flow pattern significantly depleting the volume of the water in the aquifer. This may cause the shallow wells located in the area to dry up, heavy constructions on shallow footings may experience additional settlement, and subsidence over part of the area might occur in time.

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Chapter I

INTRODUCTION.

I.1 BACKGROUND.

Fresh water is truly needed for life - a motto says " NO WATER, NO LIFE ".

Bandung, the capital city of West Java Province - Indonesia, needs more fresh water to fulfil the demand of its population which increases (with) about 1.9 % per year, and for industries which are also expanding in type, number and size.

Since 1971, the local government of Bandung has tried to solve the problem especially when it became apparent that the amount of the existing water supply is decreasing because :

- a. Many springs vanished or showed decreased discharges,
- b. Many river were polluted by solid and chemical wastes from some industries.

In 1973 the local government investigated the possibility of taking fresh water from Saguling and other water reservoir and also from deep groundwater. This investigation was conducted by Nielsen and Raischenberger - Cowiconsult

Consulting Engineers (Copenhagen).

They concluded that the quantity of deep groundwater in the Bandung areas is significant and that its quality is also good to use as the additional water supply.

In 1980 the local government started to use the deep groundwater by building 19 deep well pumps with a total discharge of 390 l/sec (or 1775 m³/day of discharge per well). This discharge was increased up to 500 l/sec in total (or 2275 m³/day per well, if the number of deep well pumps is not added).

Besides, the number of private firms using deep groundwater is also increasing.

This development may change the pattern of deep groundwater flow in the Bandung aquifer which may impact the (surrounding) environment by decreasing the volume of groundwater and by the subsidence of the neighbouring areas.

1.2 THE OBJECTIVE OF THE STUDY.

The objective of this study is, first, to get knowledge of how to predict the response of the aquifer system to various hydrological stresses which may occur naturally or due to the work of human beings. Second, to support (the work) of the official groundwater planning and management. By being able to predict in advance the response of the aquifer

system to any proposed work, the management can limit that work to avoid (or at least to decrease) the adverse impacts which otherwise, may occur to the environment.

1.3 THE SCOPE OF THE STUDY.

The scope of the study has been limited to the analysis of the deep groundwater flow only, while the quantitative analysis of subsidence and other impacts has not been undertaken.

1.4 THE LOCATION OF THE STUDY AREA.

The location of the study area covers Bandung city and its surroundings for about 325 km². This (location) is in West Java Province, Indonesia, between 6.83 and 7.04 South Latitude and between 107.44 and 107.76 East longitude.

The city of Bandung is located approximately in the center of this study area.

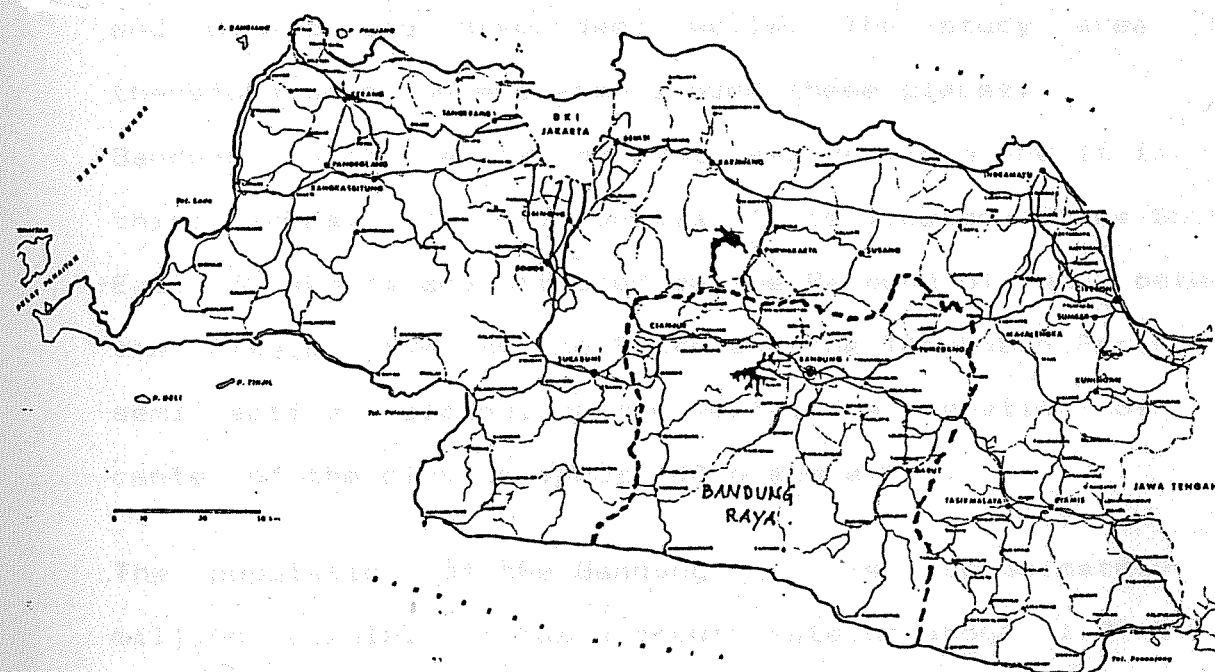
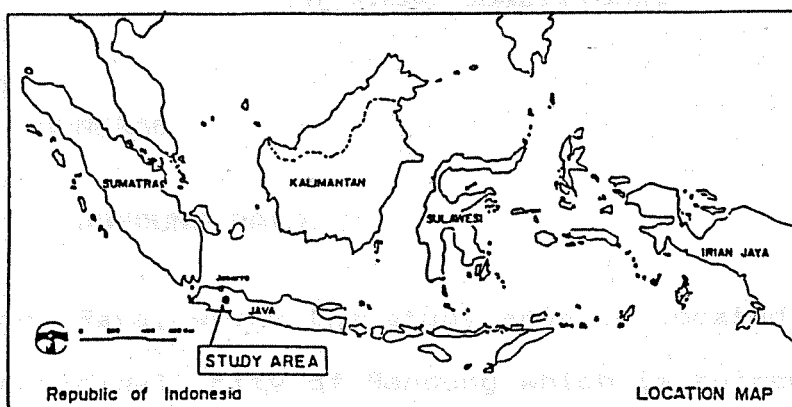


Figure I-1 The location of the study area.
(Source : Reference # 1)

Chapter II

PHYSICAL CONDITIONS.

II.1 GENERAL.

II.1.1 BANDUNG RAYA.

Bandung Raya, where the study area is located, consists of the municipal city of Bandung which is surrounded by the regency of Bandung, the administrative towns of Cimahi and Lembang, and 22 smaller places.

Among these places, only Bandung city, Cimahi, Dayeuhkolot and Ujungberung have deep wells. The study area has therefore been concentrated around these places.

Bandung is the capital of West Java Province and it is the third largest city in Indonesia. It is located 150 km South-East of Jakarta and situated on the Bandung plateau between the Citarum river on the South and the Tangkuban Perahu, a semi active volcano, on the North. The elevation of the center of the city is about 700 m above MSL.

The population of the Bandung city is approximately 1.8 million people. It has a growth rate of about 1.9 % per year.

Bandung is the capital city where the administrative bodies of the provincial, the municipal, and the regency governments are located. There are also many universities in

Bandung. This situation causes the socio-economic conditions attract trade and industry.

The city has good roadways leading to all points in Java and railroads leading to Jakarta and the eastern part of Java Island and also regular flights (connect)to Jakarta and other cities on Java (see figure I-1).

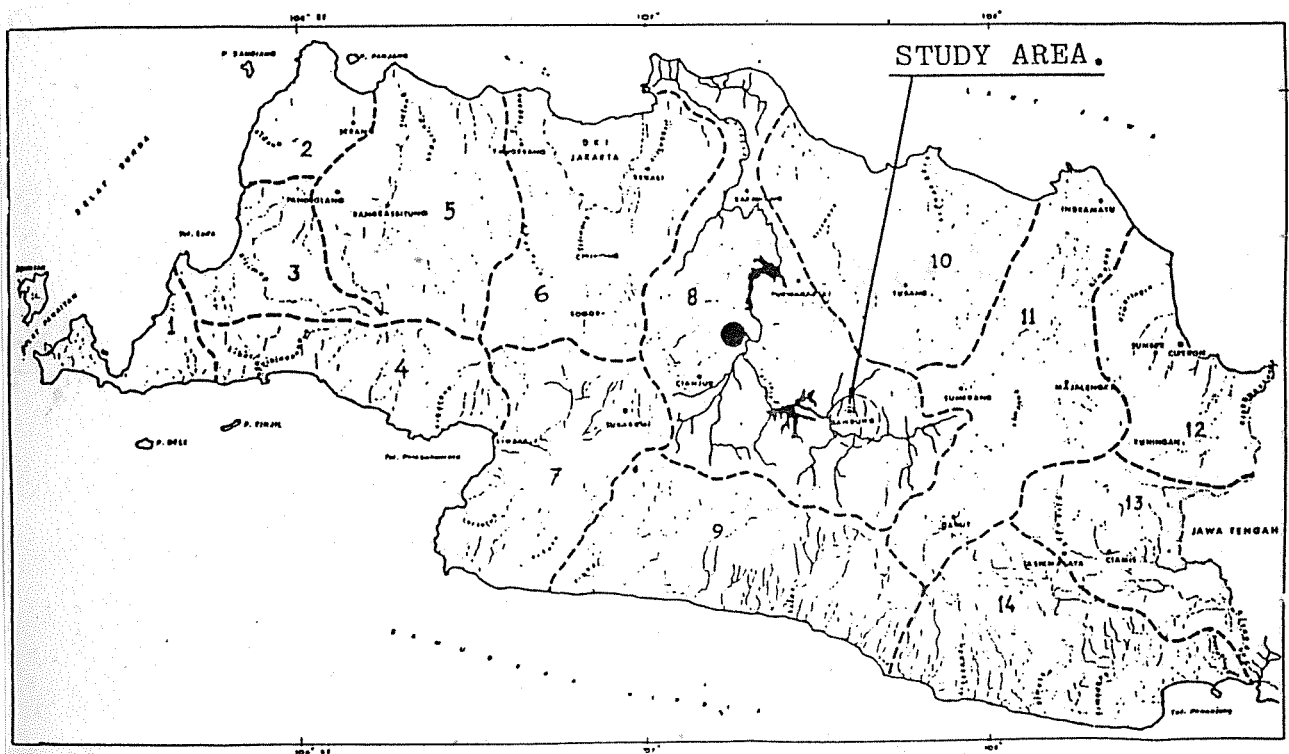
II.1.2 TOPOGRAPHY.

Bandung Raya is surrounded by mountain ranges. On the North side there are mountains namely G.Burangrang, G. Tangkuban Perahu, G. Bukit Tunggul, G. Cijambu ; on the East-West G. Bukit Carian, G. Mandalawangi ; and on the South side G. Masigit, G.Rakutak, G. Malabar, G. Tilu, and G. Patuha. The elevation of these mountain ranges reaches 2000 m to 2400 m above MSL.

The topography of Bandung Raya has a shape of a nearly flat elliptical bowl of 600 to 750 m elevation, with East-West axes of 35 km and East-West and North-South axes of 15 km in East-West and North-South directions respectively. Above 750 m elevation the ground surface has a steep slope.

Bandung plateau lies in the Citarum watershed. This basin is drained by the Citarum river which flows to the West through an opening in the hills West of Bandung, then it turns to the North-West, and finally falls out in the Java sea on the

During the year these rivers (do not) never dry up, but the flow in these decreases during the dry season.



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II.2 CLIMATE AND HYDROLOGY.

II.2.1 SEASON.

Indonesia is characterized by two seasons only, namely the wet season and the dry season.

In Java Island, where Bandung Raya is located, the wet season occurs from the month of November to April when the prevailing wind blows from West and South-West from the Indian Ocean (known as the west monsoon) ; and the dry season lasts from May to October when the dominant wind is the dry East Monsoon which originates in the Australian continent.

II.2.2 PRECIPITATION.

From the investigation report written by NR-C in 1973, the mean annual rainfall in the Bandung basin varies from 1700 mm in the center of the Bandung plateau (South-West of the city) to more than 3500 mm on the watershed North of the city, and about 3000 mm on the South of the basin.

These figures are apart from the isolated peaks which have a precipitation over 4000 mm. The Isohyetal map has been drawn in that report based on the data of more than 20 years observation period (see figure II-2).

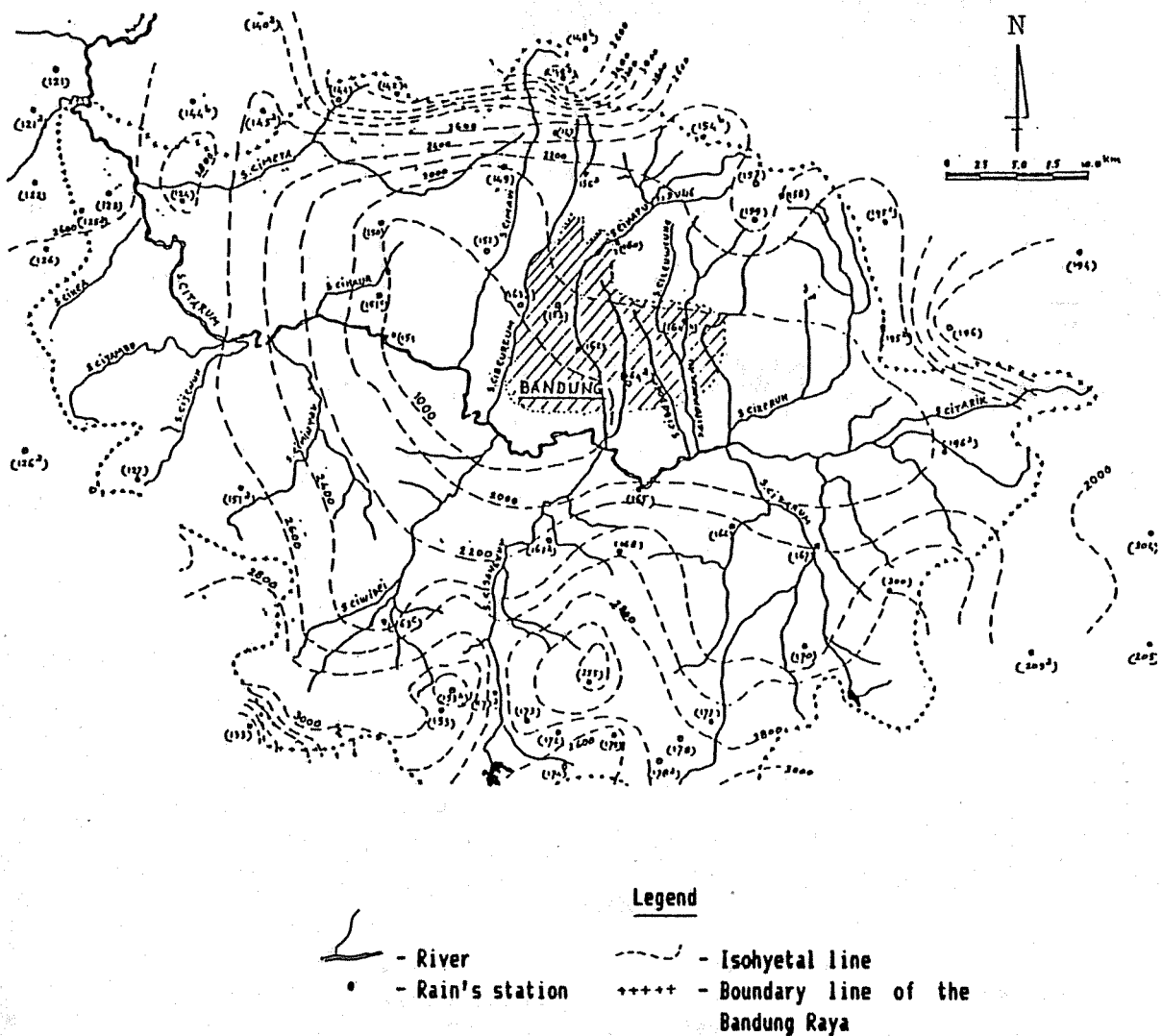


Figure II-2 Isohyetal map of Bandung Raya.
(Source : Reference # 12)

II.2.3 EVAPOTRANSPIRATION.

The climatic conditions which governs the evapotranspiration in the study area are rather uniform throughout the year, hence a fairly constant evapotranspiration might also be expected.

Few if any measurements of evapotranspiration have been carried out within the Bandung area.

From a calculation which has been done by Bakker in 1952, the evapotranspiration was determined for several watersheds in Java based on the water balance method. The results are shown in the graph on figure II- 3 below.

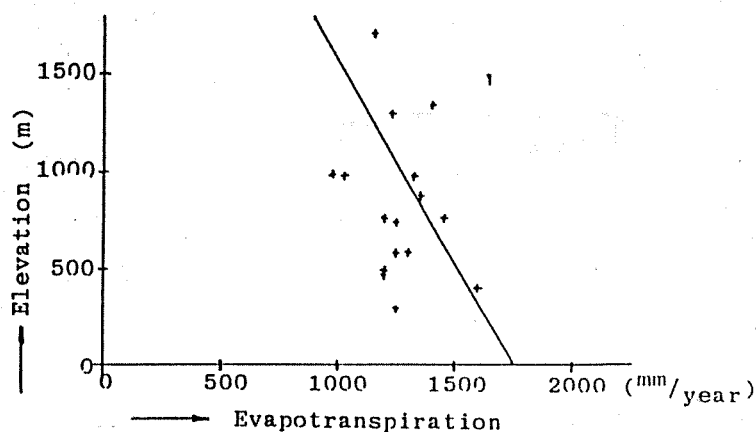


Figure II-3 Evapotranspiration vs Elevation
For Java Island.
(Source : Reference # 12)

Bakker indicates that the evapotranspiration decreases with the elevation, which is mainly caused by the decrease in temperature.

Calculations, which use the observation data during 1952 to 1970 made by NC-R, show that the evapotranspiration for the upper part of the Cikapundung (North of Bandung) is within 950 to 980 mm/year.

As an approximation, the value of 1000 mm/year may be taken

for any calculation.

II.2.4 INFILTRATION AND RUNOFF.

The investigation made by Bakker in 1952, shows that the area North of Bandung has a large infiltration capacity. Between 60% and 85% of the rainfall will infiltrate into the ground and recharge the groundwater reservoir.

Bakker has divided the rainfall by percentage into surface run-off, sub-surface flow and the basin recharge as related to the drainage area, the geological condition, the condition of the forest, and the terrain modification by terrassing. These relationships are drawn in a bar-chart type as shown in figure II-4 below.

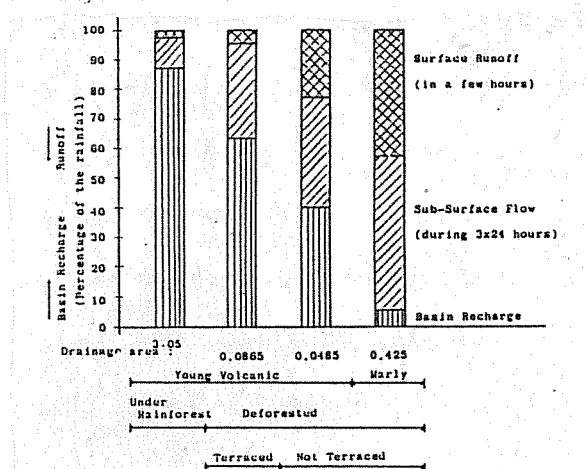


Figure II-4 The percentage of surface runoff, sub-surface flow and basin recharge in Java Island.
(Source : Reference #12).

The NR-C observation in 1970's showed that the infiltration of the same area is about 50 % of the total rainfall which

is still large but smaller than the 1952 observation. There is no information why this decrease of more than 10 % occurred.

Throughout the year, river discharge consists of two components, namely, groundwater discharge and surface runoff.

In the dry season, especially within the period June to September, the surface run-off decreases considerably but it does not become zero. During these months, the groundwater discharge is still high and the recharge of the groundwater storage still occurs in the recharge areas.

II.2.5 SURFACE WATER.

The Bandung basin is drained by the Citarum river. The river originates in the South mountain range at 1600 m elevation and 346 km distance from the Java sea. It flows north wards for 27 km while dropping to 670 m (gradient 3.5 %) and then turn to North-West and West, passing South of Bandung city with only a dropping for about 20 m over the next 60 km (gradient 0.035 %). The monthly mean discharge at Dayeuhkolot is 48 m³/sec.

The main tributaries along the Citarum river are :

- On the North side of the Citarum river : S. Cibadogol, S. Cipamokolan, S. Cikeruh, S. Cikapundung, S. Cibeureum, S. Cimahi, and S. Cimeta.

All of these tributaries originate from the North mountains range.

- On the South side of Citarum river are S. Cirosea, S. Cisangkuy, S. Ciwidey, and S. Ciminyak.

These tributaries originate in the South mountains range.

The city of Bandung lies on the North side of the Citarum river, where the West boundary of the city is coincide with S.Cibeureum, while S.Cikapundung is passing through the center of the city.

To analyse the groundwater flow in the unconfined aquifer, the parameters of interest about a river are :

- The minimum and the average elevation of the surface water in the river,
- Whether the river is partly or fully penetrating into the aquifer,
- Is there any leakage through the river bed,
- If so, the cross section of the river, the thickness and the hydraulic conductivity of any alluvial deposits the river bed should be measured .

The river system over this study area is inadequately monitored. There are only few flow gauges being operated at present and the data are very incomplete and unreliable. A complete data set is for the period between 1919 and 1933 which covers both wet and dry seasons. No measurement on the leakage problem exists.

There is no possibility of any impounding reservoirs over the study area due to the high infiltration capacity of the ground.

II.3 GEOLOGY.

II.3.1 GEOMORPHOLOGY AND STRATIGRAPHY.

Based on R.W. Van Bemmelen (1949), the West side of Java Island consists of 6 physiographic zones namely the Quaternary Volcanoes, the Alluvial plains of Northern Java, the Bogor anticlinal zone, the Domes and ridges in the central zone, the Central depression zone of Java, and the Southern mountains (see figure II-5).

Bandung Raya and its vicinities are situated in the Quaternary Volcanoes and the Central Depression Zone of Java in an area of geologically rather young sediments. The oldest of them is Mid-Tertiary. Only at a depth of some kilometers a Pretertiary basement complex is encountered.

The Tertiary zone in the Bandung Raya is represented by Miocene and Pliocene formations. The Miocene formations are developed as a series of reef limestone and tuffaceous marls. The Upper Miocene or Mio- Pliocene consists of mainly volcanic deposits which are intercalated by lignite bearing series and litoral sandstones. To the North of Bandung the area of the hilly country, South of Cimahi

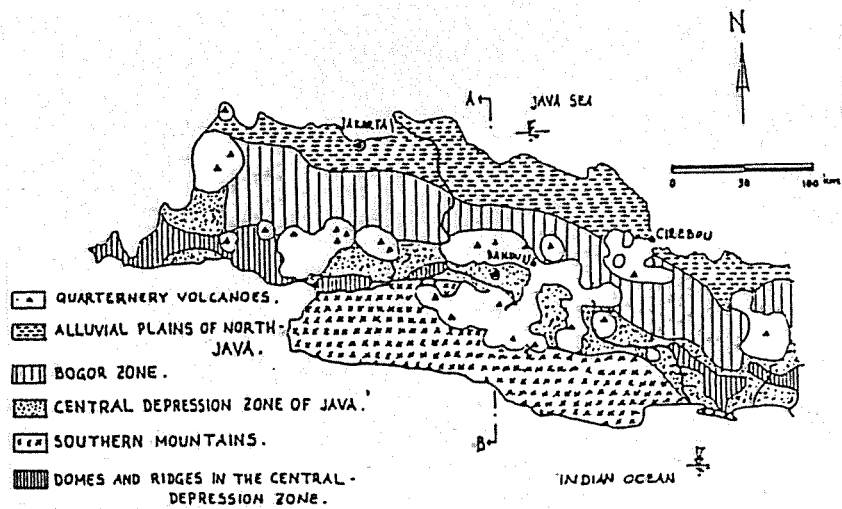


Figure II-5 Physiography Of West Java.
(Source : Reference #3)

The North-South cross section through Bandung could be seen on figure II-6.

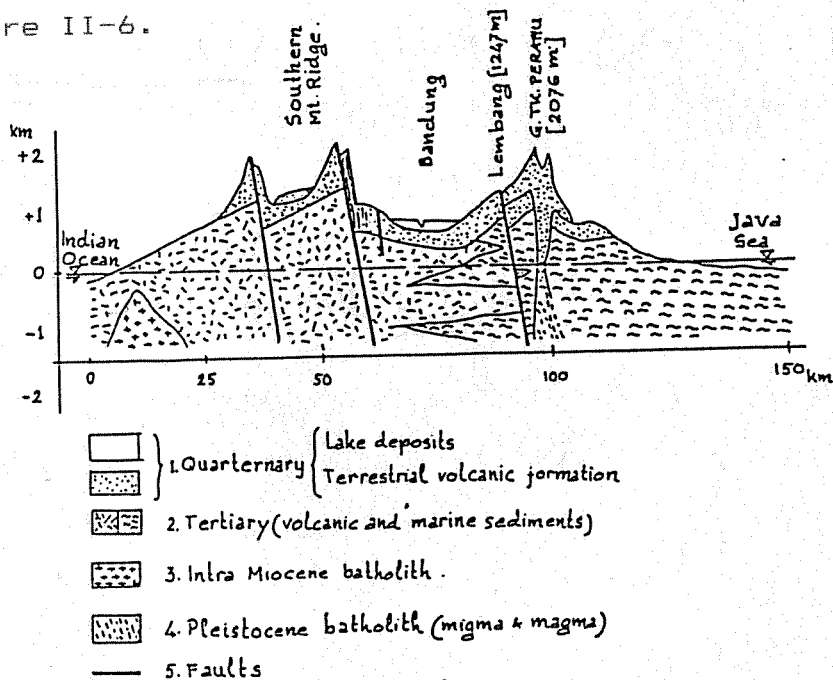


Figure II-6 Schematic Geologic Formation,
Through North-South Cross Section.
(Source : Reference #12)

consists of volcanic breccies and igneous rocks which are believed to belong to the Pliocene.

The Quaternary, especially Middle and Upper Pleistocene, is represented by the products of terrestrial volcanic activity. It consists primarily of tufs, volcanic ashes, agglomerates and water soaked mixtures of these products which as mud-flows move down the volcano slopes. Lava flows, both andesitic and basaltic also occur.

It is believed that the mountain ranges, North and South of Bandung, were been built up during this period.

The lower Pleistocene, North-East of Bandung, is developed as a series of volcanic material with lignites.

Holocene is represented by alluvial deposits (the former Bandung lake) and subrecent volcanic material, mainly from originated the product of G. Tangkuban Perahu.

II.3.2 THE VOLCANIC MOUNTAIN RANGE.

The north side of Bandung is overlooked by a mountain range in East-West direction consisting entirely of volcanic products which can be divided into Old and Young Quaternary deposits.

The Old Quaternary volcanic deposit is represented by most of the morphological units existing in this range of G. Burangrang, G. Putri, and G. Tangkuban Perahu.

Closer to Bandung, between Bandung and G. Tangkuban Perahu,

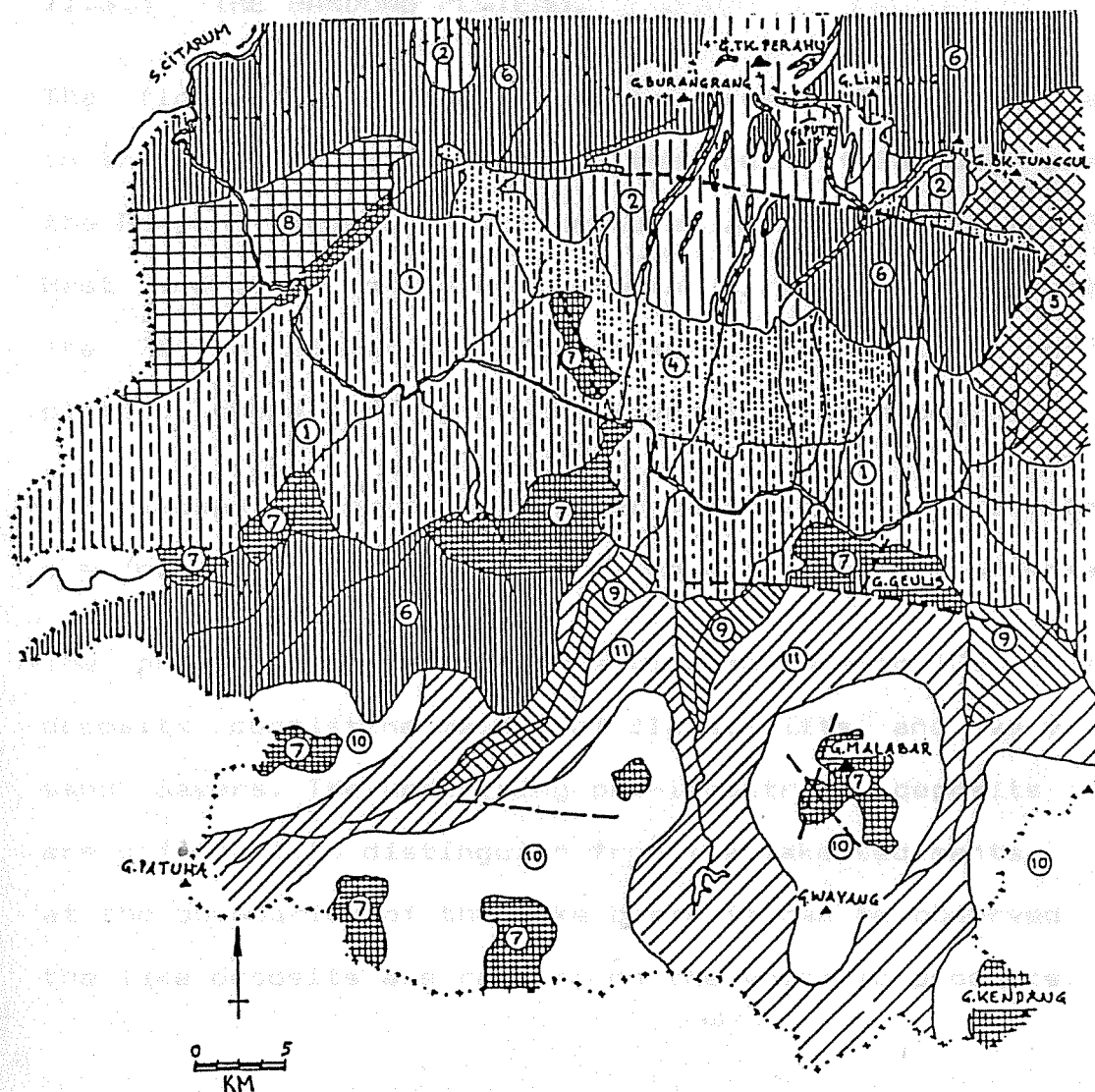
lies in the East-West direction an extensive area of old volcanic product " the Pulusari fault block ", this subsequent faulting activity reached the magma chamber giving rise to a new volcanic activity, the Young Quaternary volcanism.

This activity is mainly represented by the products of the still active Tangkuban Perahu. Reproducts of its eruptions cover the older volcanic deposits over great areas, which fill the depression area near its summit (Lembang area) and extends down as two big flows of mud, conglomerates, and tuffs. One of the two flows Southwards to the Bandung depression.

This form of a delta-like formation is of special interest from a hydrogeological view, since most of the highest yielding wells are situated in this area.

Similarly, the south side of Bandung is also overlooked by a mountain range in East-West direction, where the dominant mountain is G. Malabar. There a fault block is also encountered. It lies between G. Malabar and Bandung on East-West direction across Gunung Geulis hill.

The eruption products of G.Malabar consists of lava breccie and tuffs, and or tuffaceous breccie and lavas of andesitic to basaltic composition (see figure II-7).



Legend

- | | | | |
|--|----------------------------|--|------------|
| | - Geologic Formation | | - River |
| | - Boundary of Bandung Raya | | - Mountain |

- | | |
|--|--|
| 1. Lake deposits, recent. | 7. Volcanic and crystalline formation. |
| 2. Tuffs and ashes, G.Tk.Perahu eruption period C. | 8. Marine deposits of sandstones and limestones. |
| 3. Basaltic lava flows, eruption period B. | 9. Tuffaceous breccias and lavas of andesitic to basaltic composition. |
| 4. Tuffs and mud flows, eruption period A. | 10. Alternation of lava breccias and tuffs of andesitic. |
| 5. Undifferentiated volcanic products. | 11. Tuffs, laharic breccias contain miner of pumice and lava. |
| 6. Tuffs, tuff breccias, lava flows. | |

Figure II-7 : Geologic Formation Of Bandung Raya.
(Source reference #12 and #21).

II.3.3 THE BANDUNG PLATEAU.

The flow of the volcanic material from G. Tangkuban Perahu in the North and G. Malabar in the South of Bandung created the Bandung plateau, which measures about 35 km in the East-West and 15 km in the North-South directions respectively. The 750 m elevation is taken as the upper limit of the plateau, there the toe of the mountains range begins.

The plateau was originally inter mountainous lake created in the Younger Quaternary. It drained again shortly afterwards.

The presence of the lake gave rise to 60 m to 100 m thick deposits consisting mainly of clays, silts, and very fine sand layers. The underlying pre-lacustrine deposits which are difficult to distinguish from the lake sediments. Only at the boundaries of the lake basin it can be observed that the lake deposits are resting on the volcanic products.

II.4 HYDROGEOLOGY.

II.4.1 THE AQUIFER.

The groundwater in Bandung plateau is of abundant quantity and also of good quality (except in some areas the quality of the groundwater is lightly ferrous, which is not hazardous to health). .1s2

From the cross section along the drill logs across the North-South and the East-West directions on figures II-8a and II-8b, it can be seen that Bandung plateau has layered aquifers which might be grouped into an unconfined aquifer on the top , and a confined aquifer at the bottom.

The layer below this confined aquifer is not known since the maximum depth of rock drilling has not reached so far ; to simplify the analysis this layer will be assumed as an impermeable layer.

The thickness of the aquifers varies. The unconfined aquifer has thickness between 45 m and 55 m where the rivers partly penetrates into it ; the confined aquifer has a total thickness between 75 m and 105 m.

A few parts of the boundary layer between these two aquifers are leaky.

The lithological description of the phreatic aquifer consists mainly of tuffaceous sand. It is mixed with silt of

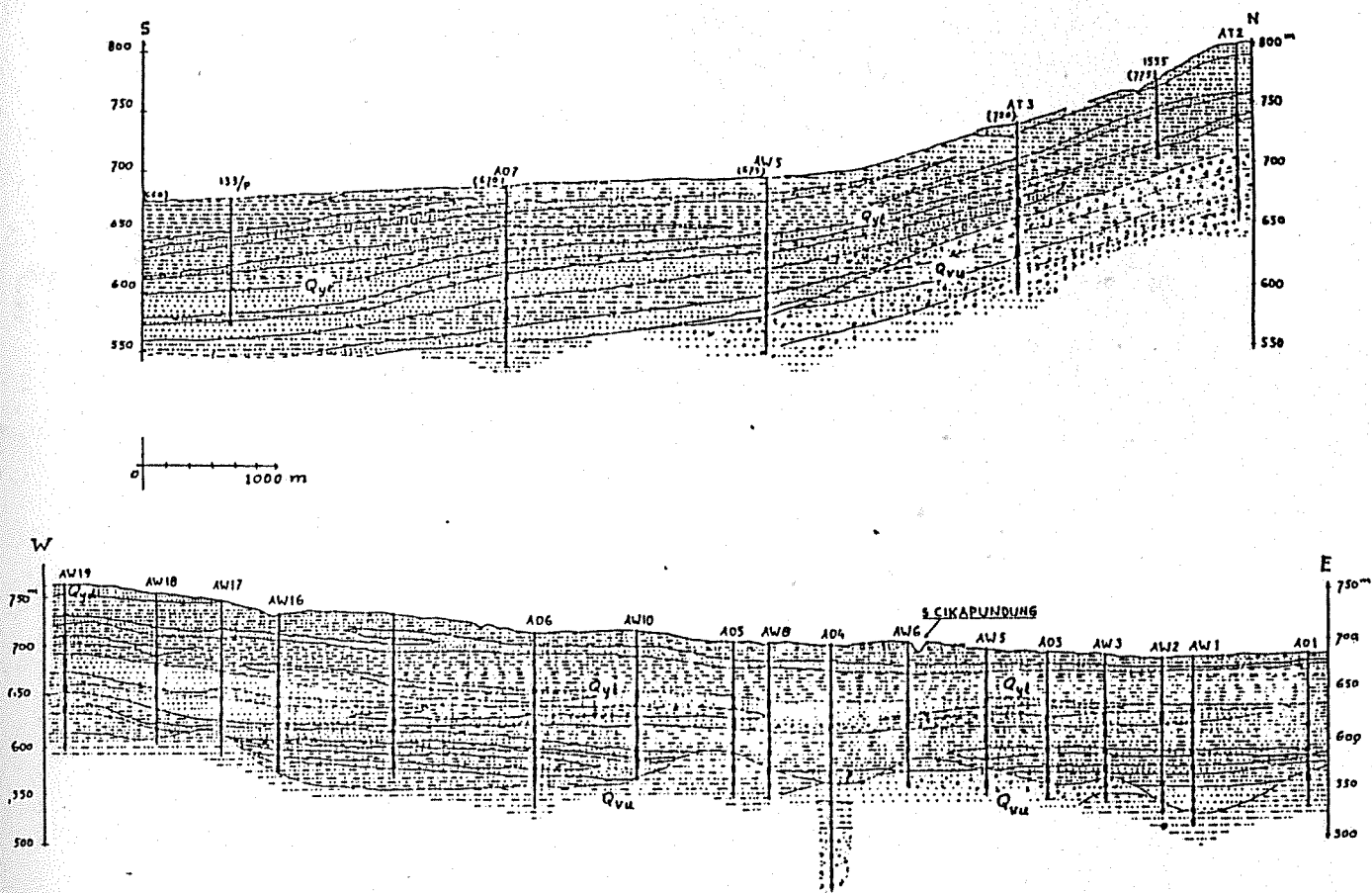
which the relative hydraulic conductivity is medium. The confined aquifer, consists partly of tuffaceous sands mixed with partly of tuffaceous sand and andesit breccie or with andesit breccie and coarse tuffaceous. The relative hydraulic conductivity of the confined aquifers range from high to very high.

The boundary layer between these aquifers, which is an aquiclude, consists of tuffaceous silt where some part of it mixed with fine sands ; and it has very low relative hydraulic conductivity.

The thickness and the the conductivity of the confined aquifer vary. Values of the parameters are shown on table II-1. These data are based on the result of rock drilling made by the German Water Engineering (G.W.E) in the 1980's.

II.4.2 THE SPRINGS.

There are about 500 springs in the Bandung area and its surroundings, especially in the North-West and in the East of the city. All of these springs are located above the 750 m elevation. The springs' yields, in general, are varied. Most of them have a small discharge and some are seasonal . By far most of the springs originate at the intersection of the contact between the youngest tuffs and the underlying older volcanic product. In some cases springs have arisen



Description :

	Age	Notation	Formation	Symbol	Lithologic Description	Relative Permeability	Type Of Layer	Other Notation
Quater		Q_1	Kosambi Formation	[Symbol]	Tuffaceous Silt and Fine Sand	Low	Aquiclude	Well Screen
		Q_{yd}	Cikidang Formation	[Symbol]	Tuffaceous Sand and Few Of Silt	Medium	Aquifer	AW/AT Production Well
		Q_{yt}	Cibeureum Formation	[Symbol]	Tuffaceous Sand	High	Aquifer	A0 Observation Well
		Q_{vu}	Cikapundung Formation	[Symbol]	Tuffaceous Sand and Andesit Breccie	High	Aquifer	Pv Private Well
				[Symbol]	Andesit Breccie, Coarse Tuffaceous and Lava Flows	Low-High	Aquifer	Formation Boundary

Figure II-8 The Profile Of The Aquifer (Top : South-North Cross Section, and Bottom : West-East Cross Section).
(Source : Reference # 14)

Table II-1 : The Aquifer Parameters .

WELLS (bor)	Kxx = Kyy (m/day)	Thickness (m)	Txx = Tyy (m2/day)	Storativity ()
East side :				
AW 1	1.71	70	120	$2.5 \times 10^{**}(-3)$
AW 2	1.46	70	102	$2.0 \times 10^{**}(-4)$
AW 3	1.36	80	108	$8.0 \times 10^{**}(-4)$
AW 4	1.10	80	88	$3.0 \times 10^{**}(-4)$
AW 5	2.70	80	216	$9.0 \times 10^{**}(-3)$
AT 1	0.50	80	40	$2.0 \times 10^{**}(-5)$
Center part :				
AW 6	6.70	100	670	$1.0 \times 10^{**}(-3)$
AW 7	8.36	100	836	$1.0 \times 10^{**}(-2)$
AW 8	12.19	70	853	-
AW 9	7.74	70	542	$1.0 \times 10^{**}(-3)$
AW10	8.86	80	693	$2.4 \times 10^{**}(-4)$
West side :				
AW11	5.63	80	450	-
AW12	5.75	80	460	$2.0 \times 10^{**}(-6)$
AW13	9.63	80	770	$1.2 \times 10^{**}(-4)$
AW14	7.09	80	567	$3.0 \times 10^{**}(-4)$
AW15	9.74	80	779	$1.0 \times 10^{**}(-3)$
AW16	8.08	80	646	$1.6 \times 10^{**}(-4)$
AW17	10.95	80	876	$1.5 \times 10^{**}(-4)$
AW18	9.94	80	795	-
AW19	13.75	80	1100	$1.5 \times 10^{**}(-3)$
AT 5	8.84	100	884	-
North side :				
AT 2	2.81	100	281	-
AT 3	1.36	110	150	-
1555	5.79	38	220	-
South side :				
131/P	2.44	50	122	-
1365	1.60	55	88	-
133/P	2.39	23	55	-
1329	4.40	40	176	-

(Source : Reference # 14) .

where young erosion activity has intersected an old buried river valley. The yield of the springs tends to grow towards G. Tangkuban Perahu due to the fact that the volcanic products become both thicker and coarser towards the eruption center.

These springs are used for the daily requirements of the people and also for small irrigation.

II.4.3 THE GROUND WATER LEVELS.

The ground water level for the unconfined aquifer varies between 10 m and 30 m below the ground surface. It depends on the topography. During the dry season this water level decreases considerably because so many wells use this shallow groundwater.

Measurements during the drilling of deep wells into the confined aquifer, have shown that the piezometric level rises with the depth of drilling. This means that upward flow of deep groundwater does occur. The piezometric head of the confined aquifer at the Bandung plateau varies between 2 m to 5 m below the surface of the ground. The schematic of groundwater flow across the aquifer may be seen on figure II-9.

From periodic measurements of piezometric level in selected wells, no indication that this deep groundwater was ever overdrawn is found.

Old Dutch measurements shows that the seasonal variation in the water level of deep groundwater surrounding Bandung is quite small.

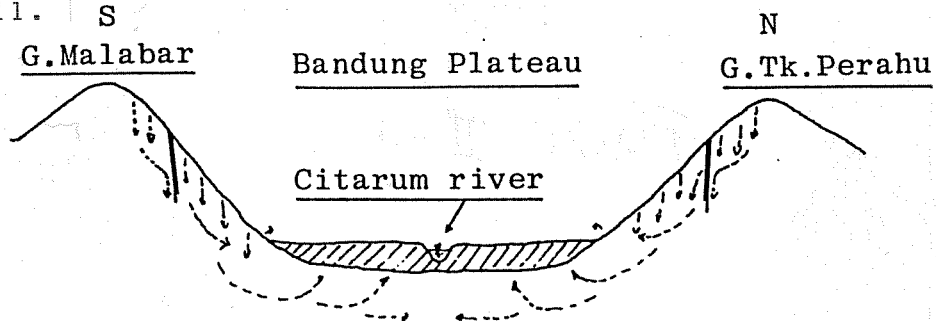


Figure II-9 Schematic of groundwater flow across Bandung aquifer.

(Source : Reference # 12)

II.4.4 THE EXISTING WELLS.

The existing wells may be divided into the shallow wells, which are scattered all over Bandung Raya, and the deep wells most of which occur in Bandung city.

Most of the deep wells in the Bandung Raya area have a specific capacity between 1 to 10 l/sec/m' drawdown (or 86.4 to 864 m³/day /m' drawdown). If every day the drawdown due to pumping out is up to 5 m (the allowable limits being suggested by Freeze and Cherry, reference #8), then the discharge of the well is between 432.0 m³/day to 4320 m³/day. Information on well losses was obtained during a step-drawdown test which was carried out after completion of some test wells. The results indicated that even at maximum discharge (75 l/sec , or 6480 m³/day) the well loss or turbulent loss was negligible. This shows that the wells

were properly designed and constructed.

At this moment, there are 19 government deep wells and more than 20 private ones around Bandung Raya. Their discharge varies between 2.90 l/sec and 50 l/sec (or 250 m³/day to 4320 m³/day).

The government deep wells are situated in the city of Bandung to supply the demand of the city, while the location of private deep wells are scattered; most of them are outside the city. The location of these deep wells may be seen on figure II-10, and the list of the wells is presented on table II-2.

In addition, the government has also built a number of deep observation wells, but unfortunately, the data about which have been collected have no information (about the datum) so that the actual drawdown cannot be calculated. However, the conclusion could be drawn from these data. There is continuing drawdown from year to year. This means that the water recharge is actually smaller than the water discharge. Three reports (including reference #15) that deal with the groundwater survey in Bandung were examined. None of these discusses the water level in the observation wells.

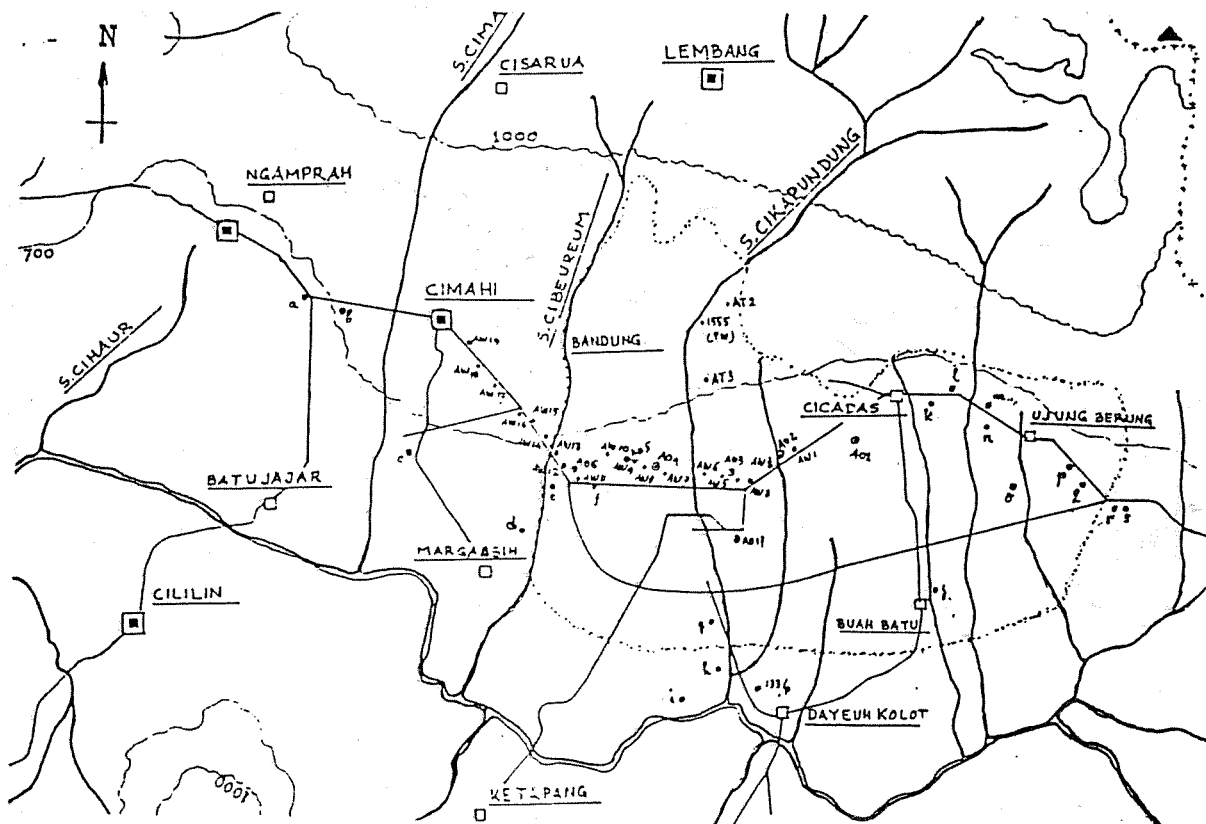


Figure II-10 The situation of deep wells.

Table II-2 : List Of Wells and Their Discharge .

CODE OF WELLS	# OF NODE	DISCHARGE			
		EXISTING		SIMULATED	
		L/SEC	M3/SEC	L/SEC	M3/SEC
Own by the government :					
AW 1	105	13.00	1123.20	25.46	2200.00
AW 2	107	8.00	691.20	25.46	2200.00
AW 3	108	8.50	734.40	25.46	2200.00
AW 4	95	19.00	1641.60	25.46	2200.00
AW 5	83	30.00	2592.00	25.46	2200.00
AW 6	82	49.00	4233.60	25.46	2200.00
AW 7	60	50.00	4320.00	25.46	2200.00
AW 8	59	47.00	4060.80	25.46	2200.00
AW 9	58	38.00	3283.20	25.46	2200.00
AW 10	56	42.00	3628.80	25.46	2200.00
AW 11	47	35.00	3024.00	25.46	2200.00
AW 12	37	27.70	2393.30	25.46	2200.00
AW 13	36	31.10	2687.00	25.46	2200.00
AW 14	27	16.80	1450.00	25.46	2200.00
AW 15	26	13.00	1123.20	25.46	2200.00
AW 16	19	19.60	1693.40	25.46	2200.00
AW 17	17	14.50	1252.80	25.46	2200.00
AW 18	18	20.20	1742.40	25.46	2200.00
AW 19	19	17.60	1522.10	25.46	2200.00
		500.00	43177.00	483.74	41800.00
Own by private firm :					
a	4	6.95	600.00	7.50	648.00
b	5	11.50	990.00	12.50	1080.00
c	13	13.90	1200.00	15.00	1296.00
d	30	9.70	840.00	10.00	864.00
e	38	6.85	590.00	7.50	648.00
f	48	7.75	670.00	10.00	864.00
g	62	11.55	1000.00	12.50	1080.00
h	75	5.55	480.00	7.50	648.00
i	76	4.05	350.00	5.00	432.00
133/p	100	6.85	590.00	7.50	648.00
j	139	5.55	480.00	7.50	648.00
k	117	7.50	650.00	10.00	864.00
l	116	19.70	1170.00	20.00	1728.00
m	126	2.90	250.00	5.00	432.00
n	137	3.70	320.00	5.00	432.00
o	148	19.70	1700.00	20.00	1728.00
p	146	5.45	470.00	7.50	648.00

(Table II-2 Continued)

CODE OF WELLS	# OF NODE	DISCHARGE			
		EXISTING		SIMULATED	
		L/SEC	M3/SEC	L/SEC	M3/SEC
q	154	9.70	840.00	12.50	1048.00
r	161	3.95	340.00	5.00	432.00
s	160	3.25	280.00	5.00	432.00
		166.05	13810.00	192.50	16600.00

Note: The existing discharges are taken from reference #15.

The simulated values are based on the assumption that the maximum discharge for each well is 25 l/sec/5 m drawdown every day.

Chapter III

THE GROUNDWATER FLOW MODELING.

III.1 THE METHOD.

There are three methods of groundwater flow modeling, namely the Physical , the Electric-Analog-Simulator , and the Digital Computer models.

In this project report, the third method is applied . The use of this method has spread very fast since the computers age began. The model is based on Darcy's law, the continuity law, and the boundary conditions of the area under investigation.

To solve the governing differential equation, either the finite difference method or the finite element method may be used. The finite element method is applied in this study.

The stages of doing the work consist of :

- i) Choosing and analyzing the area, especially its boundaries, its aquifer(s) including its parameters, and its initial ground water condition problem.
- ii) Delineating the domain (or study area) to obtain a manageable problem that simulates real world condition adequately.
- iii) Deriving the conceptual model related to the real

world condition of the study area.

- iv) Compiling the computer code, follow as the manual of the program.
- v) Inserting the input data and running the program.
- vi) Calibrating the result with the observed data.
- vii) If the step # vi above is verified properly, then prognoses may be made concerning possible scenarios. If calibration is not possible, for instance, for lack of data, then assumptions might be taken where the prognoses were still bias until such real data were encountered.

III.2 THE STUDY AREA.

The study area, the confined aquifer which would be analysed, lies below the part of the Bandung Raya region.

The boundaries of the study area are the Pulusari fault of North Mountain Range at the North side, the short fault at the West side, the fault which passes G. Geulis at the South side, and the turning fault of the Pulusari fault at the East side.

This study area covers towns of Lembang, Cisarua, Cimahi, Batujajar, Margaasih, Dayeuhkolot, Buahbatu, Cicadas, Ujungberung, and Bandung; where the city of Bandung, as the main concern, lies in the center of the study area.

The aquifer to be analysed is the deep confined aquifer.

assumed to be not leaky. This may not be quite true but in the absence of information on the exact location of any leaks, it is a reasonable approximation. It follows then that the existence of rivers which partly penetrate into the phreatic aquifer would not affect the problem .

Also, the existence of springs located above 750 m elevation has to be disregarded because they are outside the finite element grids .

The parameters of the confined aquifer are :

- i) The thickness of the aquifer (B).

In reality, the thickness of the aquifer varies ; but, since the computer code used assumes the thickness of the aquifer to be uniform, so in the program application, the value of the aquifer thickness that would be counted is uniform in thickness with the thickness of 75 m, 80 m, and 90 m.

- ii) The elevation of bottom aquifer, Z, which is 525 m above MSL is taken as zero elevation.

- iii) The hydraulic conductivities, $K_{xx} = K_{yy}$, in the study area are shown on table III-1 :

Table III-1 : Values of $K_{xx} = K_{yy}$ in the study area.

Geological Formation		$K_{xx} = K_{yy}$ (m/day) as	
Code Number	Description of the geologic formation	Normal distribution	lognormal dist.
2	Tuffs and Ashes, G.Tk Perahu eruption period C.	3.18	2.40
6	Tuffs, Tuff Breccies, Lava Flows.	?	?
4 - West & Center	Tuffs and Mudflows, G. Tk Perahu eruption period A.	8.00	8.03
4 - East	Tuffs and Mudflows, G. Tk Perahu eruption period A.	1.32	1.41
1	Lake Deposit, recent.	2.75	2.51
7	Volcanic and Crystalline Formation	0.00	0.00

Note : The calculations of the figures in this table are shown in appendix C.

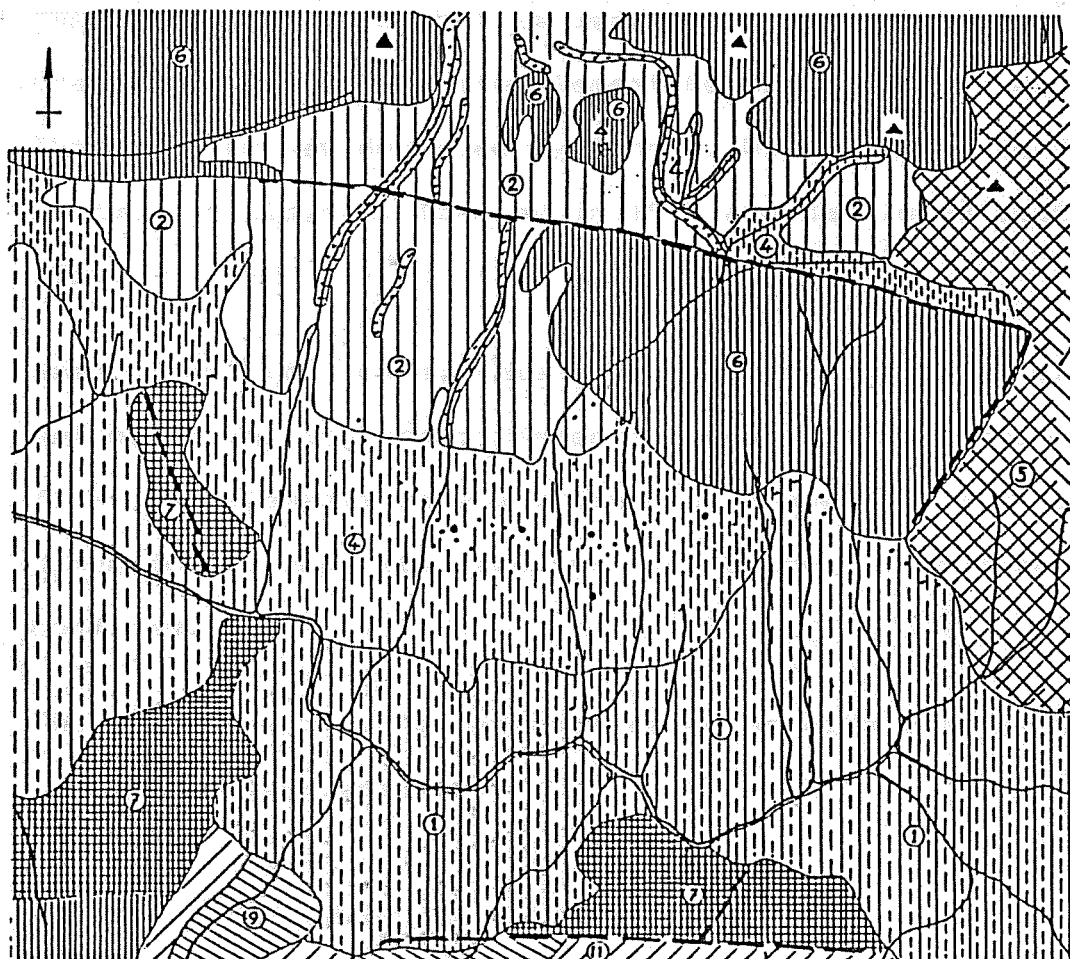
(?) No data are available so that the conductivity which may be fall must be estimated based on the type of the geological formation, the gradation of the soil material or the fisures of the rock.

The initial condition of the deep groundwater flow in the study area, was assumed as follow :

- The groundwater is flowing from the recharge area in the North and South of the mountain ranges to the bottom of the Bandung plateau, while in this flat region of the Bandung plateau this groundwater is flowing slowly from the East to the West side.

- At the toe of the surrounding mountain ranges a constant hydraulic head is assumed. This is caused by a constant recharge from higher elevation (note : It is easier to investigate the height of the hydraulic head than the value of the side fluxes on the field). However, in time, the declining environmental conditions in the mountain range areas will cause the value of this constant head to decrease.
- There are also side fluxes which enter into the finite element grids from the East side, which are also dependent on what happens in the recharge area. These assumptions must be checked properly with the actual conditions.

The geological formation of the study area is shown on figure III-1.



Legend

- | | |
|--------------|-----------|
| ▲ - Mountain | ~ - River |
| --- - Fault | • - Wells |

Geologic Formation:

- 1 - Lake Deposits, recent.
- 2 - Tuffs and Ashes, G.Tk.Perahu eruption period C
- 4 - Tuffs and Mudflows, eruption period A
- 6 - Tuffs, Tuffbreccies, lava Flows.

Figure III-1 The Geologic Formation of the Study Area.

III.3 THE COMPUTER CODE.

III.3.1 GENERAL.

The computer code that is used is the AQUIFEM-1, which stands for Aquifer Finite Element Method - 1 layer aquifer. The program was designed by John L. Wilson, Antonio Sa da Costa, and Lloyd R. Townley in 1977 and developed again in 1980.

Seen from its name, this code uses the finite element method in solving the differential equation of groundwater flow. The elements have a triangular shape. The flow is two dimensional and its aquifer is either unconfined or confined.

The code can run on a personal computer with a large memory in Fortran language.

III.3.2 THE GOVERNING EQUATION.

The governing differential equation, used by the code is based on Darcy's law and the continuity law :

$$S \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left(T_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(T_{yy} \frac{\partial h}{\partial y} \right) + Q + \frac{K'}{B'} (h' - h)$$

Where :

S = Storativity, (dimensionless).

h = Hydraulic head or piezometric head, (m).

t = Time, (day).

x, y = Cartesian Coordinate Axes.

T_{xx} = Transmissivity on x plane along x direction,
(m^2/day).

T_{yy} = Transmissivity on y plane along y direction,
(m^2/day).

Q = Net discharge of source or sink, (m^3/day).

K' = Hydraulic conductivity of the adjacent leaky
aquifer either on top or bottom of the main
aquifer, (m/day).

B' = the thickness of the adjacent leaky aquifer,
(m).

h' = the hydraulic head of the adjacent aquifer,
(m).

The transmissivity, is the product of the conductivity and the layer thickness.

$$T = K * B$$

The differential equation, does not include the terms of T_{xy} and T_{yx} . The reason for this is that in the solution procedure of the main equation, the principal axes of the aquifer are chosen colinear with the axes of the whole system so that the terms T_{xy} and T_{yx} are zero. This also means that the code is valid for horizontal aquifers only. Related to this reason, the area of the finite element

grids is taken somewhat smaller than the study area, because the steep slope of the hill adjacent above the 750 m elevation is eliminated.

III.3.3 LIMITATIONS OF THE CODE.

The computer code of this program has certain limitations that it can be used only for a roughly horizontal aquifer. In other words, any steep region cannot be included in the computation.

Otherwise the code is very flexible to allow the following features :

- i) The aquifer may be confined, or unconfined.
- ii) The aquifer may be homogeneous, or heterogeneous (where $K_{xx} = K_{yy}$, or $K_{xx} \neq K_{yy}$ respectively).
- iii) The aquifer may have leakage from its adjacent aquifer, and/or from the bottom of the river bed.
- iv) The flow of groundwater may be steady or transient.
- v) The sources /or sinks may occur from wells on each node, and /or water ponds on each element.
- vi) The value of boundary conditions (either the specified head of the 1st type boundary condition or the side fluxes of the 2nd type boundary condition or sources /sinks, rising water level in a large excavation) may vary along the whole period of calculation time.

vii) Changing of the aquifer type from confined to unconfined.

viii) Problem of dewatering a large excavation.

III.3.4 THE INPUT.

The input to be inserted into the program is :

- The type of the aquifer which relates to linearity of the problem to solved.
- Are there any leakage from or into the adjacent aquifer ?
- The type(s), the value(s), and the time steps of this value of the boundary conditions.
- (for the unconfined aquifer) Is there any leakage from or into the river bed which partly or fully penetrates into this aquifer ?
- The type of the triangular finite element grids which shall be represented in the form of nodes number and elements number, including their coordinates and scale. These nodes should be set up in sequential numbers from the left to the right and from the bottom to the top. The bandwidth type of numbers' row should not intersect each others.
- The values of aquifer parameters to be inserted may be in the form of hydraulic conductivity (K) or transmissivity (T), and also may be put on every node or every element of the grid.

- The location and the discharge of any sources /or sinks.
- The initial condition of the hydraulic head of all nodes, either being generated by the computer or being supplied by the user.

III.3.5 THE OUTPUT.

The outputs consist of the echo of the input data, the hydraulic head on each node, the drawdown, the discharge of sources (or sinks) and side fluxes, the mass water balance, and a graphical plot of the finite element grids (in a chosen scale) which shows the hydraulic head on every node.

All of these output are available for the chosen time period. However, on the graph, the equipotential lines and the groundwater flows are not yet drawn. These should be drawn by the user .

Chapter IV

PROGRAM APPLICATION.

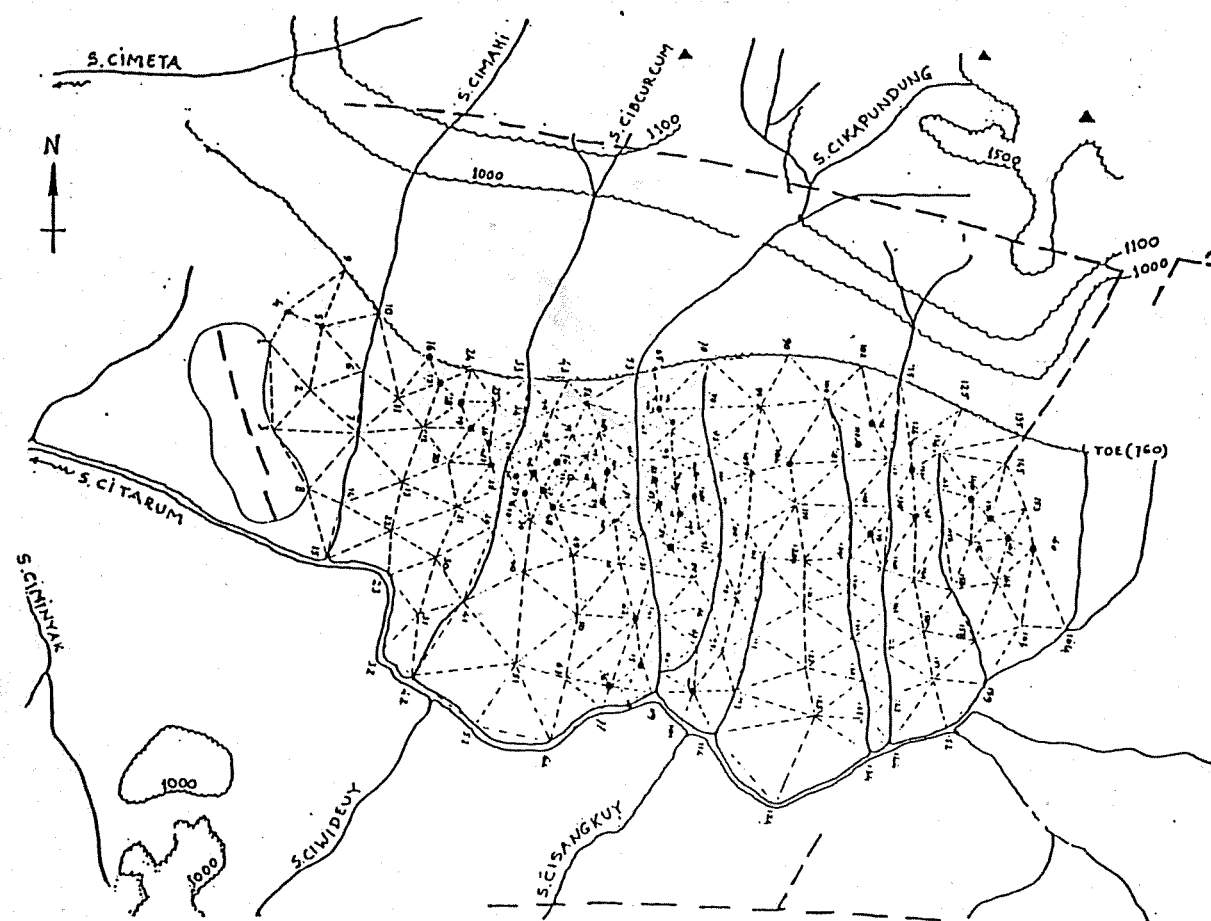
IV.1 THE CONCEPTUAL MODEL OF THE STUDY AREA.

The conceptual model of the study area is represented in the form of triangular finite element grid where the coordinates of every node are given relative to a selected coordinate system.

The design of the finite element grid follows Tailored grid method as being explained in reference #18. Due to the incompleteness of data and the purpose of this work as a study case, the finite element grid is not as dense as it should be for more detailed work.

Figure IV-1 shows the finite elements, where the number of nodes and elements are 164 and 289 respectively. These nodes and elements cover the nearly flat region of the study area.

The grid covers an area of about 325 km². The Northern side is along the toe of the North mountain range, the Eastern side is along the turning Pulusari fault and continues to the farthest turning of the Citarum river, the Southern side is along the Citarum river, and the Western side is along a small impermeable rock formation where a short fault occurs.



Legend

-  - River
-  - Mountain
-  - Wells
-  - Side of elements

Figure IV-1 The Finite Element Grid.

The x,y coordinate system is taken to be colinear with the North-South and the West-East direction. The scale of plotting output is 1 : 60000, which is the smallest ratio in order to avoid some nodes to overlap each other.

In this program application, the boundary conditions and the initial condition of these finite elements consist of :

- The specified head of the 1st type boundary condition which occurs along the Northern side of the grids.
- The specified fluxes of the 2nd type boundary condition entering the grids from the Eastern side.
- The sources consist of the results of pumping out from wells, which are acting on certain nodes with varied amount of discharge.
- The initial condition of hydraulic head on every node which would be supplied related to the assumption being taken (see Scenarios ch. IV.2).

As the size of the study area decreases due to the limitation of the computer code, the types of geological formation of the aquifers being encountered in the finite element grids would decrease, that consists of :

- a) Tuffs and Mudflows, G.Tangkuban Perahu eruption period A.
- b) Lake deposit, recent.

The values of the hydraulic conductivity of these aquifers could be seen on the table IV-1 below.

Table IV-1 : Values of $K_{xx} = K_{yy}$ for program application.

Geological Formation .		$K_{xx} = K_{yy}$
Description of the geologic formation	Location in F.E grids	(m/day)
Tuffs and Mud Flows, Eruption period A	West & Center part	8.00
dito	East part	1.32
Lake Deposit, Recent	South part	2.75

Note : The calculation of $K_{xx} = K_{yy}$ could be seen in the appendix C.

The chosen time for printing and plotting output are 365, 730, 1095 (days), or 1 year, 2 years and 3 years respectively, which might portray the changes of the groundwater flow pattern after some period of time.

IV.2 THE SCENARIOS OF THE PROGRAM APPLICATION.

Program AQUIFEM-1 is demonstrated by analyzing the pattern of the groundwater flows in the deep aquifer at Bandung basin. The use of the table IV-2 presents hypothetical scenarios which have been analysed by the program.

Table IV-2 : SCENARIOS.

Case #	Thickness of aqui. (m)	Kxx = Kyy (m/day)			1st Type B.C (m)			2nd Type B.C (m2/day)			Wells' Disch. [#]
Case A.1	75	3.18	8.00	1.32	1.55	1.45	1.35	0.22	0.15	0.07	existing
Case A.2	75		dito			dito			dito		simulated
Case B.1	80		dito			dito		0.24	0.16	0.08	existing
Case B.2	80		dito			dito			dito		simulated
Case C.1	90		dito			dito		0.27	0.18	0.09	existing
Case C.2	90		dito			dito			dito		simulated
Case D.1	75		dito			dito		0.22	0.15	0.07	+3 Wells,exis
Case D.2	75		dito			dito			dito		+3 Wells,simu

Note : (*) Values of wells discharge, either for the existing or the simulated conditions could be seen on table II-2/p.27

In the scenarios, there are four main cases, namely, case A, case B, case C and case D. These cases are sub-divided into two sub-cases, sub-case 1 and sub-case 2. And then, to every case, we would see the condition of the groundwater flow at the time of one year, two years and three years after the operation of wells began. Hence, the scenarios would consist of 24 programs of application.

Case A, B, and C differ in the thickness of the aquifer, and in the value of the side fluxes. The thickness of the aquifer of case A is 75 m, which represents the smallest thickness of the aquifer. The thickness of the aquifer of case B and case C are gradually increased, that are 80 m and 90 m respectively. These increases are related to the real

condition of the aquifer that has different thicknesses, yet the computer code could be used for uniformity of thickness of aquifer. Besides, the sensitivity of the computation for errors in the aquifer's thickness could be assessed.

Subscript 1 and subscript 2 refer only to the well discharges. Subscript 1 represents the existing discharge, and subscript 2 is for the simulated discharge. In the existing condition, the discharge from the government wells differs considerably. Some wells have discharge more than recommended that is 10 l/sec/1 m drawdown (or 4320 m³/day/5 m drawdown). Some of these wells broke down in 1989. In the simulated condition, the discharge of all government wells are taken to be not more than 5 l/sec/1 m drawdown (or 2200 m³/day/5 m drawdown) as being suggested by Freeze and Cherry. The broken wells were assumed to be repaired.

The case D is nearly the same as case A, but 3 wells were added at nodes 66, 91, and 110. These nodes are in an open area that is being developed in the city of Bandung.

The value of the 1st type boundary condition (the specified head at certain nodes), and the value of 2nd type boundary condition (fluxes through certain sides of elements) are dependent on the real conditions. However, due to lack of data relating to these boundary conditions and the initial condition, all of these values had to be assumed. These assumptions would be correlated with the situation and the

condition of the study area, are :

- The initial condition of the groundwater flow, which is represented by the initial condition of the values of hydraulic heads at all nodes, as being discussed in chapter III-2 (The Study Area), is given on the basis of:
 - First, values of piezometric heads that were observed when the wells were constructed.
 - Second, the configuration of the groundwater flow of which pattern is assumed to have a direction from the top to the toe of the hill. After passing this toe, in the nearly flat region, the groundwater flow must turn smoothly to the East due to the flow from the East to the West direction.

The schematic diagram of the initial condition of the groundwater flow is shown on figure IV-2.

- It is assumed that the specified heads along the nodes which are located at the toe of the hill will assume to be decreasing after certain periods of time, from 155 m to 145 m and finally, 135 m. This assumption portrays the changes in infiltration capacity at the recharge area. It is due to environmental degradation as a consequence of, deforestation on the hills of the North mountain range. This occurrence may affect and change the values of the boundary condition.

The changes of this value can be expressed in a type of histogram as seen on figure IV-3 (top part).

- The values of the sides' fluxes entering the grids from the Eastern side, were assumed to be 0.22 m²/day, 0.24 m²/day, 0.27 m²/day for the aquifer thickness of 75 m, 80 m and 90 m respectively. Environmental degradation is also assumed in the East side of the study area, because more people will build deep well pumps to obtain the fresh water they need). These values of sides' fluxes are assumed to decrease up to 70 % .

The histogram of this sides' fluxes is drawn as figure IV-3 (middle part).

- The sources are well discharged at certain nodes. The discharge of each well, either for the existing condition or the simulated, is shown on table II-2/page 27.

The histogram of the wells' discharges, which is shown on figure IV-3 (bottom part), is constant for the whole period of calculation time.

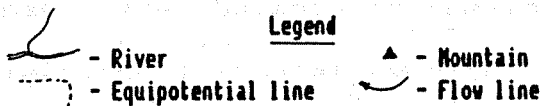
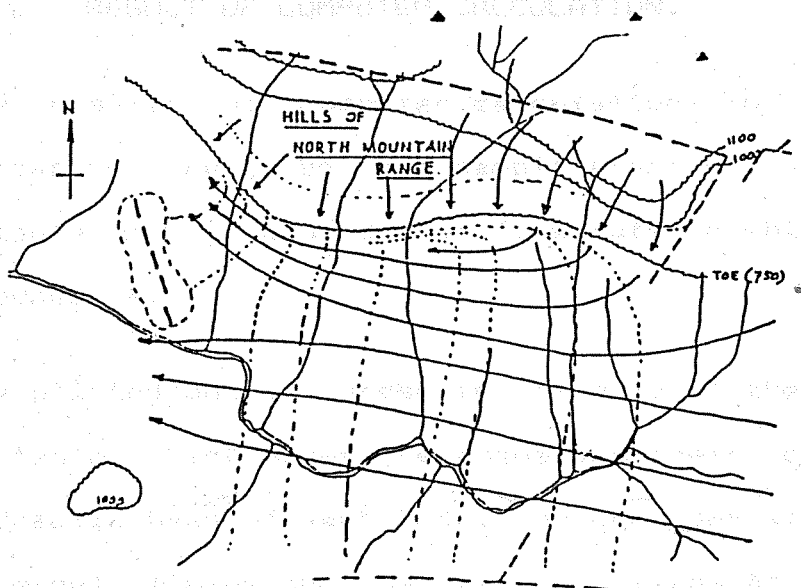
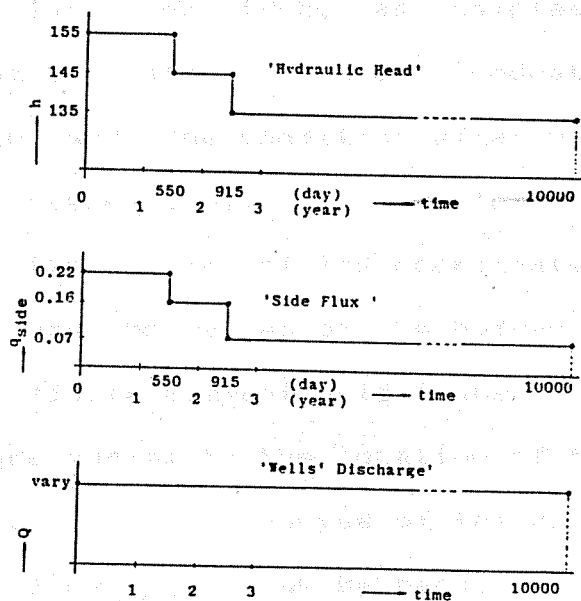


Figure IV-2 The schematic diagram of the initial condition of the groundwater flow.



Note

h = hydraulic head (m) q = sideflux (m²/day)
 Q = wells discharge (m³/day) t = time (day)

Figure IV-3 Histograms of the boundary conditions.

IV.3 RESULT OF COMPUTER CALCULATION.

The results of computer calculation for the different scenarios, are given on a sample print out and a plot of the outputs of the groundwater flow pattern which is shown in appendix A.

The printed output presents the echo of the input data and a table which shows the nodes and their coordinates, the hydraulic head of each node, the drawdown at each node, the internal fluxes and the external fluxes at each node, and the mass water balance of the total external fluxes.

The meaning of a negative sign in a flux is that the flow of the flux is going outwards of the finite elements.

Figures IV-4 and IV-5, as samples of plotted graphs, represent the pattern of the groundwater flow at its initial condition and the condition after one year operation for case A.1 respectively. The computer's plotted graphs just to express the frame of the coordinate axes including its scales, and the values of the hydraulic head at every node of the finite element grid (where the location of the nodes are marked by the location of the decimal points of these values). All curves of the equipotential lines and the flow lines are drawn by hand.

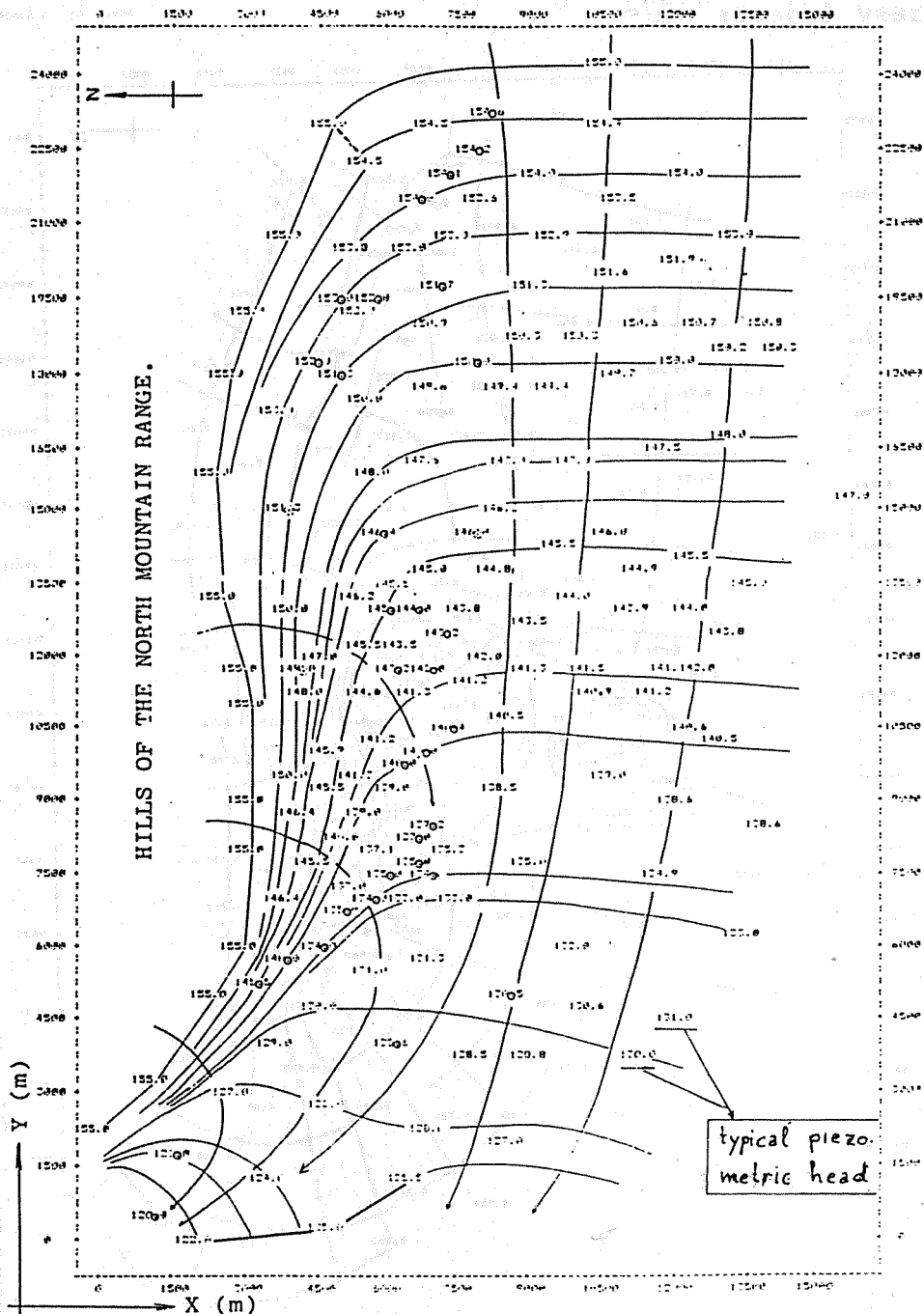
Figure IV-4 and IV-5 represent the initial condition and the condition after one year operation respectively. The decimal points mark the location of nodes.

Figure IV-4 and IV-5 represent the initial condition and the condition after one year operation respectively. The decimal points mark the location of nodes.

A STUDY CASE OF GROUND WATER FLOW - BAKING - GUITER
TIME = 1.0.0.0

THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS

SCALE : 1/ 60000



Note : All real numbers represent piezometric heads, where the decimal points mark the location of nodes.

Figure IV-4 The initial condition of the groundwater flow as the result of computer.

A STUDY CASE OF GROUND WATER FLOW - PAIDUNG AQUIFER (CASE : A/1)
 TIME = 365.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE 1 1/ 40000.

Case : A.1-1
 Where: $B_{aquifer} = 75 \text{ m.}$
 $Q_{well} = \text{Existing.}$
 Time after 1 year.

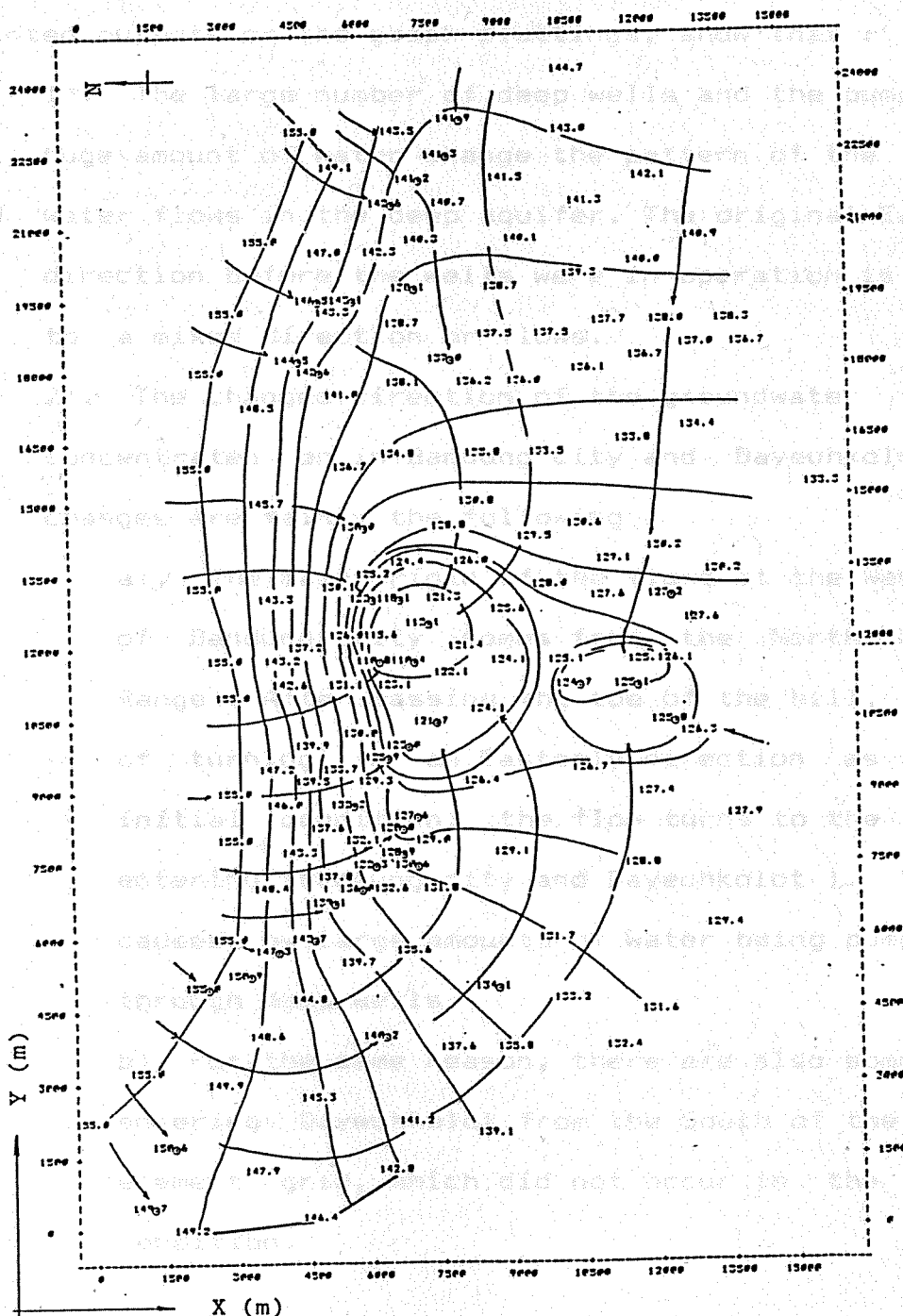


Figure IV-5 The pattern of the groundwater flow for case A.1 after all wells are operated for one year operation.

IV.4 ANALYSIS OF THE RESULTS.

The results of computations, in the form of either the printed outputs or the graph plottings, show that :

1). The large number of deep wells and the pumping of huge amount of water change the pattern of the ground-water flows in the deep aquifer. The original East-West direction before the wells were in operation is changed to a mixed direction of flows.

2). The changed direction of the groundwater flow is concentrated on in Bandung city and Dayeuhkolot. The changes are mainly the following :

a). The main origin of the flows at the West side of Bandung city comes from the North Mountain Range . After passing the toe of the hill, instead of turning in an Easterly direction as is the initial condition, the flow turns to the West (entering Bandung city and Dayeuhkolot). This is caused by large amounts of water being pumped out through deep wells.

b). For the same reason, there are also some flows entering Dayeuhkolot from the South of the finite element grid, which did not occur in the initial condition.

3). The hydraulic heads in case A/1 are lower than in case B/1 which is lower than that in case C/1. This

would be expected since the thickness of A/1 is less than B/1 which is less than C/1, while the other parameters are the same. Similar situations also occur within the group of A/2, B/2, and C/2. 6). Also the hydraulic head in case A/1 is lower than that in case D/1, which is also logical since in case D/1 there are more wells than in case A/1, while the other parameters in both cases are equal. The same condition exists for the group of A/2, and D/2.

4). When the result of print outputs are compiled and expressed as shown in table IV-3 below, it can be concluded, that even for the existing discharges of the wells, the net flows into/or from the area of the finite element grids show already a deficit for the first year which increases on the second and the third years (this means that the amount of the discharge through the wells is greater than the recharge from the side fluxes through the toe of the hills plus the far East side of the grid).

5). In no cases are hydraulic heads are found which are less than the thickness of the aquifer. This means that during the chosen time of output, there would be no subsidence over the concerned area due to the drawdown in the deep aquifer; however, within the next twenty years, if the operation of pumping from deep ground-

water does not decrease, this subsidence might occur at some places of the study area.

Table IV-3 Net Flow Into The Aquifer For Each Case.

(As the sortening result from computerization)

CASE	CONDITION OF THE AQUIFER WITHIN THE GRIDS				NET FLOW INTO THE AQUIFER (M3/DAY)		
	B (m)	1st type B.C (m)	2nd type B.C (m2/day/length)	Q wells (m3/day)	1st year	2nd year	3rd year
A/1	75	155 ; 145 ; 135	0.22;0.15;0.07	existing	-261.006	-1690.370	-1871.068
A/2	75	dito	dito	changed	-270.463	-1704.608	-1885.070
B/1	80	dito	0.24;0.16;0.08	existing	-185.526	-1536.570	-1649.274
B/2	80	dito	dito	changed	-185.914	-1547.213	-1663.161
C/1	90	dito	0.27;0.18;0.09	existing	-74.072	-1248.940	-1304.546
C/2	90	dito	dito	changed	-71.492	-1248.587	-1469.125
D/1	75	dito	0.22;0.15;0.07	existing	-284.757	-1710.510	-2945.494
D/2	75	dito	dito	changed	-320.597	-1747.629	-1803.261

Note : The results of computer process is shown in appendix A.

IV.5 THE SENSITIVITY ANALYSIS.

A sensitivity analysis was performed with different values of the parameters. The parameters that have been checked are the thickness of the aquifer, the specified head of the 1st boundary condition, the side fluxes of the 2nd boundary condition, and the discharge of wells.

The program application consists of 24 cases which can be sorted into 4 main groups A, B, C and D. Three of these main groups (A, B and C) have different thicknesses, and also being computed with different specified head of 1st type

boundary condition, and different sides' fluxes of 2nd type boundary condition. In the analysis, the histograms of the boundaries conditions would be taken more into consideration.

For group D, its aquifer has equal thickness, 1st and 2nd type boundary conditions with group A. However, it has more wells than group A.

Besides that, the method of grouping could be made based on the type of wells' discharges, namely group one (A/1, B/1, C/1 and D/1) and group two (A/2, B/2, C/2 and D/2).

From the plotted graphs, the printed outputs, and table IV-3, it was observed that :

1). There is no significant difference in net flow into the aquifer between group one and group two. The range of the difference is between .2 % to 12.6 %.

2). There is significant difference in that net flow into the aquifer between first year output and second year output where the range is about 550 %, but not for that between second year output and third year output with the range of about 10.7 % .

The reasons for this are :

a). The histograms of the 1st and 2nd type of boundary conditions have a sudden drop from the first year to the second year,

b). However, the drop on the histogram between the second year and the third year is not so emphasized, it happens in the middle of the second year, hence the histogram from the second year to the third year is nearly the same.

3) The difference in thickness (B) give different result either on the values of the hydraulic heads or on the net flow into the aquifer. Thicker aquifer gives less deficit of net flow into it. The reduction of the deficit due to the change of the thickness from 75 m to 80 m (the difference is 5 m) is about 40.8 % ; and the reduction due to the change of thickness from 80 m to 90 m (the difference is 10 m, or twice as much as before) is about 150.9 % . However, these results should not be taken as a criterion for making any general rule for extrapolation of conditions for greater aquifer thicknesses.

IV.6 ENVIRONMENTAL IMPACT ASSESSMENT.

Environmental impacts, primary and secondary impacts, may occur due to the changes of groundwater flow patterns in the deep aquifer over the study area as the result of large water withdrawals through deep wells. Primary impacts are firstly the depletion of volume of groundwater in storage , secondly additional settlement that may occur for some

buildings, and thirdly the subsidence of the region may also happen. Secondary impacts, are socio-economic effects which will not be analyzed.

The first impact, depletion of the groundwater reservoir is a definite possibility.

As the result of program application through AQUIFEM-1, there are deficits in the net flows into or from the aquifer, the wells' discharge are either in existing or in simulated conditions, and eventhough the specified head of the 1st boundary condition was assumed to be at full level. If withdrawals continues over a long period of time, one day the groundwater in the study area may be depleted, or at least significantly reduced.

As far as the second impact is concerned, it is known that in reality some small regions in the study area have leaky aquifers (which in the program were assumed to be not leaky since such data about the exact location of the leakages are available). If the hydraulic heads of the main confined aquifer in this leaky region drops, to the extent that they become lower than the hydraulic heads of the unconfined aquifer, then groundwater may leak from the top aquifer to the aquifer below. This means that, in the region of the leakage, the phreatic water level may drop considerably. The following sequence results may occur. First, the shallow wells belonging to the people who lived on that region would

dry up. Second, the buildings or constructions in this region which have shallow footings may undergo additional settlement. Figure IV-6 portrays this phenomenon more clearly.

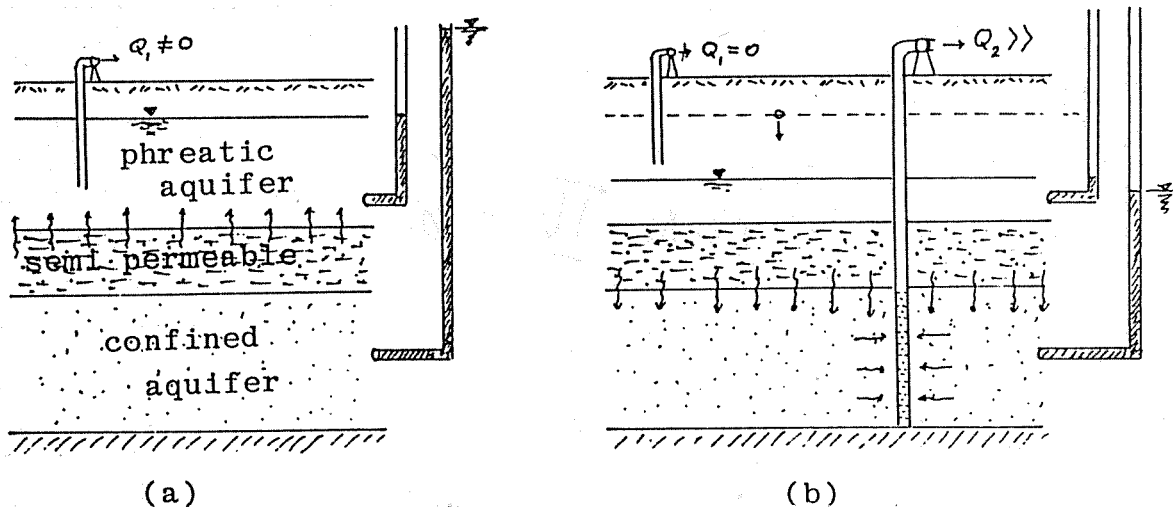


Figure IV-6 Sketch of the groundwater condition in a leaky aquifer (a. without deep well, b. with deep wells)

If the government does not decrease withdrawal from the deep wells to keep the water balance in the aquifer in equilibrium, a third environmental impact may occur, namely subsidence on some region above the concerned aquifer.

To overcome these negative impacts, first, the government should decrease the total withdrawals from the deep wells. Second, the environment at the North mountain range and at the East part of the study area should be kept in good condition so that the infiltration is not reduced.

It is realized that these conclusions are based on a study

in which many assumptions had to be made because of inadequate data. To get more precise information, on the situation, additional studies with more complete data are still needed.

Chapter V.

SUMMARY AND CONCLUSIONS.

The main points of this study and the conclusions are summarized as follow :

- 1). The problem is to analyze the groundwater flow in the deep aquifer in a study area in the Bandung Basin.
- 2). The study area is lying within the Pulusari fault on the North and the South fault which is passing G. Geulis. The study area has a nearly a flat region as well as a steep region; the boundary line between the two regions is at about 750 m elevation.
- 3). The computer code which has been used to represent the groundwater system is AQUIFEM-1, which solves the differential equation based on Darcy's law and the continuity law by means of a finite element method, where the shape of each element is triangular.
- 4). A limitation of the computer program, AQUIFEM-1, is that it can only represent nearly horizontal layers. As a result, the area to be studied had to be smaller than what is mentioned under (2), because the steep region could not be included.
- 5). The area of the region that is actually analyzed, and which is covered by the finite element grid, is

about 325 km², represented by 164 nodes and 289 elements.

6). In this area, the government has 19 deep wells with an existing total discharge of 500 m³/day, and the private firms have 20 deep wells where the existing total discharge is about 166 m³/day.

7). The confined aquifer being studied consists of 3 different formations, which thicknesses are assumed to be uniform. In order to see the sensitivity of the results, the thickness is varied in the program application from 75 to 90 m, which represents the smallest thickness to the nearly thickest aquifer.

8). The boundary conditions consist of :

- the specified heads of 1st type boundary condition which occur along the North side of the grids,
- Side fluxes of 2nd type boundary condition entering the aquifer along the far East side of the finite element grid, and
- the sources or water discharge through wells at certain nodes within the grid.

The histogram of the values of the boundary conditions is assumed to decrease representing declining environmental conditions such as deforestation at some areas of the North mountain range and many additional private pumping wells at the East region of the grid.

9). The initial condition is assumed so that the groundwater flow occurs from the top of the North mountain range. Flow moves down, in a southward direction, to its toe. Then after passing the toe, in the nearly flat region, the flow turns to the East due to the groundwater flows from the East to the West direction.

10). The chosen times for the program outputs are 365, 730, and 1095 (in days), or 1,2, and 3 years respectively.

11). The conclusions drawn from the results of the study application are:

- First, the operation of the wells clearly affects the pattern of the groundwater flows, from the initial East-West direction to mixed directions, so that some flows now come from the South side of the grid and move to the wells situated at Dayeuhkolot.
- Second, groundwater flows are concentrating on two groups of wells. Those are located in Bandung city and at Dayeuhkolot.
- Third, the operation of the wells causes a depletion of the water in the aquifer, which is shown quantitatively from the deficit in net flows into the aquifer within the grid (see table IV-3).

- Fourth, this withdrawals may result in the lowering of the hydraulic heads of the aquifer .

- Fifth, if the hydraulic heads of this deep confined aquifer become lower than those of the upper unconfined aquifer, leakage between the two aquifers would occur from the upper unconfined aquifer to the lower confined aquifer. As a result, the water level in this upper aquifer will decrease which may cause the shallow wells to dry up. Also settlements of heavy constructions which have shallow footings may occur.

- Sixth, the changed groundwater flow pattern will have implications for the choice of waste disposal sites that may cause groundwater contamination.

- Seventh, a severe depletion of groundwater may bring subsidence over some parts of the study area.

- Eighth, the sensitivity analysis shows that errors in the assumed thickness of the aquifer do not affect the conclusions very much. Errors in the assumed boundary conditions are more serious.

12). A detailed study is needed to obtain better information of the real conditions. These should cover a larger area including the South mountain range.

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APPENDICES

Appendix A :

- A.1. Sample of an input of the program application.
- A.2. Sample of a printed output.
- A.3. Graphs of all cases.

Appendix B :

- B.1. The pattern of the finite element grid :
 - a). Drawn by hand,
 - b). Drawn by the computer,
 - c). Numbering of the finite elements.
- B.2. Variation of hydraulic conductivities in the F.E Grid.
- B.3. The initial condition of the groundwater flow.

Appendix C :

- Calculation of Hydraulic Conductivity.

Appendix D :

- Calculation of side flux, precipitation, and infiltration.

Appendix E :

- Procedure of arranging the conceptual model.

A. 1

SAMPLE OF AN INPUT
TO THE PROGRAM APPLICATION

APPENDIX A.

The input to the program application .

This appendix is related with the input, especially for the case A.1.a, where the thickness of the aquifer is 75 m, and the output time is one year.

The explanation could be seen at the end of this appendix.

START :

ct 1) A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE # A/1,a)

ct 2)	F	F	F	T	F	T						
ct 3)	289	164	F	F	1	1	289	164				
ct 4)	2	0	F	T								
ct 5a)	14	3	0	0	0	0	0	7	3	38	2	
ct 5b)	0	0	0	F	0	0	T	F	T			
ct 6)		0.0	10000.0	0.1	0	5		2.0	1.0	1.4	2	
ct 7)	-1	1	1	-1	0	2	60000.0		0.0	1	0	1
ct 8)		1	2187.0		0.0							
		2	3594.0		1250.0							
		3	4844.0		156.0							
		4	1250.0		500.0							
		5	1710.0		1562.0							
		6	2968.0		2812.0							
		7	4870.0		2656.0							
		8	6562.0		1250.0							
		9	0.0		2188.0							
		10	1250.0		3282.0							
		11	3750.0		3906.0							
		12	4688.0		4688.0							
		13	6250.0		4062.0							
		14	7031.0		2188.0							
		15	8750.0		1875.0							
		16	2500.0		4844.0							
		17	3282.0		5200.0							
		18	3910.0		5781.0							
		19	4688.0		6094.0							
		20	5750.0		5500.0							
		21	7000.0		5781.0							
		22	7937.0		3750.0							
		23	9218.0		3750.0							
		24	3000.0		6094.0							
		25	3906.0		6875.0							
		26	5200.0		6750.0							
		27	5781.0		6875.0							
		28	6562.0		7050.0							
		29	7660.0		6875.0							
		30	8750.0		5000.0							
		31	10312.0		4688.0							
		32	11406.0		3594.0							
		33	3125.0		7968.0							
		34	4557.0		7825.0							
		35	5310.0		7340.0							
		36	6120.0		7500.0							

37	6750.0	7815.0
38	6975.0	7385.0
39	7500.0	8005.0
40	9075.0	7800.0
41	10000.0	5925.0
42	12180.0	4495.0
43	3240.0	9090.0
44	4218.0	8694.0
45	5212.0	8225.0
46	6010.0	8125.0
47	6692.0	8285.0
48	7038.0	8625.0
49	8590.0	9215.0
50	10750.0	9515.0
51	11850.0	7500.0
52	13580.0	6250.0
53	3125.0	11130.0
54	4050.0	9615.0
55	4910.0	9215.0
56	5680.0	8750.0
57	6195.0	9215.0
58	6400.0	9870.0
59	6900.0	10165.0
60	7500.0	10505.0
61	8750.0	10725.0
62	10457.0	11220.0
63	12148.0	9102.0
64	14062.0	8594.0
65	2972.0	11727.0
66	4212.0	11875.0
67	4425.0	11200.0
68	4825.0	10000.0
69	5550.0	9650.0
70	5910.0	10350.0
71	6715.0	11250.0
72	7887.0	11460.0
73	9137.0	11762.0
74	10412.0	11925.0
75	11800.0	11420.0
76	12440.0	10462.0
77	13125.0	10262.0
78	2650.0	13290.0
79	4075.0	13125.0
80	4738.0	12148.0
81	5625.0	11250.0
82	6250.0	11800.0
83	7035.0	11870.0
84	8238.0	12160.0
85	9218.0	12952.0
86	10000.0	13450.0
87	11250.0	13125.0
88	12025.0	11915.0
89	12650.0	11800.0
90	2500.0	15781.0
91	3937.0	15000.0

92	5505.0	13333.0
93	5625.0	12288.0
94	6450.0	12300.0
95	7300.0	12500.0
96	7800.0	13125.0
97	8450.0	13750.0
98	9700.0	14237.0
99	11450.0	13850.0
100	12500.0	13000.0
101	13245.0	12630.0
102	2800.0	18025.0
103	3775.0	17035.0
104	5750.0	15781.0
105	5913.0	14665.0
106	6250.0	13590.0
107	6075.0	13100.0
108	6760.0	13100.0
109	7048.0	13750.0
110	7937.0	14575.0
111	8550.0	15000.0
112	10775.0	14688.0
113	12500.0	14175.0
114	13750.0	13600.0
115	3150.0	19219.0
116	4525.0	18288.0
117	5050.0	17912.0
118	5625.0	17500.0
119	6925.0	16038.0
120	8675.0	16250.0
121	10000.0	16250.0
122	11850.0	16350.0
123	13200.0	16637.0
124	15900.0	15468.0
125	3900.0	20781.0
126	5000.0	19520.0
127	5550.0	19250.0
128	7000.0	17712.0
129	8550.0	17712.0
130	9568.0	17712.0
131	10925.0	17825.0
132	12180.0	18145.0
133	13210.0	18335.0
134	14375.0	18358.0
135	4875.0	22862.0
136	5387.0	20437.0
137	5745.0	19528.0
138	7028.0	18920.0
139	7942.0	18250.0
140	8950.0	18750.0
141	10200.0	18750.0
142	11450.0	18850.0
143	12650.0	19000.0
144	14070.0	18975.0
145	5690.0	22340.0
146	6732.0	21400.0

147	6550.0	20472.0
148	7200.0	19700.0
149	9218.0	19700.0
150	10770.0	20000.0
151	12163.0	20300.0
152	13475.0	20705.0
153	7043.0	22960.0
154	7325.0	21875.0
155	8125.0	21400.0
156	7510.0	20600.0
157	9548.0	20798.0
158	10960.0	21540.0
159	12230.0	21850.0
160	8175.0	23225.0
161	7968.0	22500.0
162	9350.0	22063.0
163	10625.0	22887.0
164	10635.0	24222.0

ct 9)

1	1	3	2
2	4	1	5
3	1	2	5
4	5	2	6
5	6	2	7
6	2	3	7
7	3	8	7
8	9	4	5
9	9	5	10
10	10	5	6
11	10	6	11
12	6	7	11
13	11	7	12
14	7	13	12
15	7	14	13
16	7	8	14
17	8	15	14
18	10	11	16
19	16	11	17
20	17	11	12
21	17	12	18
22	18	12	19
23	19	12	20
24	12	13	20
25	20	13	21
26	13	22	21
27	13	14	22
28	14	15	22
29	22	15	23
30	16	17	24
31	17	18	24
32	24	18	25
33	18	19	25
34	25	19	26
35	19	20	26
36	26	20	27
37	20	21	27

38	27	21	28
39	28	21	29
40	29	21	30
41	21	22	30
42	22	23	30
43	30	23	31
44	23	32	31
45	24	25	33
46	33	25	34
47	25	26	34
48	34	26	35
49	26	27	35
50	35	27	28
51	35	28	36
52	36	28	37
53	37	28	38
54	28	29	38
55	38	29	39
56	39	29	40
57	29	41	40
58	29	30	41
59	30	31	41
60	41	31	42
61	31	32	42
62	33	44	43
63	33	34	44
64	44	34	45
65	34	35	45
66	45	35	46
67	35	36	46
68	46	36	37
69	46	37	47
70	37	38	39
71	47	37	39
72	47	39	48
73	48	39	49
74	39	40	49
75	49	40	50
76	40	51	50
77	40	41	51
78	41	42	51
79	51	42	52
80	43	54	53
81	43	44	54
82	54	44	55
83	44	45	55
84	55	45	56
85	45	46	56
86	56	46	47
87	56	47	57
88	57	47	48
89	57	48	58
90	58	48	59
91	59	48	60
92	48	49	60

93	60	49	61
94	49	50	61
95	61	50	62
96	62	50	63
97	50	51	63
98	63	51	64
99	51	52	64
100	65	53	66
101	53	67	66
102	53	54	67
103	54	68	67
104	54	55	68
105	68	55	69
106	55	56	69
107	69	56	57
108	69	57	58
109	69	58	70
110	70	58	59
111	70	59	71
112	71	59	60
113	71	60	72
114	60	61	72
115	72	61	73
116	61	62	73
117	73	62	74
118	74	62	75
119	62	76	75
120	62	63	76
121	76	63	77
122	63	64	77
123	78	65	66
124	78	66	79
125	79	66	80
126	66	67	80
127	67	81	80
128	67	68	81
129	68	69	70
130	68	70	81
131	81	70	71
132	81	71	82
133	82	71	83
134	71	72	83
135	83	72	84
136	72	73	84
137	84	73	85
138	73	74	85
139	85	74	86
140	86	74	87
141	74	88	87
142	74	75	88
143	88	75	89
144	75	76	89
145	89	76	77
146	78	91	90
147	78	79	91

148	91	79	92
149	79	60	92
150	80	93	92
151	80	81	93
152	81	82	93
153	93	82	94
154	82	83	94
155	94	83	95
156	83	84	95
157	95	84	96
158	96	84	97
159	84	85	97
160	97	85	86
161	97	86	98
162	98	86	99
163	86	87	99
164	99	87	100
165	87	88	100
166	88	89	100
167	100	89	101
168	90	103	102
169	90	91	103
170	103	91	104
171	91	105	104
172	91	92	105
173	92	106	105
174	92	107	106
175	92	93	107
176	93	94	107
177	107	94	108
178	94	95	108
179	108	95	96
180	108	96	109
181	109	96	97
182	109	97	110
183	110	97	98
184	110	98	111
185	111	98	112
186	98	99	112
187	112	99	113
188	99	100	113
189	113	100	114
190	100	101	114
191	102	116	115
192	102	103	116
193	103	117	116
194	103	118	117
195	103	104	118
196	118	104	119
197	104	105	119
198	107	108	106
199	106	108	109
200	106	109	105
201	105	109	110
202	105	110	119

203	119	110	111
204	119	111	120
205	120	111	121
206	111	112	121
207	121	112	122
208	112	113	122
209	122	113	123
210	113	114	123
211	123	114	124
212	115	126	125
213	115	127	126
214	115	116	127
215	116	117	127
216	117	118	127
217	127	118	128
218	118	119	128
219	119	120	128
220	128	120	129
221	129	120	130
222	120	121	130
223	130	121	131
224	121	122	131
225	131	122	132
226	122	123	132
227	132	123	133
228	133	123	134
229	123	124	134
230	125	136	135
231	125	126	136
232	126	137	136
233	126	127	137
234	127	138	137
235	127	128	138
236	128	139	138
237	128	129	139
238	139	129	140
239	129	130	140
240	140	130	141
241	130	131	141
242	141	131	142
243	131	132	142
244	142	132	143
245	132	133	143
246	143	133	144
247	133	134	144
248	135	136	145
249	136	146	145
250	136	147	146
251	136	137	147
252	137	148	147
253	137	138	148
254	138	139	140
255	138	140	148
256	148	140	149
257	140	141	149

258	149	141	150
259	141	142	150
260	150	142	151
261	142	143	151
262	151	143	144
263	151	144	152
264	145	154	153
265	145	146	154
266	146	155	154
267	146	156	155
268	146	147	156
269	147	148	156
270	148	149	156
271	156	149	157
272	149	150	157
273	157	150	158
274	150	151	158
275	158	151	159
276	151	152	159
277	153	161	160
278	153	154	161
279	154	155	161
280	161	155	162
281	155	156	157
282	155	157	162
283	162	157	158
284	162	158	163
285	163	158	159
286	163	159	164
287	161	162	160
288	160	162	163
289	160	163	164

ct 10)		0.0	75.0	2.75E+00	2.75E+00	5.0E-4
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ct 11)	112	60
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ct 12)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	33	34	35	36	37	38	39	40	41	42	43	45	46	47	48	49
	50	51	52	53	54	55	56	57	58	59	62	63	64	65	66	67
	68	69	70	71	72	73	74	75	76	77	80	81	82	83	84	85
	86	87	88	89	90	91	92	93	94	95	96	97	102	103	104	105
	106	107	108	109	110	111	112	113	114	115	116	117	128	129	130	131

ct 10)		0.0	75.0	8.0E+00	8.0E+00	5.0E-4
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ct 12)	100	101	123	124	125	126	127	132	133	134	135	136	137	138	139	146
	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	168
	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184
	195	196	197	198	199	200	201	202	203	204	218	219				

ct 10)		0.0	75.0	1.32E+00	1.32E+00	5.0E-4
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ct 14)	0.0	550.0	10000.0
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ct 15)	9	155.0	155.0	145.0
	10	155.0	155.0	145.0
	16	155.0	155.0	145.0
	24	155.0	155.0	145.0
	33	155.0	155.0	145.0
	43	155.0	155.0	145.0
	53	155.0	155.0	145.0

	65	155.0	155.0	145.0	
	78	155.0	155.0	145.0	
	90	155.0	155.0	145.0	
	102	155.0	155.0	145.0	
	115	155.0	155.0	145.0	
	125	155.0	155.0	145.0	
	135	155.0	155.0	145.0	
ct 22)	0.0	550.0	10000.0		
ct 23)	145	153	0.22	0.22	0.15
	153	160	0.22	0.22	0.15
	160	164	0.22	0.22	0.15
	164	159	0.22	0.22	0.15
	159	152	0.22	0.22	0.15
	152	144	0.22	0.22	0.15
	144	134	0.22	0.22	0.15
ct 24)	0.0	10000.0			
ct 25)	4	0.0	-6.0E+2		
	5	0.0	-9.9E+2		
	13	0.0	-1.2E+3		
	17	0.0	-1.3E+3		
	18	0.0	-1.7E+3		
	19	0.0	-1.5E+3		
	26	0.0	-1.1E+3		
	27	0.0	-1.5E+3		
	30	0.0	-8.4E+2		
	36	0.0	-2.7E+3		
	37	0.0	-2.4E+3		
	38	0.0	-5.9E+2		
	47	0.0	-3.0E+3		
	48	0.0	-6.7E+2		
	56	0.0	-3.6E+3		
	58	0.0	-3.3E+3		
	59	0.0	-4.1E+3		
	60	0.0	-4.3E+3		
	62	0.0	-1.0E+3		
	75	0.0	-4.8E+2		
	76	0.0	-3.5E+2		
	82	0.0	-4.2E+3		
	83	0.0	-2.6E+3		
	95	0.0	-1.6E+3		
	100	0.0	-5.9E+2		
	105	0.0	-1.1E+3		
	107	0.0	-6.9E+2		
	108	0.0	-7.3E+2		
	116	0.0	-1.7E+3		
	117	0.0	-6.5E+2		
	126	0.0	-2.5E+2		
	137	0.0	-3.2E+2		
	139	0.0	-4.8E+2		
	146	0.0	-4.7E+2		
	148	0.0	-1.7E+3		
	154	0.0	-8.4E+2		
	160	0.0	-2.8E+2		
	161	0.0	-3.4E+2		
ct 31)	1	122.0			

2	124.0
3	125.0
4	120.0
5	123.0
6	127.0
7	128.0
8	125.5
9	155.0
10	155.0
11	129.0
12	130.0
13	128.6
14	128.0
15	127.0
16	155.0
17	145.5
18	140.0
19	134.0
20	131.0
21	131.3
22	128.5
23	128.8
24	155.0
25	146.4
26	135.0
27	134.0
28	133.0
29	133.0
30	130.5
31	130.6
32	130.0
33	155.0
34	145.5
35	137.0
36	135.0
37	135.0
38	134.0
39	135.3
40	135.0
41	132.0
42	131.0
43	155.0
44	146.4
45	140.0
46	137.1
47	137.0
48	137.2
49	138.5
50	139.0
51	134.9
52	133.0
53	155.0
54	150.0
55	145.5
56	139.0

57	139.0
58	140.0
59	140.0
60	140.4
61	140.5
62	140.9
63	138.6
64	138.6
65	155.0
66	149.0
67	148.0
68	145.9
69	141.3
70	141.2
71	141.3
72	141.2
73	141.3
74	141.5
75	141.2
76	140.6
77	140.5
78	155.0
79	150.0
80	147.0
81	144.0
82	143.2
83	142.0
84	142.0
85	143.5
86	144.0
87	143.9
88	141.9
89	142.0
90	155.0
91	151.3
92	146.2
93	145.5
94	143.5
95	143.2
96	143.8
97	144.8
98	145.5
99	144.9
100	144.0
101	143.8
102	155.0
103	153.0
104	146.0
105	146.4
106	145.5
107	145.0
108	144.0
109	145.0
110	146.0
111	146.2

112	146.0
113	145.5
114	145.0
115	155.0
116	152.0
117	151.3
118	150.0
119	147.6
120	147.0
121	147.0
122	147.5
123	148.0
124	147.0
125	155.0
126	153.0
127	152.0
128	149.6
129	149.4
130	149.4
131	149.7
132	150.0
133	150.2
134	150.3
135	155.0
136	153.8
137	152.0
138	150.9
139	150.0
140	150.3
141	150.3
142	150.6
143	150.7
144	150.8
145	154.5
146	154.0
147	153.0
148	151.7
149	151.3
150	151.6
151	151.9
152	153.0
153	154.5
154	154.1
155	153.6
156	153.0
157	152.9
158	153.5
159	154.0
160	154.6
161	154.2
162	154.0
163	154.4
164	155.0

ct 32) 365.0

ct 33) 0.0 365.0

ct 34) 6
ct 35) 46 57 70 84 94 104
FINISH.

Explanation :

1). The input consists of sequent card types, from ct1 until ct35; however, for every certain problem need not the whole card types.

2). For this program application, only ct1, ct2, ct3, ct4, ct5, ct6, ct7, ct8, ct9, ct10, ct11, ct12, ct10, ct12, ct10, ct14, ct15, ct22, ct23, ct24, ct25, ct31, ct32, ct33, ct34, and ct35.

3). The input could be separated into 3 main parts, there are :

- First, that which consists of ct1 until ct7,
- Second, that which consists of ct8 until ct31, and
- Third, that which consist of ct32 until ct35.

4). Ct1 until ct7 are related with the problem to be computed :

Ct1) Title of the problem.

Ct2) The problem parameters which consist of :

Is it for confined or phreatic aquifer which should be expressed as linear or not linear, steady or transient flow, should the initial condition be guessed by the computer or should be supplied by the user, is the final solution to be steady state or not, is the calculation to be done just until checking the input data or until whole computation are finished, and is table of

hydraulic heads of concerned nodes needed to be tabulated.

Put T for true, and F for false.

Ct3) Geometric Parameters which consist of :

Number of elements and number of nodes in the finite element grid, is the geometric data need to be printed out, is the graph of grid need to be plotted, scaling factor of x and y coordinates, the largest element identification number, and the largest node identification number.

Ct4) Aquifer property parameters which consist of :

number of aquifer regions minus one (as the default region), number of nodes or elements for which special aquifer properties are defined individually (different from the default properties and the regionally defined properties as described before), are the aquifer properties given by nodes or by elements, are the hydraulic conductivities supplied or transmissivities.

Ct5a) Boundary and initial condition parameters which consist of :

Number of specified heads of the 1st type boundary condition. (NHNODE), number of times when the NHNODE are given, zero, zero, zero, zero, zero, number of element sides where sides' fluxes of the 2nd type boundary condition occur (NFLXS),

number of times when NFLXS are given, number of nodes where point source/sink are prescribed (NFLXN), and number of times when NFLXN are given.
number of times

Ct5b) (Continuing of ct5a)

Zero, zero, zero, is there any leakage from the adjacent aquifer, zero,zero, is the leaky adjacent aquifer on top or bottom of the concerned aquifer, are the hydraulic heads in the leaky adjacent aquifer vary in space or not, and should the initial condition of hydraulic head at every node need to be read by the computer or not.

Ct6) Time integration and iteration parameters which consist of :

The starting time for computations, the ending time for unsteady computations, tolerance (TOL)for convergence criterion for iterative nonlinear solutions, indicator for the norm to be used for checking convergence (0 if the root mean square error is compared with TOL, and 1 if the maximum absolute deviation between iterations is used), maximum number of iterations for an iterative solution (default 5), initial time interval for unsteady problems, time integration parameter for unsteady problems, time interval parameter for varying of delta time (DT), IDT which is

indicator for the method of changing DT (0 if no change occurs, 1 if $DT = DT * DTPARM$ after NDT time steps, and 2 for $DT = DT + DTPARM$ after NDT time steps), number of constant length time steps between changing DT according to IDT, and number of iterations for nonlinear problems.

Ct7) The output control parameters which consist of :

First time step number when printed output is required (-1 is to reset to 10^6 , and no output will be printed unless $NOUT > 0$), number of time steps between printed outputs, number of special printed output times when solution is specially calculated, first time step number when a print-plot of piezometric heads is required, number of time steps between print-plots, number of special print-plot times when solution is specially calculated, scale of print-plot, increment for labelling axes of print-plot (0 if the computer should arrange the suitable increment), is rotation of the x-y axes needed to be done or not (1 if there is no need to rotate the x-y axes, 0 if the plot is rotated so that the largest dimension of the plot runs down the page, 2 if the rotation is forced to occur and the y-axes is printed across the page), zero, number of digits printed after the decimal point for print-plotted

heads.

5) Ct8 until ct31 relate with the real input data, that are:

Ct8) Node points and their coordinates, which should be set sequantially relating with the continuing bandwidth of its row (there should be no jumping nodes are allowed). And every node should be written in seperate line.

Ct9) Elements' number and its connectivities' nodes, where the rule of writing might follow ct8 but, in this case, it is allow to write jumping elements.

Ct10) Default aquifer properties.

The aquifer might consist of such number of different geologic formations. The properties of the largest area of the geologic formation might be taken as the default data.

The properties consist of :

- Default bottom elevation Z above datum,
- Default thickness B,
- Default Kxx or Txx,
- Default Kyy or Tyy
- Default aquifer storativity S (for confined aquifers only),
- Default specific yield Sy (for phreatic aquifer only), none in this problem,
- Default property K'/B' of semi-permeable layer between the main aquifer and an adjacent leaky

aquifer, none in this problem.

Ct11) Number of nodes/or elements in each different
aquifer property region.

Ct12) Set of node/or element numbers which have
different properties with the default properties.

Ct14) Times for fixed specified head of 1st type of
boundary condition, which should be related with
its histogram.

Ct15) Set of nodes with their specified head, which
should be related with its histogram.

Ct22) Times for prescribed sides' fluxes of the 2nd type
boundary condition, which should be related with
its histogram.

Ct23) Set of side of elements with their fluxes' values,
which should be related with its histogram.

Ct24) Times for prescribed nodal fluxes (or wells),
which should be related with its histogram.

Ct25) Set of nodes where wells are existed with the
values of the discharge.

Ct31) Set of initial condition, the nodes and all of
hydraulic heads, which could be written randomly.

6) Ct32 until ct35 relate with the choosing type of
solution to be presented by the computer, that are :

Ct32) Special times for printing output, such as first
time, second time, and so on.

Ct33) Special times for plotted output.

Ct34) Number of nodes at which a hydrograph of piezometric head is to be printed.

Ct35) Set of nodes that the hydrograph of piezometric head is to be printed which would be written in table form.

7) All of these input should be presented properly where :

a). All explanations should be erased,

b). Ct1 should be put at the first line and the word A should be placed at the first column.

c). The position of all continuing lines should be set as it is, because the format s are already being set.

d). There should be no empty lines in between until the last line.

8) Program weditf from watfor77 could be used for editing.

A.2

SAMPLE OF
A PRINTED OUTPUT

AQUIFEM-1

TWO DIMENSIONAL FINITE ELEMENT MODEL
OF GROUNDWATER FLOW WITH
LINEAR TRIANGULAR ELEMENTS

DEPARTMENT OF CIVIL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS, 02139

NOVEMBER 1979 VERSION

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE # A/1,a)

PROBLEM DESCRIPTION

TYPE OF AQUIFER.....LINEAR= .F.
LINEAR=.T. LINEAR (CONFINED) OR LINEARIZED AQUIFER
LINEAR=.F. NONLINEAR (UNCONFINED OR MIXED) AQUIFER

TYPE OF PROBLEM.....STEADY= .F.
STEADY=.T. STEADY STATE PROBLEM
STEADY=.F. UNSTEADY OR TRANSIENT PROBLEM

INITIAL CONDITIONS/GUESSES PARAMETER.....INITAL= .F.
INITAL=.T. COMPUTE LINEAR SOLUTION AS A FIRST GUESS FOR A NONLINEAR PROBLEM
AND/OR INITIAL STEADY STATE SOLUTION FOR AN UNSTEADY PROBLEM
INITAL=.F. READ INITIAL CONDITIONS OR GUESSES

FINAL STEADY STATE SOLUTION PARAMETER.....FINAL= .T.
FINAL=.T. COMPUTE FINAL STEADY STATE SOLUTION WITH BOUNDARY CONDITIONS AT TIME=ENDTIM
FINAL=.F. DO NOT COMPUTE FINAL STEADY STATE SOLUTION

DATA CHECK PARAMETER.....CHECK= .F.
CHECK=.T. CHECK DATA THEN STOP
CHECK=.F. EXECUTE PROGRAM NORMALLY

FINITE ELEMENT GRID PARAMETERS

NUMBER OF ELEMENTS.....NUMEL= 289

NUMBER OF NODE POINTS.....NUMNP= 164
 FLAG FOR PRINTING GEOMETRIC DATA.....PRGEOM= .F.
 PRGEOM=.T. PRINT GEOMETRIC DATA
 PRGEOM=.F. DO NOT PRINT GEOMETRIC DATA
 FLAG FOR PRINT-PLOTTING GEOMETRIC DATA.....PLGEOM= .F.
 PLGEOM=.T. PLOT GEOMETRIC DATA
 PLGEOM=.F. DO NOT PLOT GEOMETRIC DATA
 SCALING FACTOR FOR X-COORDINATES.....XSCALE= 1.000
 SCALING FACTOR FOR Y-COORDINATES.....YSCALE= 1.000
 LARGEST ELEMENT IDENTIFICATION NUMBER.....MAXELT= 289
 LARGEST NODE IDENTIFICATION NUMBER.....MAXNOD= 164

1
 AQUIFER PROPERTY PARAMETERS
 =====
 NUMBER OF REGIONS WITH REGIONALLY DEFINED AQUIFER PROPERTIES.....NAGR= 2
 NUMBER OF INDIVIDUAL ELEMENTS OR NODES WITH SPECIALLY DEFINED AQUIFER PROPERTIES.....NSPEC= 0
 METHOD BY WHICH AQUIFER PROPERTIES ARE GIVEN.....BYNODE= .F.
 BYNODE=.T. BY NODES
 BYNODE=.F. BY ELEMENTS
 METHOD BY WHICH HYDRAULIC PROPERTIES ARE GIVEN.....PERM= .T.
 PERM=.T. PERMEABILITIES KXX,KYY ARE GIVEN
 PERM=.F. TRANSMISSIVITIES TXX,TTY ARE GIVEN

1
 BOUNDARY CONDITION PARAMETERS
 =====
 NUMBER OF PRESCRIBED BOUNDARY HEAD NODES.....NNODE= 14
 NUMBER OF TIMES WHEN PRESCRIBED HEAD BOUNDARY CONDITIONS ARE SET.....NTBH= 3
 NUMBER OF NODES WHERE GROUND LEVELS ARE SPECIFIED.....NGRD= 0
 NUMBER OF TIMES WHEN GROUND LEVELS ARE SET.....NTGRD= 0
 NUMBER OF FLUX ELEMENTS.....NFLXE= 0
 NUMBER OF TIMES WHEN PRESCRIBED BOUNDARY FLUXES ARE SET.....NTFLXE= 0
 NUMBER OF REGIONS WITH REGIONAL ELEMENT FLUX.....NEFR= 0
 NUMBER OF FLUX SIDES.....NFLXS= 7

NUMBER OF TIMES WHEN PRESCRIBED SIDE FLUXES ARE SET.....NTFLXS= 3
 NUMBER OF FLUX NODES.....NFLXN= 38
 NUMBER OF TIMES WHEN PRESCRIBED NODE FLUXES ARE SET.....NTFLXN= 2

 NUMBER OF 3RD-TYPE BOUNDARY SIDES.....NBC3= 0
 NUMBER OF TIMES WHEN 3RD-TYPE BOUNDARY HEADS ARE SET.....NTBC3= 0
 NUMBER OF NODES ON THE 3RD-TYPE BOUNDARY SIDES.....NNOD3= 0

 3RD-TYPE BOUNDARY PARAMETER.....BEDBC3= .F.
 BEDBC3=.T. USE RIVER BED LEVELS TO MODIFY 3RD-TYPE INFLOWS
 BEDBC3=.F. DO NOT USE RIVER BED LEVELS

 NUMBER OF NODES WHERE HEADS IN ADJACENT AQUIFER ARE GIVEN.....NHADJ= 0
 NUMBER OF TIMES WHEN HEADS IN ADJACENT AQUIFER ARE SET.....NTHADJ= 0

 ADJACENT AQUIFER PARAMETER.....ATTOP= .T.
 ATTOP=.T. ADJACENT AQUIFER IS ABOVE AQUIFER UNDER STUDY
 ATTOP=.F. ADJACENT AQUIFER IS NOT AT TOP

 METHOD OF SUPPLYING ADJACENT HEADS.....HAVARY= .F.
 HAVARY=.T. ADJACENT HEADS VARY IN SPACE
 HAVARY=.F. ADJACENT HEADS ARE CONSTANT

 TYPE OF INITIAL CONDITIONS/GUESSES IF INITIAL=.F.....ICVARY= .T.
 ICVARY=.T. INITIAL CONDITIONS VARY IN SPACE
 ICVARY=.F. INITIAL CONDITIONS ARE CONSTANT

 1 SOLUTION STRATEGY
 =====
 START TIME.....STRTIM= .0000
 END TIME.....ENDTIM=10000.0000
 TOLERANCE FOR CONVERGENCE.....TOL= .1000
 INDICATOR FOR CONVERGENCE CRITERION.....ITOL= 0
 ITOL=0 ROOT MEAN SQUARE ERROR CRITERION
 ITOL=1 MAXIMUM ABSOLUTE ERROR CRITERION
 MAXIMUM NUMBER OF ITERATIONS.....MAXIT= 5
 TIME STEP.....DT= 2.00000
 ALPHA PARAMETER FOR TIME INTEGRATION SCHEME.....ALPHA= 1.0000

TIME STEP PARAMETER.....DTPARM= 1.4000

INDICATOR FOR CHANGING TIME STEP.....IDT= 2

IDT=0 NO CHANGE OF TIME STEP

IDT=1 DT=DT*DTPARM AFTER NDT TIME STEPS

IDT=2 DT=DT+DTPARM AFTER NDT TIME STEPS

NUMBER OF CONSTANT LENGTH TIME STEPS BEFORE CHANGING ACCORDING TO IDT.....NDT= 1

NUMBER OF ITERATIONS WITH SAME LEFT HAND SIDE SYSM MATRIX.....NSYS= 2

NSYS=999 REFORM SYSM ONCE EACH TIME STEP

1
OUTPUT CONTROL
=====

FIRST TIME STEP FOR PRINTED OUTPUT.....ISTPRT= 1000000

NUMBER OF TIME STEPS BETWEEN PRINTED OUTPUTS.....NDTPRT= 1

NUMBER OF SPECIAL PRINTED OUTPUT TIMES.....NDOUT= 1

FIRST TIME STEP FOR PLOTTED OUTPUT.....ISTPLT= 1000000

NUMBER OF TIME STEPS BETWEEN PLOTTED OUTPUTS.....NDTPLT= 1

NUMBER OF SPECIAL PLOTTED OUTPUT TIMES.....NPLT= 2

PLOT SCALING FACTOR.....PSCALE= 60000.00

INCREMENT FOR LABELLING PLOT AXES.....PDELTA= .00

ROTATION PARAMETER.....NRFLAG= 1

NRFLAG=0 ROTATION OF PLOT IS ALLOWED

NRFLAG=1 NO ROTATION IS ALLOWED, X-AXIS ACROSS THE PAGE

NRFLAG=2 ROTATION IS FORCED, Y-AXIS ACROSS THE PAGE

NUMBER OF ROWS/COLUMNS AROUND PLOT BOUNDARY.....NBOUND= 3

NUMBER OF DECIMAL PLACES IN PLOTTED VALUES OF HEAD.....NDP= 1

1
NUMBER OF ELEMENTS (NK) IN SYMMETRIC COMPACTED MATRIX IS 1842

BANDWIDTH OF MATRIX IN FULL FORM WOULD BE 31

30332 WORDS OF STORAGE HAVE BEEN USED OUT OF A TOTAL ALLOCATION OF 75000

CALCULATIONS ARE IN DOUBLE PRECISION

1

AQUIFER CHARACTERISTICS

=====

ELEMENT NO	BOTTOM ELEVATION	AQUIFER THICKNESS	KXX	KYY	STORATIVITY	SPECIFIC YIELD	CONF. LAYER K'/B'
1	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
2	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
3	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
4	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
5	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
6	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
7	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
8	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
9	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
10	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
11	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
12	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
13	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
14	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
15	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
16	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
17	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
18	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
19	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
20	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
21	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
22	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
23	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
24	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
25	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
26	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
27	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
28	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
29	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
30	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
31	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
32	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
33	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
34	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
35	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
36	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
37	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
38	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
39	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
40	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
41	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
42	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
43	.00	75.00	8.000E+00	8.000E+00	5.000E-04	0.000E+00	0.000E+00
44	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00

265	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
266	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
267	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
268	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
269	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
270	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
271	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
272	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
273	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
274	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
275	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
276	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
277	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
278	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
279	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
280	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
281	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
282	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
283	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
284	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
285	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
286	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
287	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
288	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00
289	.00	75.00	2.750E+00	2.750E+00	5.000E-04	0.000E+00	0.000E+00

1
 PRESCRIBED HEAD BOUNDARY DATA - SPECIFIED PIEZOMETRIC HEADS AND ASSOCIATED NODE NUMBERS

=====

TIMES.....

.000 550.000 10000.000

NODE NO HEADS UP TO AND INCLUDING THE ABOVE TIMES.....

9	155.000	155.000	145.000
10	155.000	155.000	145.000
16	155.000	155.000	145.000
24	155.000	155.000	145.000
33	155.000	155.000	145.000
43	155.000	155.000	145.000
53	155.000	155.000	145.000
65	155.000	155.000	145.000
78	155.000	155.000	145.000
90	155.000	155.000	145.000
102	155.000	155.000	145.000
115	155.000	155.000	145.000
125	155.000	155.000	145.000
135	155.000	155.000	145.000

1
 PRESCRIBED LATERAL FLUXES ALONG SIDES (L2/T) - VOLUME PER UNIT TIME PER UNIT LENGTH OF ELEMENT SIDE
 REPRESENTING KNOWN LATERAL FLUXES INTO OR OUT OF AQUIFER DOMAIN

=====

TIMES.....

.000 550.000 10000.000

NODES DEFINING SIDE FLUXES UP TO AND INCLUDING THE ABOVE TIMES FLOW IN(+),FLOW OUT(-)

145	153	.2200	.2200	.1500
153	160	.2200	.2200	.1500
160	164	.2200	.2200	.1500
164	159	.2200	.2200	.1500
159	152	.2200	.2200	.1500
152	144	.2200	.2200	.1500
144	134	.2200	.2200	.1500

1 PRESCRIBED FLUXES CONCENTRATED AT NODES (L3/T) - VOLUME PER UNIT TIME

REPRESENTING LOCALIZED RECHARGE OR PUMPING WELLS

TIMES.....

.000 10000.000

NODE NO FLUXES UP TO AND INCLUDING THE ABOVE TIMES FLOW IN(+),FLOW OUT(-)

4	.00	-600.00
5	.00	-990.00
13	.00	-1200.00
17	.00	-1300.00
18	.00	-1700.00
19	.00	-1500.00
26	.00	-1100.00
27	.00	-1500.00
30	.00	-840.00
36	.00	-2700.00
37	.00	-2400.00
38	.00	-590.00
47	.00	-3000.00
48	.00	-670.00
56	.00	-3600.00
58	.00	-3300.00
59	.00	-4100.00
60	.00	-4300.00
62	.00	-1000.00
75	.00	-480.00
76	.00	-350.00
82	.00	-4200.00
83	.00	-2600.00
95	.00	-1600.00
100	.00	-590.00
105	.00	-1100.00
107	.00	-690.00
108	.00	-730.00
116	.00	-1700.00
117	.00	-650.00
126	.00	-250.00
137	.00	-320.00
139	.00	-480.00
146	.00	-470.00

148	.00	-1700.00
154	.00	-840.00
160	.00	-280.00
161	.00	-340.00

1 INITIAL HEAD VECTOR

NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD	NODE	HEAD
1	122.00	2	124.00	3	125.00	4	120.00	5	123.00	6	127.00	7	128.00	8	125.50	9	155.00	10	155.00
11	129.00	12	130.00	13	128.60	14	128.00	15	127.00	16	155.00	17	145.50	18	140.00	19	134.00	20	131.00
21	131.30	22	128.50	23	128.80	24	155.00	25	146.40	26	135.00	27	134.00	28	133.00	29	133.00	30	130.50
31	130.60	32	130.00	33	155.00	34	145.50	35	137.00	36	135.00	37	135.00	38	134.00	39	135.30	40	135.00
41	132.00	42	131.00	43	155.00	44	146.40	45	140.00	46	137.10	47	137.00	48	137.20	49	138.50	50	139.00
51	134.90	52	133.00	53	155.00	54	150.00	55	145.50	56	139.00	57	139.00	58	140.00	59	140.00	60	140.40
61	140.50	62	140.90	63	138.60	64	138.60	65	155.00	66	149.00	67	148.00	68	145.90	69	141.30	70	141.20
71	141.30	72	141.20	73	141.30	74	141.50	75	141.20	76	140.60	77	140.50	78	155.00	79	150.00	80	147.00
81	144.00	82	143.20	83	142.00	84	142.00	85	143.50	86	144.00	87	143.90	88	141.90	89	142.00	90	155.00
91	151.30	92	146.20	93	145.50	94	143.50	95	143.20	96	143.80	97	144.80	98	145.50	99	144.90	100	144.00
101	143.80	102	155.00	103	153.00	104	148.00	105	146.40	106	145.50	107	145.00	108	144.00	109	145.00	110	146.00
111	146.20	112	146.00	113	145.50	114	145.00	115	155.00	116	152.00	117	151.30	118	150.00	119	147.60	120	147.00
121	147.00	122	147.50	123	148.00	124	147.00	125	155.00	126	153.00	127	152.00	128	149.60	129	149.40	130	149.40
131	149.70	132	150.00	133	150.20	134	150.30	135	155.00	136	153.80	137	152.00	138	150.90	139	150.00	140	150.30
141	150.30	142	150.60	143	150.70	144	150.80	145	154.50	146	154.00	147	153.00	148	151.70	149	151.30	150	151.60
151	151.90	152	153.00	153	154.50	154	154.10	155	153.60	156	153.00	157	152.90	158	153.50	159	154.00	160	154.60
161	154.20	162	154.00	163	154.40	164	155.00												

1 TABLE OF PRINTED OUTPUT TIMES

365.0000

1 TABLE OF PRINT-PLOT TIMES

.0000 365.0000

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE # A/1,a)

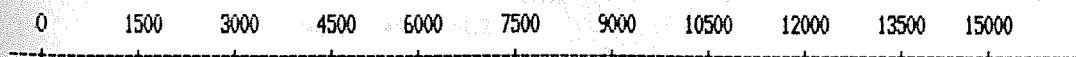
TIME = .00000

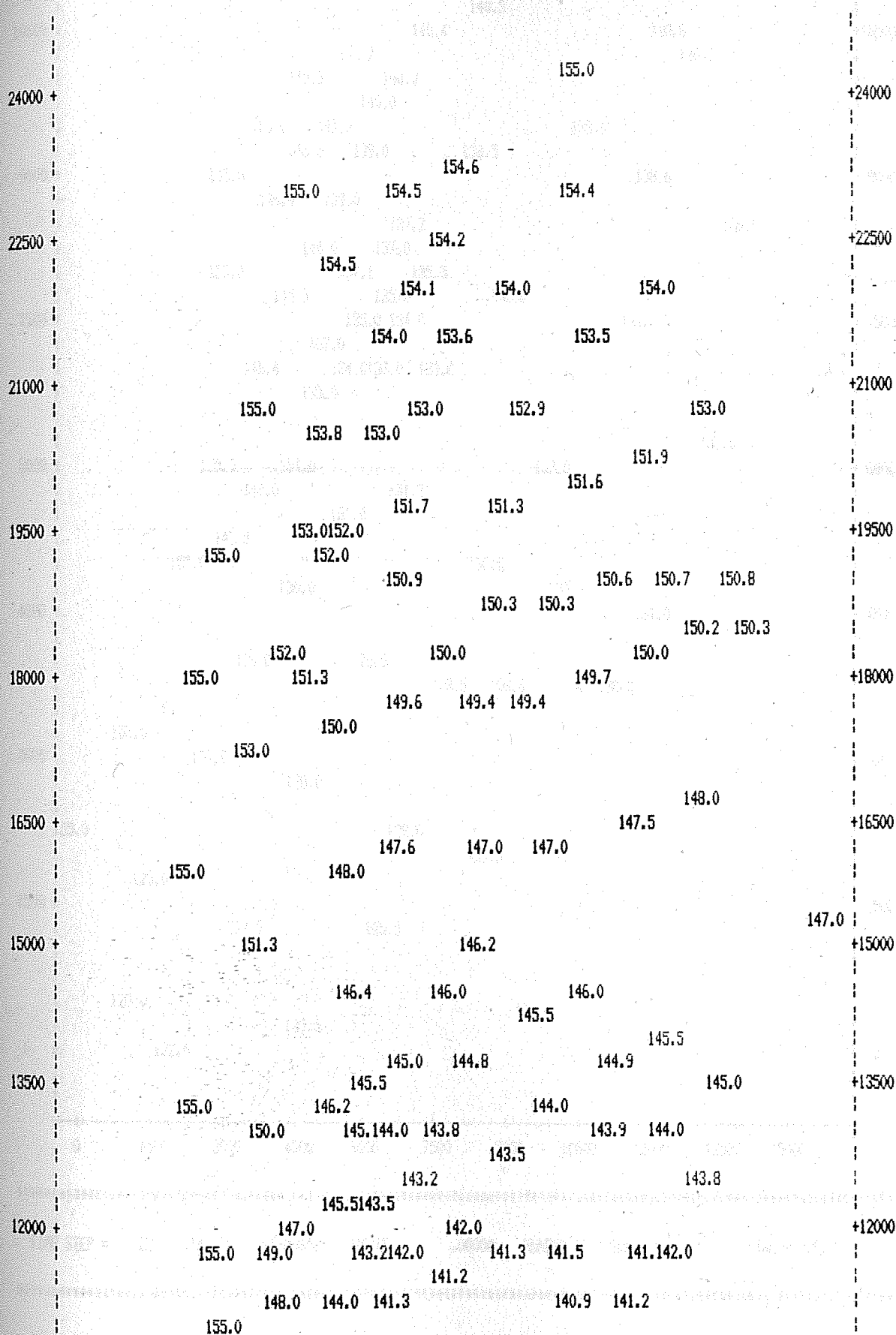
X COORDINATES RANGE FROM .00 TO 15900.00

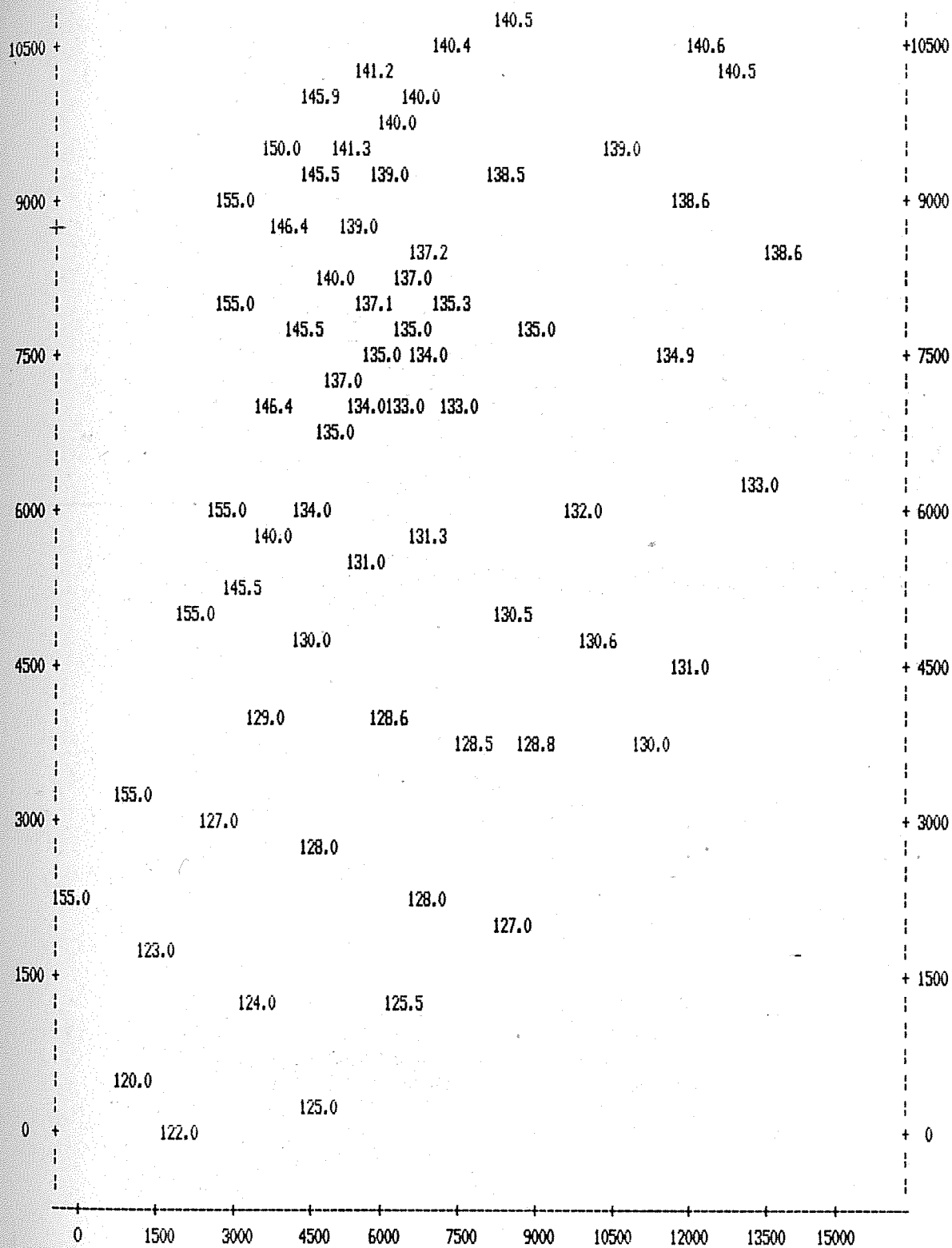
Y COORDINATES RANGE FROM .00 TO 24222.00

THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS

SCALE : 1/ 60000.







TIME STEP = 22 TIME = 365.00000 ERROR = .00000 NUMBER OF ITERATIONS = 1 LINEAR = F.

NODE NO	PIEZOMETRIC HEAD		INTERNAL FLUXES		EXTERNAL FLUXES			LOCATION OF NODE		
	HEAD	DRAWDOWN	QX	QY	(THROUGH THE BOUNDARIES)			ID	X	Y
					SOURCE/SINK INFLOWS	LEAKAGE INFLOWS	INFLOWS AT BOUNDARIES			
	(L)	(L)	(L2/T)	(L2/T)	(L3/T)	(L3/T)	(L3/T)		(L)	(L)
1	149.181	-27.181	.597	-.249	.000	.000	.000	0	2187.000	.000
2	147.905	-23.905	.916	-.143	.000	.000	.000	0	3594.000	1250.000
3	146.376	-21.376	.922	.144	.000	.000	.000	0	4844.000	156.000
4	149.665	-29.665	.760	-.836	-600.000	.000	.000	0	1250.000	500.000
5	150.562	-27.562	.970	-.792	-990.000	.000	.000	0	1710.000	1562.000
6	149.869	-22.869	1.336	-.522	.000	.000	.000	0	2968.000	2812.000
7	145.296	-17.296	1.395	.275	.000	.000	.000	0	4870.000	2656.000
8	142.763	-17.263	1.080	.367	.000	.000	.000	0	6562.000	1250.000
9	155.000	.000	1.136	-1.151	.000	.000	1518.918	1	.000	2188.000
10	155.000	.000	1.551	-1.151	.000	.000	3414.692	1	1250.000	3282.000
11	148.591	-19.591	2.020	-.486	.000	.000	.000	0	3750.000	3906.000
12	144.763	-14.763	2.295	.504	.000	.000	.000	0	4688.000	4688.000
13	140.188	-11.588	1.488	.791	-1200.000	.000	.000	0	6250.000	4062.000
14	141.167	-13.167	1.088	.729	.000	.000	.000	0	7031.000	2188.000
15	139.121	-12.121	.849	.787	.000	.000	.000	0	8750.000	1875.000
16	155.000	.000	2.501	-1.169	.000	.000	6059.408	1	2500.000	4844.000
17	150.896	-5.396	3.208	-.300	-1300.000	.000	.000	0	3282.000	5200.000
18	147.326	-7.326	3.771	-.069	-1700.000	.000	.000	0	3910.000	5781.000
19	142.739	-8.739	3.060	.593	-1500.000	.000	.000	0	4688.000	6094.000
20	139.745	-8.745	2.064	1.133	.000	.000	.000	0	5750.000	5500.000
21	135.645	-4.345	1.280	1.290	.000	.000	.000	0	7000.000	5781.000
22	137.637	-9.137	.963	.944	.000	.000	.000	0	7937.000	3750.000
23	135.843	-7.043	.641	.766	.000	.000	.000	0	9218.000	3750.000
24	155.000	.000	4.542	-.783	.000	.000	8118.279	1	3000.000	6094.000
25	148.378	-1.978	4.526	-.201	.000	.000	.000	0	3906.000	6875.000
26	139.058	-4.058	3.647	.706	-1100.000	.000	.000	0	5200.000	6750.000
27	135.998	-1.998	2.151	1.522	-1500.000	.000	.000	0	5781.000	6875.000
28	132.640	.360	1.645	2.069	.000	.000	.000	0	6562.000	7050.000
29	131.814	1.186	.557	1.297	.000	.000	.000	0	7660.000	6875.000
30	134.123	-3.623	.754	1.084	-840.000	.000	.000	0	8750.000	5000.000
31	133.174	-2.574	.358	.469	.000	.000	.000	0	10312.000	4688.000
32	132.425	-2.425	.265	.123	.000	.000	.000	0	11406.000	3594.000
33	155.000	.000	4.918	-.228	.000	.000	7262.445	1	3125.000	7968.000
34	143.292	2.208	4.769	.160	.000	.000	.000	0	4557.000	7825.000
35	137.798	-.798	3.893	.973	.000	.000	.000	0	5310.000	7340.000
36	132.334	2.666	3.084	1.886	-2700.000	.000	.000	0	6120.000	7500.000
37	128.903	6.097	1.413	1.716	-2400.000	.000	.000	0	6750.000	7815.000
38	130.575	3.425	.233	2.084	-590.000	.000	.000	0	6975.000	7385.000
39	128.957	6.343	-.006	1.367	.000	.000	.000	0	7500.000	8005.000
40	129.124	5.876	.141	.984	.000	.000	.000	0	9075.000	7800.000
41	131.656	.344	.285	.681	.000	.000	.000	0	10000.000	5925.000
42	131.596	-.596	.132	.199	.000	.000	.000	0	12180.000	4495.000
43	155.000	.000	5.515	.027	.000	.000	9219.728	1	3240.000	9090.000
44	145.956	.444	5.263	.052	.000	.000	.000	0	4218.000	8694.000

45	137.602	2.398	5.009	.706	.000	.000	.000 0	5212.000	8225.000
46	132.099	5.001	3.725	1.203	.000	.000	.000 0	6010.000	8125.000
47	127.981	9.019	1.777	.883	-3000.000	.000	.000 0	6692.000	8285.000
48	127.576	9.624	.496	1.641	-670.000	.000	.000 0	7038.000	8625.000
49	126.400	12.100	-.311	1.239	.000	.000	.000 0	8590.000	9215.000
50	126.679	12.321	-.122	.767	.000	.000	.000 0	10750.000	9515.000
51	128.793	6.107	.081	.410	.000	.000	.000 0	11850.000	7500.000
52	129.445	3.555	.043	.166	.000	.000	.000 0	13580.000	6250.000
53	155.000	.000	4.193	.310	.000	.000	6186.374 1	3125.000	11130.000
54	147.192	2.808	5.578	.328	.000	.000	.000 0	4050.000	9615.000
55	139.498	6.002	5.504	.296	.000	.000	.000 0	4910.000	9215.000
56	132.229	6.771	4.348	.685	-3600.000	.000	.000 0	5680.000	8750.000
57	129.278	9.722	3.089	.801	.000	.000	.000 0	6195.000	9215.000
58	125.930	14.070	3.687	1.284	-3300.000	.000	.000 0	6400.000	9870.000
59	123.031	16.969	2.309	.990	-4100.000	.000	.000 0	6900.000	10165.000
60	121.733	18.667	-.331	1.057	-4300.000	.000	.000 0	7500.000	10505.000
61	124.089	16.411	-.606	.648	.000	.000	.000 0	8750.000	10725.000
62	124.725	16.175	-.183	.294	-1000.000	.000	.000 0	10457.000	11220.000
63	127.374	11.226	-.047	.331	.000	.000	.000 0	12148.000	9102.000
64	127.888	10.712	.005	.160	.000	.000	.000 0	14062.000	8594.000
65	155.000	.000	.915	.201	.000	.000	1008.382 1	2972.000	11727.000
66	143.238	5.762	.916	.163	.000	.000	.000 0	4212.000	11875.000
67	142.634	5.366	4.023	.371	.000	.000	.000 0	4425.000	11200.000
68	139.876	6.024	5.451	.531	.000	.000	.000 0	4825.000	10000.000
69	133.727	7.573	5.097	.324	.000	.000	.000 0	5550.000	9650.000
70	129.959	11.241	4.779	.552	.000	.000	.000 0	5910.000	10350.000
71	123.053	18.247	1.906	.931	.000	.000	.000 0	6715.000	11250.000
72	122.056	19.144	-.552	.422	.000	.000	.000 0	7887.000	11460.000
73	124.085	17.215	-.375	.021	.000	.000	.000 0	9137.000	11762.000
74	125.139	16.361	-.114	-.262	.000	.000	.000 0	10412.000	11925.000
75	125.124	16.076	-.102	-.063	-480.000	.000	.000 0	11800.000	11420.000
76	125.794	14.806	-.079	.139	-350.000	.000	.000 0	12440.000	10462.000
77	126.291	14.209	-.047	.158	.000	.000	.000 0	13125.000	10262.000
78	155.000	.000	.781	.049	.000	.000	1509.697 1	2650.000	13290.000
79	143.291	6.709	.882	-.011	.000	.000	.000 0	4075.000	13125.000
80	137.209	9.791	1.053	.123	.000	.000	.000 0	4738.000	12148.000
81	131.078	12.922	3.336	.754	.000	.000	.000 0	5625.000	11250.000
82	110.783	32.417	1.098	.797	-4200.000	.000	.000 0	6250.000	11800.000
83	110.409	31.591	-.375	.678	-2600.000	.000	.000 0	7035.000	11870.000
84	121.387	20.613	-.520	-.051	.000	.000	.000 0	8238.000	12160.000
85	125.646	17.854	-.170	-.173	.000	.000	.000 0	9218.000	12952.000
86	127.963	16.037	-.096	-.304	.000	.000	.000 0	10000.000	13450.000
87	127.645	16.255	-.033	-.339	.000	.000	.000 0	11250.000	13125.000
88	125.910	15.990	-.055	-.274	.000	.000	.000 0	12025.000	11915.000
89	126.063	15.937	-.158	-.107	.000	.000	.000 0	12650.000	11800.000
90	155.000	.000	.619	-.035	.000	.000	1389.510 1	2500.000	15781.000
91	145.687	5.613	.699	-.121	.000	.000	.000 0	3937.000	15000.000
92	130.058	16.142	.908	-.165	.000	.000	.000 0	5505.000	13333.000
93	125.998	19.502	1.478	-.089	.000	.000	.000 0	5625.000	12288.000
94	115.648	27.852	.721	-.608	.000	.000	.000 0	6450.000	12300.000
95	112.059	31.141	-.311	-.459	-1600.000	.000	.000 0	7300.000	12500.000
96	121.335	22.465	-.426	-.586	.000	.000	.000 0	7800.000	13125.000
97	126.009	18.791	-.181	-.313	.000	.000	.000 0	8450.000	13750.000
98	129.549	15.951	-.079	-.352	.000	.000	.000 0	9700.000	14237.000
99	129.138	15.762	-.036	-.403	.000	.000	.000 0	11450.000	13850.000

100	127.211	16.789	-.104	-.349	-530.000	.000	.000 0	12500.000	13000.000
101	127.623	16.177	-.244	-.284	.000	.000	.000 0	13245.000	12630.000
102	155.000	.000	1.016	-.182	.000	.000	1598.529 1	2800.000	18025.000
103	148.467	4.533	.658	-.081	.000	.000	.000 0	3775.000	17035.000
104	136.669	11.331	.462	-.265	.000	.000	.000 0	5750.000	15781.000
105	129.967	16.433	.389	-.394	-1100.000	.000	.000 0	5913.000	14665.000
106	125.215	20.285	.497	-.536	.000	.000	.000 0	6250.000	13590.000
107	122.458	22.542	.968	-.466	-690.000	.000	.000 0	6075.000	13100.000
108	118.082	25.918	.195	-.767	-730.000	.000	.000 0	6760.000	13100.000
109	124.375	20.625	-.006	-.560	.000	.000	.000 0	7048.000	13750.000
110	128.828	17.172	-.026	-.410	.000	.000	.000 0	7937.000	14575.000
111	130.850	15.350	-.004	-.366	.000	.000	.000 0	8550.000	15000.000
112	130.625	15.375	-.033	-.365	.000	.000	.000 0	10775.000	14688.000
113	130.165	15.335	-.084	-.352	.000	.000	.000 0	12500.000	14175.000
114	130.221	14.779	-.101	-.303	.000	.000	.000 0	13750.000	13600.000
115	155.000	.000	1.095	-.553	.000	.000	1826.561 1	3150.000	19219.000
116	144.532	7.468	1.077	-.373	-1700.000	.000	.000 0	4525.000	18288.000
117	142.594	8.706	.638	-.033	-650.000	.000	.000 0	5050.000	17912.000
118	141.002	8.998	.398	-.187	.000	.000	.000 0	5625.000	17500.000
119	134.765	12.835	.123	-.296	.000	.000	.000 0	6925.000	16038.000
120	133.841	13.159	.095	-.301	.000	.000	.000 0	8675.000	16250.000
121	133.543	13.457	.003	-.364	.000	.000	.000 0	10000.000	16250.000
122	133.758	13.742	-.019	-.331	.000	.000	.000 0	11850.000	16350.000
123	134.385	13.615	-.036	-.283	.000	.000	.000 0	13200.000	16637.000
124	133.258	13.742	-.032	-.260	.000	.000	.000 0	15900.000	15468.000
125	155.000	.000	1.010	-.490	.000	.000	2264.779 1	3900.000	20781.000
126	146.492	6.508	1.002	-.489	-250.000	.000	.000 0	5000.000	19520.000
127	143.336	8.664	.676	-.383	.000	.000	.000 0	5550.000	19250.000
128	138.070	11.530	.304	-.202	.000	.000	.000 0	7000.000	17712.000
129	136.236	13.164	.139	-.265	.000	.000	.000 0	8550.000	17712.000
130	136.006	13.394	.026	-.312	.000	.000	.000 0	9568.000	17712.000
131	136.120	13.580	-.002	-.317	.000	.000	.000 0	10925.000	17825.000
132	136.671	13.329	-.012	-.313	.000	.000	.000 0	12180.000	18145.000
133	136.994	13.206	.015	-.333	.000	.000	.000 0	13210.000	18335.000
134	136.724	13.576	-.001	-.280	.000	.000	75.710 2	14375.000	18358.000
135	155.000	.000	1.076	-.455	.000	.000	1401.813 1	4875.000	22862.000
136	146.978	6.822	.988	-.441	.000	.000	.000 0	5387.000	20437.000
137	143.137	8.863	.787	-.359	-320.000	.000	.000 0	5745.000	19528.000
138	138.723	12.177	.398	-.101	.000	.000	.000 0	7028.000	18920.000
139	136.994	13.006	.174	-.206	-480.000	.000	.000 0	7942.000	18250.000
140	137.466	12.834	.032	-.215	.000	.000	.000 0	8950.000	18750.000
141	137.479	12.821	-.007	-.289	.000	.000	.000 0	10200.000	18750.000
142	137.700	12.900	-.020	-.303	.000	.000	.000 0	11450.000	18850.000
143	138.046	12.654	-.026	-.319	.000	.000	.000 0	12650.000	19000.000
144	138.276	12.524	-.032	-.348	.000	.000	276.950 2	14070.000	18975.000
145	149.106	5.394	1.000	-.357	.000	.000	163.712 2	5690.000	22340.000
146	142.634	11.366	.688	-.279	-470.000	.000	.000 0	6732.000	21400.000
147	142.272	10.728	.708	-.418	.000	.000	.000 0	6550.000	20472.000
148	138.099	13.601	.256	-.269	-1700.000	.000	.000 0	7200.000	19700.000
149	138.721	12.579	-.021	-.303	.000	.000	.000 0	9218.000	19700.000
150	139.262	12.338	-.030	-.279	.000	.000	.000 0	10770.000	20000.000
151	139.961	11.939	-.046	-.300	.000	.000	.000 0	12163.000	20300.000
152	140.942	12.058	-.058	-.312	.000	.000	382.499 2	13475.000	20705.000
153	143.480	11.020	.633	-.247	.000	.000	291.598 2	7043.000	22960.000
154	141.211	12.889	.587	-.201	-840.000	.000	.000 0	7325.000	21875.000

155	140.726	12.874	.070	-.148	.000	.000	.000	0	8125.000	21400.000
156	140.253	12.747	.140	-.331	.000	.000	.000	0	7510.000	20600.000
157	140.098	12.802	-.009	-.238	.000	.000	.000	0	9548.000	20798.000
158	141.340	12.160	-.054	-.266	.000	.000	.000	0	10960.000	21540.000
159	142.129	11.871	-.062	-.276	.000	.000	499.411	2	12290.000	21850.000
160	141.907	12.693	-.066	-.226	-280.000	.000	419.866	2	8175.000	23225.000
161	141.349	12.851	.085	-.186	-340.000	.000	.000	0	7968.000	22500.000
162	141.473	12.527	-.066	-.205	.000	.000	.000	0	9350.000	22063.000
163	142.965	11.435	-.093	-.253	.000	.000	.000	0	10625.000	22887.000
164	144.725	10.275	-.102	-.271	.000	.000	610.132	2	10635.000	24222.000

TOTALS	-55760.000	.000	55498.994
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NET FLOW INTO AQUIFER (L3/T) -261.006

**** WARNING **** NEXT TIME WILL EXCEED PRTIME(NOUT) - LAST SPECIAL OUTPUT WILL BE AT TIME=ENDTIM

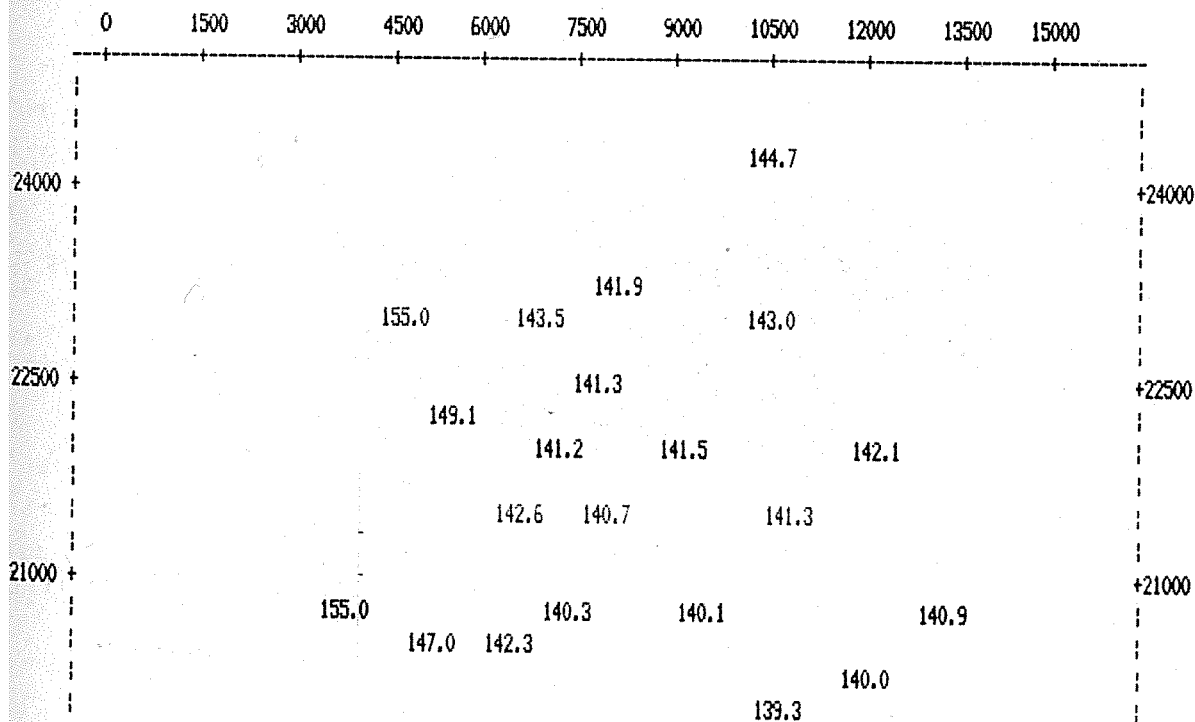
1

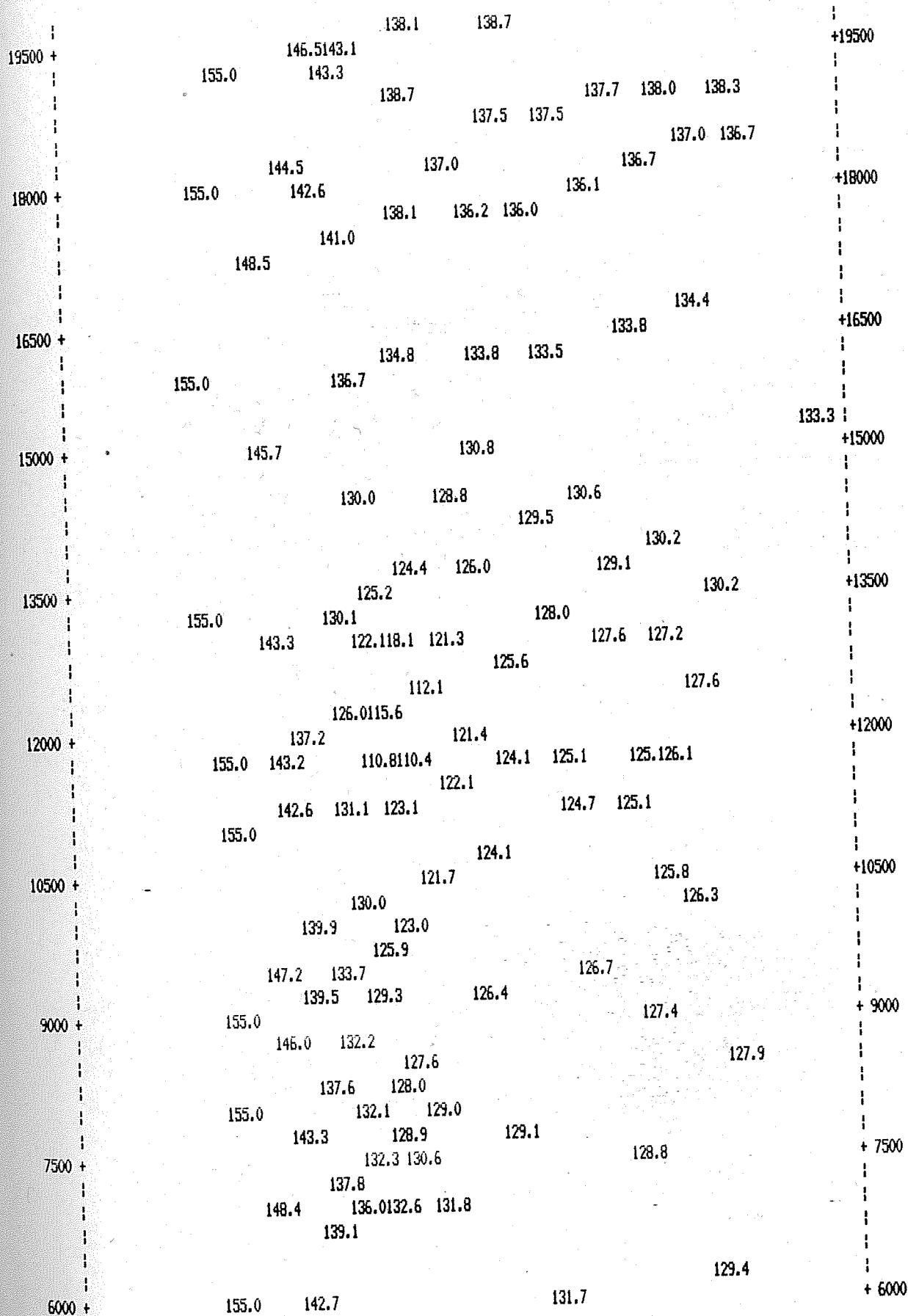
A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # A/1,a)

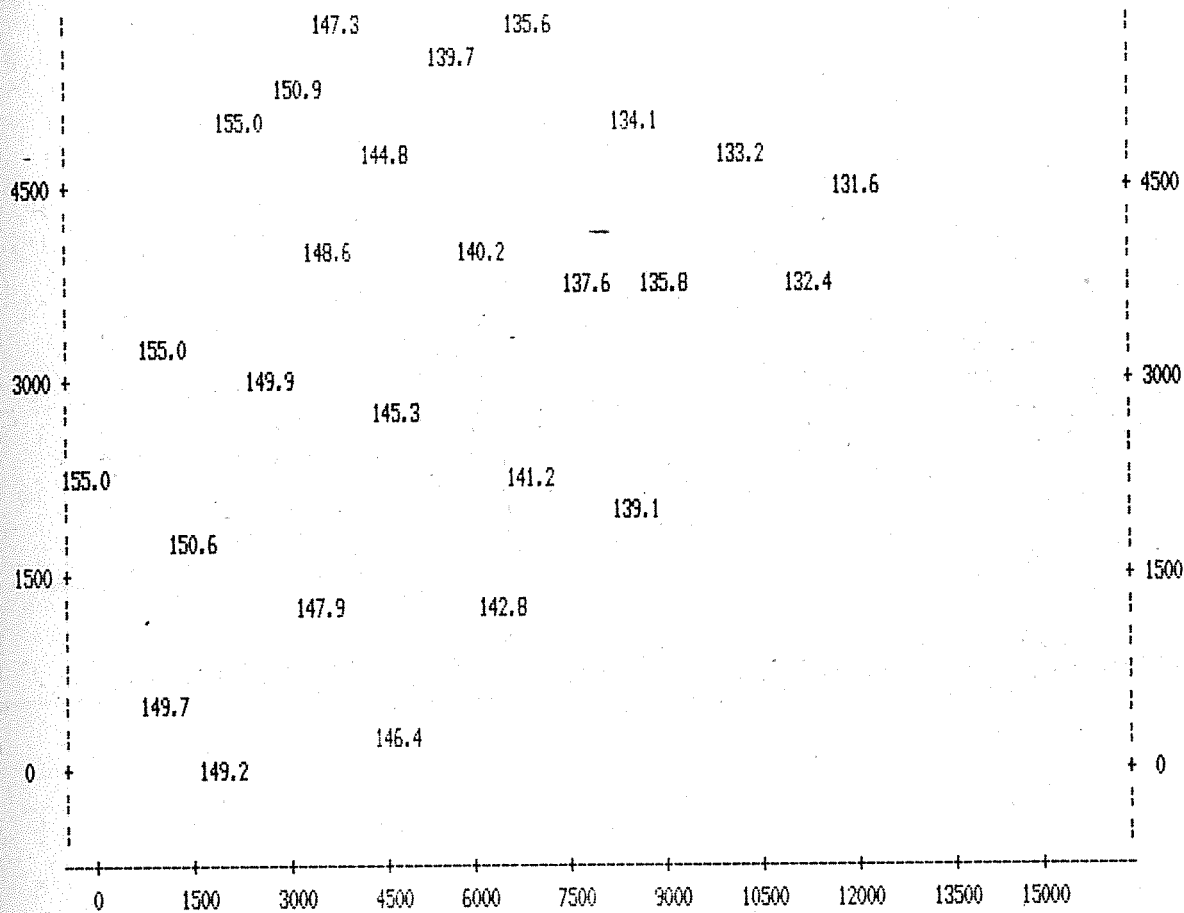
TIME = 365.00000

THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS

SCALE : 1/ 60000.







6 NODES HAVE BEEN SPECIFIED FOR TABULATED OUTPUT

TIME	46	57	70	84	94	104

2.0	135.76	136.61	139.46	140.44	138.27	148.05
5.4	131.44	130.50	136.74	140.42	137.05	148.14
10.2	133.08	131.30	133.48	133.64	123.05	146.98
16.4	133.31	131.24	132.51	129.72	120.10	145.74
24.0	133.38	131.07	132.06	127.58	119.03	144.40
33.0	133.38	130.89	131.72	126.23	118.21	143.13
43.4	133.33	130.72	131.45	125.30	117.60	142.04
55.2	133.23	130.55	131.23	124.60	117.16	141.13
68.4	133.10	130.39	131.04	124.04	116.84	140.38
83.0	132.96	130.23	130.87	123.57	116.60	139.76
99.0	132.83	130.07	130.71	123.17	116.41	139.22
116.4	132.70	129.93	130.57	122.82	116.25	138.77
135.2	132.58	129.80	130.45	122.51	116.09	138.37
155.4	132.48	129.69	130.35	122.24	115.95	138.03
177.0	132.39	129.59	130.25	122.02	115.83	137.74
200.0	132.32	129.51	130.17	121.82	115.73	137.49
224.4	132.26	129.44	130.11	121.67	115.65	137.28
250.2	132.21	129.39	130.05	121.55	115.60	137.11
277.4	132.17	129.35	130.01	121.45	115.57	136.97
306.0	132.13	129.31	129.98	121.38	115.55	136.85
336.0	132.11	129.28	129.96	121.33	115.54	136.76
365.0	132.10	129.28	129.96	121.39	115.65	136.67

A.3

GRAPHS OF ALL CASES

A STUDY CASE OF GROUND WATER FLOW - BANGUNG AQUIFER (CASE : A.1-1)

TIME = 365.00000

THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS

SCALE : 1/ 60000.

Case : A.1-1

Where: Baquifer = 75 m.

Qwell = Existing.

Time after 1 year.

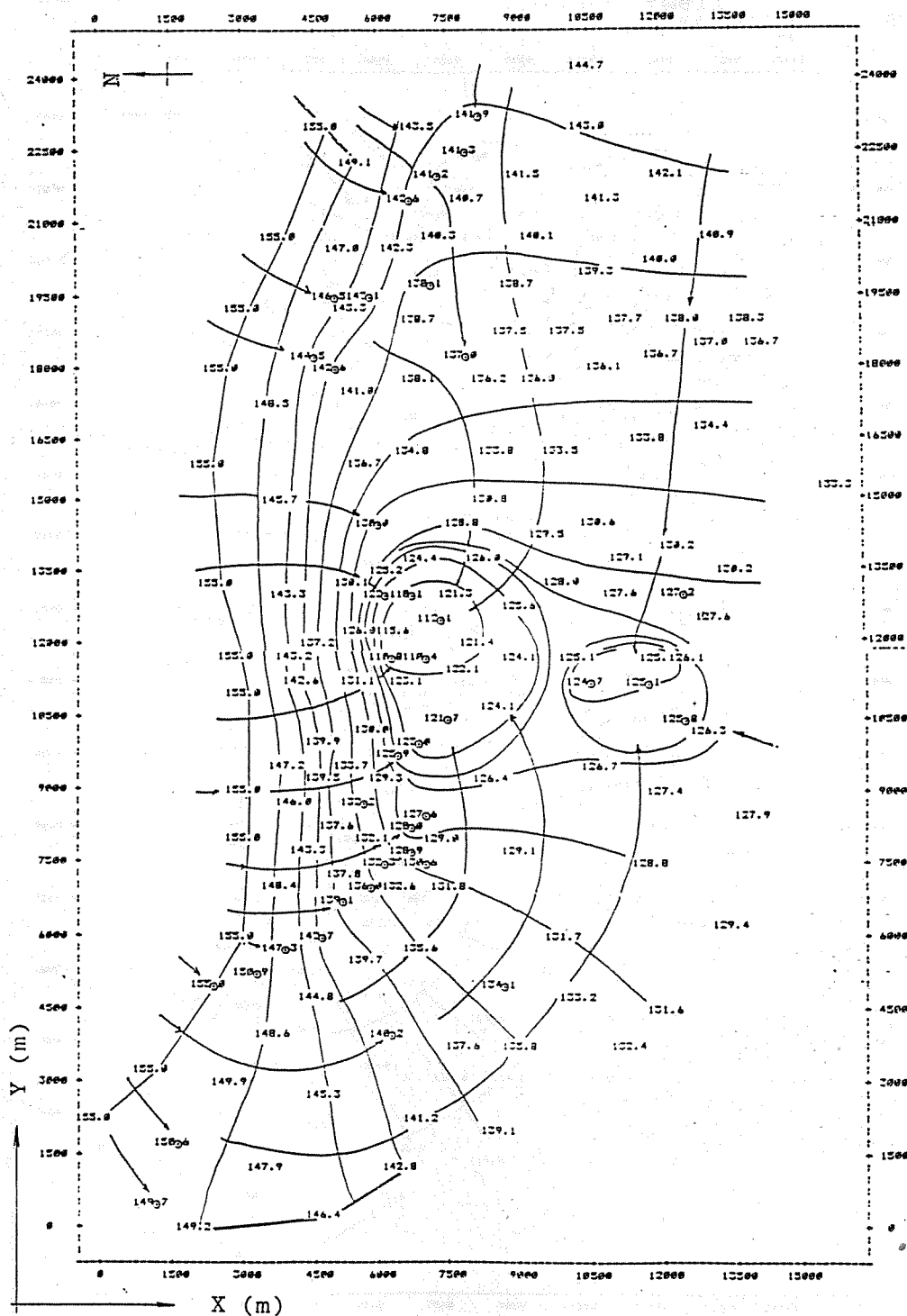


Figure App.A-3.1 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE # A/1)
 TIME = 738.88888
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : A.1-2

Where: $B_{\text{aquifer}} = 75 \text{ m.}$
 $Q_{\text{well}} = \text{Existing.}$
 Time after 2 year.

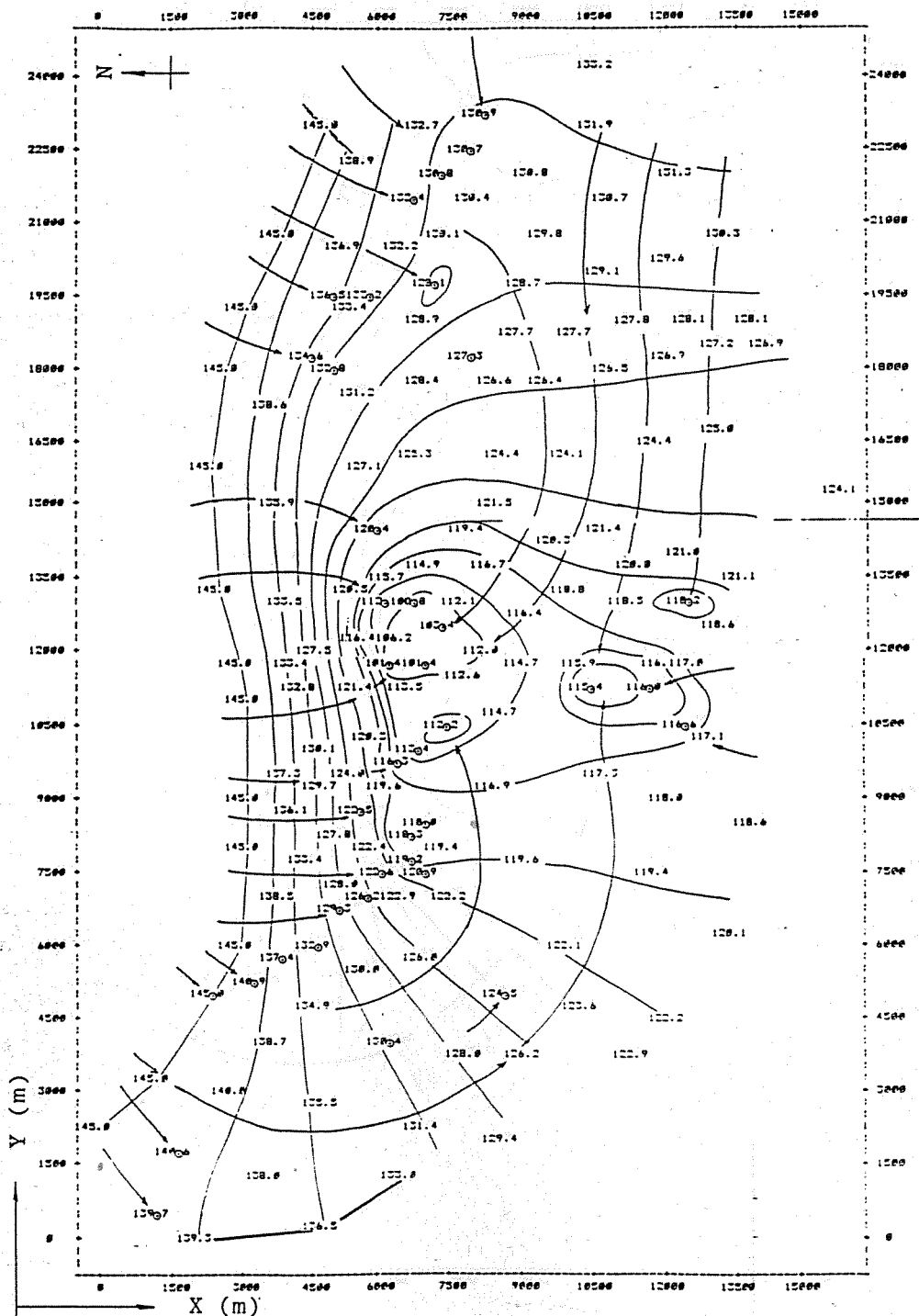


Figure App.A-3.2 : Plotted graph as the output of the application program.

Case : A.1-3
 Where: $B_{aquifer} = 75 \text{ m.}$
 $Q_{well} = \text{Existing.}$
 Time after 3 year.

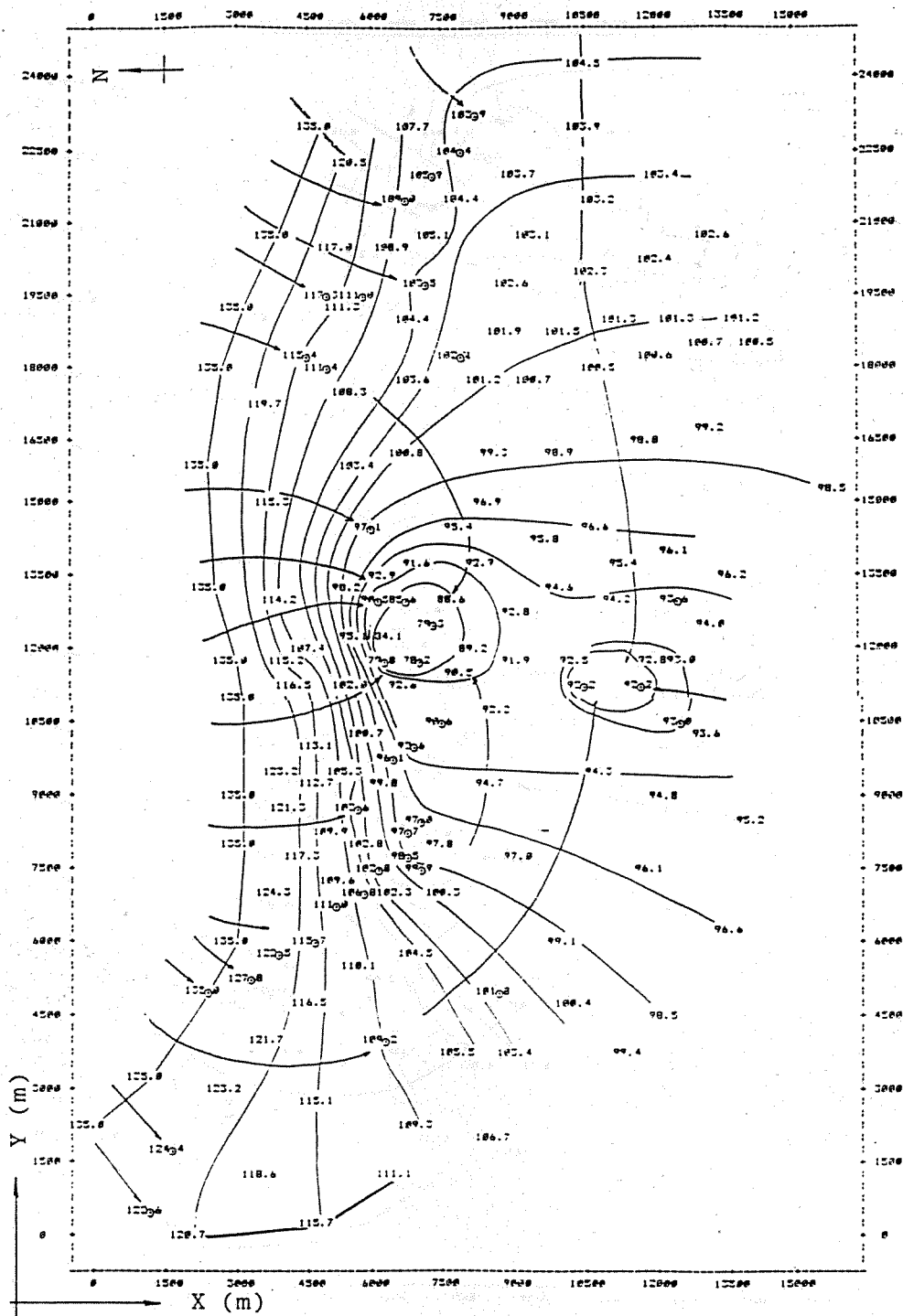


Figure App.A-3.3 : Plotted graph as the output of the application program.

#A/2)
 TIME = 365.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : A.2-1
 Where: $B_{\text{aquifer}} = 75 \text{ m.}$
 $Q_{\text{well}} = \text{Simulated.}$
 Time after 1 year.

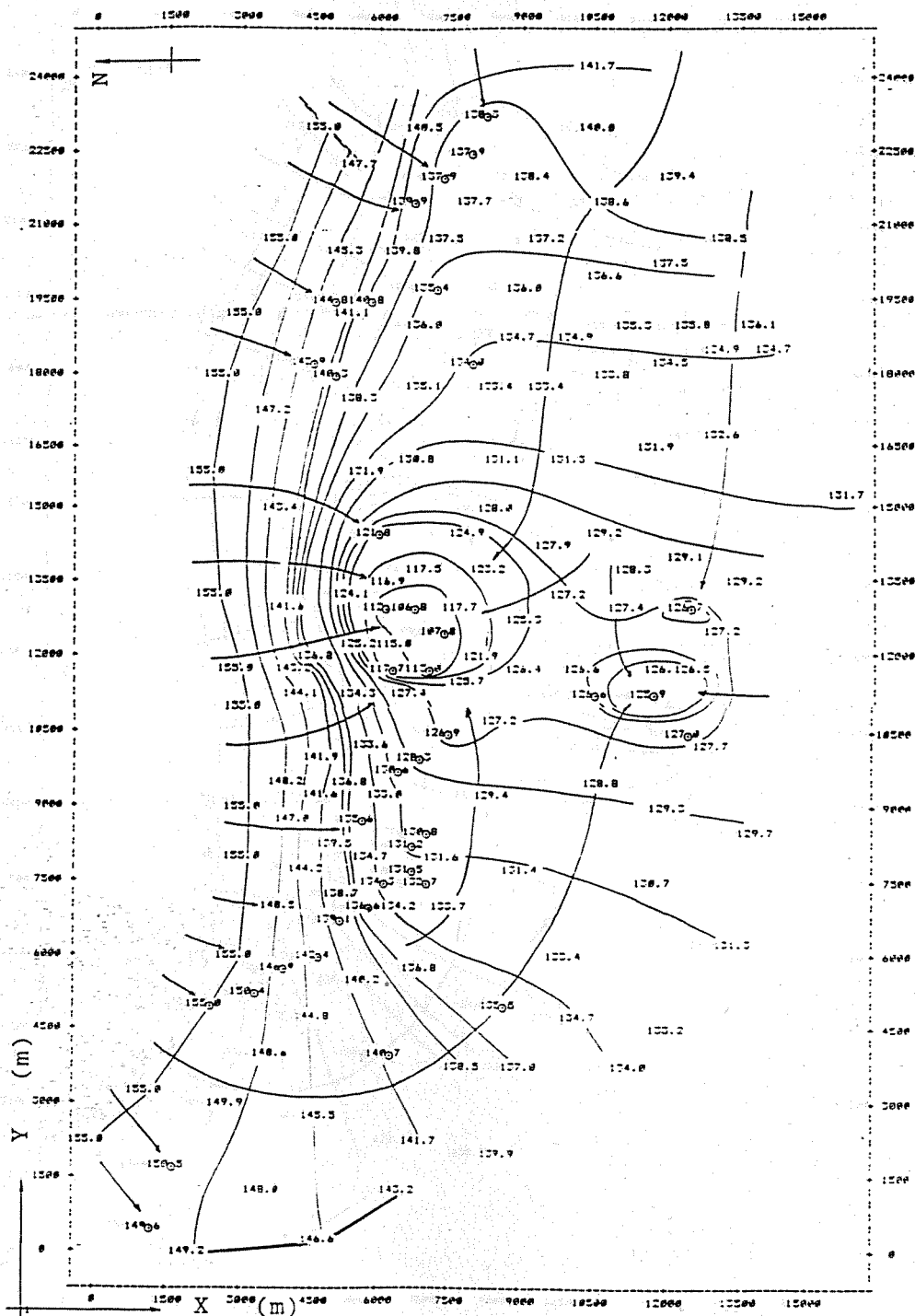


Figure App.A-3.4 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # A/2.1)
 TIME = 738.88888
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.

Case : A.2-2

Where: B_{aquifer} = 75 m.
 Q_{well} = Simulated.
 Time after 2 year.

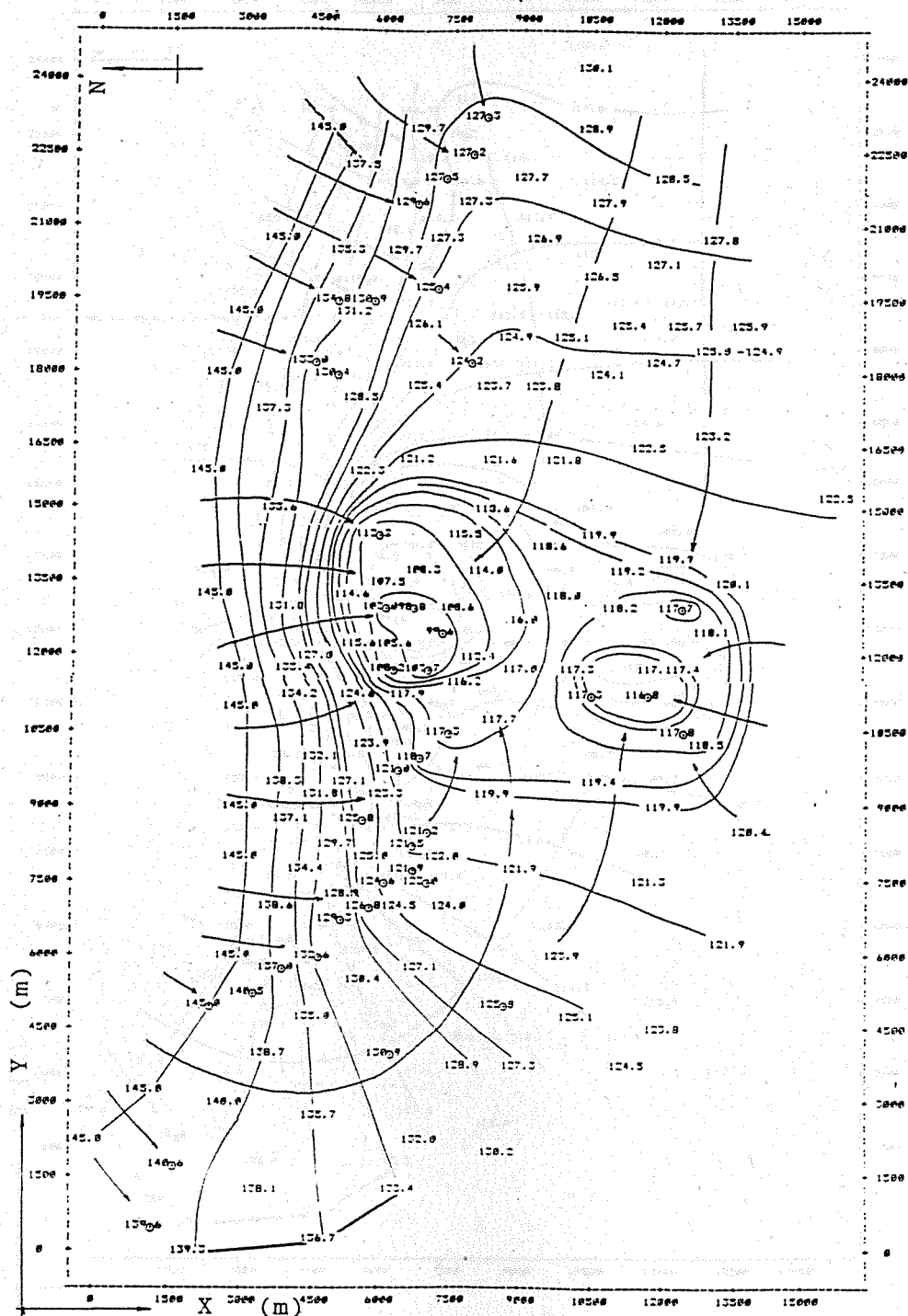


Figure App.A-3.5 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # 4/2)
 TIME = 1095.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : A.2-3

Where: B_{aquifer} = 75 m.
 Q_{well} = Simulated.
 Time after 3 year.

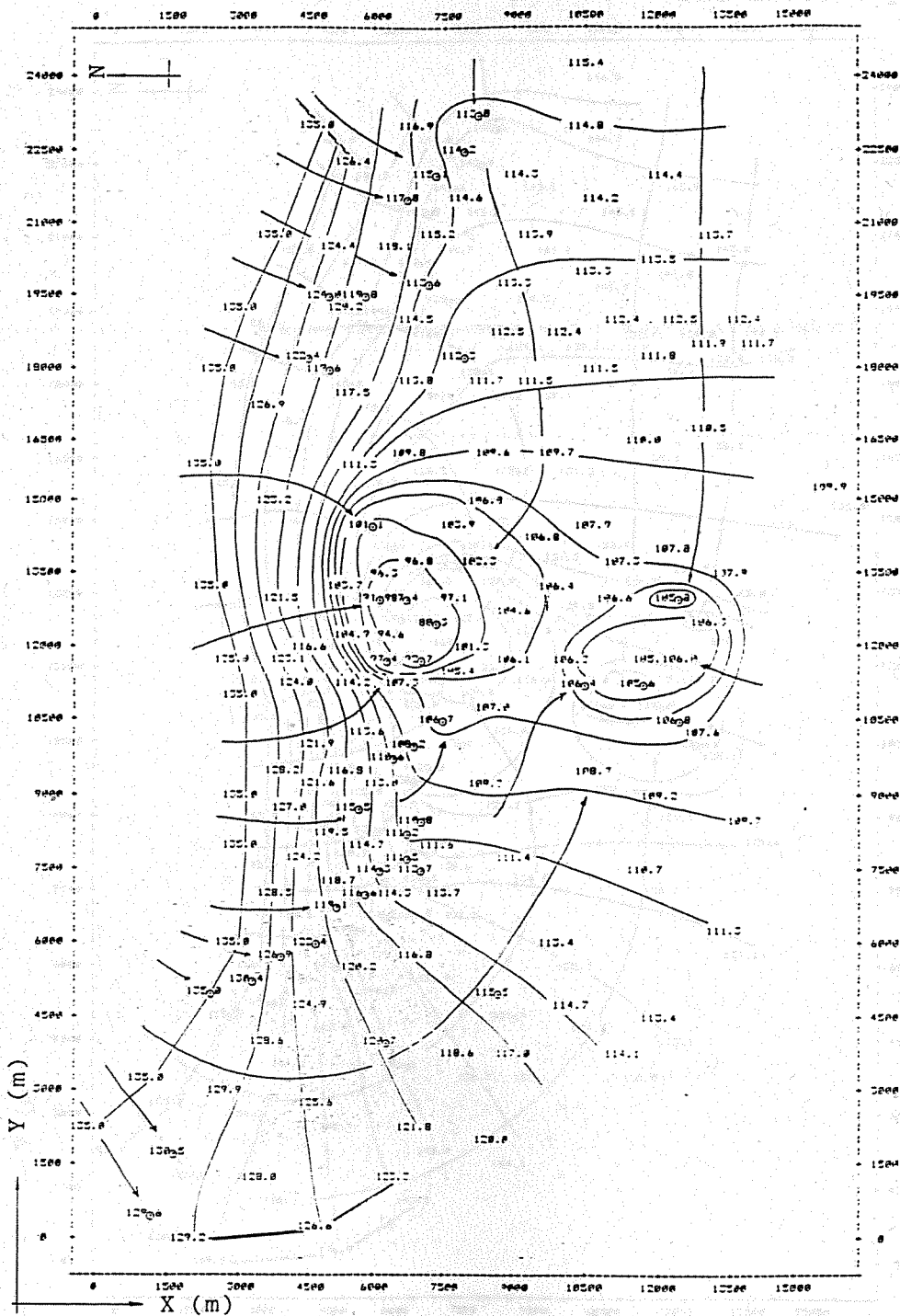


Figure App.A-3.6 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE B.1)
 TIME = 365.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.

Case : B.1-1

Where: $B_{aquifer}$ = 80 m.
 Q_{well} = Existing.
 Time after 1 year.

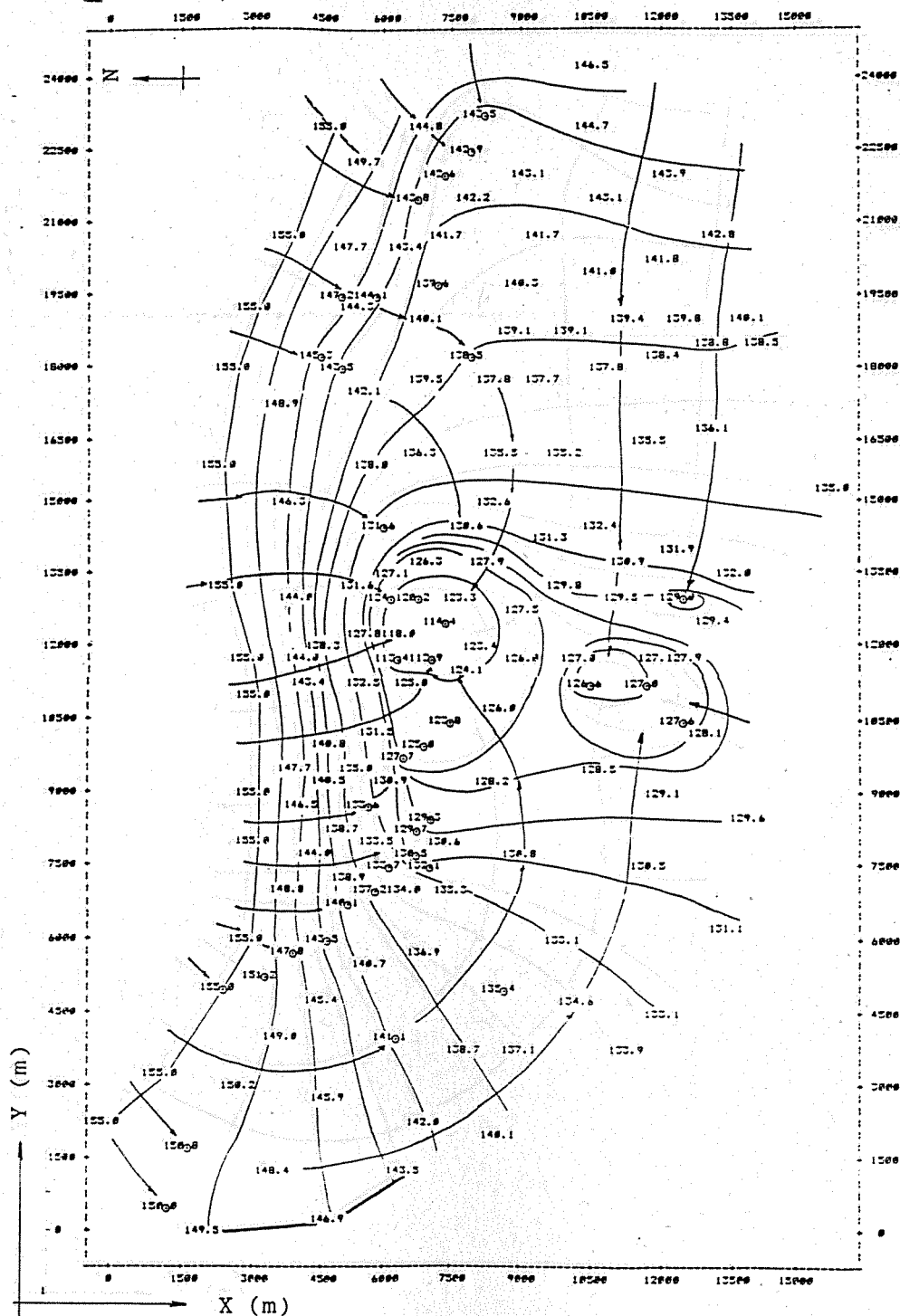


Figure App.A-3.7 : Plotted graph as the output of the application program.

1
A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE #3/1)
TIME = 739.88888
THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
SCALE : 1/ 60000.

Case : B.1-2

Where: $B_{aquifer} = 80 \text{ m.}$
 $Q_{well} = \text{Existing.}$
Time after 2 year.

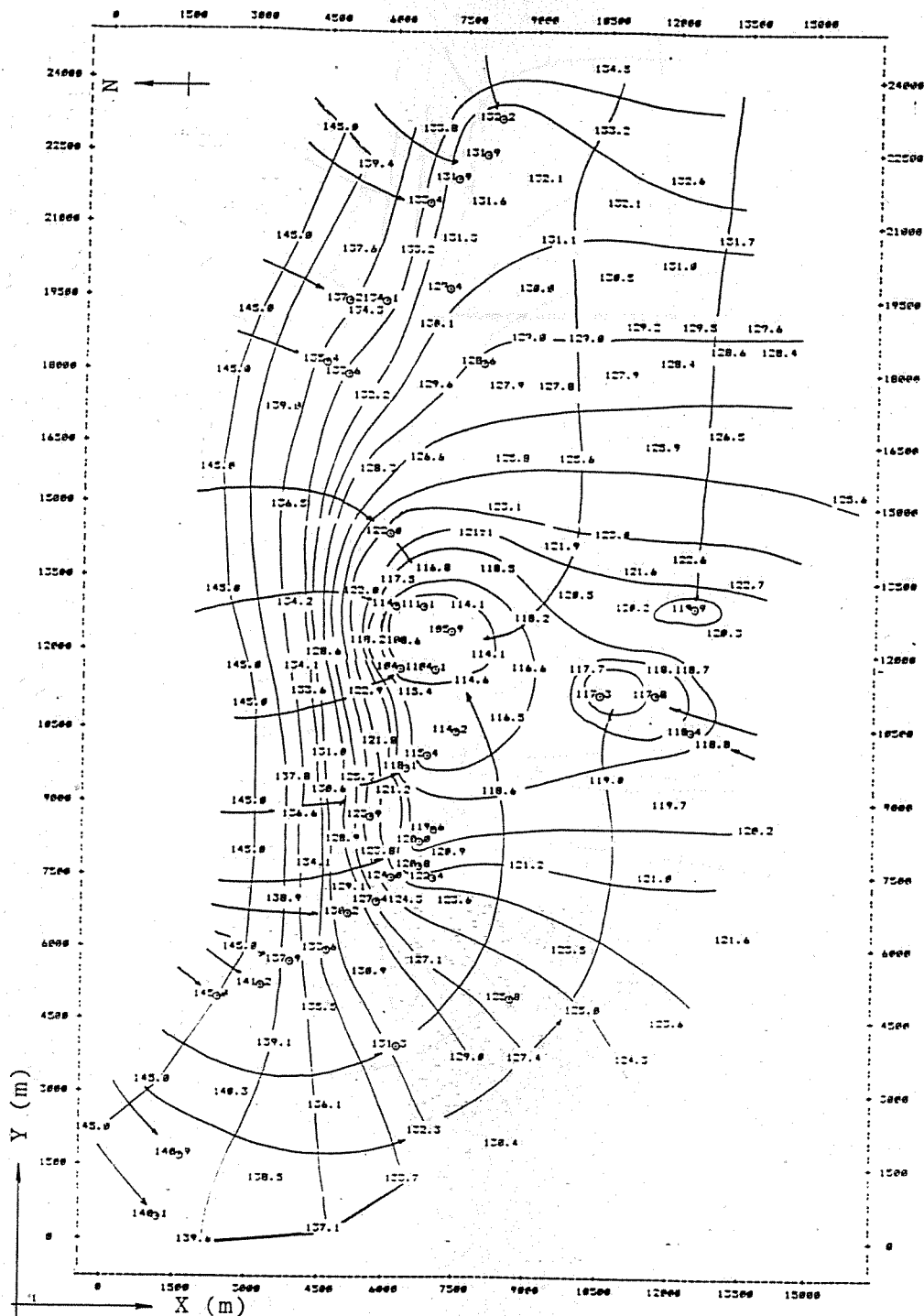


Figure App.A-3.8 : Plotted graph as the output of the application program.

Case : B.2-1
 Where: Baquifer = 80 m.
 Qwell = simulated.
 Time after 1 year.

Case : B.2-1

Where: Baquifer = 80 m.
 Qwell = simulated.
 Time after 1 year.

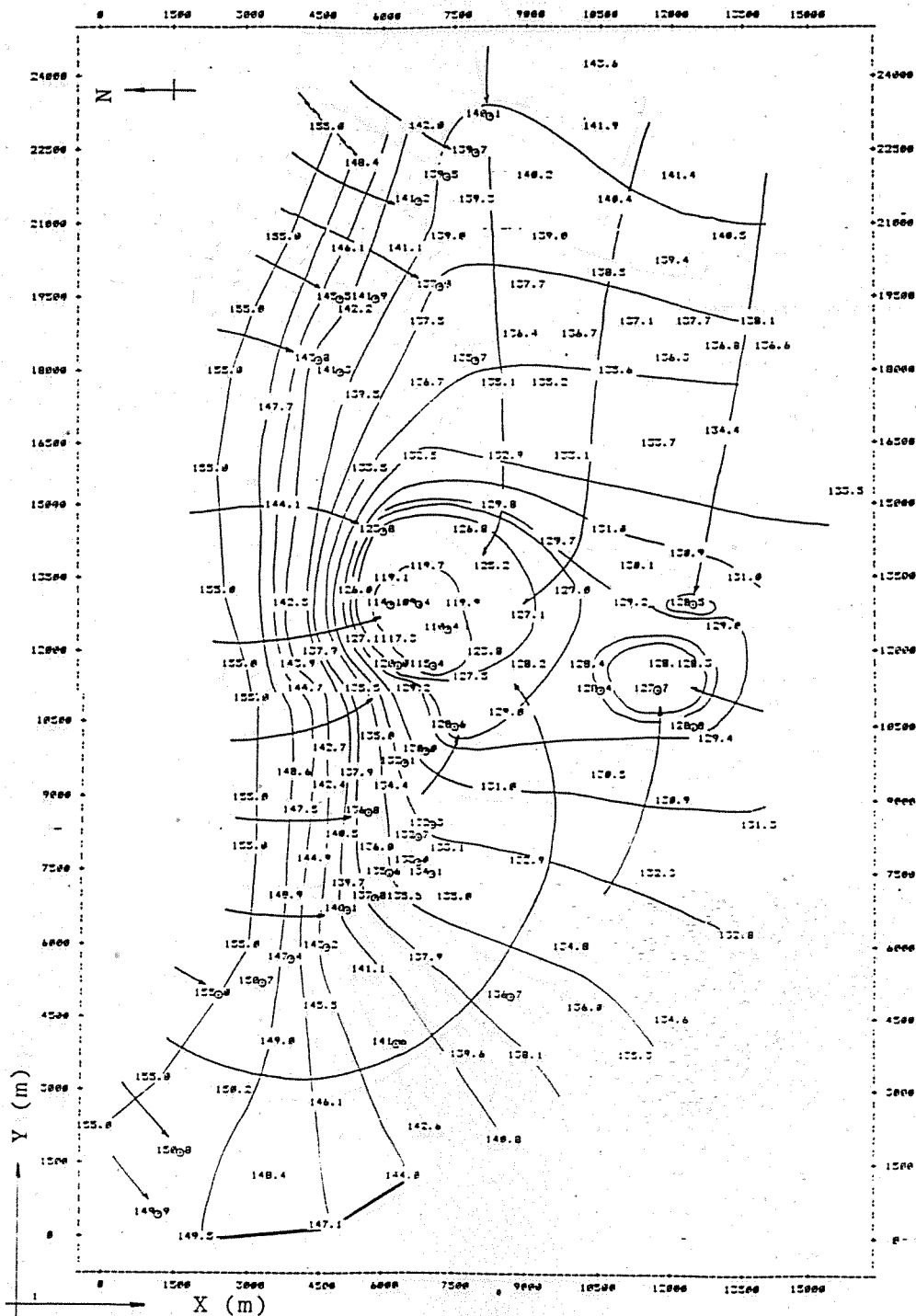


Figure App.A-3.10 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE B.2-2)
 TIME = 720.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE Y AXIS
 SCALE : 1/ 60000.

Case : B.2-2
 Where: B = 80 m.
 Q_{well} = Simulated.
 Time after 2 year.

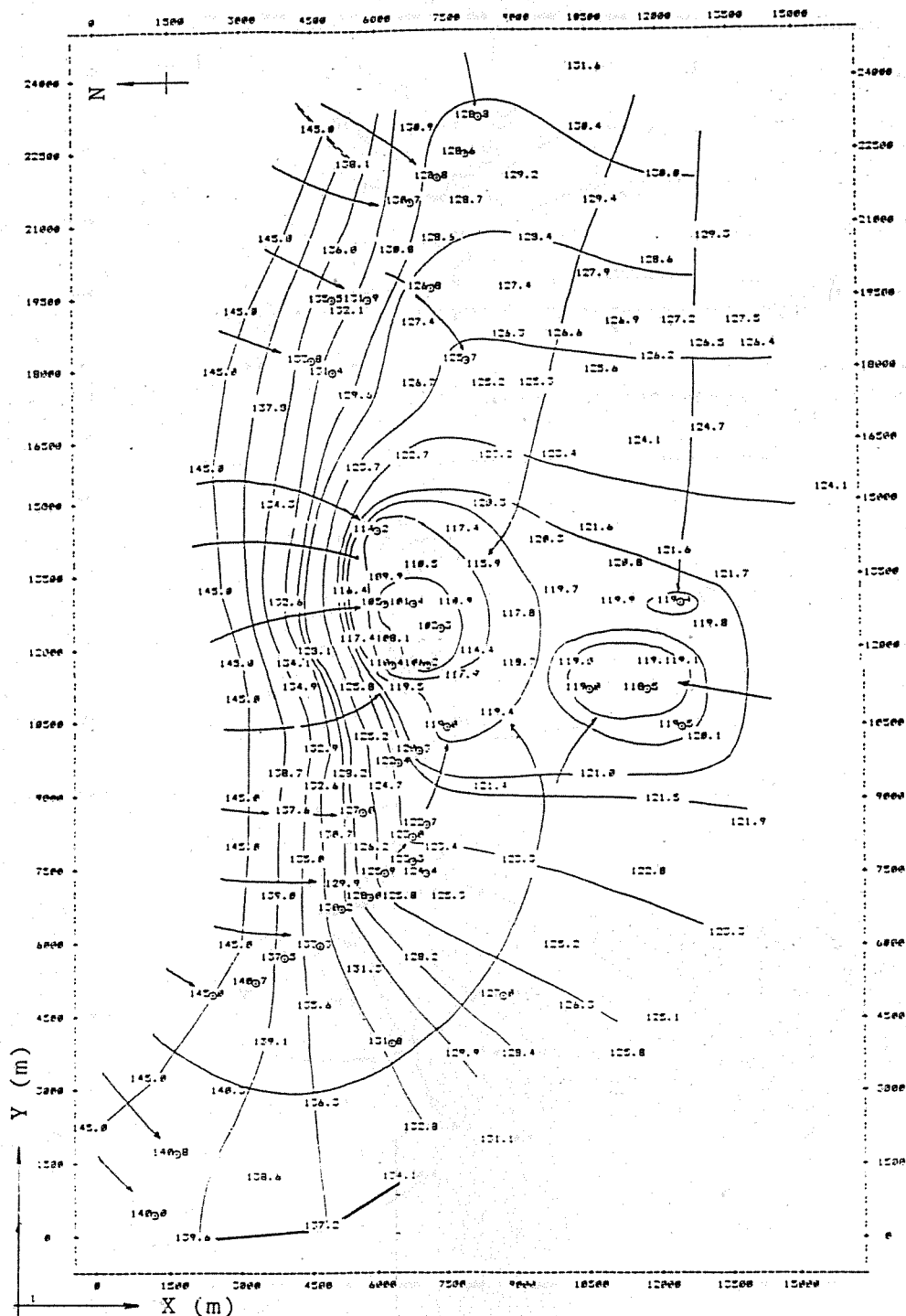


Figure App.A-3.11 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # 8/2)
 TIME = 1095.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : B.2-3
 Where: $B_{\text{aquifer}} = 80 \text{ m.}$
 $Q_{\text{well}} = \text{Simulated.}$
 Time after 3 year.

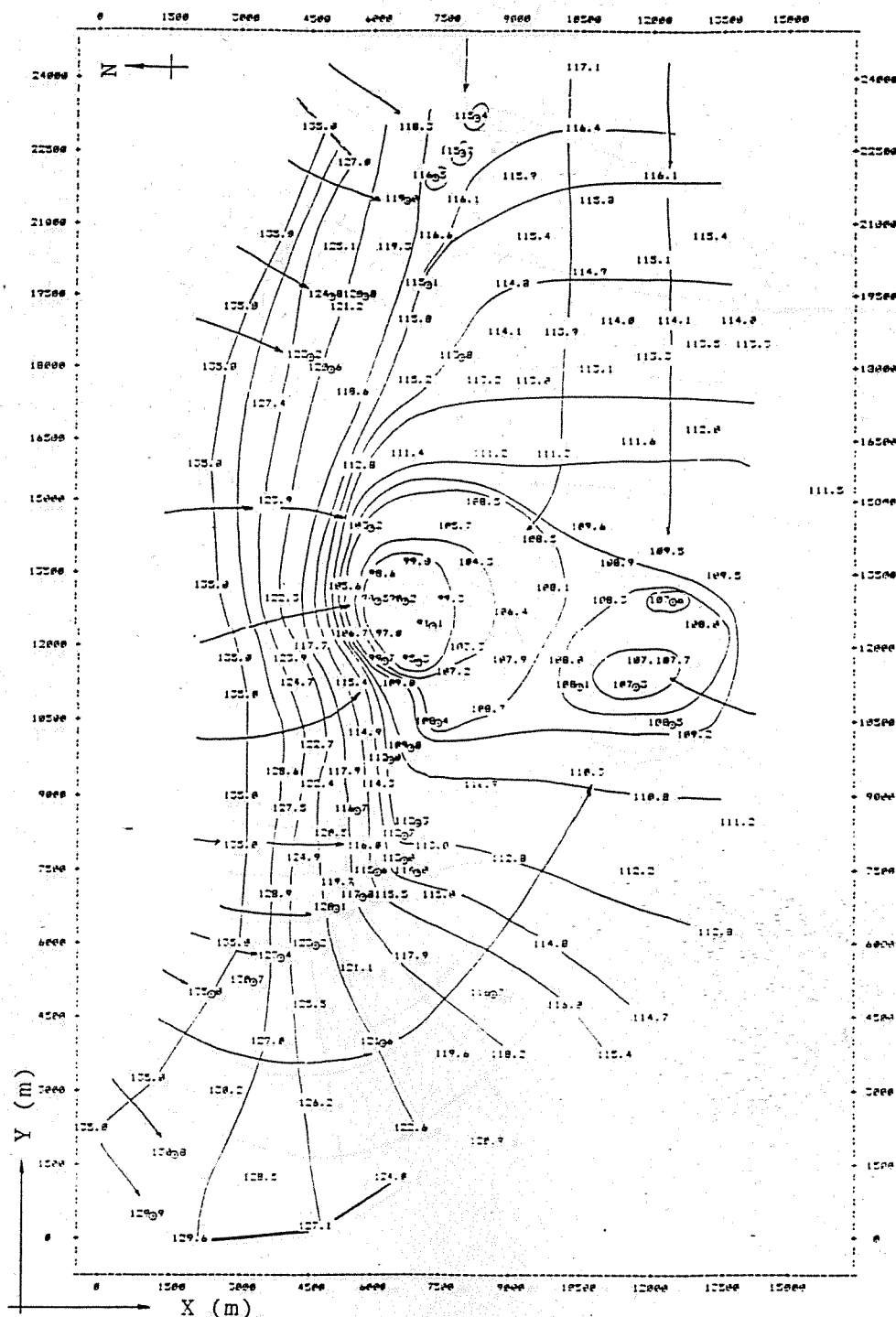


Figure App.A-3.12 : Plotted graph as the output of the application program.

1
A STUDY CASE OF GROUND WATER FLOW - SANDUNG AQUIFER (CASE # C/1)
TIME = 365.00000
THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
SCALE : 1 / 40000.

Case : C.1-1

Where: $B_{\text{aquifer}} = 90 \text{ m.}$
 $Q_{\text{well}} = \text{Existing.}$
Time after 1 year.

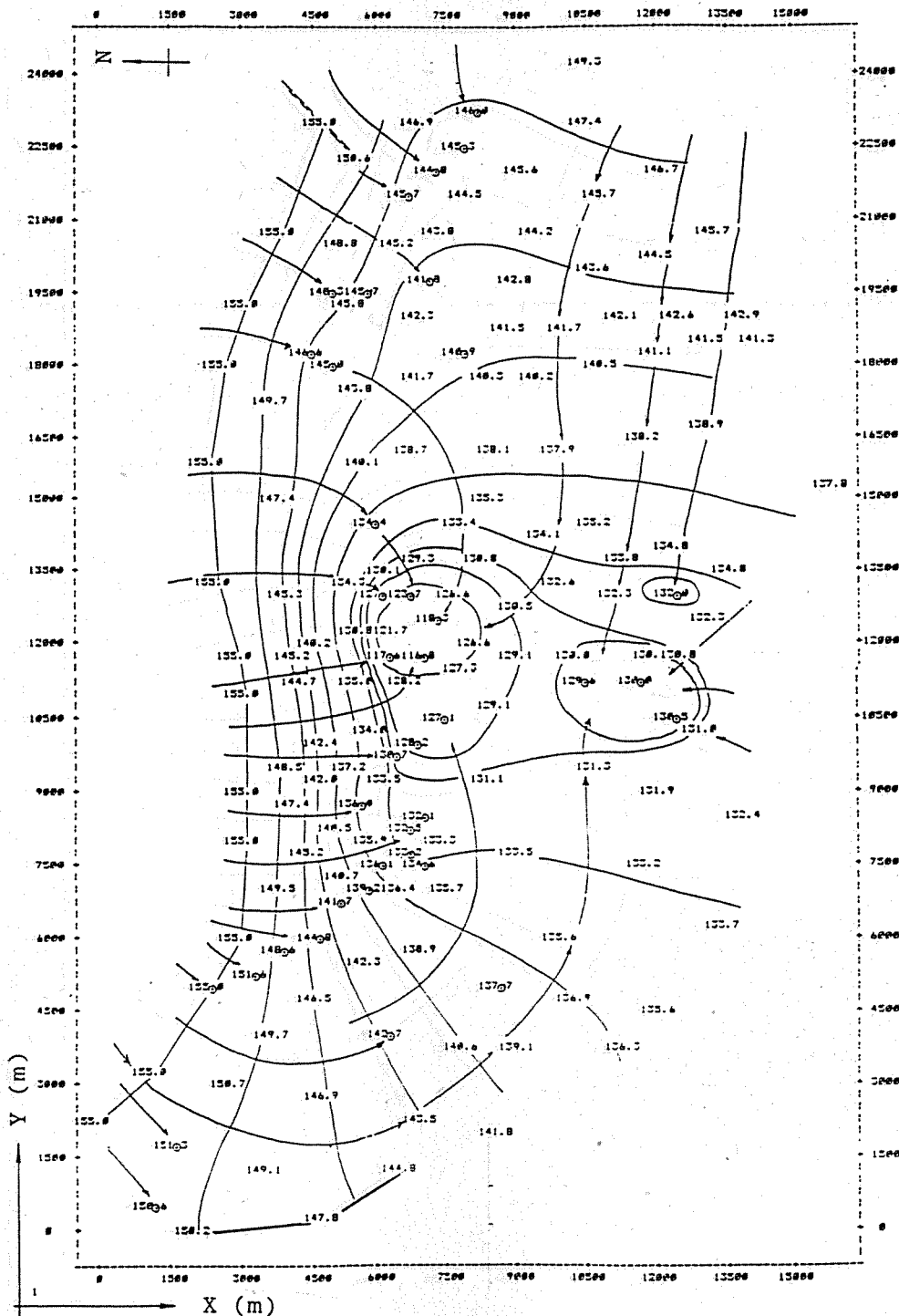


Figure App.A-3.13 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - SANDUNG AQUIFER (CASE # C/1)
 TIME = 728.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : C.1-2
 Where: B_{aquifer} = 90 m.
 Q_{well} = Existing.
 Time after 2 year.

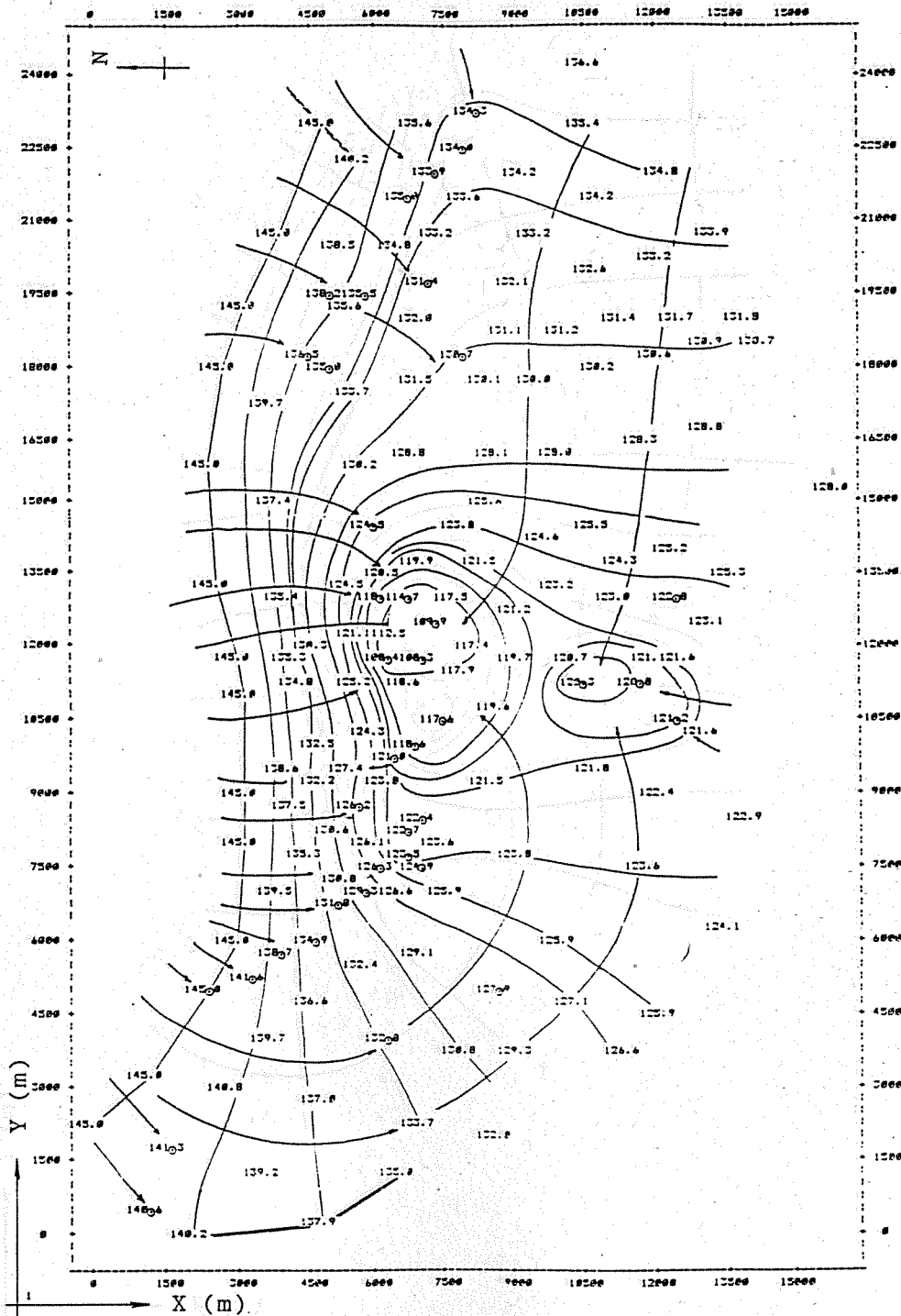


Figure App.A-3.14 : Plotted graph as the output of the application program.

STUDY OF GROUNDWATER FLOW - UNCONFINED AQUIFER (CASE # C.1)
 TIME = 1875.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1 / 40000.

Case : C.1-3
 Where: Baquifer = 90 m.
 Qwell = Existing.
 Time after 3 year.

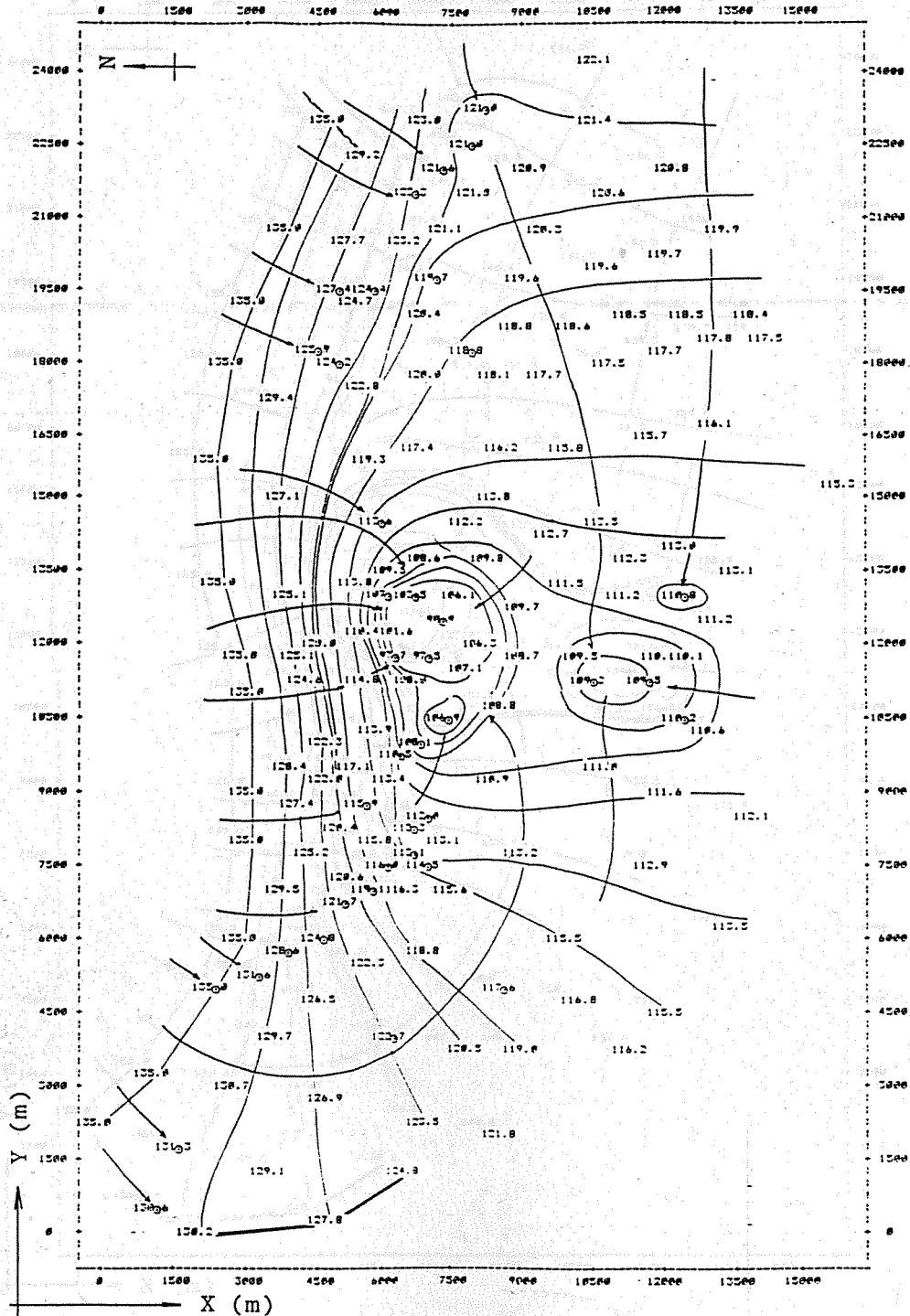


Figure App.A-3.15 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - PANDUNG AQUIFER (CASE # C/2)
 TIME = 365.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.

Case : C.2-1
 Where: $B_{\text{aquifer}} = 90 \text{ m.}$
 $Q_{\text{well}} = \text{Simulated.}$
 Time after 1 year.

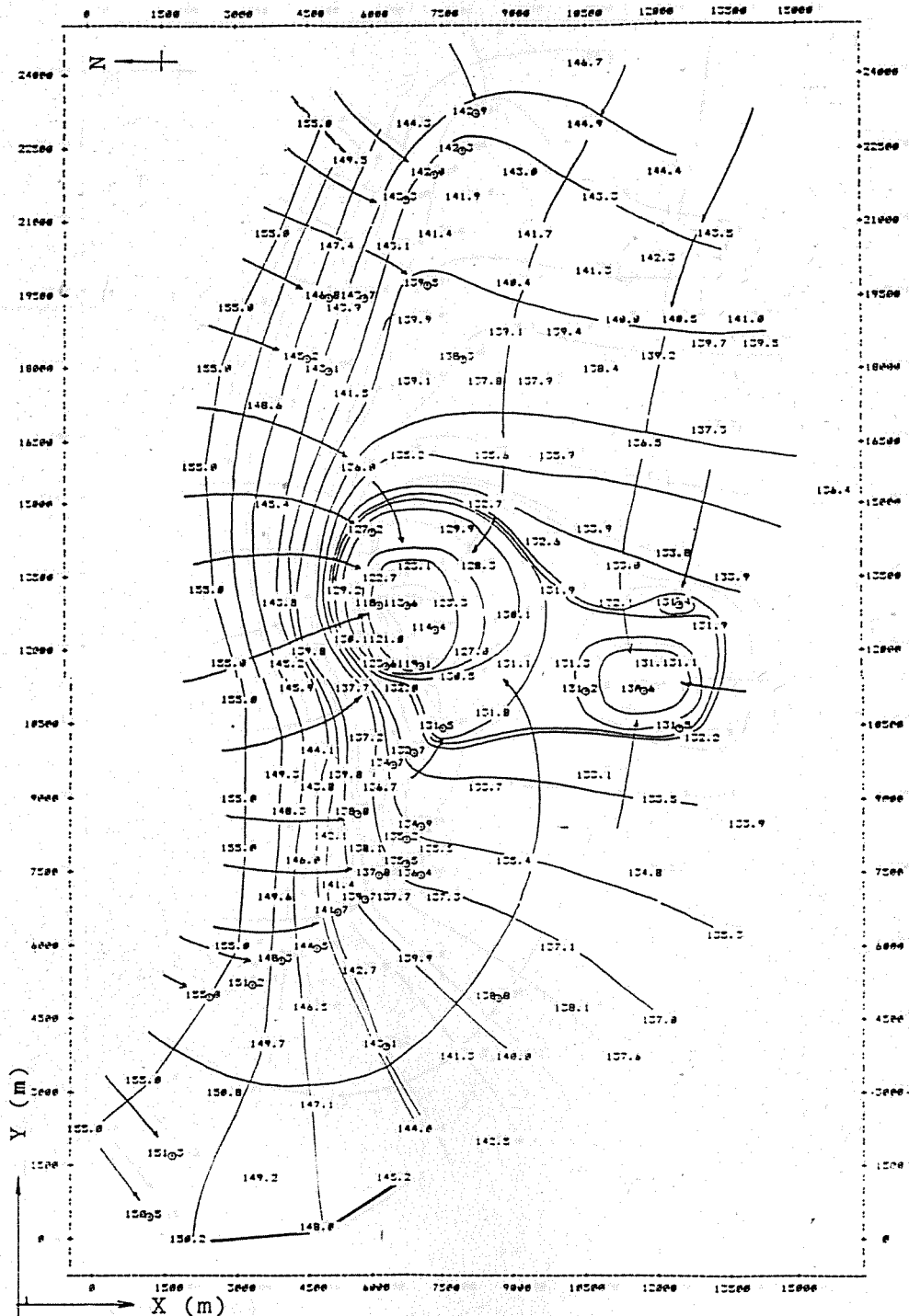


Figure App.A-3.16 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # C.2)
 TIME = 720.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.

Case : C.2-2

Where: Baquifer = 90 m.
 Qwell = Simulated.
 Time after 2 year.

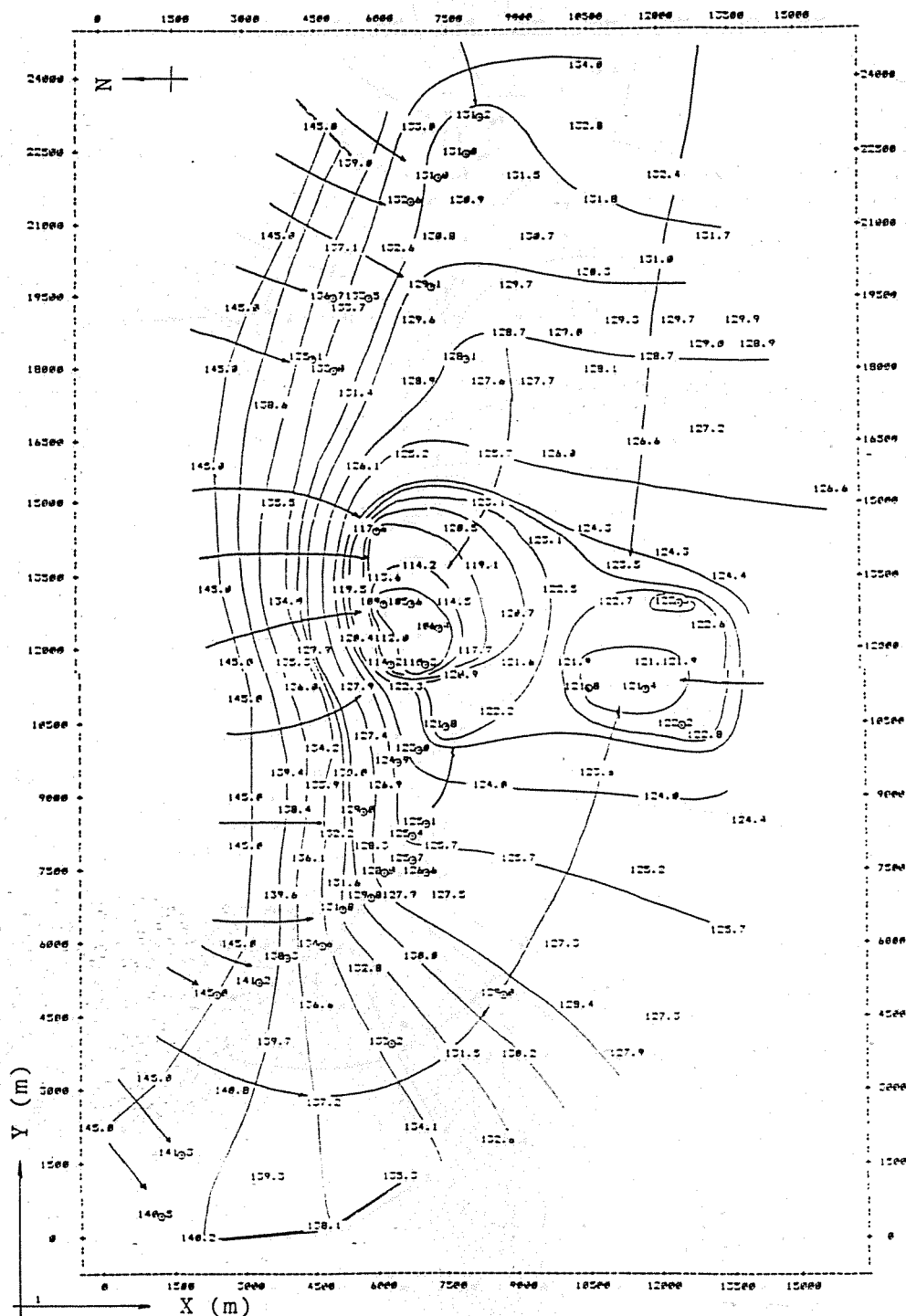


Figure App.A-3.17 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # C/2)
 TIME = 1095.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1 / 60000.

Case : C.2-3

Where: B aquifer = 90 m.
 Q_{well} = simulated.
 Time after 3 year.

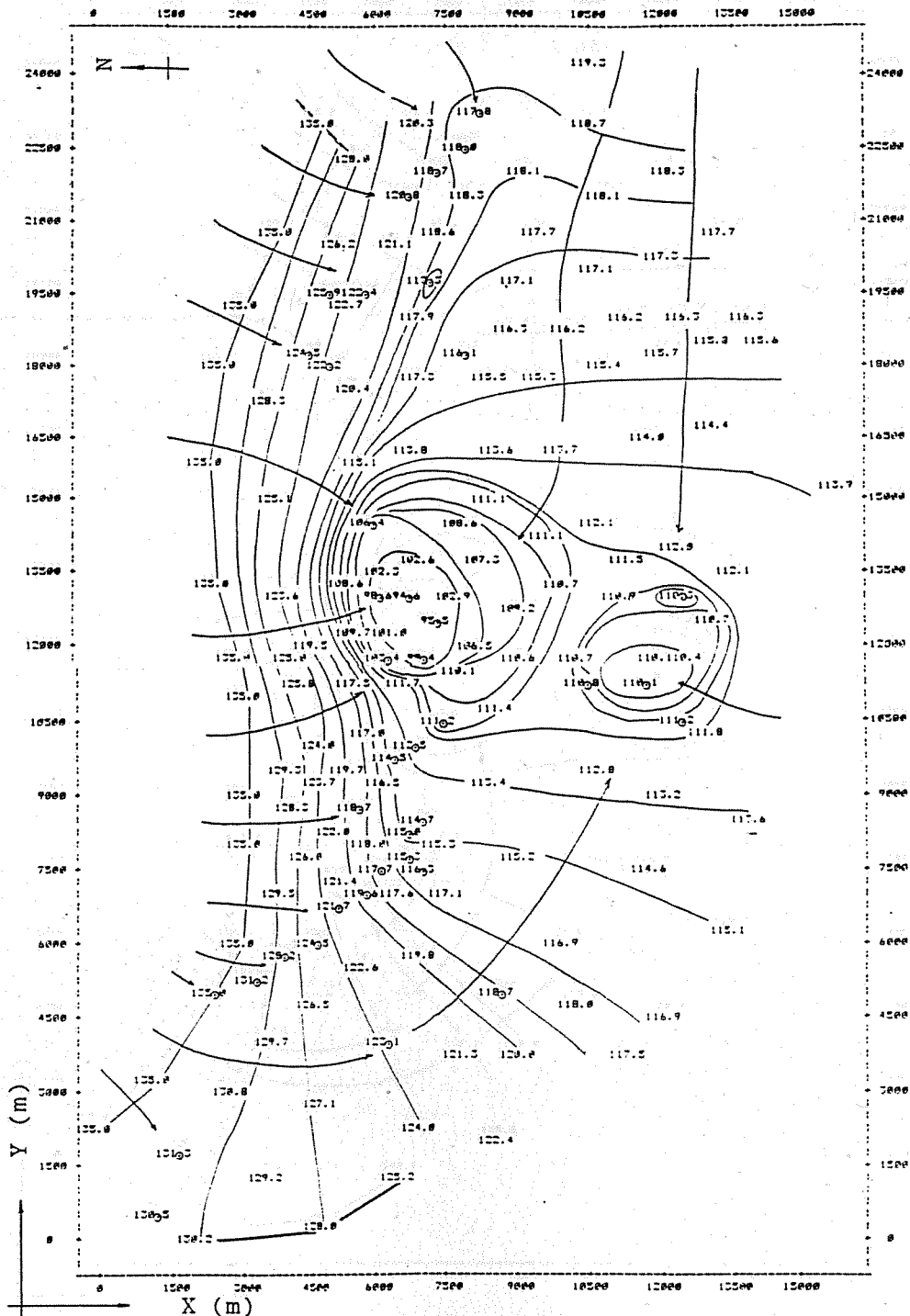


Figure App.A-3.18 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE # D/1)
 TIME = 365.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : D.1-1
 Where: $B_{\text{aquifer}} = 75 \text{ m.}$
 $Q_{\text{well}} = \text{Existing.}$
 Time after 1 year.

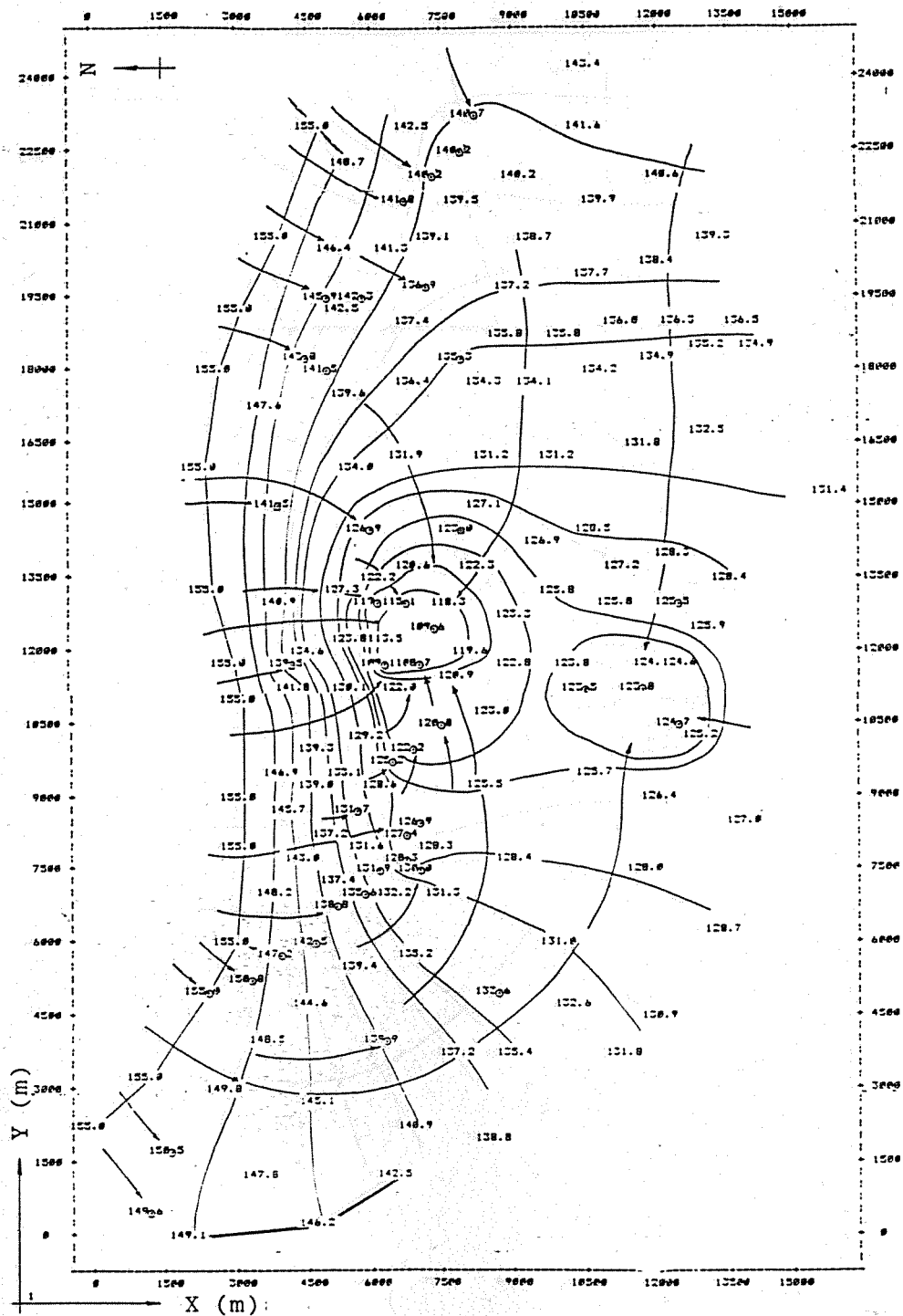
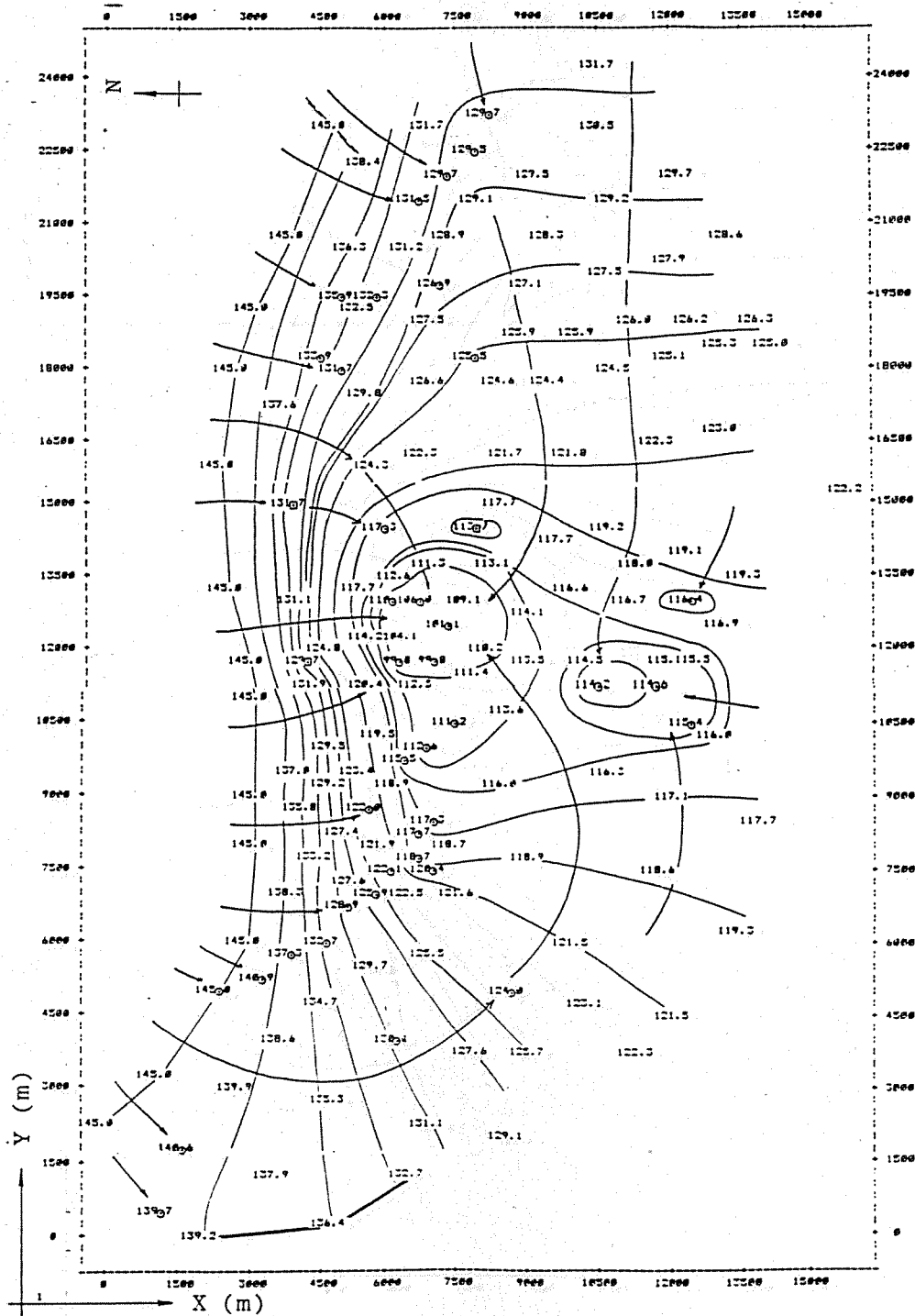


Figure App.A-3.19 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (CASE : D.1/1)
 TIME = 739.99999
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : D.1-2
 Where: $B_{\text{aquifer}} = 75 \text{ m.}$
 $Q_{\text{well}} = \text{Existing.}$
 Time after 2 year.



1
A STUDY CASE OF GROUND WATER FLOW - SANDUNG AQUIFER (CASE # D/1)
TIME = 1895.00000
THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
SCALE : 1/ 40000.

Case : D.1-3

Where: Baquifer = 75 m.
Qwell = Existing.
Time after 3 year.

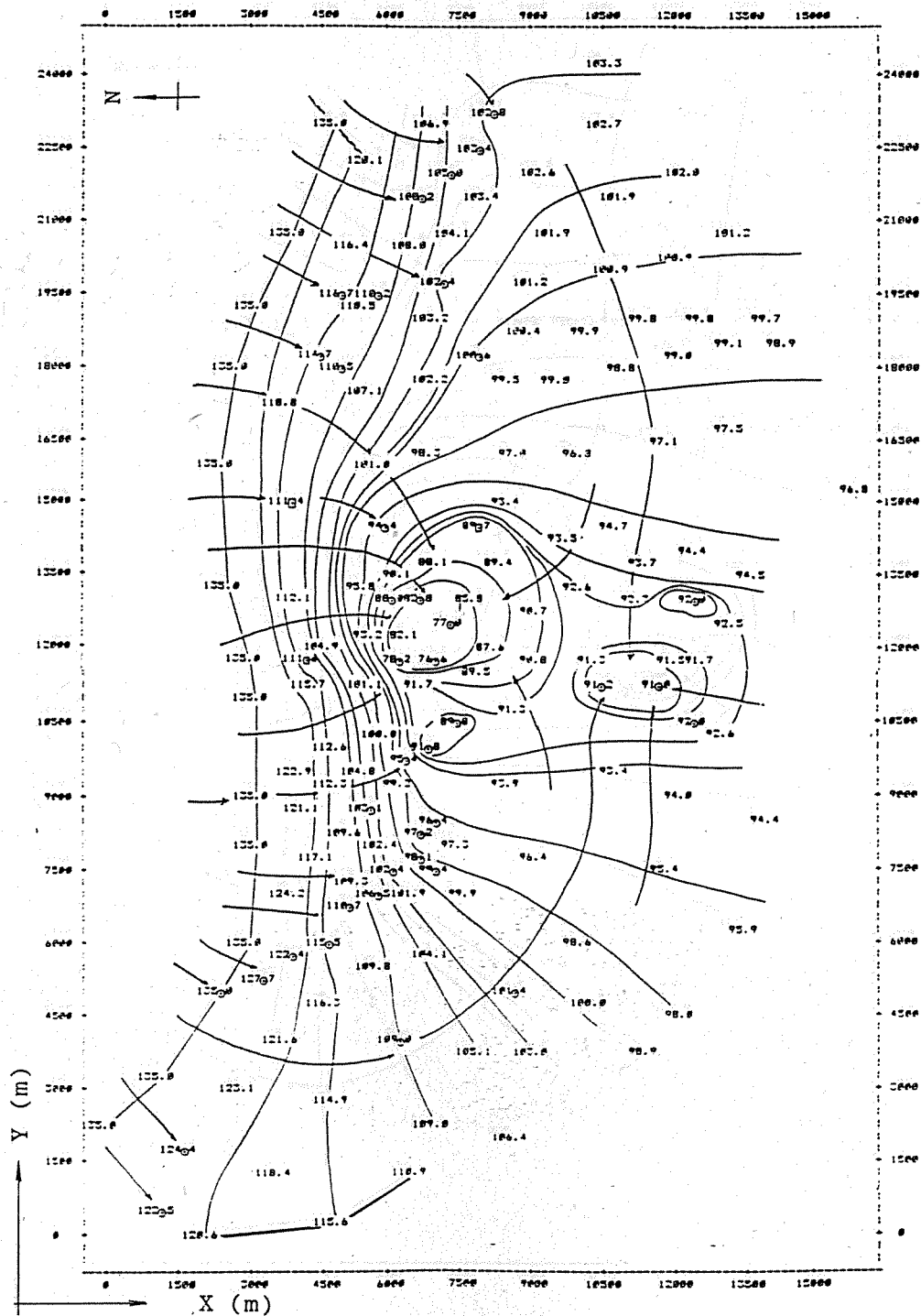


Figure App.A-3.21 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # D/2)
 TIME = 365.000000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.

Case : D.2-1
 Where: B_{aquifer} = 75 m.
 Q_{well} = Simulated.
 Time after 1 year.

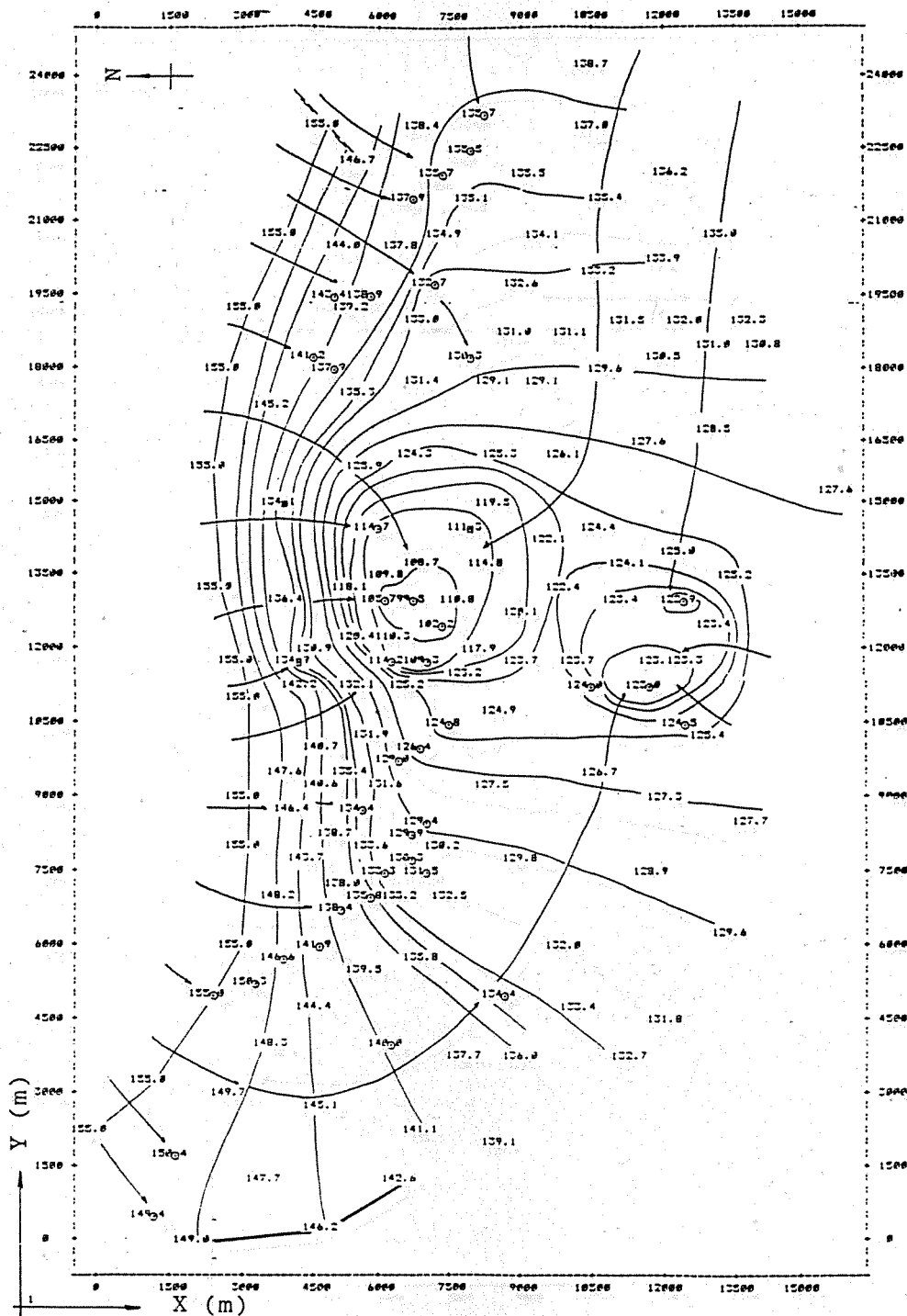


Figure App.A-3.22 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANGUNG AQUIFER (CASE # 0/2)
 TIME = 736.64400
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 66666.

Case : D.2-2

Where: $B_{\text{aquifer}} = 75 \text{ m.}$
 $Q_{\text{well}} = \text{simulated.}$
 Time after 2 year.

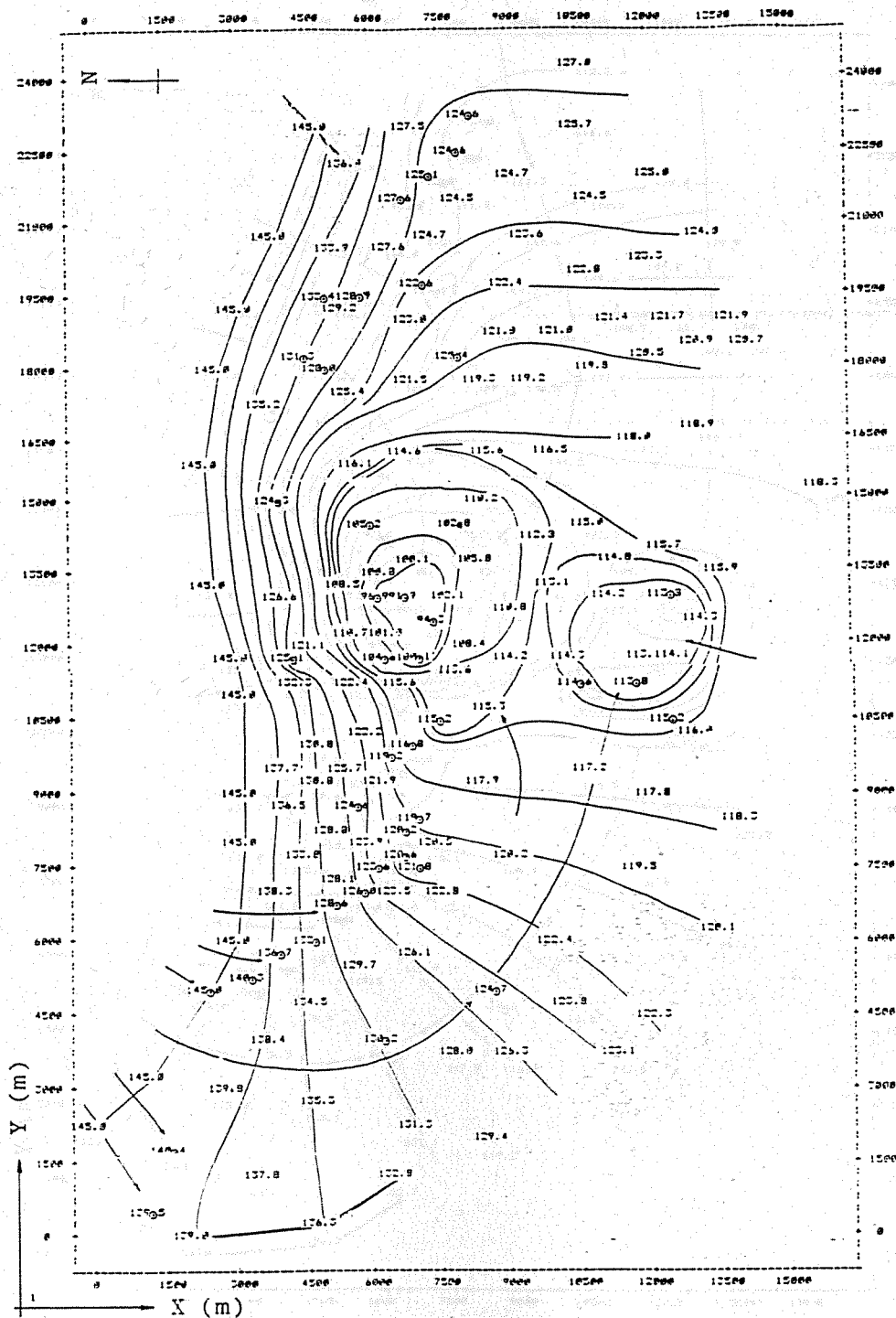


Figure App.A-3.23 : Plotted graph as the output of the application program.

A STUDY CASE OF GROUND WATER FLOW - BANDING AQUIFER (CASE # D/2)
 TIME = 1895.00000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.

Case : D.2-3
 Where: B_{aquifer} = 75 m.
 Q_{well} = Simulated.
 Time after 3 year.

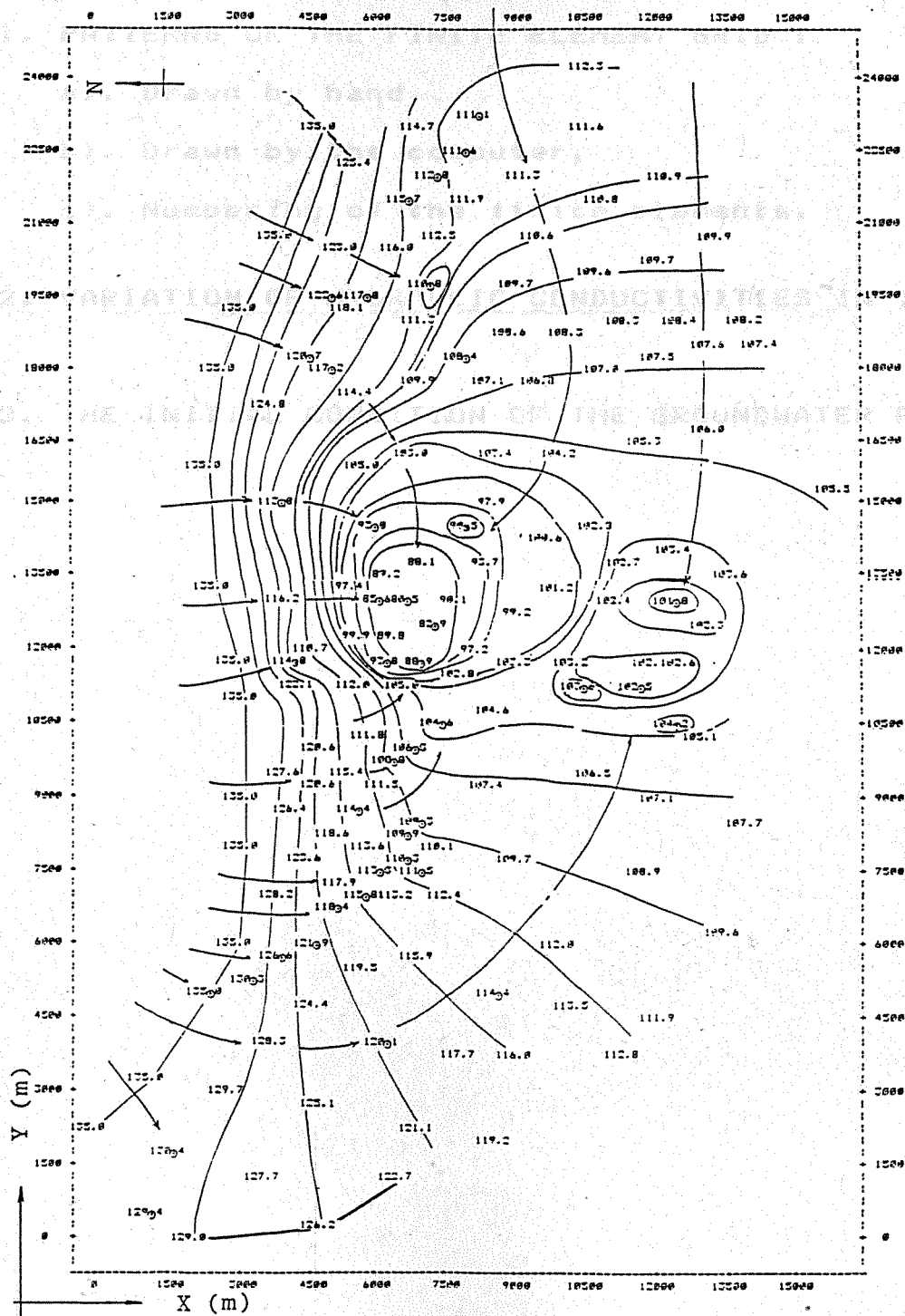
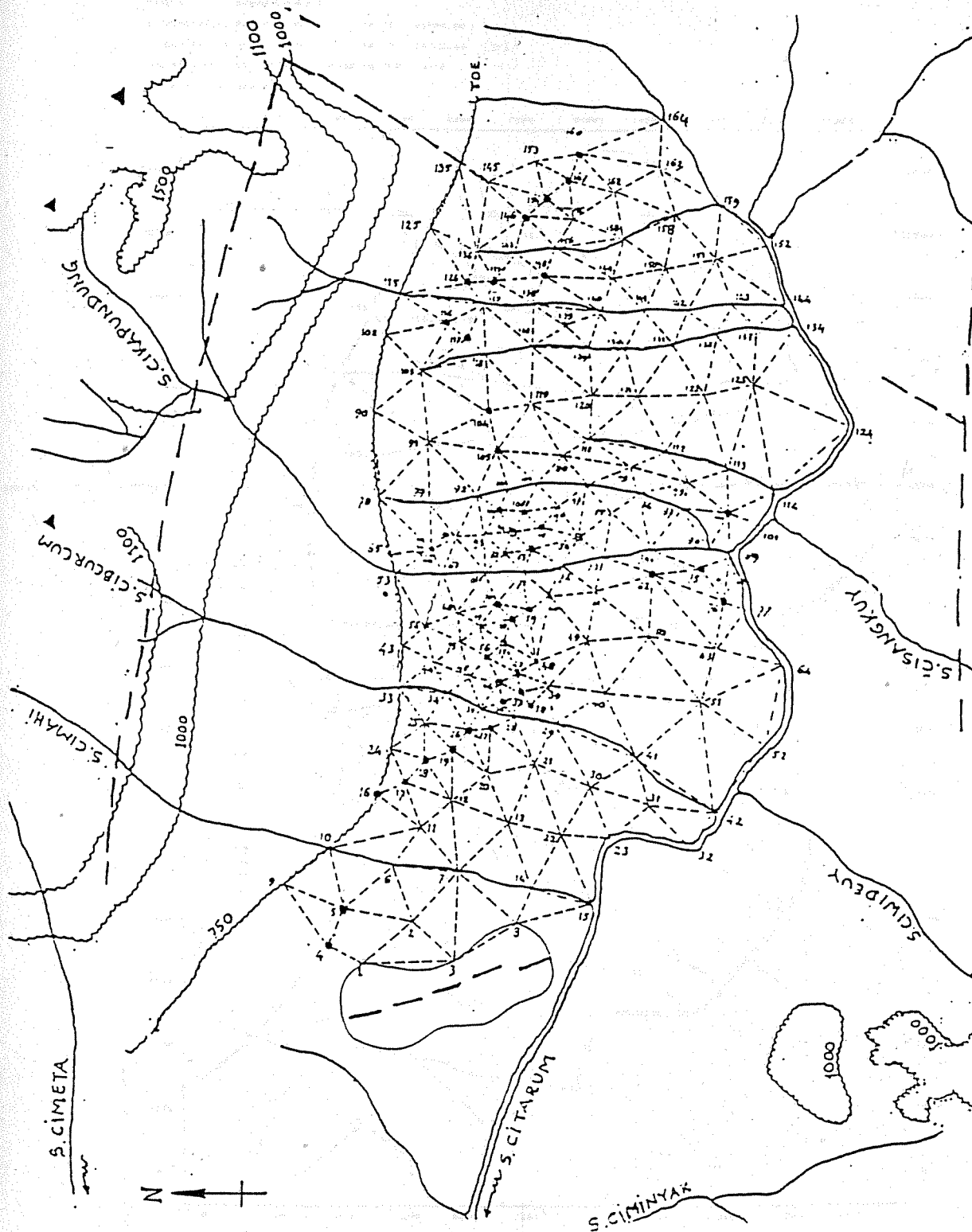


Figure App.A-3.24 : Plotted graph as the output of the application program.

B

- B.1. PATTERNS OF THE FINITE ELEMENT GRID :
 - a). Drawn by hand,
 - b). Drawn by the computer,
 - c). Numbering of the finite elements.
- B.2. VARIATION OF HYDRAULIC CONDUCTIVITIES IN THE F.E.
GRID.
- B.3. THE INITIAL CONDITION OF THE GROUNDWATER FLOW.

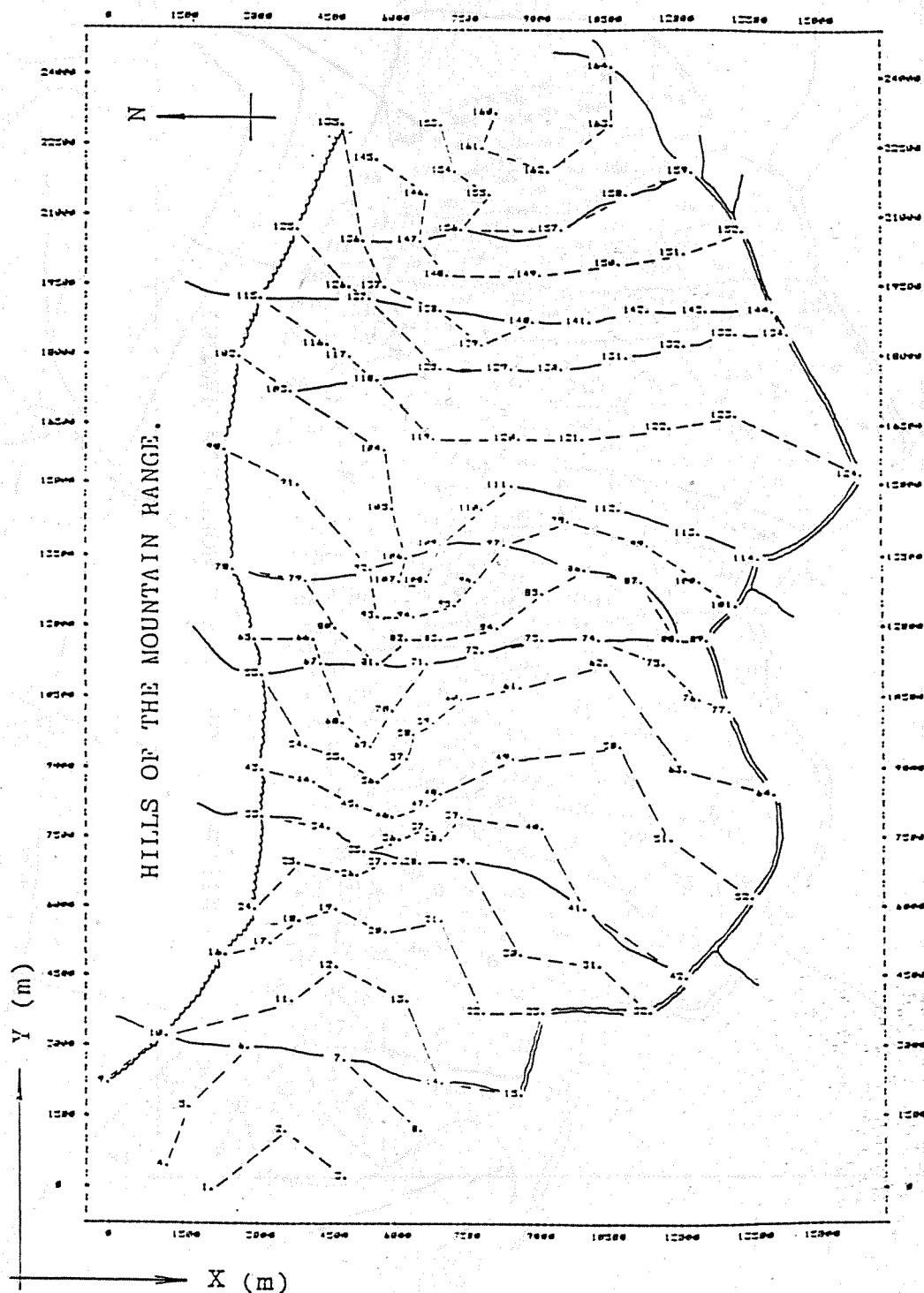


Legend

-  - River
-  - Mountain
-  - Wells
-  - Side of grids

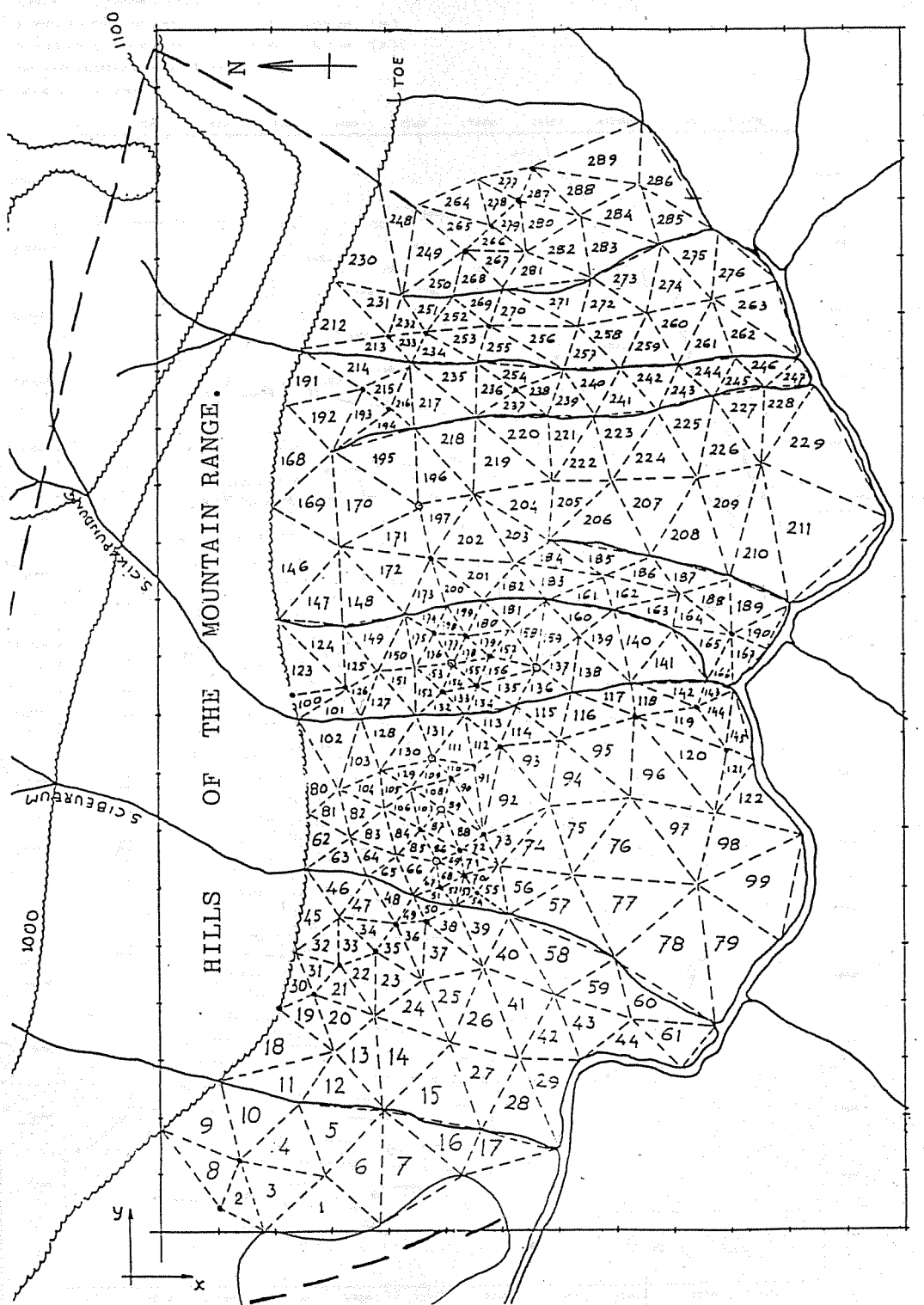
Figure App.B-1: The pattern of the F.E Grids by hand writing.

A STUDY CASE OF GROUND WATER FLOW - SANDHOLE AQUIFER - (SEE NUMBERS OF THE F.E. GRIDS)
 TIME = .00000 (day)
 X COORDINATES RANGE FROM .00 TO 12500.00 (m)
 Y COORDINATES RANGE FROM .00 TO 24000.00 (m)
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1 / 40000.



Note : The location of dots denote the location of nodes.
 All lines are drawn by hand.

Figure App.B-2: The pattern of the F.E Grids from the computer output.



Legend

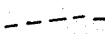
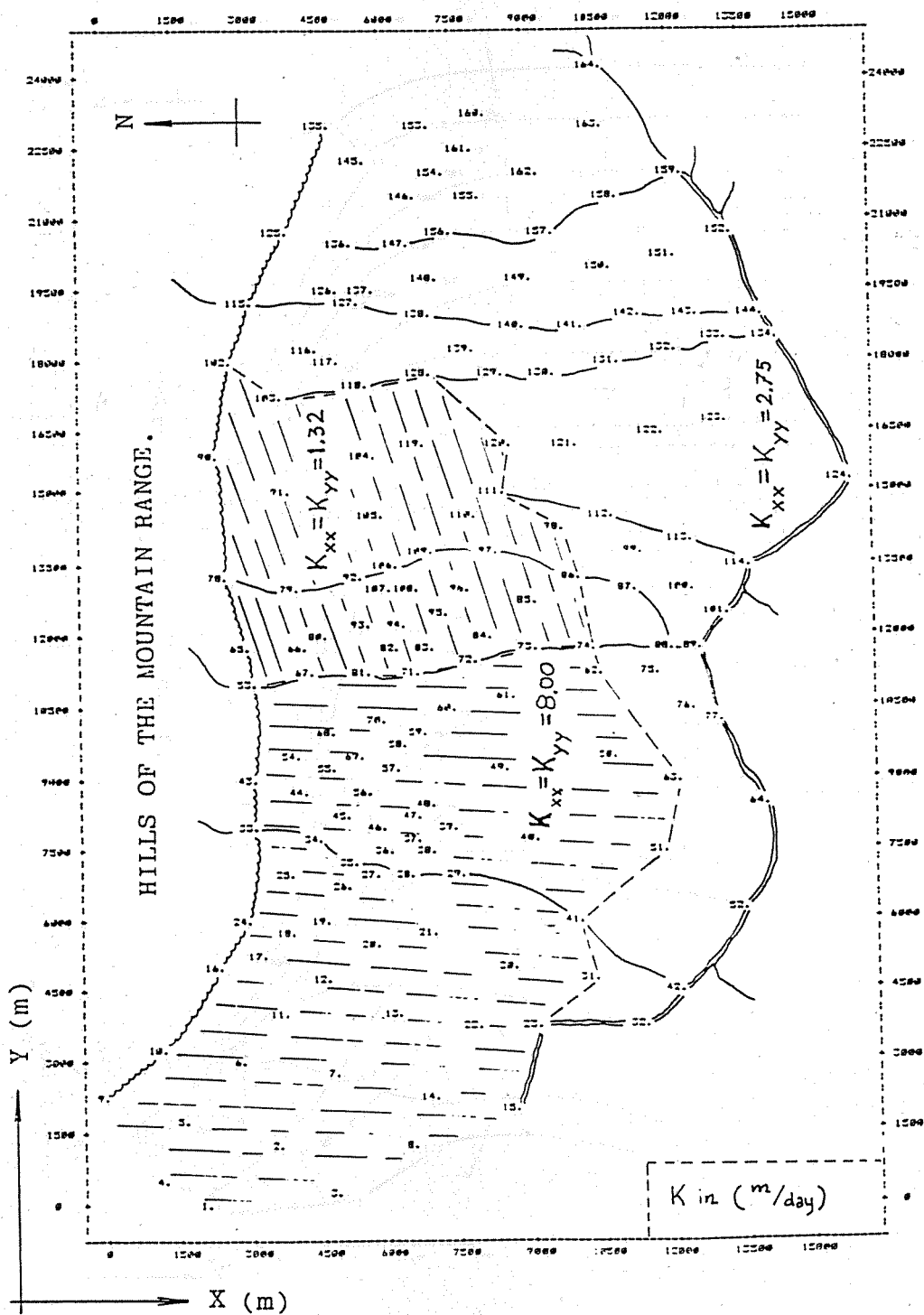
-  - River
-  - Contour
-  - Wells
-  - Side of grids

Figure App.B-3: The Elements Numbering Of The Grids.

A STUDY CASE OF GROUND WATER FLOW - BANDUNG AQUIFER (NODE NUMBERS OF THE F.E. GRIDS)
 TIME = .00000 (day)
 X COORDINATES RANGE FROM .00 TO 13999.00 (m)
 Y COORDINATES RANGE FROM .00 TO 24222.00 (m)
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 60000.



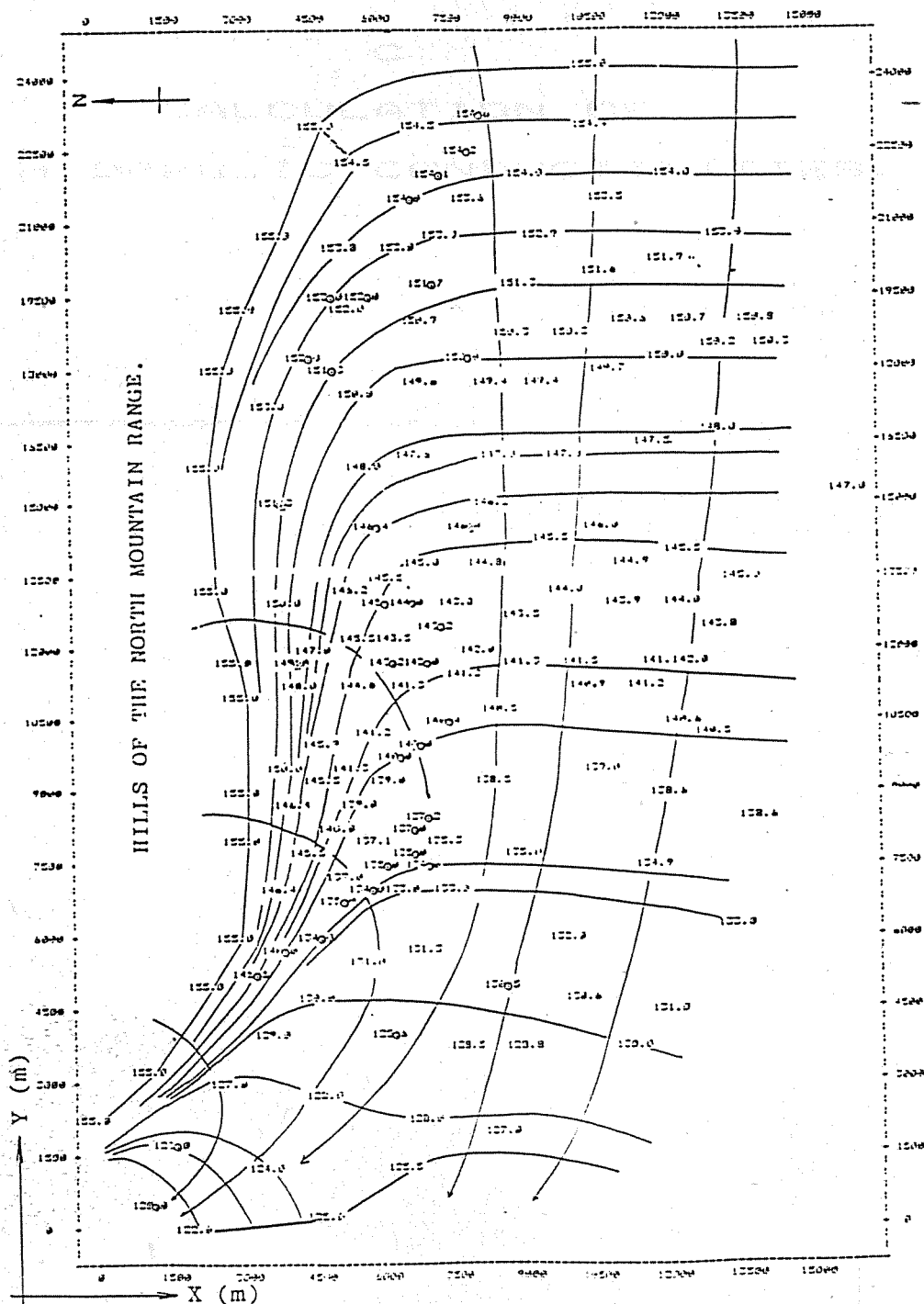
Legend

- River

17. - Node number

Figure App.B-4: Variation In Hydraulic Conductivities

A STUDY CASE OF GROUNDWATER FLOW - DRAINING AQUIFER
 TIME = 10000
 THE AXIS PLOTTED ACROSS THE PAGE IS THE X AXIS
 SCALE : 1/ 40000.



Legend

155.0 - Hydraulic head,
 — Equipotential line, - Flow line.

Figure App.B-5: The Initial Condition Of Groundwater Flows.

C
CALCULATION OF
HYDRAULIC CONDUCTIVITIES.

**CALCULATION OF THE VALUE OF THE HYDRAULIC CONDUCTIVITY
OF EVERY GEOLOGIC FORMATION
OF THE AQUIFER**

A. General.

The value of the hydraulic conductivity of an aquifer could be found from pumping test from many wells in a certain field investigation which might represent that aquifer, or from permeability tests which could be done on samples in a laboratory. But, the result from laboratory is not as good as from field tests. The reason is that the condition of the sample for the laboratory test is disturbed.

There is more than one method for doing the pumping test, such as pumping out test (or Pecker test), pumping in test; and also there is more than one formula to find the value of the hydraulic conductivity which should be related with the type of the aquifer being tested (unconfined or confined, leaky or not leaky). These formulas consist of Theis, Hantush, Hantush and Jacob, Walton, and approximate Theis.

To know the value of the hydraulic conductivity for xx or yy directions, the observation wells should be more than two (four is better) and the system should be arranged as such so the test well is located on the center and the observation wells are surrounding it perpendicularly between

each other. If the drawdown in all observation wells are equal, these mean that $K_{xx} = K_{yy}$, otherwise, $K_{xx} \neq K_{yy}$.

B. Hydraulic Conductivity for the program application.

It could be seen that the aquifer in the study area consists of five types of geologic formations, namely :

- Tuffs and Ashes on the North-West side,
- Tuffs, Tuffbreccias, Lava Flows on the North-East side,
- Tuffs and Mudflows on the center part,
- Volcanic and crystalline formation on the West side, and
- Lake deposits on the East side and turn to the South side.

The data of the hydraulic conductivities for the study area is presented on table App.B.1 below.

Table App.B.1 : The Aquifers' Parameters Of Each Wells.

WELLS	$K_{xx} = K_{yy}$ (m/day)	Thickness (m)	$T_{xx} = T_{yy}$ (m ² /day)	Storativity ()	Type of the aquifer
AW 1	1.71	70	120	$2.5 \times 10^{**}(-3)$	The East side of eruption period A
AW 2	1.46	70	102	$2.0 \times 10^{**}(-4)$	
AW 3	1.36	80	108	$8.0 \times 10^{**}(-4)$	
AW 4	1.10	80	88	$3.0 \times 10^{**}(-4)$	
AW 5	2.70	80	216	$9.0 \times 10^{**}(-3)$	
AT 1	0.50	80	40	$2.0 \times 10^{**}(-5)$	The Center part of Tuffs and Mudflows, G.Tk.Perahu eruption period A
AW 6	6.70	100	670	$1.0 \times 10^{**}(-3)$	
AW 7	8.36	100	836	$1.0 \times 10^{**}(-2)$	
AW 8	12.19	70	853	-	
AW 9	7.74	70	542	$1.0 \times 10^{**}(-3)$	
AW10	8.86	80	693	$2.4 \times 10^{**}(-4)$	

(Table App.B.1 continued)

AW11	11	5.63	80	450	-	
AW12	11	5.75	80	460	$12.0 \times 10^{**}(-6)$	
AW13	11	9.63	80	770	$11.2 \times 10^{**}(-4)$	
AW14	11	7.09	80	567	$13.0 \times 10^{**}(-4)$	The West side of
AW15	11	9.74	80	779	$11.0 \times 10^{**}(-3)$	
AW16	11	8.08	80	646	$11.6 \times 10^{**}(-4)$	Tuffs and Mudflows,
AW17	11	10.95	80	876	$11.5 \times 10^{**}(-4)$	6.Tk.Perahu eruption
AW18	11	9.94	80	795	-	period A
AW19	11	13.75	80	1100	$11.5 \times 10^{**}(-3)$	
AT 5	11	8.84	100	884	-	
AT 2	11	2.81	100	281	-	Tuffs and ashes,
AT 3	11	1.36	110	150	-	6.Tk.Perahu eruption
1555	11	5.79	38	220	-	period C
131/P	11	2.44	50	122	-	
1365	11	1.60	55	88	-	Lake deposits,
133/P	11	2.39	23	55	-	recent
1329	11	4.40	40	176	-	

Source : Reference #14, except for the type of the aquifer which is taken from reference #12 and reference #21.

- Note : 1). Base on the geohydraulic map (reference #21), the hydraulic conductivity of the Volcanic and Crystalline formation is assumed to be zero, which means that this type of aquifer is impermeable.
- 2). There is no data for the formation of Tuffs, Tuffbreccias, lava flows. However, since this formation lies on the outside of the finite element grids, so it is no used to assume the hydraulic conductivity value for this formation.

The distribution of data would be assumed as normal or log-normal distribution, hence the representative value of the hydraulic conductivity of each geologic formation is calculated by taking the mean value of the data after that data is drawn on the probabilistic paper as could be seen on figures App.C.1 until figure App.C.4.

A. Tuffs and Ashes aquifer on the North side. to the South.

A.1 If it is assumed as normal distribution .

Plotting on prob. paper		
Wells	Kxx = Kyy m/day	p(m) %
AT3	1.296	16.7
AT2	2.765	50.0
PW1	5.789	83.3

Note : For the rule of plotting , Hazen method is used .

From the straight line , the mean of $K_{xx} = K_{yy} = 3.18$

and its standard deviation $S = 2.02$

A.2 If it is assumed as log-normal distribution .

Plotting on prob. paper		
Wells	log Kxx m/day	p(m) %
AT3	0.113	16.7
AT2	0.442	50.0
PW1	0.763	83.3

Note : For the rule of plotting , Hazen method is used .

From the straight line , the mean of $\log K_{xx} = 0.23$

or $K_{xx} = K_{yy} = 2.40$

and $\log S = 0.23$; or $S = 1.70$

B) Lake Deposit Aquifer on the East which turn to the South.

The data representing this aquifer is also being plotted on

B.1 If it is assumed as normal distribution .

the probability paper (either as normal distribution

Plotting on prob. paper		
Wells	Kxx = Kyy m/day	p(m) %
1365	1.642	12.5
133/P	2.333	37.5
131/P	2.419	62.5
1329	4.320	87.5

Note : For the rule of plotting , Hazen method is used .

From the straight line , the mean of Kxx = Kyy = 2.75

and its standard deviation S = 1.50

sedimentation which causes different values for hydraulic

B.2 If it is assumed as log-normal distribution .

Plotting on prob. paper		
Wells	log Kxx m/day	p(m) %
1365	0.215	12.5
133/P	0.368	37.5
131/P	0.384	62.5
1329	0.635	87.5

Note : For the rule of plotting , Hazen method is used .

Plotting on prob. paper

From the straight line , the mean of log Kxx = 0.40

or Kxx = Kyy = 2.512

and log S = 0.18 ; or S = 1.513

or Kxx = Kyy = 2.512

and log S = 0.18 ; or S = 1.513

or Kxx = Kyy = 2.512

and log S = 0.18 ; or S = 1.513

or Kxx = Kyy = 2.512

and log S = 0.18 ; or S = 1.513

or Kxx = Kyy = 2.512

and log S = 0.18 ; or S = 1.513

C) Tuffs and Mudflows Aquifer.

The data representing this aquifer , after being plotted on the probabilistic paper (either as normal distribution , or log-normal) has three different groups of straight lines .

This could be expressed as one regression line, by doing transformation using the polynomial regression equation.

However, in the geologic problem, that procedure could not be followed; because it relates with the difference hystory

of the process of the existence of the geologic formation.

In this case, this aquifer should be consisted of three different densities relating with different type of its sedimentation which causes different values of hydraulic conductivities.

Let's say that these three groups are denoted as WEST SIDE , CENTER PART, and EAST SIDE .

C.WEST SIDE .

1. If it is assumed as normal distribution .

Wells	Plotting on prob. paper	
	$K_{xx} = K_{yy}$ m/day	p(m) %
AW11	5.616	4.54
AW12	5.702	13.64
AW14	7.171	22.72
AW 9	7.603	31.82
AW16	8.035	40.91
AW10	8.640	50.00
AW13	9.590	59.09
AW15	9.763	68.18

(table - continued)

AW18	9.763	77.27
AW17	10.627	86.36
AW19	14.083	95.45

Note : For the rule of plotting , Hazen method is used .

From the straight line , the mean of $K_{xx} = K_{yy} = 8.60$

and its standard deviation $S = 2.35$

2. If it is assumed as log-normal distribution .

Wells	Plotting on prob. paper	
	Log K_{yy} m/day	p(m) %
AW11	0.749	4.54
AW12	0.756	13.64
AW14	0.856	22.72
AW9	0.881	31.82
AW16	0.905	40.91
AW10	0.937	50.00
AW13	0.982	59.09
AW15	0.990	68.18
AW18	0.990	77.27
AW17	1.026	86.36
AW19	1.149	95.45

From the straight line , the mean of $\log K_{xx} = 0.91$

or $K_{xx} = K_{yy} = 8.13$

and $\log S = 0.11$; or $S = 1.29$

C.CENTER PART.

1. If it is assumed as normal distribution .

Wells	Plotting on prob. paper	
	$K_{xx} = K_{yy}$ m/day	p(m) %
AW5	2.6784	12.5
AW6	6.653	37.5
AW7	8.294	62.5
AW8	12.096	87.5

From the straight line , the mean of $K_{xx} = K_{yy} = 7.40$
and its standard deviation $S = 4.20$

2. If it is assumed as log-normal distribution .

Wells	Plotting on prob. paper	
	Log K_{yy} m/day	p(m) %
AW5	0.428	12.5
AW6	0.823	37.5
AW7	0.881	62.5
AW8	0.919	87.5

From the straight line , the mean of $\log K_{xx} = 0.90$

or $K_{xx} = K_{yy} = 7.943$

and $\log S = 0.07$; or $S = 1.175$

Notes: The hydraulic conductivity graphs are drawn on separate sheets.

C.EAST SIDE . about 80% of the hydraulic conductivity listed

1. If it is assumed as normal distribution . listed as follows :

Plotting on prob. paper		
Wells	Kxx = Kyy m/day	p(m) %
AW4	1.1232	12.5
AW3	1.296	37.5
AW2	1.3824	62.5
AW1	1.5552	87.5

From the straight line , the mean of $K_{xx} = K_{yy} = 1.32$
and its standard deviation $S = 0.14$

2. If it is assumed as log-normal distribution .

Plotting on prob. paper		
Wells	Log Kxx m/day	p(m) %
AW4	0.050	12.5
AW3	0.113	37.5
AW2	0.141	62.5
AW1	0.192	87.5

From the straight line , the mean of $\log K_{xx} = 0.15$

or $K_{xx} = K_{yy} = 1.413$

and $\log S = 0.12$; or $S = 1.318$

Note : The probabilistic line graphs are drawn on separate papers .

- Code's number 4, East (Tuffs and Mudflows),
- Code's number 1 (Lake Deposits).

And then, as the values between that which calculated base on normal distribution and that calculated base on log-normal distribution are very close and in the same order of magnitude, hence in the application program the value of the hydraulic conductivity of the geologic formations in the aquifer would only be taken as one group of values, that is from normal assumption .

The values of the hydraulic conductivity of the aquifer could be seen on table App.B.3 below.

Table App.B.2 : $K_{xx} = K_{yy}$ for the program application.

Geologic Formation		$K_{xx} = K_{yy}$
code's number	Description of the formation	(m/day)
4 - West & Center	Tuffs and Mudflows, G.Tk Pe & rahu eruption period A.	8.00
4 - East	ditto	1.32
1	Lake Deposit, recent	2.75

...oOo...

Figure App. C-2) Data of each group are separated.

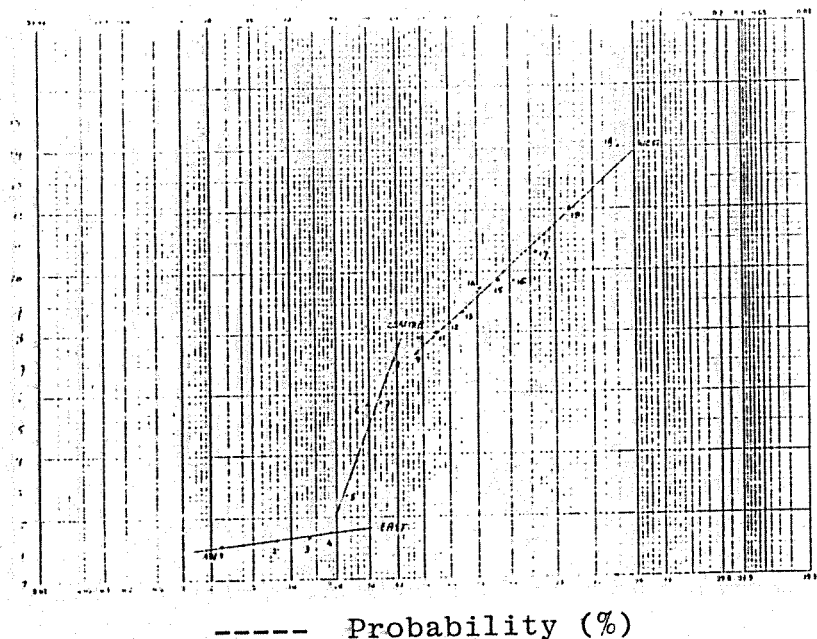


Figure App.C-1: All data are drawn on one paper.

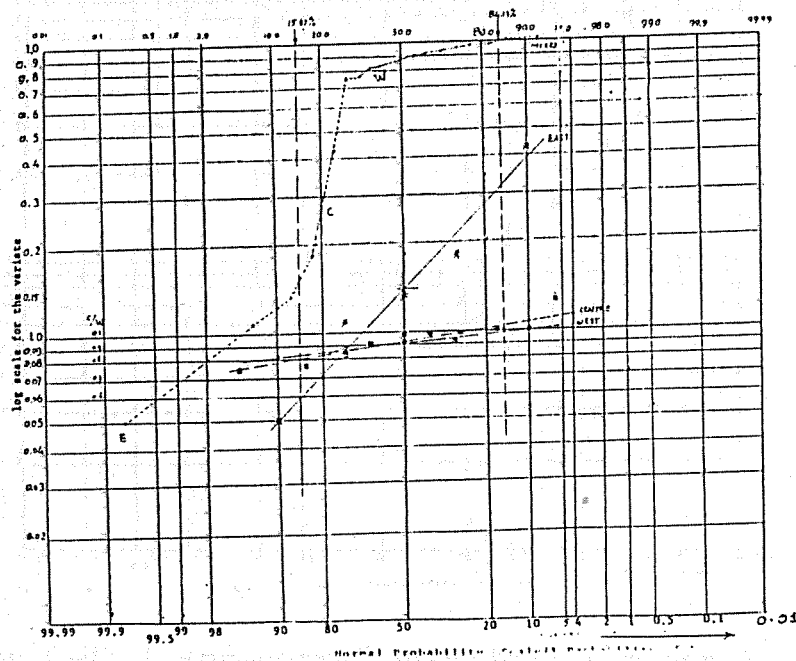


Figure App.C-2: Data of each group are separated.

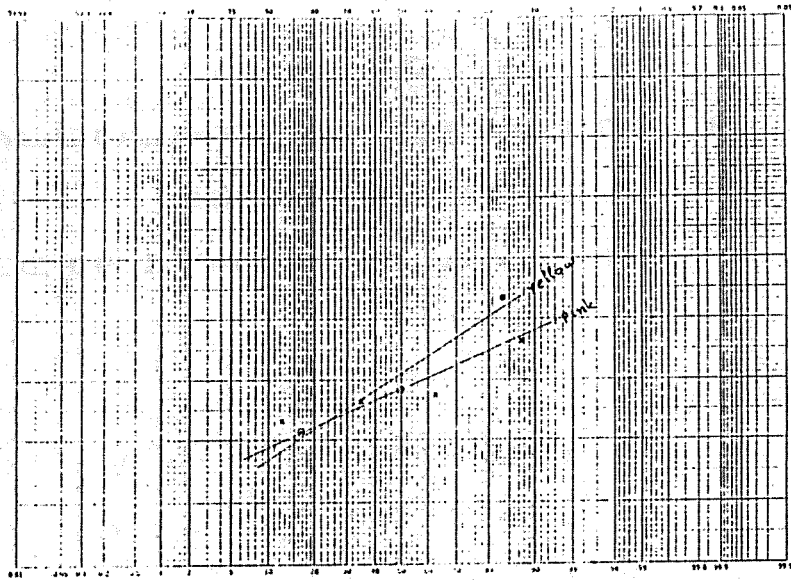


Figure App.C-3: pink is for lake deposits, recent. (1)
yellow is for tuffs and ashes, eruption
period C. (2)

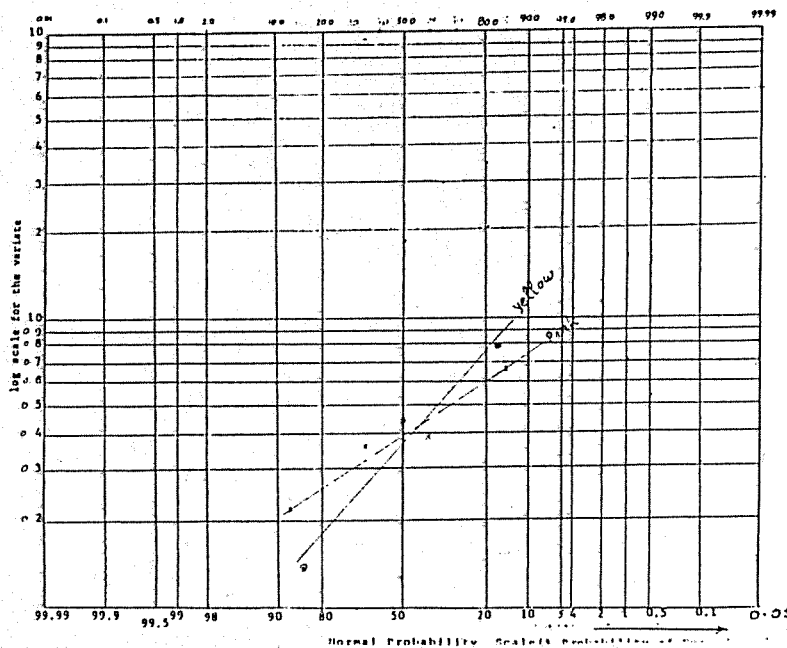


Figure App.C-4: (log-normal probability paper).

D
CALCULATION OF SIDE FLUXES
RELATING TO
PRECIPITATION and INFILTRATION.

**CALCULATION OF SIDE FLUX
RELATING TO
THE INFILTRATION IN THE MOUNTAINOUS RIDGE
NORTHERN SIDE OF BANDUNG.**

(Source : Reference 17, based on Maxey and Eaken, 1949).

Due to be not enough data, relating with the type and the thickness of the aquifer which lies in the hill above the toe, the North-South cross section from the toe up to the summit of this study area might be assumed as seen on figure App.D.1 below.

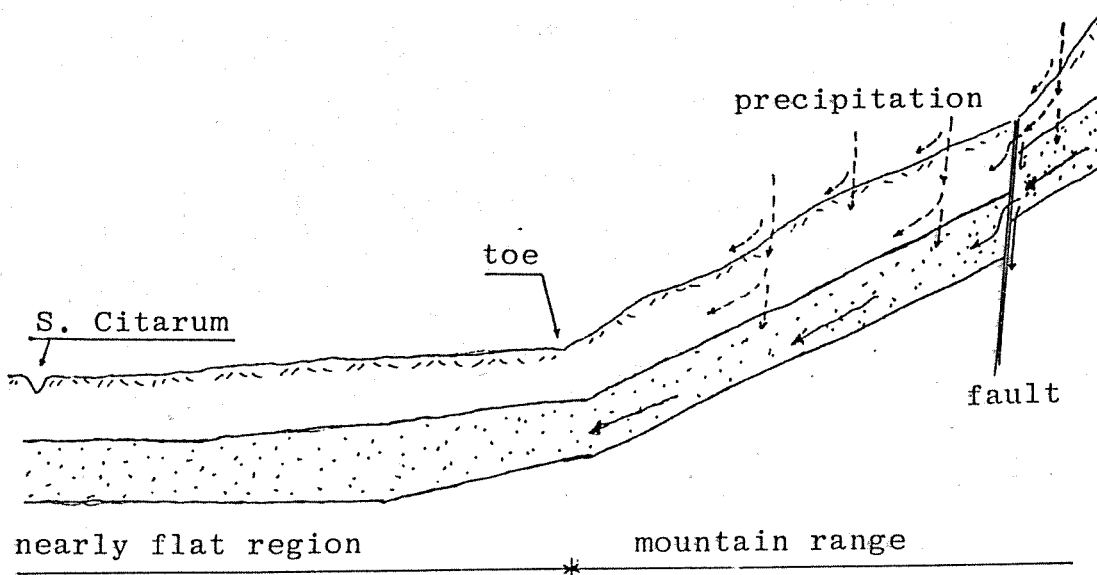


Figure App.D.1 : Schematic of the occurrence of the side flux.

It could be seen from the figure above that the water recharge into the aquifer lies in the hill might come from the infiltration, which might come from the precipitation on the mountain range.

The formula of the water recharge into the deep aquifer might be written as :

$$S.F = I_{1,b} + I_{2,c} \quad (\text{formula App.D.1})$$

$$I_{1,b} = \alpha_1 * I_1 \quad (\text{formula App.D.2})$$

$$I_{2,c} = \beta_1 * I_2 \quad (\text{formula App.D.3})$$

$$I_1 = \alpha_2 * \text{Precip}_1 \quad (\text{formula App.D.4})$$

$$I_2 = \beta_2 * \text{Precip}_2 \quad (\text{formula App.D.5})$$

Alpha and beta are coefficients which their values depends on the condition of the hill, the land-use, the type of the ground surface, leaky or not leaky between top and bottom aquifers, and the thickness of the fissures on the fault.

In this case, these values would be assumed as :

$$- \alpha_1 = 0.40$$

$$- \alpha_2 = 0.50$$

$$- \beta_1 = 0.50$$

$$- \beta_2 = 0.50$$

$$\begin{aligned} \text{hence : } S.F &= 0.2 * \text{Precip}_1 + 0.25 * \text{Precip}_2 \\ &= 0.2 * 0.006 + 0.25 * 0.007 = \\ &= 0.003 \text{ m/day} \end{aligned}$$

Then side fluxes for aquifer's thickness of :

$$75 \text{ m} \dots\dots\dots \rightarrow S.F = 75 * 0.003 = 0.22 \text{ m}^2/\text{day}$$

$$80 \text{ m} \dots\dots\dots \rightarrow S.F = 80 * 0.003 = 0.24 \text{ m}^2/\text{day}$$

$$90 \text{ m} \dots\dots\dots \rightarrow S.F = 90 * 0.003 = 0.27 \text{ m}^2/\text{day}$$

where :

S.F = Side flux(es) .

$I_{1,b}$ = Infiltration in region 1, seeping the b layer.

$I_{2,c}$ = Infiltration in region 2, seeping the concern aquifer which lying below the region 2 .

I_1 & I_2 = Infiltration in region 1 & 2 respectively.

Precip₁ & Precip₂ = Precipitation in region 1 & 2 respectively.

Region 1 is located between the toe and the fault.

Region 2 is located above the fault until the summit.

CALCULATION OF PRECIPITATION 1 & 2 :

The value of precipitation is calculated on the basis of the isohyetal map which is drawn already by other resource .

A). Precipitation 1 :

Zone	$I_n + I_{(n+1)}$ (mm/year)	Planimet. reading1	Planimet. reading2	Average Reading	Area (A)	$A * (I_n + I_{(n+1)})$
1	2600 + 2400 = 5000	0.55	0.52	0.535	7.87	39 350
2	2400 + 2200 = 4600	1.87	1.86	1.805	26.54	122 084
3	2200 + 2000 = 4200	5.01	5.00	5.005	73.60	309 120
4	2000 + 1800 = 3800	1.60	1.63	1.615	23.75	90 250
					131.76	560 804

Note : The calibration of the planimeter is 0.425 = 6.25 km².

$$\begin{aligned}
 \text{Precipitation, } P &= \frac{A * (I_n + I_{(n+1)})}{2 * A} = \frac{560804}{2 * 131.76} \\
 &= 2128.13 \text{ mm/year} \\
 &= .006 \text{ m/day}
 \end{aligned}$$

B). Precipitation 2 :

Zone	In + I(n+1) (mm/year)	Planimet. reading1	Planimet. reading2	Average Reading	Area (A)	A * (In + I(n+1))
1	3400 + 3200 = 6600	0.19	0.20	0.195	2.868	18 928.80
2	3200 + 3000 = 6200	0.26	0.23	0.245	3.603	22 338.60
3	3000 + 2800 = 5800	0.34	0.34	0.345	5.000	29 000.00
4	2800 + 2600 = 5400	0.80	0.79	0.795	11.691	63 131.40
5	2600 + 2400 = 5000	1.07	1.04	1.055	15.515	77 575.00
6	2400 + 2200 = 4600	2.84	2.71	2.775	40.809	187 721.40
7	2600 + 2400 = 5000	0.57	0.58	0.575	8.456	42 280.00
8	2400 + 2200 = 4600	0.20	0.22	0.21	3.088	14 204.80
					91.03	455 180.00

$$\begin{aligned}
 P &= \frac{455180.0}{2 * 91.03} = 2500.16 \text{ mm/year} \\
 &= 0.007 \text{ m/day}
 \end{aligned}$$

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- PROCEDURE OF ARRANGING THE CONCEPTUAL MODEL.

PROCEDURE OF ARRANGING THE CONCEPTUAL MODEL.

The stages of how to derive the conceptual model which should portray the domain of the concern area might be explained as follows :

1). Monitor carefully the existing condition of the concerned area, especially the type and the geologic formation of the aquifers (the concern aquifer and its adjacent aquifers complete with its leaky area), the boundary conditions of these aquifers, all rivers in the concern area (complete data as their cross sections with it sizes, the type and the thickness of the river bed, the water level in the river), elevations of all layers of the aquifers including the water and piezometric levels which should have the same datum, and the location of all wells.

2). Draw a rough sketches of the area of concern, complete with all informations relating to the study problem. From this drawing, all boundary lines (which separate the different types of might be the geologic formations of the concern aquifer, the thickness of the concern aquifer, the rivers, the leaky area, the location of the wells) should be sketched properly.

3). Set up the X and Y coordinate system including the chosen scale. It might be better if the X direction is

colinear with the shorter side of the concerned area. The reason is that the computer time will be shorter due to there need no rotation of the coordinate system and shorter matrix multiplication in the program.

4). Draw the mesh of the finite element grid , where the node should be put on these boundary lines.

5). The pattern of the element should be :

- Each element should have a triangular shape,
- The type of one triangle and its neighbouring element should follow the rule being picturized as:

yes.



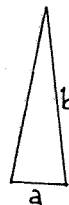
no.



preferred.



discouraged
but still accepted.



$$\frac{a}{b} > \frac{1}{5}$$

- On the area which surrounding a well, the size of the element should be small enough so the mesh as a whole would be denser on this area and that would be coarser for the area which has no wells. However,

the variation in the element sizes should be reasonably smooth and regular.

- The drawing of the finite element grid as a whole should please the eye, which would not make any difficulty in setting the number of nodes and elements.

6). Set up the number of all nodes and elements. Nodes' numbers should be arranged in sequence from the far left to the right (when it is finish for one row then the continuing number should be started from the second far left again) and from the bottom to the top. For the elements' number, similar rule as for node might be followed, but in this case, jumping number on the sequent elements is allowed.

7). Set up the coordinate X,Y of every node.

8). Set up the parameter of the aquifer over the whole elements. The parameter which cover the largest number of elements might be taken as the default input.

9). Set up all boundaries values problem (1st type boundary condition, 2nd type boundary condition, 3rd type boundary condition, mixed 3rd type boundary condition, rising water level boundary condition, source / sink wells, ponding water which might evaporate or infiltrate into the ground, leaky area), which occurs on a certain

number of elements or nodes.

All values of the boundary should have consistant units,
such as :

- Length in meter,
- Area in square meter,
- Volume in cubic meter,
- Time in day.

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