APPENDIX - 6

"DETAILED STUDY OF GROUNDWATER

IN THE K.LENGKONG BASIN"

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1. GENERAL

(1) Background

The study area located in the southeastern slope of Mt. Semeru has an abundant amount of rainfall in the rainy season, however, a shortage of irrigation water more or less appears in certain areas during the dry season.

Groundwater is recognized as a stable and economical water resource and is expected to be one of the solutions to resolve this shortage of irrigation water.

From the macroscopic results of groundwater study, discussed in Part C of Supporting Report 5 submitted in March, 1984, the K. Lengkong basin can be considered to have the most adequate groundwater basin structure for the storage of a large enough volume of groundwater and, moreover, this basin will be included in the first priority project area of the K. Rejali sediment control works.

(2) Objective

The principle objective of this study is to roughly evaluate the groundwater resources development potential to be realised by the artificial groundwater level control of the K. Lengkong groundwater basin.

(3) Approach to the Study

The main part of this study will be dedicated to the groundwater level fluctuation analysis related to rainfall in the K. Lengkong groundwater basin, where the existence of a long narrow impermeable ridge was verified at the prospective site of the Tumpak Nanas sabo dam from the electric sounding and drilling results.

An hourly rainfall amount analysis will be dealt with here to clarify the characteristics of the rainfall occurrence and intensity at the observation well fields, using the rainfall data obtained in their surrounding areas.

These studies will contribute to a deeper understanding of groundwater behaviour in close relation to rainfall occurrence, and will help in the evaluation of the groundwater resource development potential in the hinterland of the Tumpak Nanas sabo dam.

(4) Study Items

Principal study items are as follows:

① Groundwater level fluctuation analysis
- Graphical interpretation
- Analytical interpretation

② Hourly rainfall amount analysis

③ Evaluation of the groundwater resources development potential

Flow charts of these studies are as shown in Fig.-1.
Moreover, basic data of groundwater level observation collected upto June, 1984 is given in the Appendix, "Groundwater Level Observation Data".

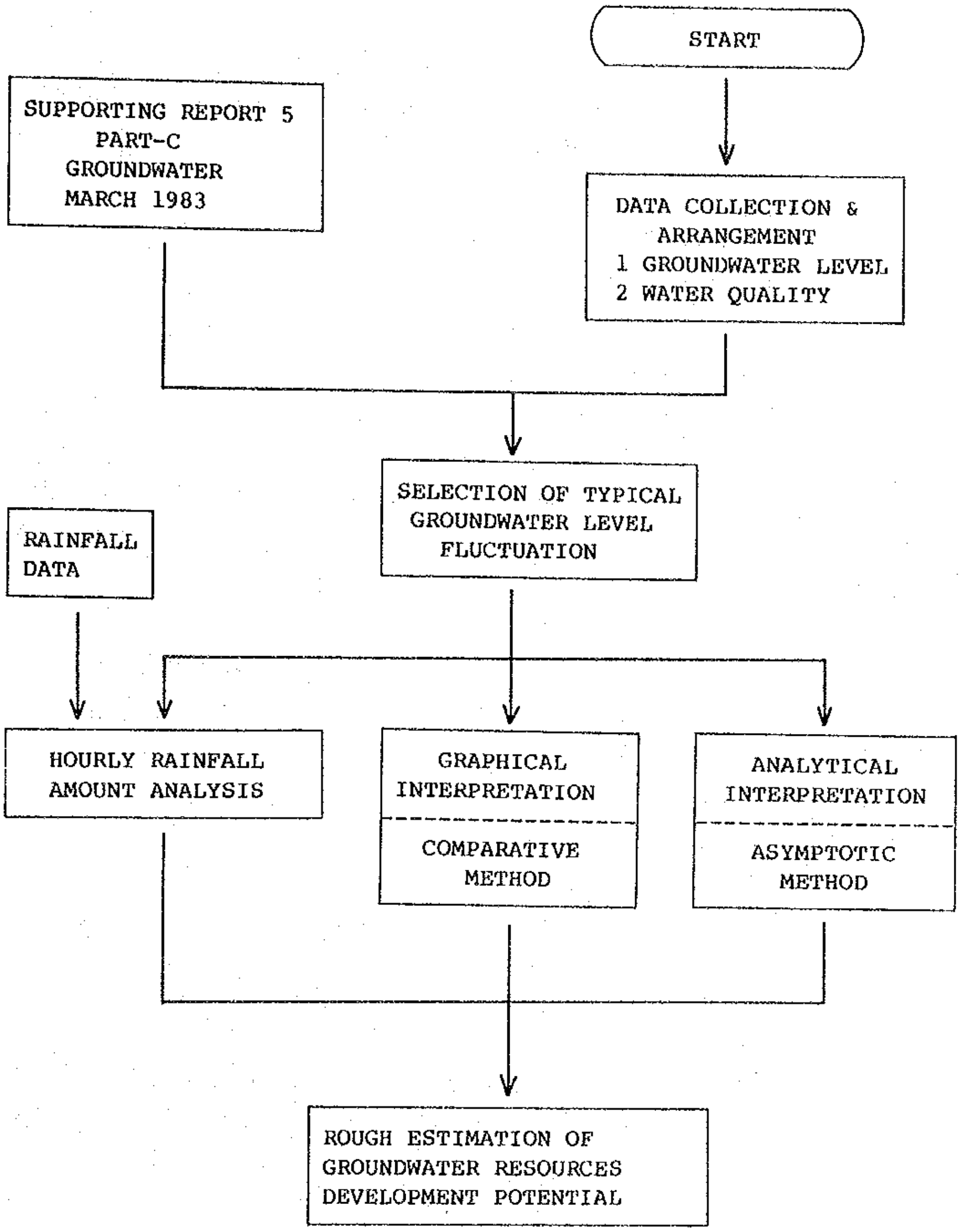


Fig.-1 Flow Chart of the Detailed Study of Groundwater in the K. Lengkong Groundwater Basin

2. GROUNDWATER LEVEL FLUCTUATION

2.1 GRAPHICAL INTERPRETATION

(1) Location of the Groundwater Level Observation Wells

There are three groundwater level observation wells in the K. Lengkong groundwater basin, i.e. Sumber Urip Krajan, Reksan and Tumpak Nanas, as shown in Table-1 and Fig.-2.

Table-1 Groundwater Level Observation Wells

Well	Location	Well Depth (Bottom)	Hydrogeological Remarks
Sumber Urip Krajan	X: 112°58'30,24"E Y: 8°12'15,72"S Z: 760.81 m	1.65 m	- Volcanic fan - Older lahar deposit - Unconfined aquifer - Right bank of K. Lengkong
Reksan	X: 112°58'39,07"E Y: 8°12'34,08"S Z: 718.23 m	3.80 m	- Volcanic fan - Older lahar deposit - Unconfined aquifer - Right bank of K. Lengkong
Tumpak Nanas	X: 112°05' 54"E Y: 8°12'55,74"S Z: 696.76 m	4.27 m	- Piedmont of tertiary mountains - Tuff - Unconfined aquifer - Left bank of K. Lengkong

Note: Commencing date of observation is 25 June, 1982.

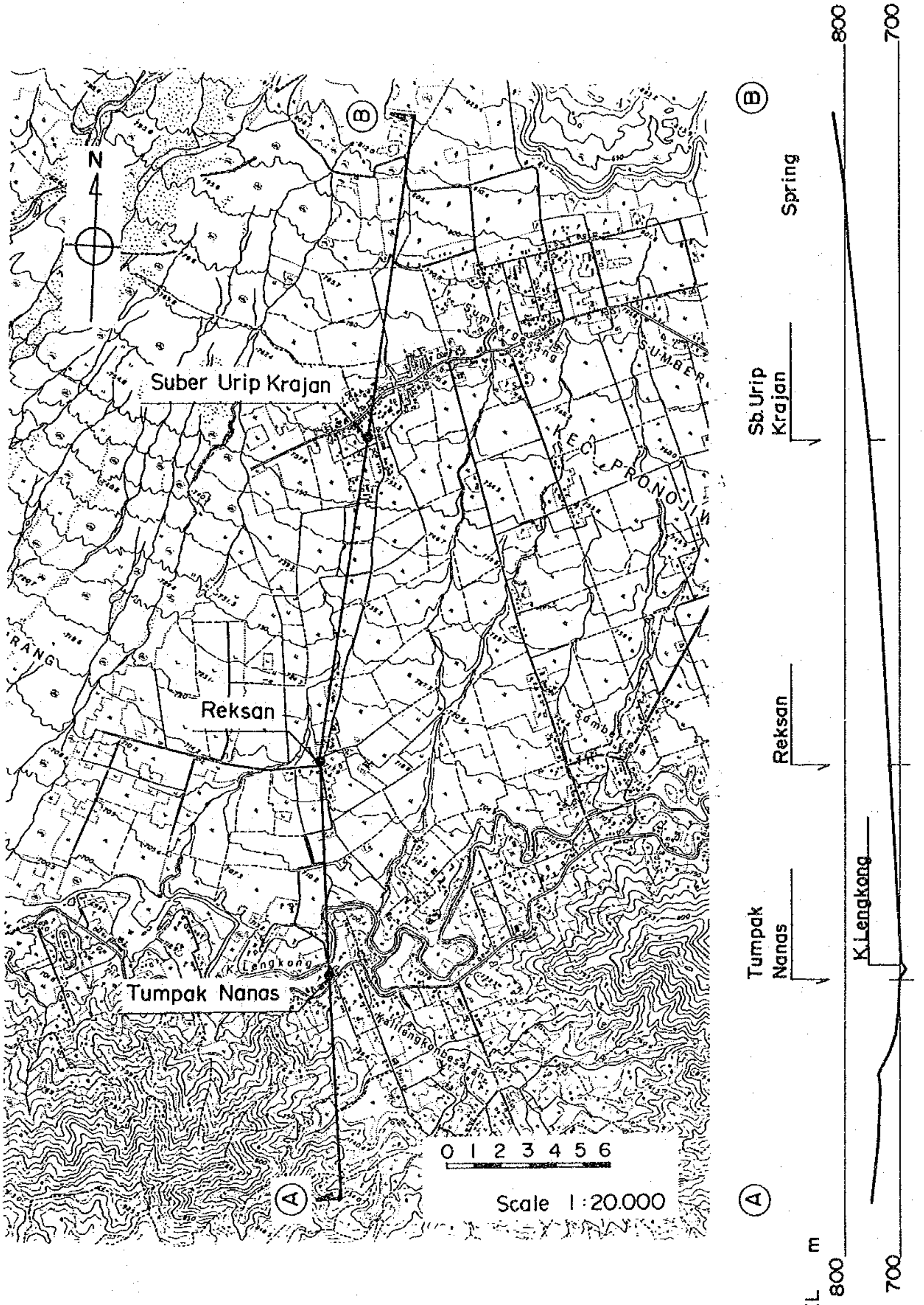


Fig.-2 Location of Groundwater Level Observation Wells

(2) Selection of Typical Fluctuations

When obtaining the comparative aspect of groundwater level fluctuations among three observation wells, the following conditions are taken into consideration:

① Clearness of fluctuation profile without blot and interruption

② Comparison possibility of three fluctuations

③ Representative fluctuation due to high rainfall intensity.

The periods selected as typical fluctuations are as shown in Table-2.

Table-2 Periods Selected as Typical Fluctuations

Case	Period	Case	Period
1	17 Jan. to 21 Jan., 1983	9	30 Jun. to 7 Jul., 1983
2	6 Feb. to 11 Feb., 1983	10	27 Oct. to 3 Nov., 1983
3	25 Feb. to 3 Mar., 1983	11	16 Dec. to 21 Dec., 1983
4	21 Apr. to 27 Apr., 1983	12	2 Feb. to 8 Feb., 1984
5	29 Apr. to 5 May, 1983	13	1 Mar. to 7 Mar., 1984
6	6 May to 11 May, 1983	14	5 Apr. to 8 Apr., 1984
7	12 May to 18 May, 1983	15	26 Apr. to 1 May, 1984
8	25 May to 31 May, 1983	16	10 Jun. to 17 Jun., 1984

(3) Graphical Representation

The graphical representation of groundwater level fluctuations at three wells and rainfall are as shown in Fig.-3(1) to Fig.-3(16).

The fluctuation profiles of each observation can be described as follows:

① Sumber Urip Krajan

- Response to rainfall is quick and sensitive.
- Height of peak fluctuation is 0.10 to 0.45m.
- Length of fluctuation is about 1 day.

② Reksan

- Response to rainfall is generally quick and its amplitude is bigger than that of Sumber Urip Krajan, however, small fluctuation occurring just after a large one are sometimes faint.

- Height of peak fluctuation is 0.25 to 1.35m and the amplitude is generally greater than that at Sumber Urip Krajan.

- Length of fluctuation is nearly same as that of Sumber Urip Krajan.

③ Tumpak Nanas

- Response to rainfall is complex, consisting of a quick one and a slow one; the appearance of the quick one depends on the rainfall pattern and intensity.

- Height of peak fluctuation of the quick response is 0.10 to 0.55m and that of the slow response is 0.10 to 0.80m.

- Length of fluctuation of the quick response is about 6 to 12 hours and that of the slow response is about 2 to 7 days.

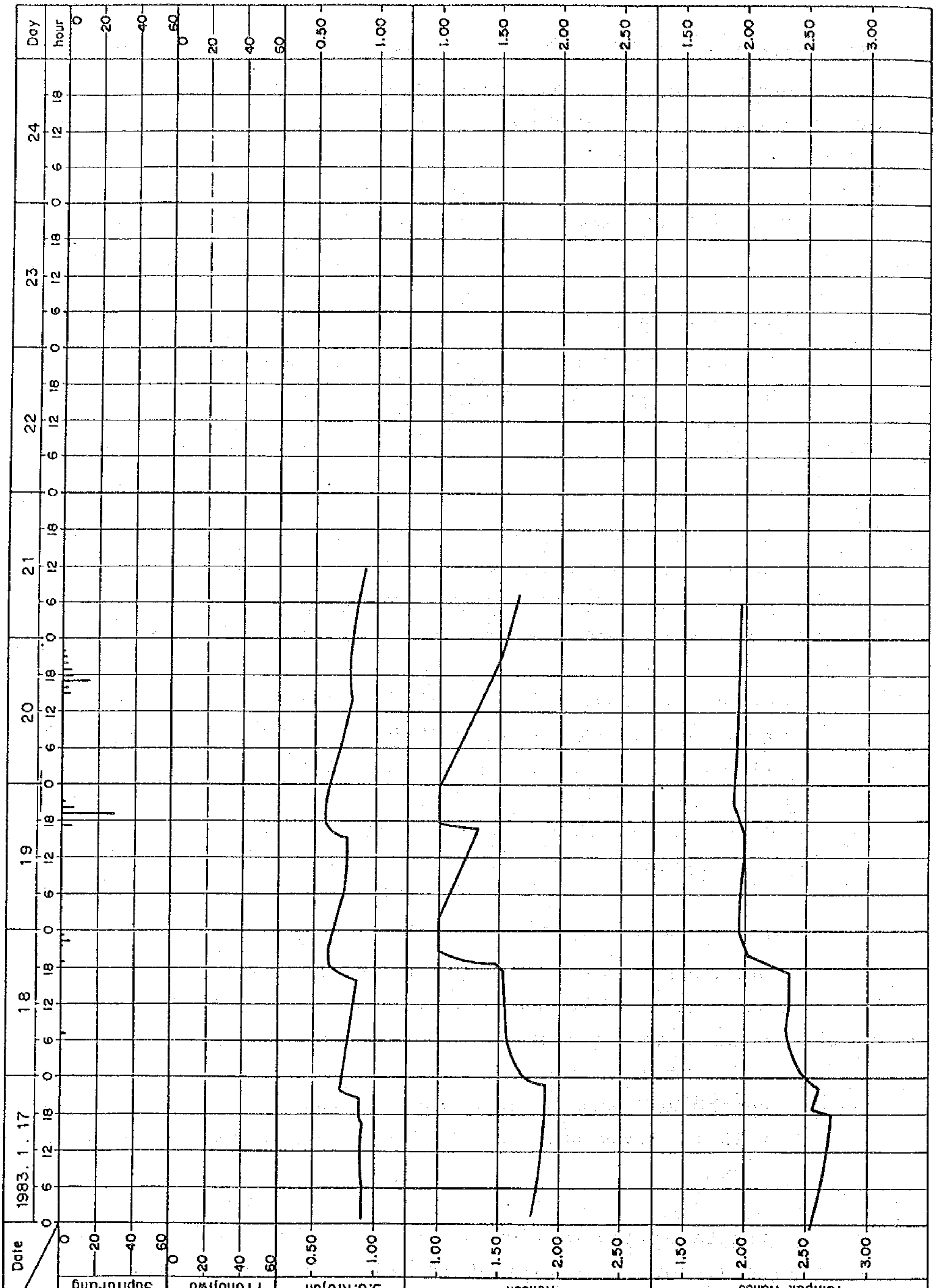


Fig. - 3(1) Groundwater Level Fluctuation in K. Lengkong Basin

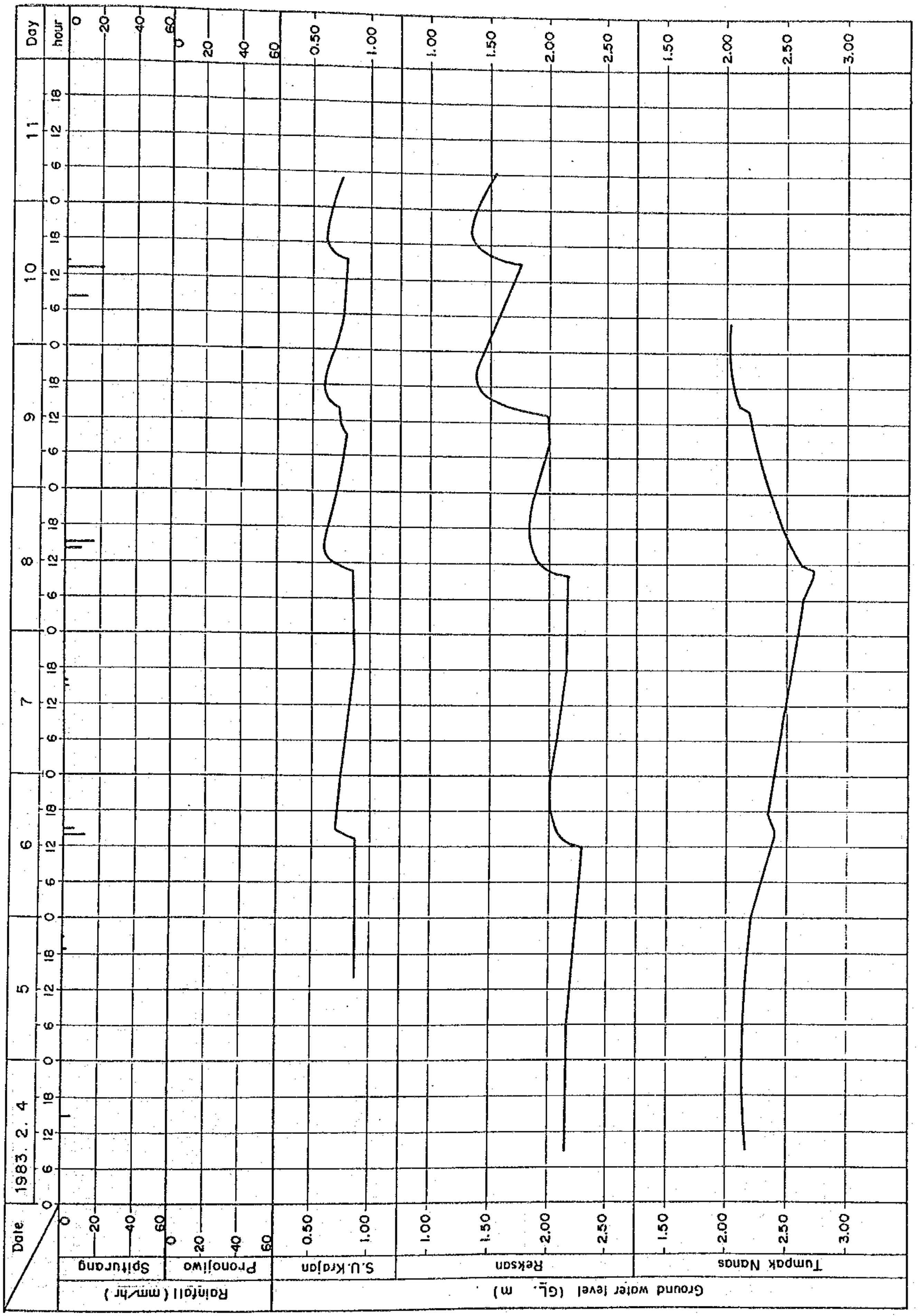


Fig. – 3(2) Groundwater Level Fluctuation in K. Lengkong Basin

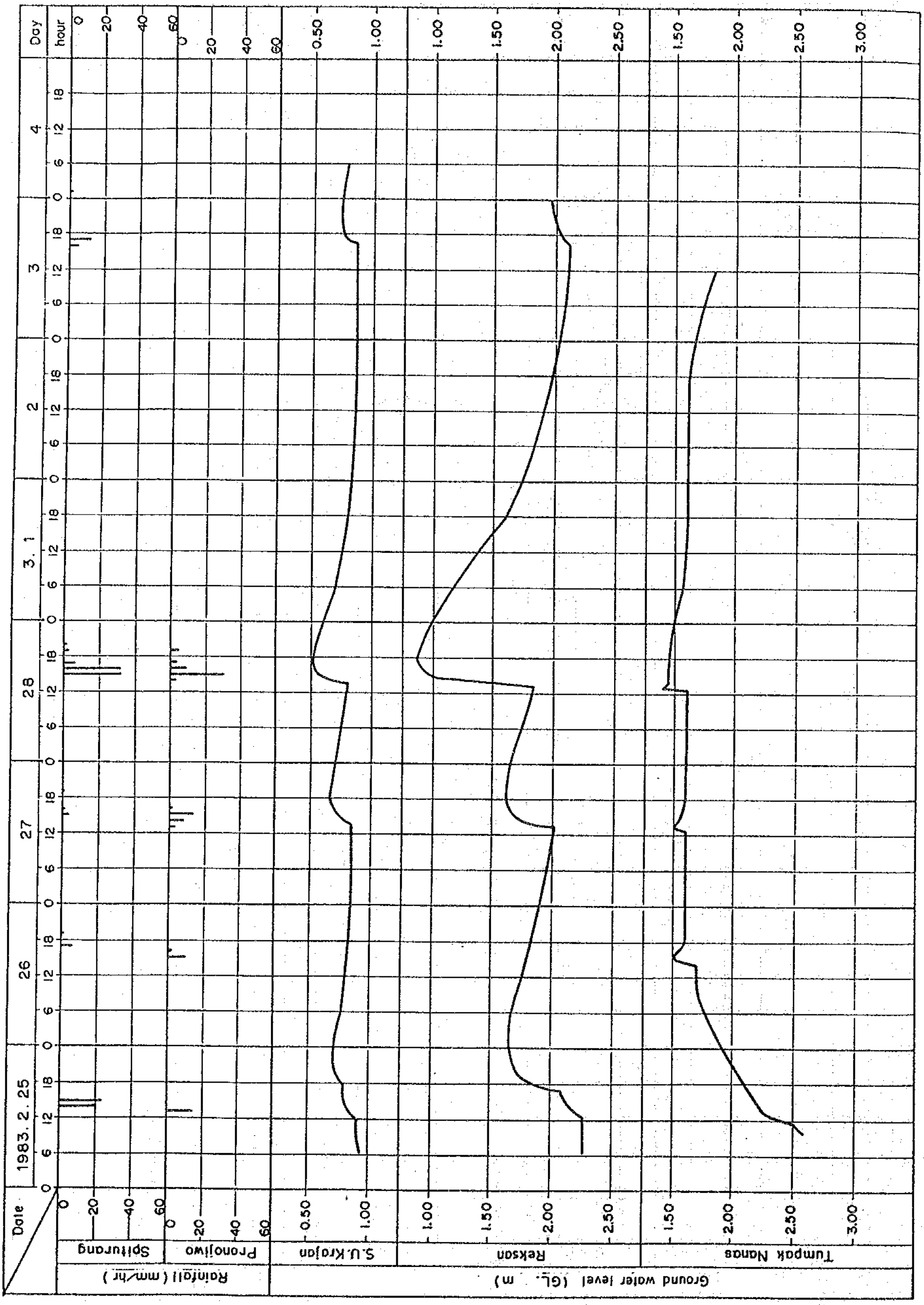


Fig. — 3(3) Groundwater Level Fluctuation in K. Lengkong Basin

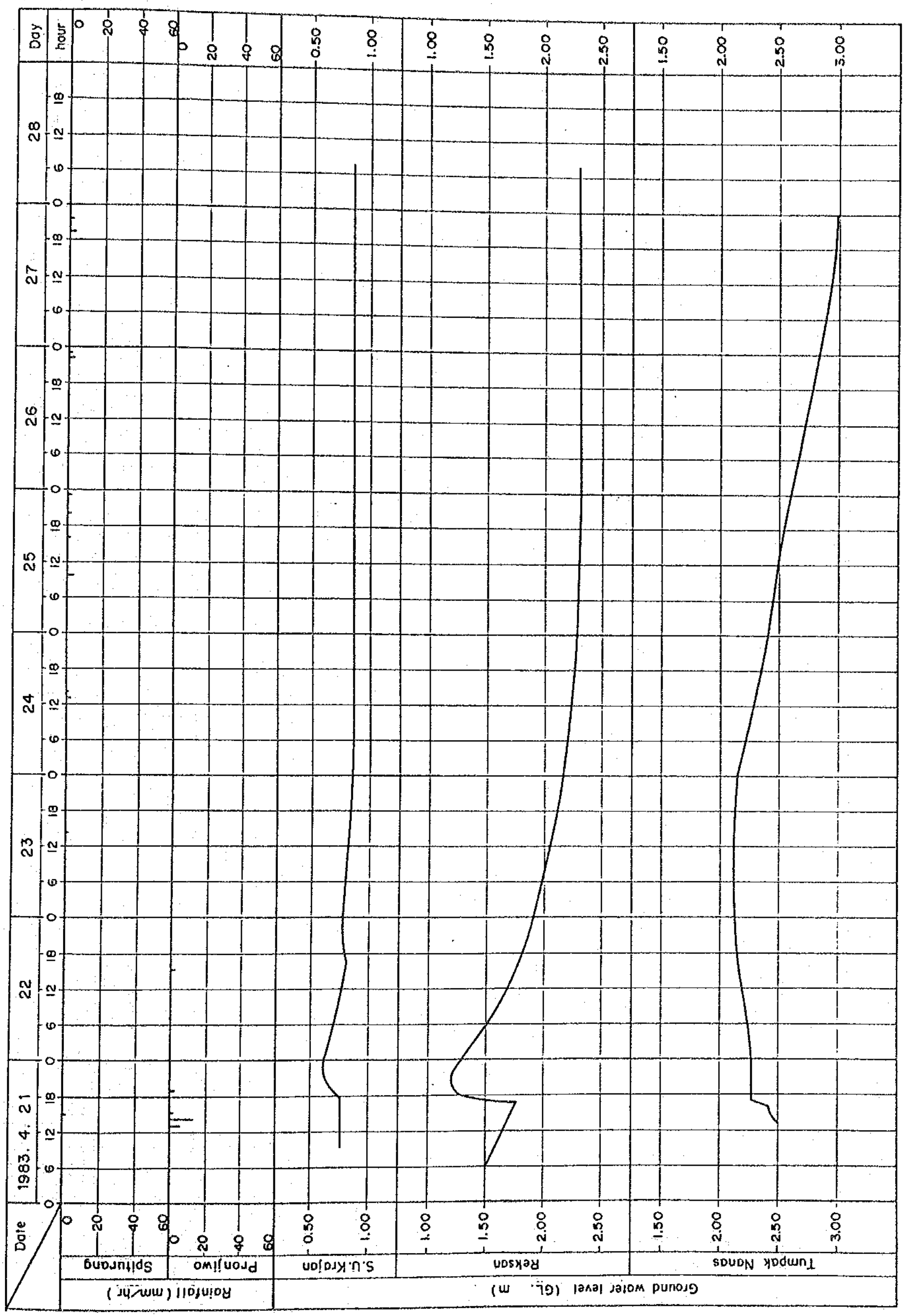


Fig. – 3(4) Groundwater Level Fluctuation in K. Lengkong Basin

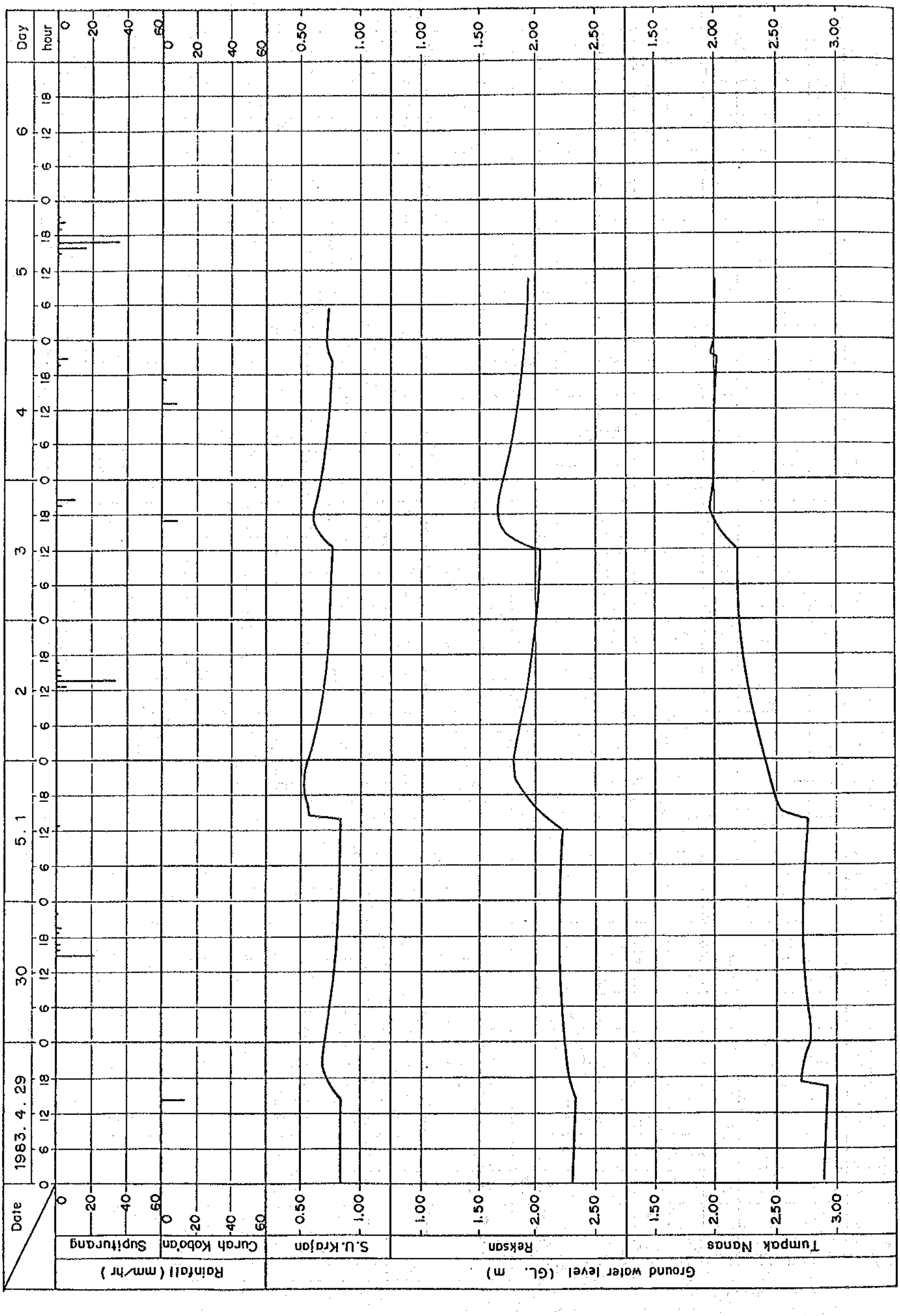


Fig. – 3(5) Groundwater Level Fluctuation in K. Lengkong Basin

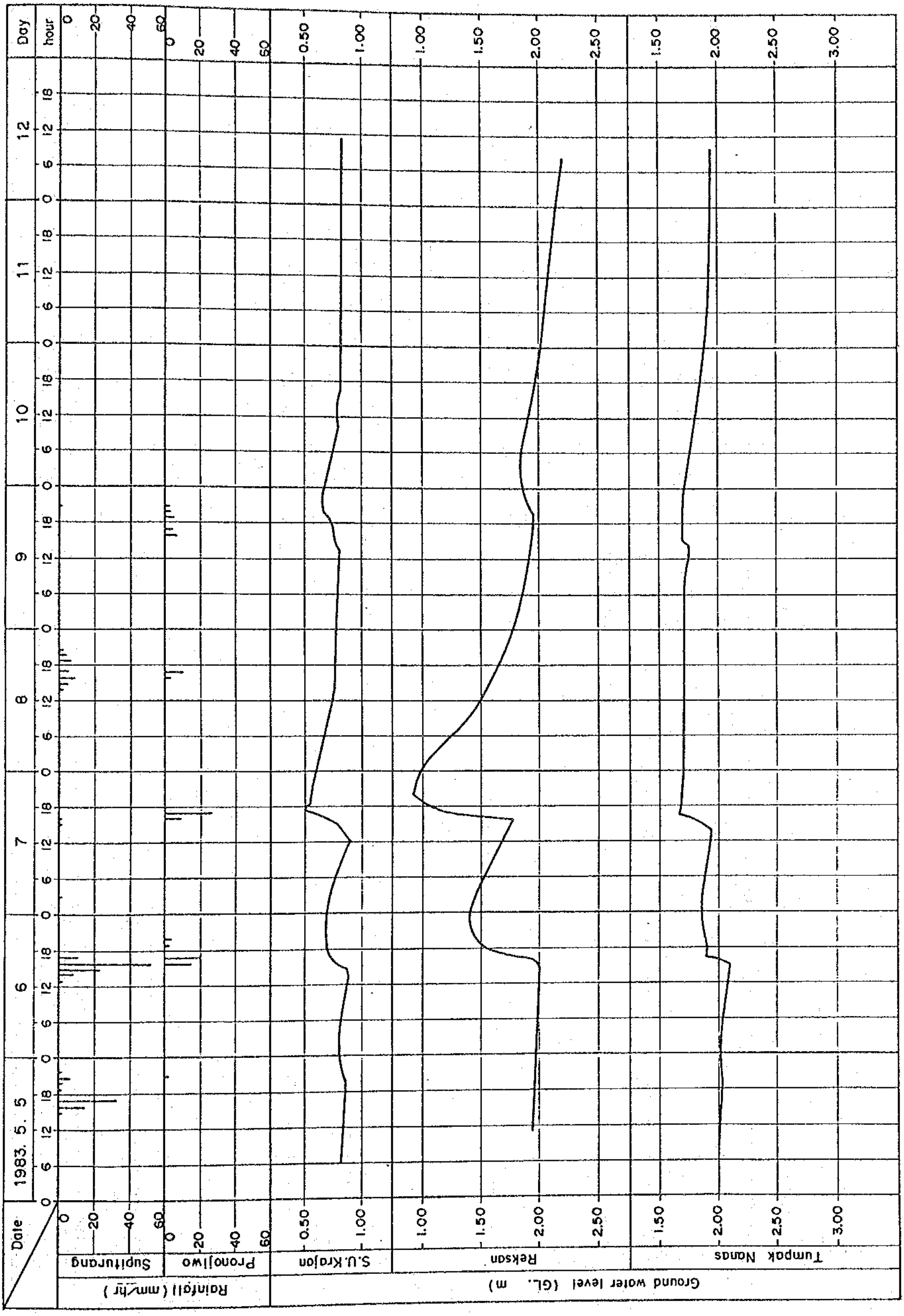


Fig. – 3(6) Groundwater Level Fluctuation in K. Lengkong Basin

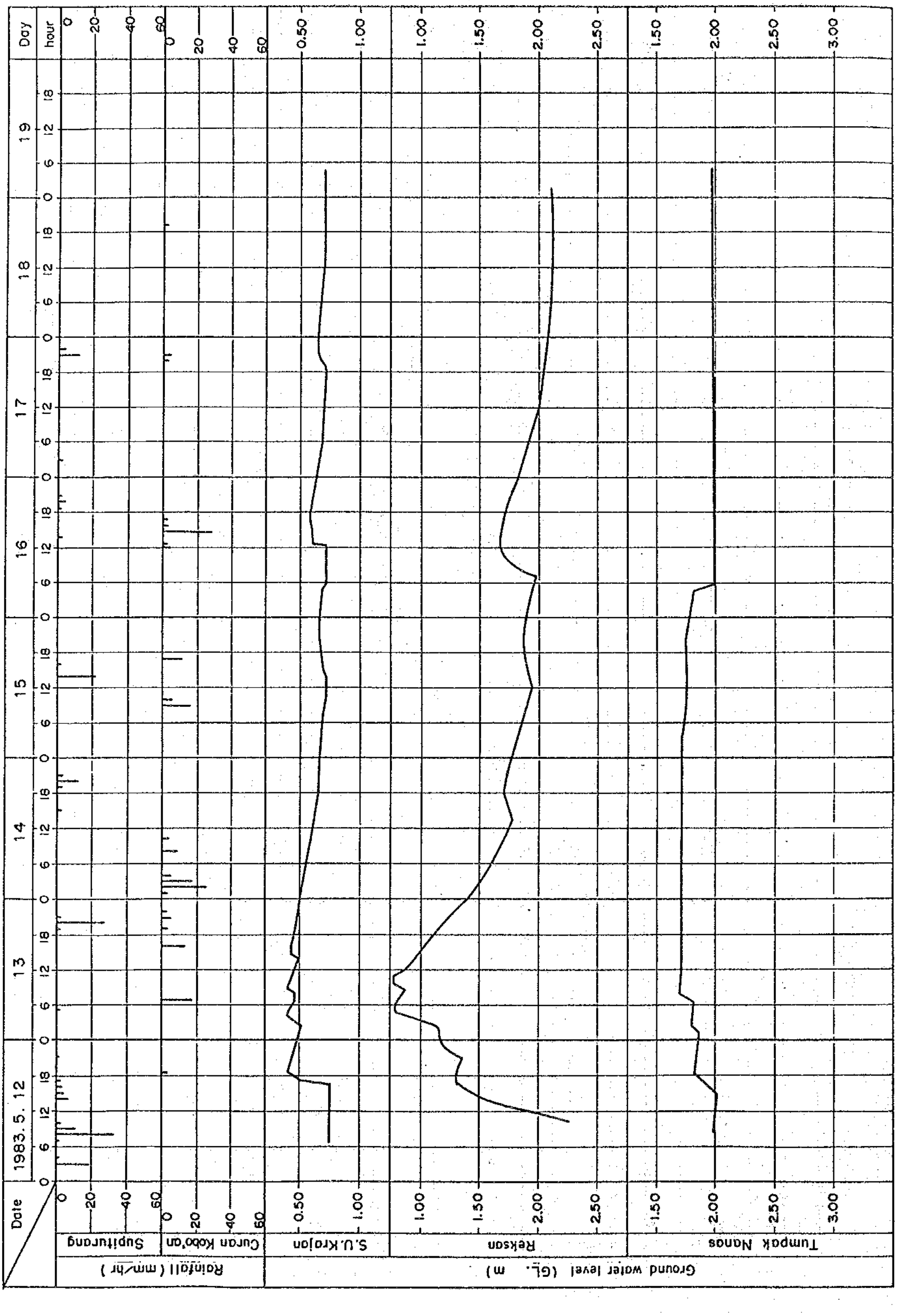


Fig. - 3(7) Groundwater Level Fluctuation in K. Lengkong Basin

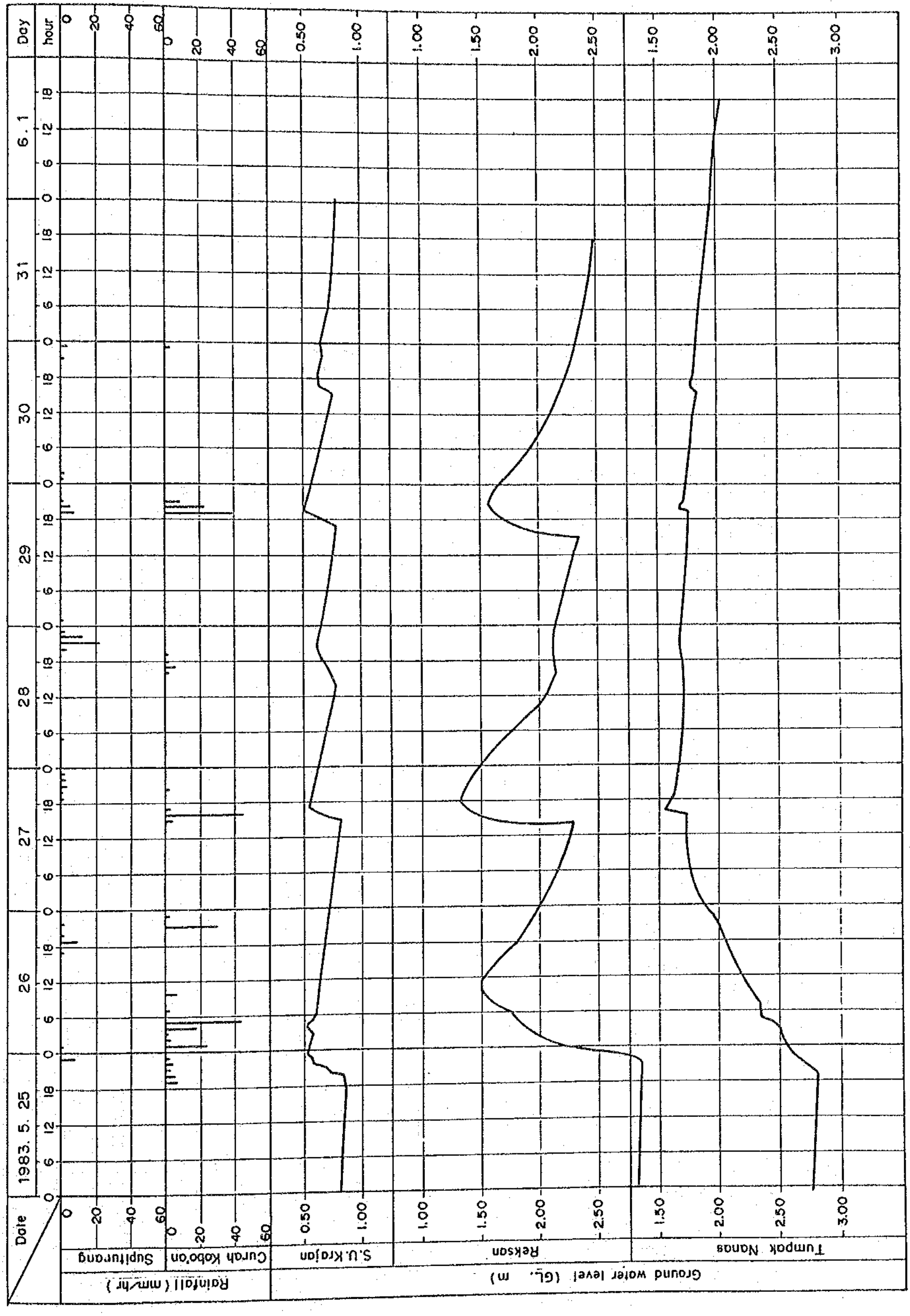


Fig. – 3(8) Groundwater Level Fluctuation in K. Lengkong Basin

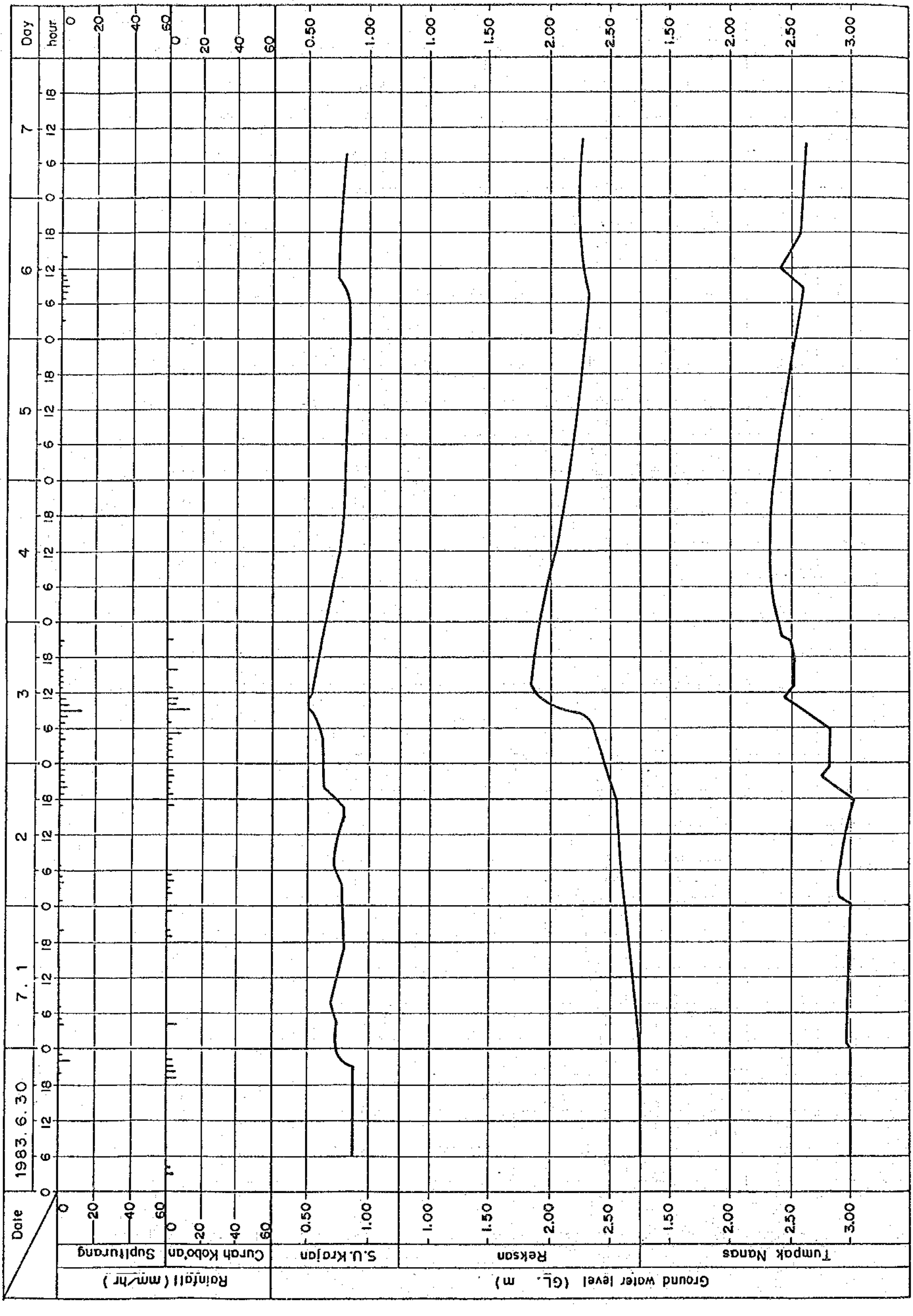


Fig. - 3(9) Groundwater Level Fluctuation in K. Lengkong Basin

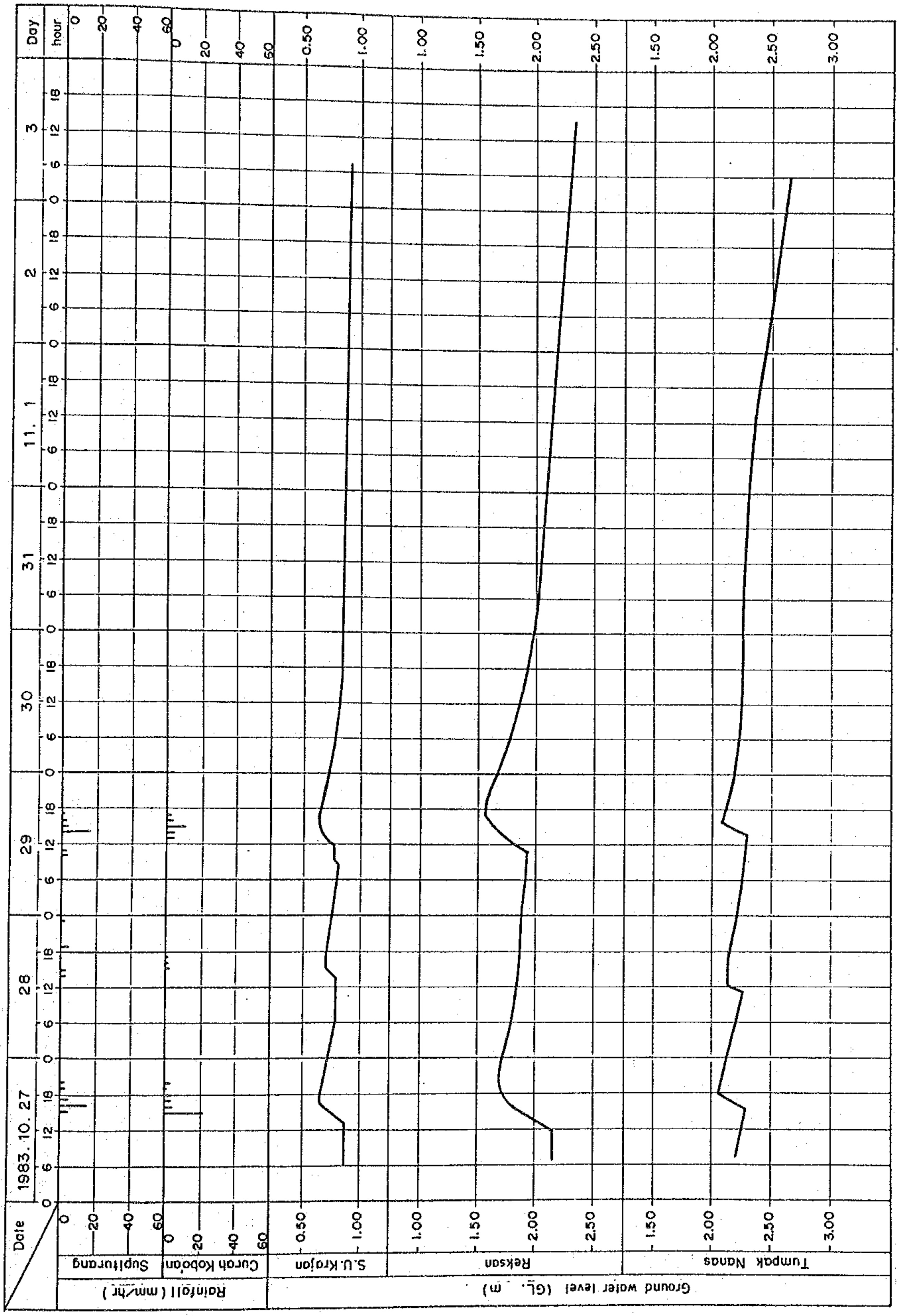


Fig. - 3(10) Groundwater Level Fluctuation in K. Lengkong Basin

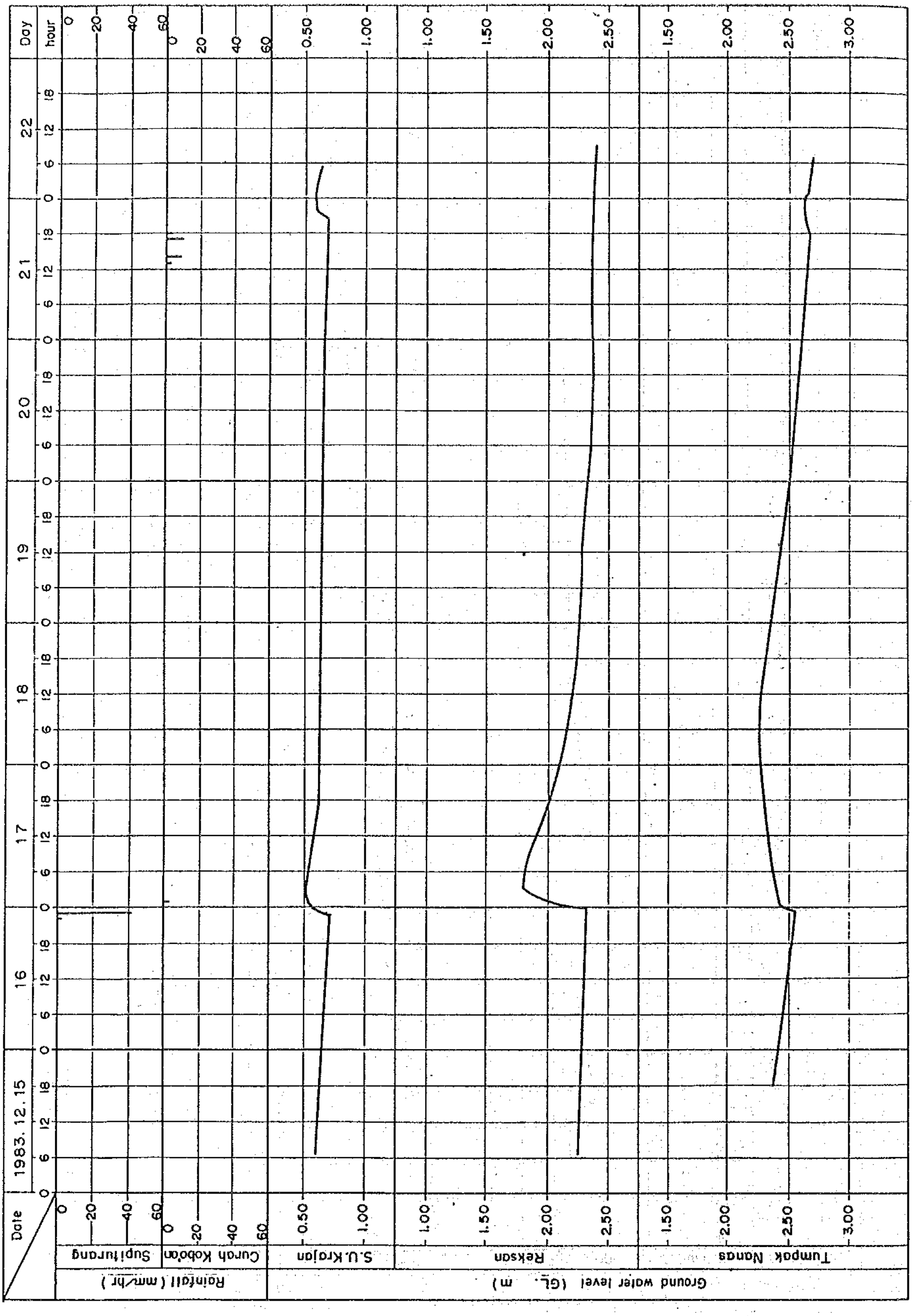


Fig. – 3(11) Groundwater Level Fluctuation in K. Lengkong Basin

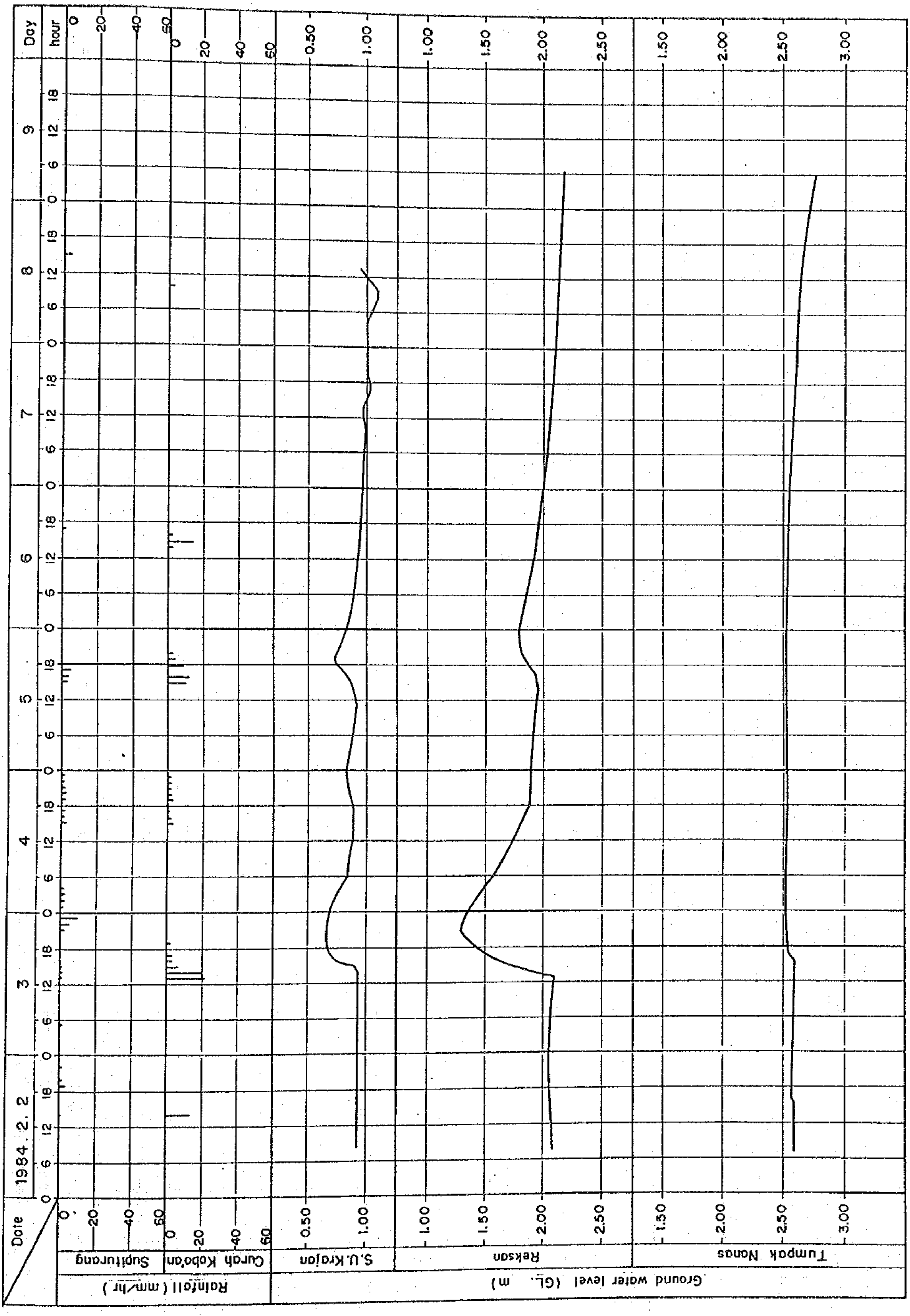


Fig. -3(12) Groundwater Level Fluctuation in K. Lengkong Basin

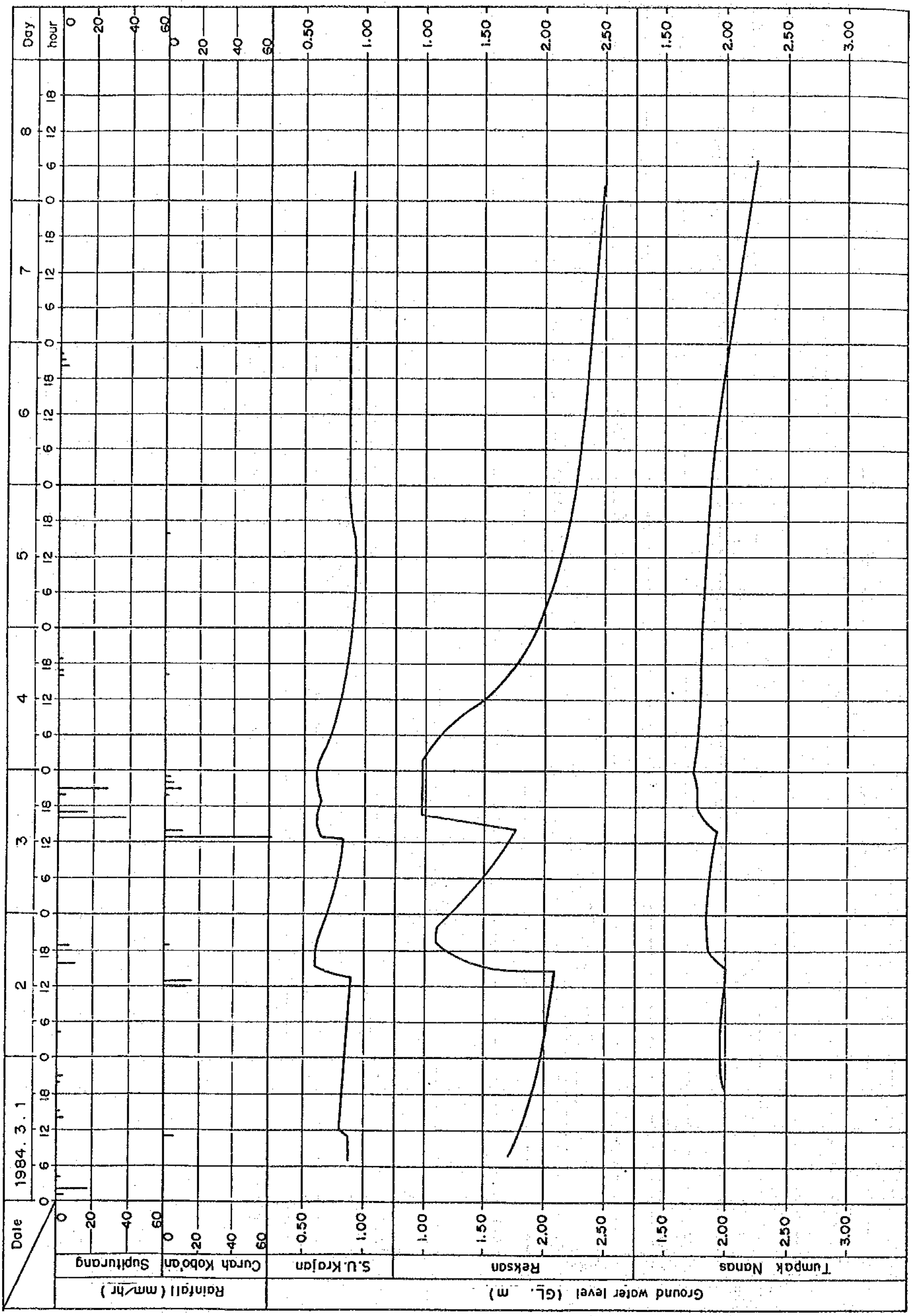


Fig. – 3(13) Groundwater Level Fluctuation in K. Lengkong Basin

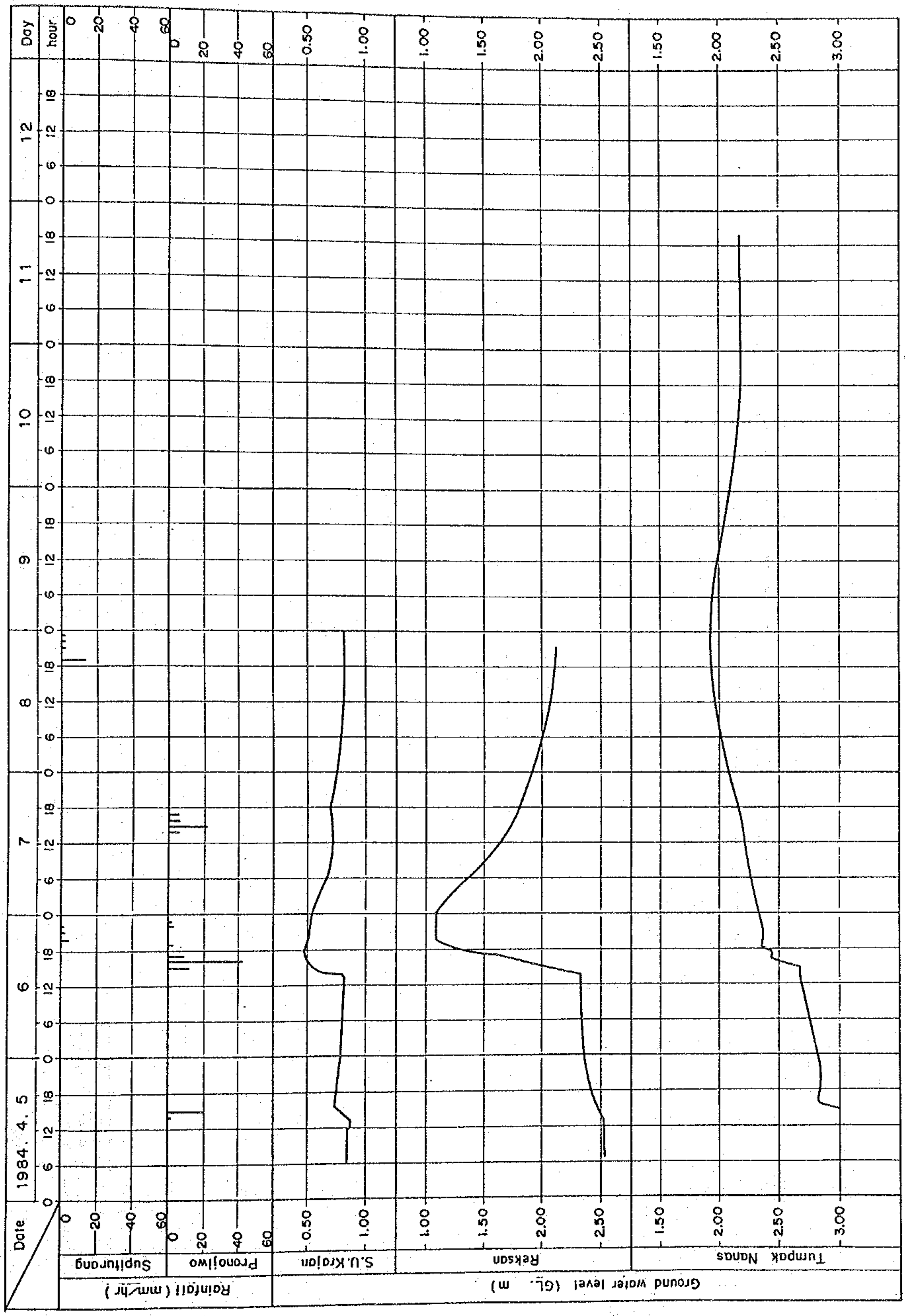


Fig. -3(4) Groundwater Level Fluctuation in K. Lengkong Basin

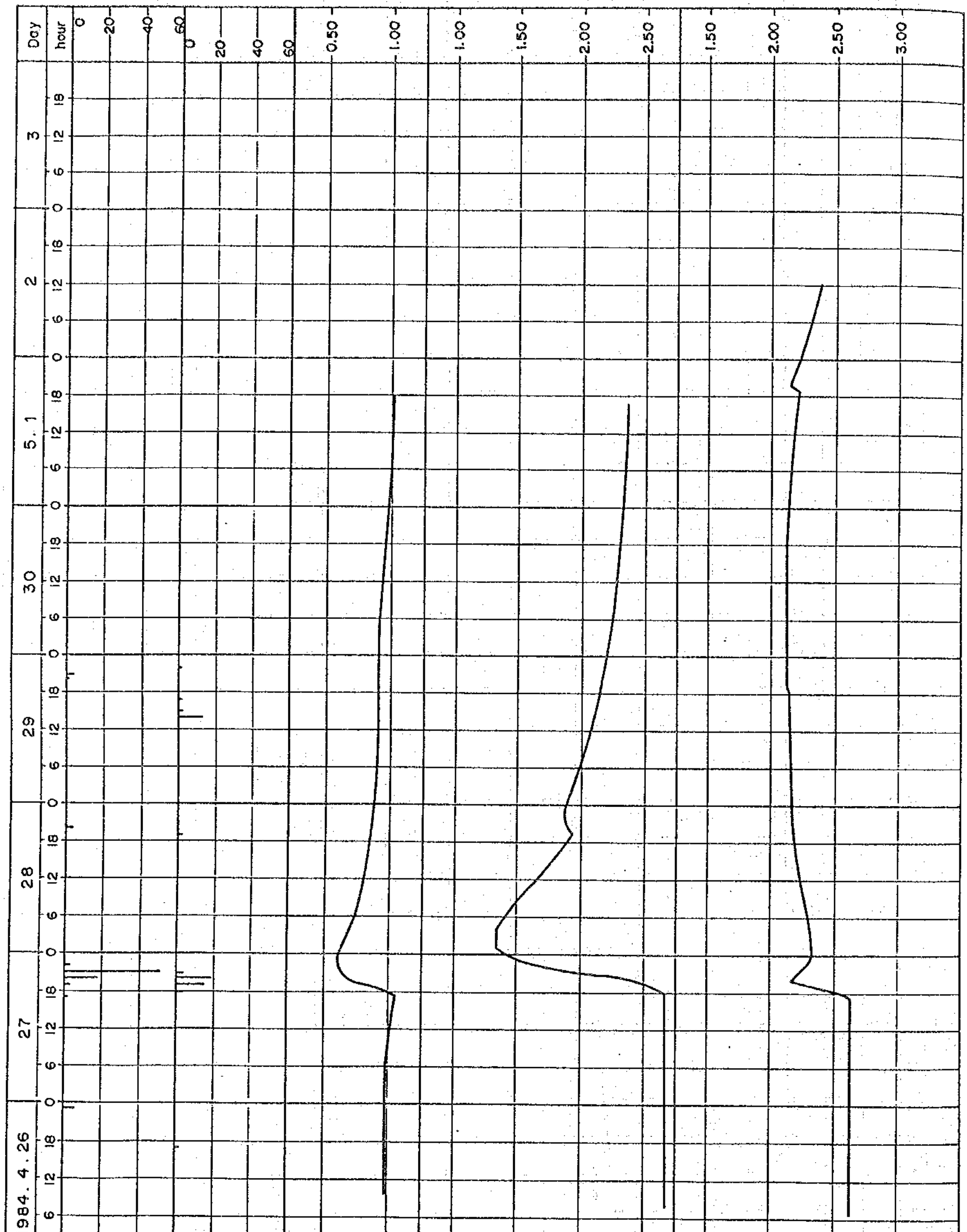


Fig. – 3(15) Groundwater Level Fluctuation in K. Lengkong Basin

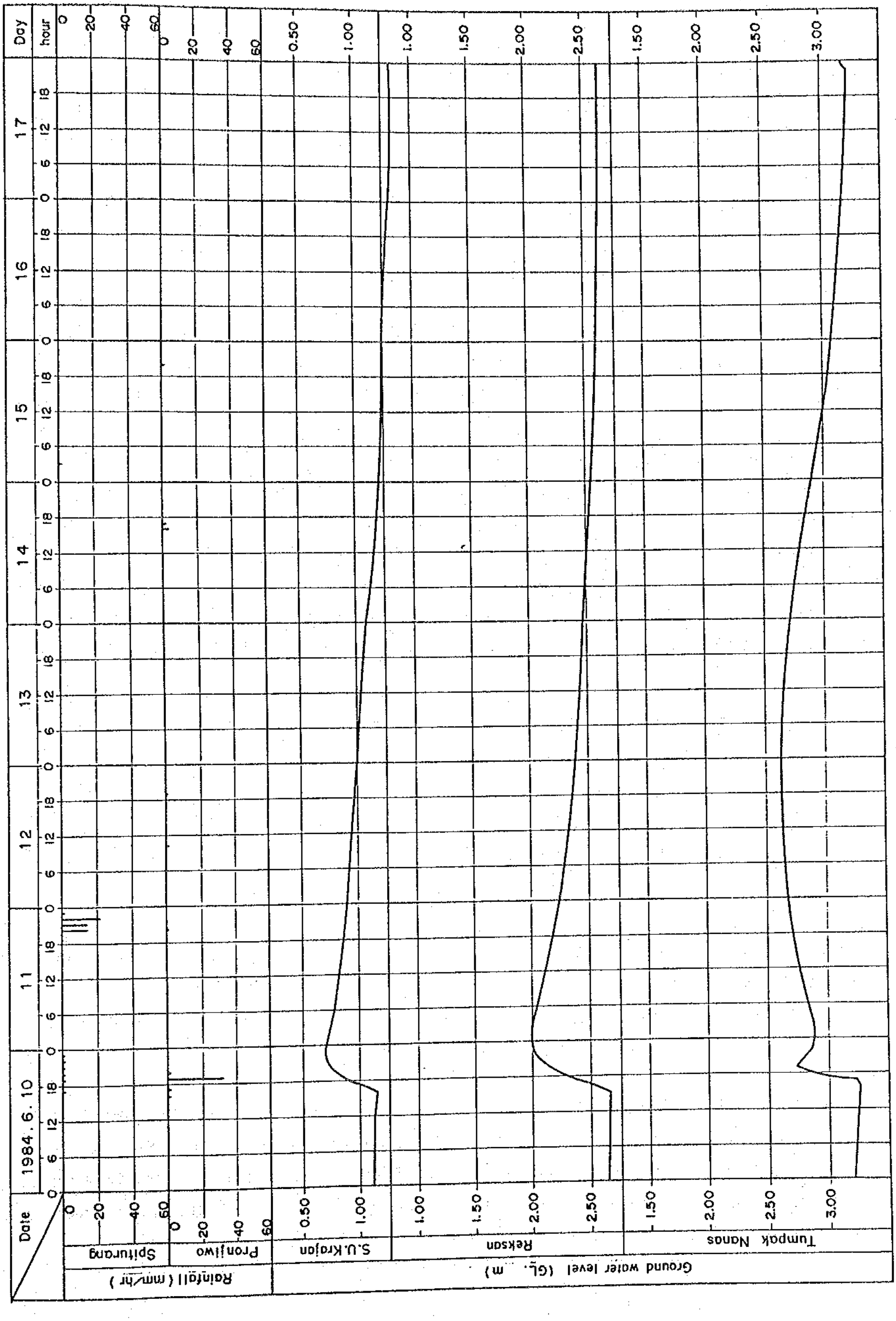


Fig. - 3(16) Groundwater Level Fluctuation in K. Lengkong Basin

(4) Fluctuation Characteristics in the K. Lengkong Fan

The volcanic fan of Mt. Semeru extends largely in the right bank of the K. Lengkong. It is estimated that the volcanic products of Mt. Semeru are deposited parallel to the slope of the present ground surface. Springs are mainly found along the contour line of 800m in elevation, corresponding to the inflection point of slope.

Two observation wells, Sumber Urip Krajan and Reksan, are found in the lower stream from the spring distribution line. Sumber Urip Krajan (EL. 761m) is 1.2km north of Reksan (EL. 718m).

From the histogram of the peak occurrence of fluctuations, as shown in Fig.-4, the lag time mainly consists of 1 to 3 hours and the rate of the lateral fluctuation profile of the groundwater level in time is estimated as shown in Fig.-5.

According to Darcy's Law governing the mass transfer in porous media, the real groundwater velocity is expressed by:

$$v = \frac{\tau}{\lambda} K \cdot I \qquad \text{(1)}$$

where, v: real velocity
τ: tortuosity
λ: porosity
K: permeability
I: hydraulic gradient

From the field reconnaissance, these values can be roughly evaluated as: $\tau = 1.4$, $\lambda = 0.5$, $K = 10^{-3}$ cm/sec and $I = 1/30$. Submitting these values in Eq.(3.1), the real groundwater velocity is nearly 9×10^{-5} cm/sec (0.3m/hr).

On the other hand, the distance between Sumber Urip Krajan and Reksan is about 1.2km and the lag time of peak occurrence is 1 to 3 hours. The groundwater velocity is estimated to be 400 to 1,200m/hr. The observation velocity is a thousand times greater than the value calculated using Darcy's Law.

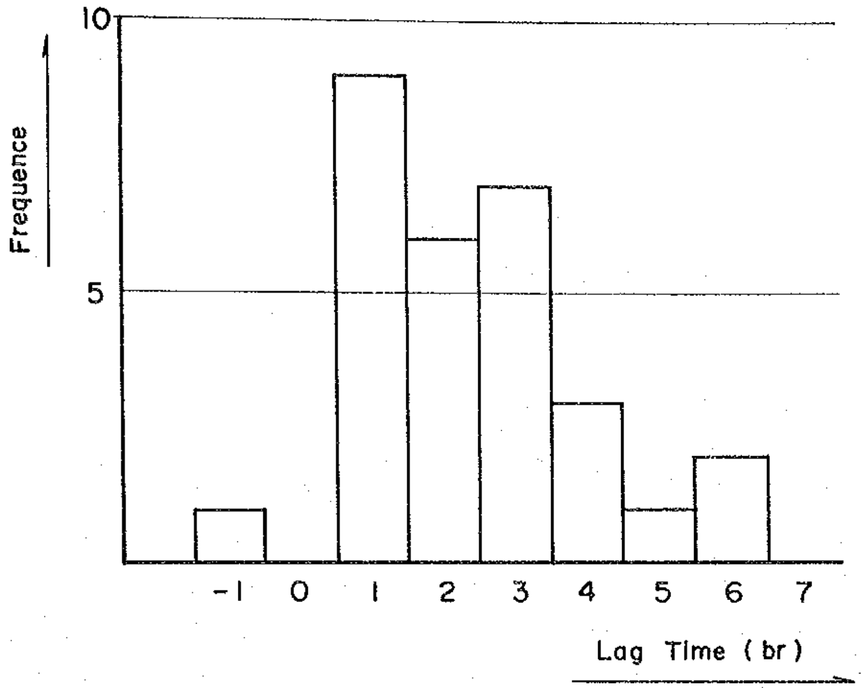


Fig.-4 Histogram of Lag Time of Peak Occurrence at Reksan

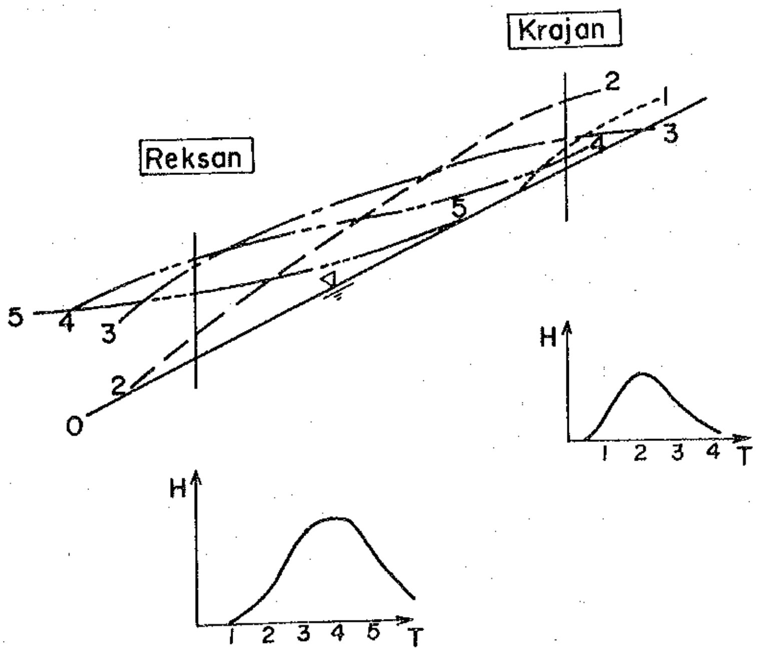


Fig.-5 Propagation of Groundwater Level Fluctuation

Therefore, the existence of a water-veins system can be thought to play a major role in the microscopic phenomena of groundwater level fluctuation.

(5) Fluctuation Characteristics in the Piedmont of the Tertiary Mountains

From the macroscopic point of view, the groundwater level fluctuation at Tumpak Nanas has annual fluctuation characteristics, i.e. high level in the rainy season and a low level in the dry season.

The microscopic characteristics are as follows:

① The fluctuation profiles at Tumpak Nanas, situated in the left bank of the K. Lengkong, differ from the fluctuation profiles at Sumber Urip Krajan and Reksan, situated in the right bank. The fluctuation profile is generally flat and long.

② In the left bank of the K. Lengkong, vegetation is very rich and a thick weathered layer of the tertiary system covers the surface. Therefore, the duration of the groundwater recharge effect seems to be slow and long.

③ The complexity sometimes observed in the fluctuation profiles may be explained by the existence of small pipes with diameters varying from 1 to 3cm, running through the weathered layer.

2.2 ANALYTICAL INTERPRETATION

(1) Asymptotic Function

Groundwater level fluctuation observed at three observation wells in the K. Lengkong basin represent one of the behaviors of an unconfined aquifer system, belonging to the hydrological water budget system, as shown in Fig.-6.

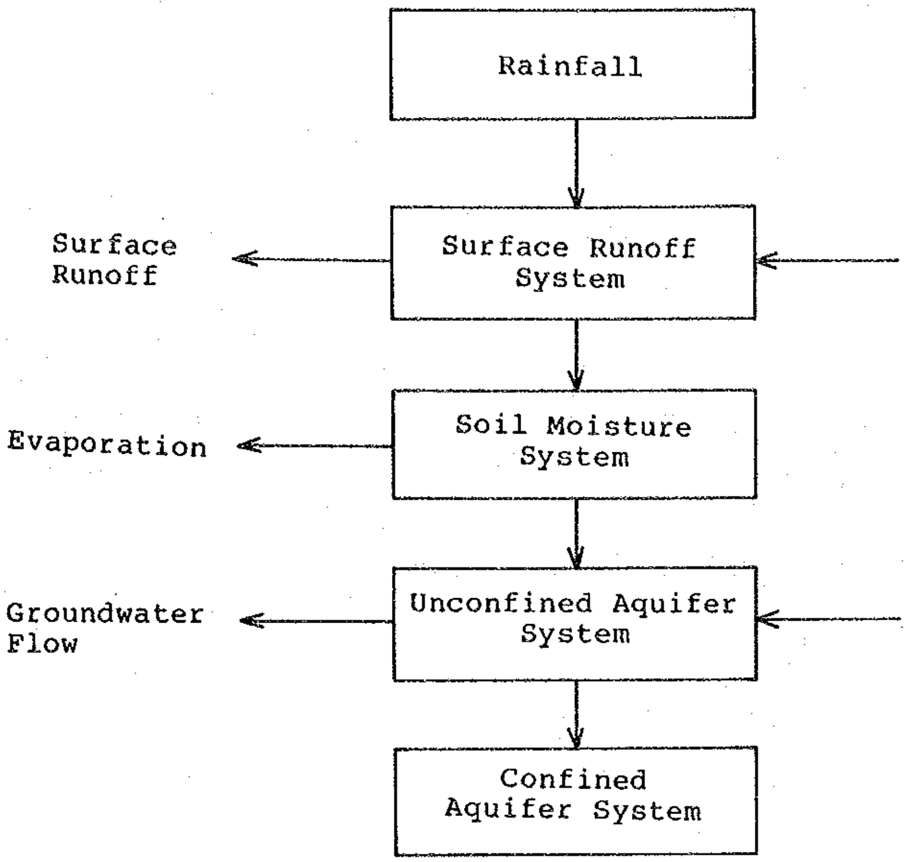


Fig.-6 Conceptual Hydrological Water Budget System

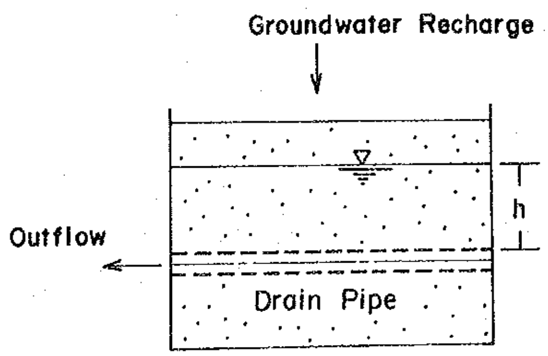


Fig.-7 Simplified Model of Unconfined Aquifer System

As the unconfined aquifer system of the K. Lengkong groundwater basin is characterized by the existence of water-veins system in the porous media, a simplified model of an unconfined aquifer, as shown in Fig.-7, is introduced to build up an asymptotic function.

The model consists of a reservoir filled up by porous media. A drain-pipe is installed in the lower part of the reservoir to represent the water-veins system.

The water budget in this simplified model is as follows:

(a) Inflow from soil moisture system and groundwater inflow from upstream can be expressed as a function of the groundwater recharge potential.

(b) Leakage between an unconfined aquifer and a confined aquifer is considered to be negligibe in the short response.

(c) Storage amount of an unconfined aquifer system can be assimilated by the water level of the reservoir in the simplified model.

(d) Groundwater outflow to downstream can be expressed by the outflow discharge through a drain pipe.

Assuming that outflow discharge through a drain pipe is proportional to the hydraulic head in the reservoir, the decrease behaviour of the water level in the reservoir can be expressed by an exponential function:

$$h = \alpha . e^{-\beta t} \quad \text{.................................} \quad (2)$$

where,

h: Hydraulic potential representing the height from the center of the drain-pipe.

α, β: Constants

t: Time

On the other hand, the rate of the groundwater recharge effect in time will converge to a limited value if the outflow discharge through a drain-pipe is closed.

As the response of the groundwater level fluctuation to rainfall is quick, the following function is introduced to express the groundwater recharge effect in time:

$$h = \alpha' . e^{-\frac{\beta'}{t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where, α', β': Constants

From the equations (2) and (3), the combined effect of outflow and the groundwater recharge in the solitary fluctuation of the groundwater level can be expressed by:

$$H = a.e^{-\frac{b}{t}-ct} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where, H: Height of the groundwater level from the initial level

a: Constant related to the groundwater recharge intensity

b: Constant related to the duration of the recharge effect

c: Constant related to the decrease of the groundwater level.

(2) Application of Asymptotic Function

The asymptotic function will be applied to solitary fluctuations among typical fluctuations as shown in Section 2.1.

The determination process of constants a, b and c is as follows:

(i) Constant c

Constant c is found from the linear relationship between the logarithmic value of the groundwater level and the time on the semi-logarithmic graph.

(ii) Constant b

Constant b is calculated from the peak condition where the differential of the groundwater level in time is equal to zero:

$$\frac{H}{t} = 0 \;;\; \frac{b}{t_p^2} - c = 0$$

$$b = ct_p^2 \qquad \text{.........................} \qquad (5)$$

where, t_p: Peak occurrence time (hr)

(iii) Constant a

Submitting b, c and t_p in Eq. (5), the following equation is obtained to determine constant a.

$$a = \frac{Hp}{e^{-2ctp}} \qquad \text{.........................} \qquad (6)$$

where, Hp: Peak height of the groundwater level from the initial level

(3) Calculation Results

The Asymptotic function is applied to the solitary fluctuations of which the periods are as follows:

Case 1: From 28 Feb. to 2 Mar., 1983
Case 2: From 21 Apr. to 23 Apr., 1983
Case 3: From 29 Oct. to 1 Nov., 1983
Case 4: From 17 Dec. to 18 Dec., 1983
Case 5: From 10 Jun. to 13 Jun., 1984

The calculation results are as shown in Fig.-8(1) to Fig.-8(15).

From the comparison of the calculation results with the observation of the groundwater level, the application of the asymptotic function to the solitary fluctuation can be evaluated as follows:

① Calculation results of Sumber Urip Krajan and Reksan have good concordance with observation. Asymptotic function can be estimated to be available for the analytical interpretation of the groundwater level characteristics.

② Calculation results of Tumpak Nanas have good concordance with quick response fluctuation, but a slow response fluctuation will be expressed by the combined type of asymptotic equation:

$$H = \sum_i a_i e^{-\frac{bi}{t} - c_i t} \qquad \cdots\cdots\cdots\cdots \qquad (7)$$

(4) Consideration

Constants related to the asymptotic function will be discussed here in order to clarify the characteristics of such fluctuation as the groundwater recharge potential and the decrease ratio of the groundwater level.

① Groundwater Recharge Potential

The tentative index representing the groundwater recharge potential is as shown in Table-3 and is expressed by:

$$P = \lim_{t \to \infty} \int_0^t a \cdot e^{-\frac{b}{t}} \, dt = \frac{a}{b} \qquad \cdots\cdots\cdots \qquad (8)$$

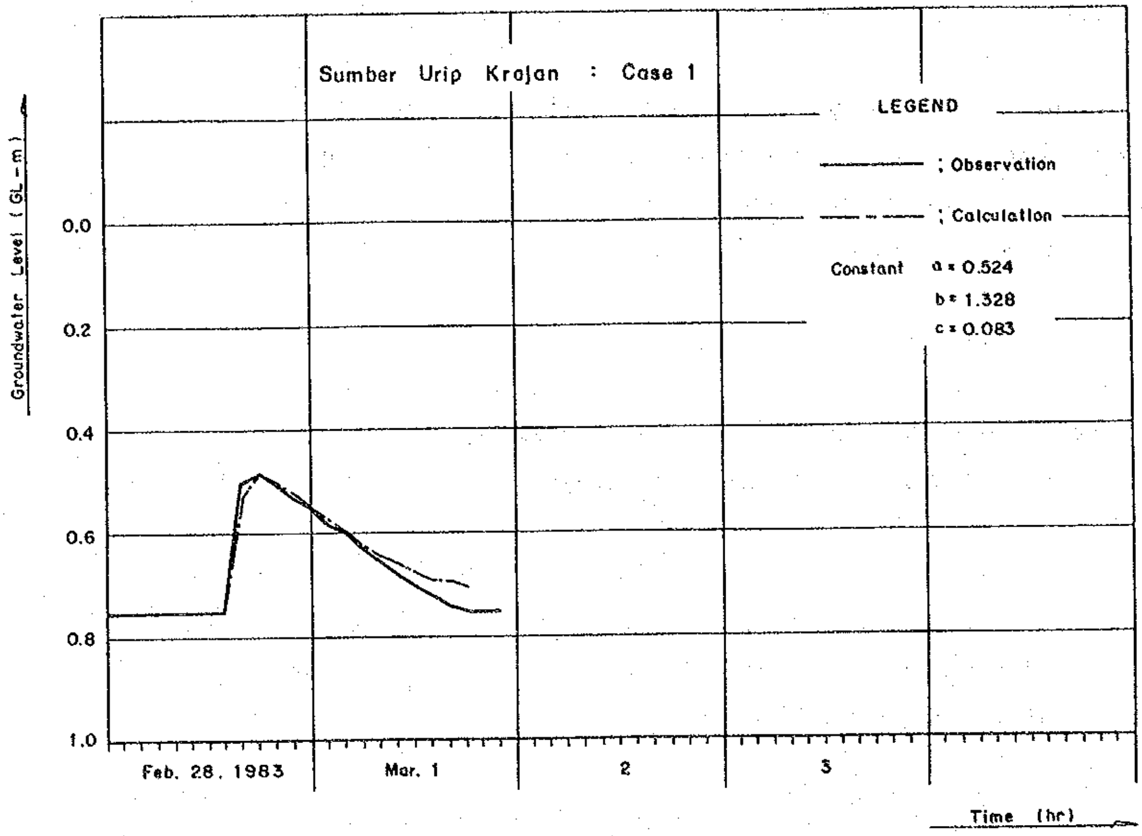


Fig.-8(I) Calculation Result of Asymptotic Function

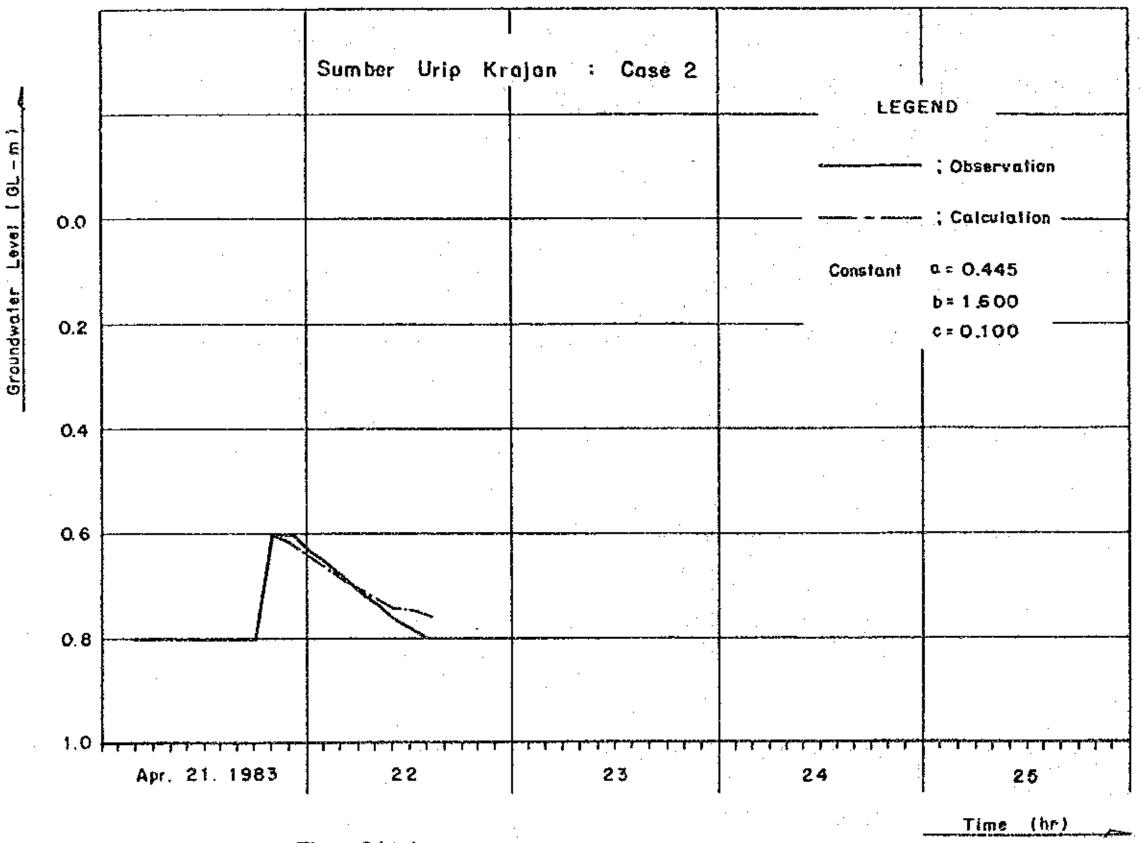


Fig.-8(2) Calculation Result of Asymptotic Function

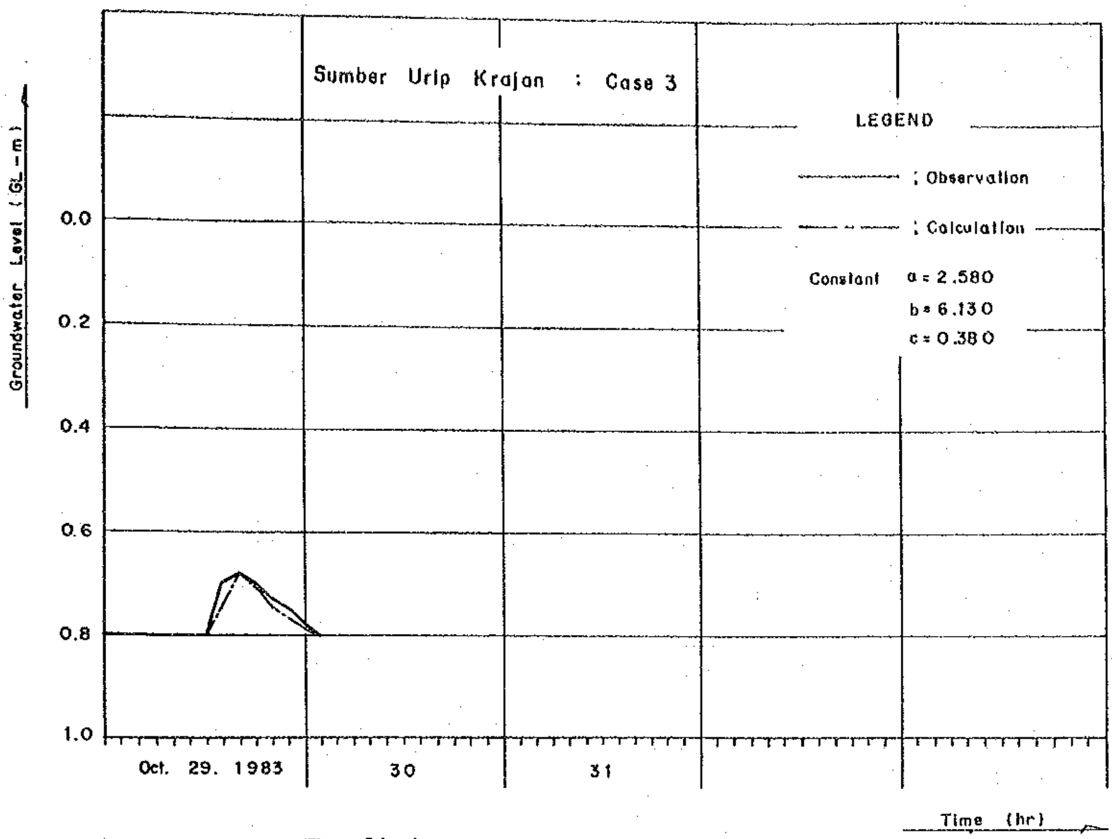


Fig.-8(3) Calculation Result of Asymptotic Function

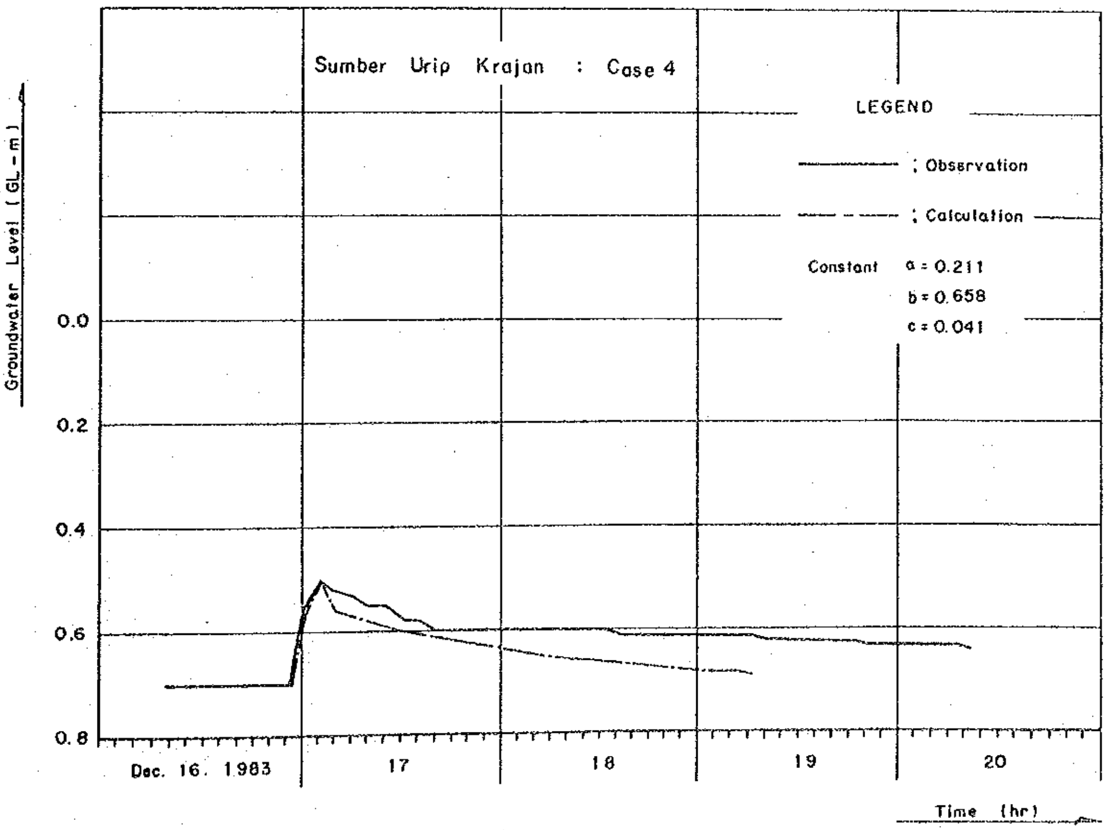


Fig.-8(4) Calculation Result of Asymptotic Function

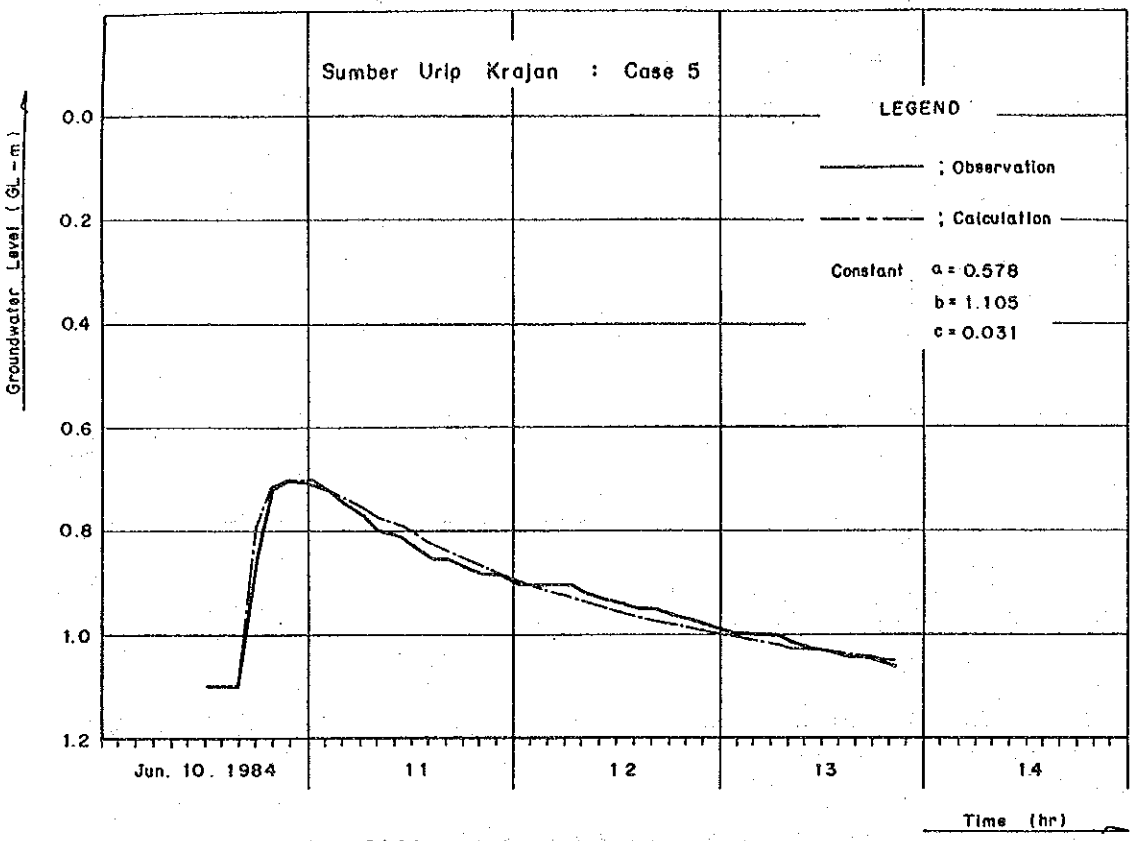


Fig.-8(5) Calculation Result of Asymptotic Function

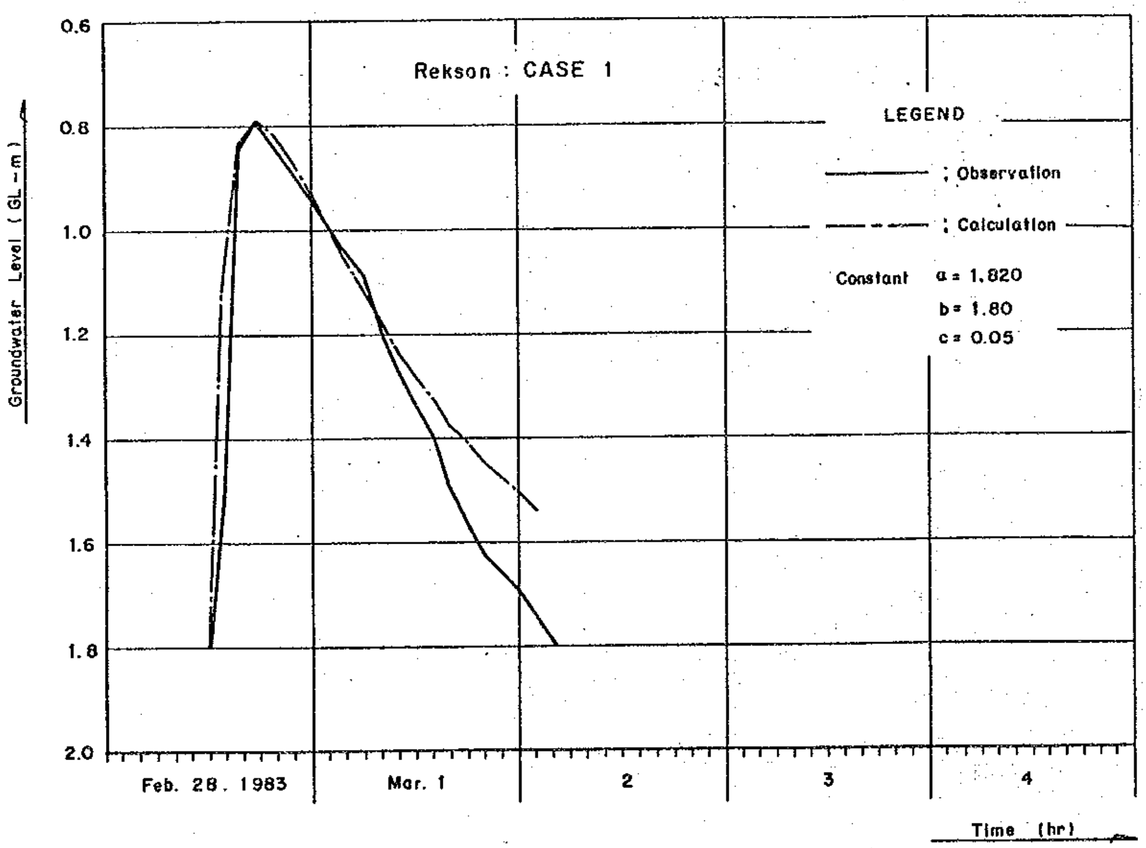


Fig.-8(6) Calculation Result of Asymptotic Function

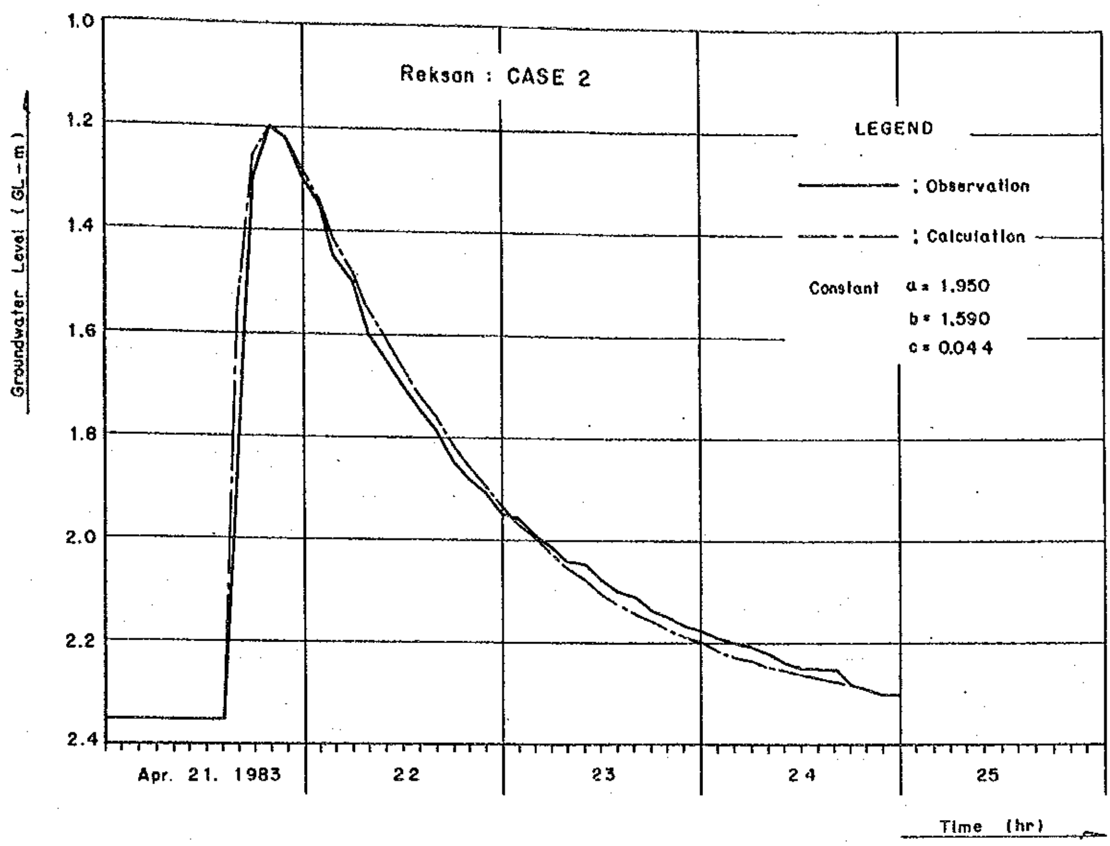


Fig.-8(7) Calculation Result of Asymptotic Function

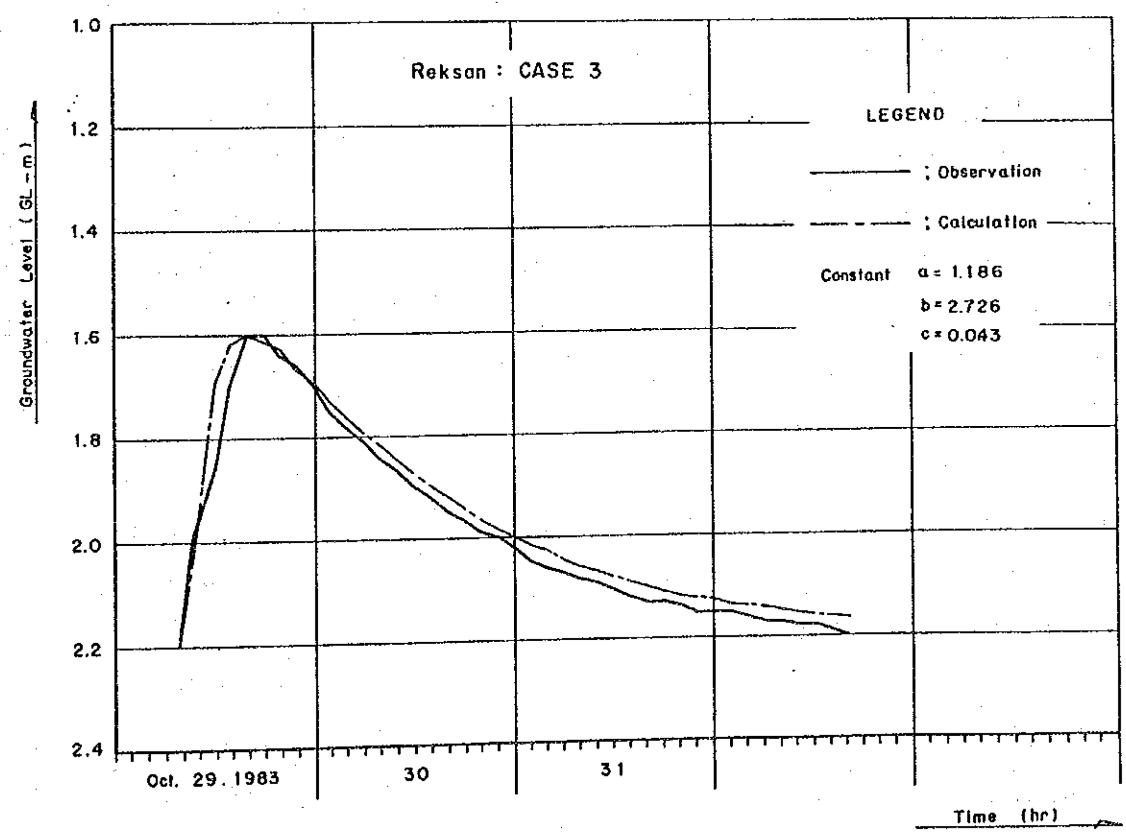


Fig.-8(8) Calculation Result of Asymptotic Function

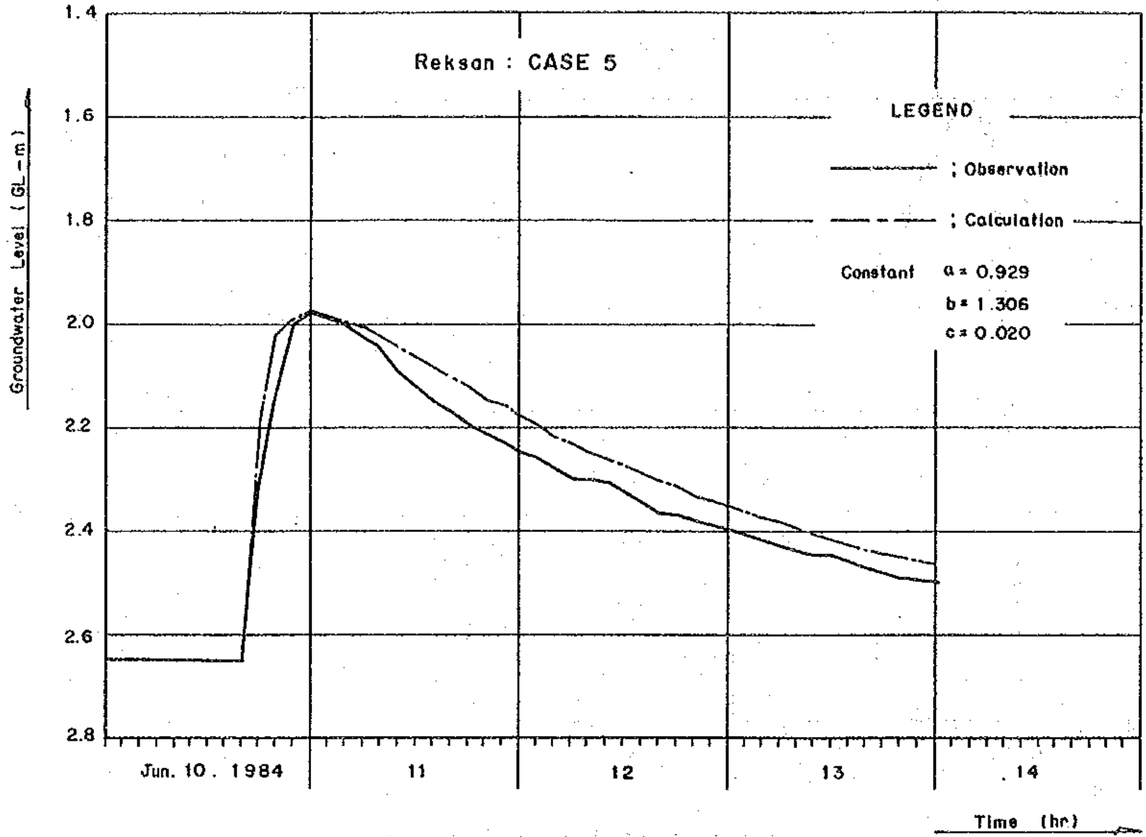


Fig.-8(10) Calculation Result of Asymptotic Function

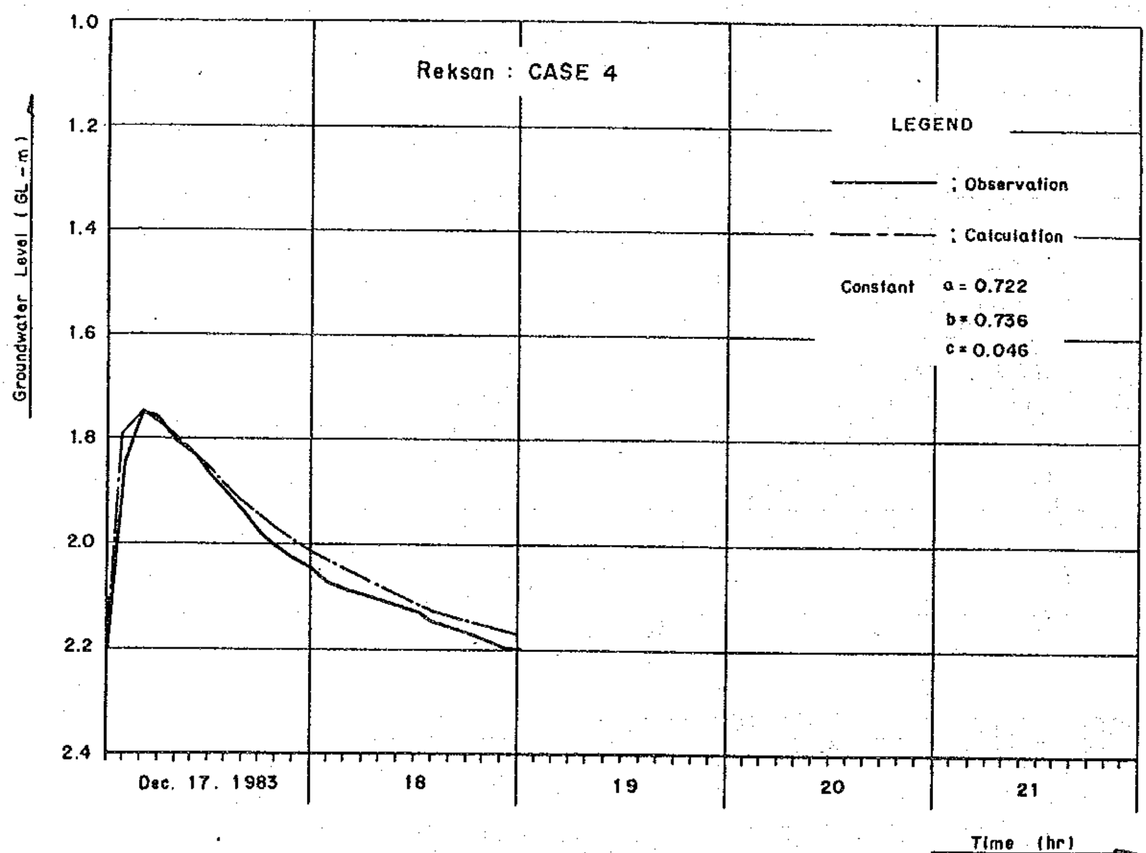


Fig.-8(9) Calculation Result of Asymptotic Function

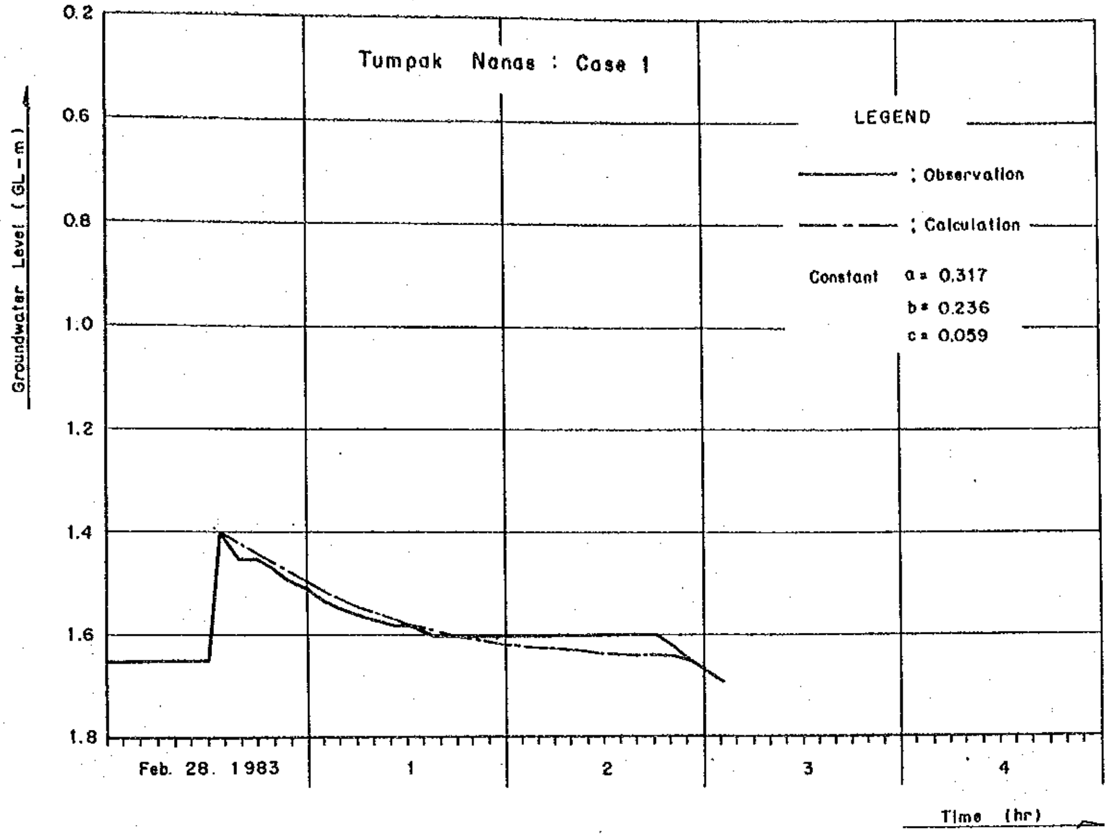


Fig.-8(11) Calculation Result of Asymptotic Function

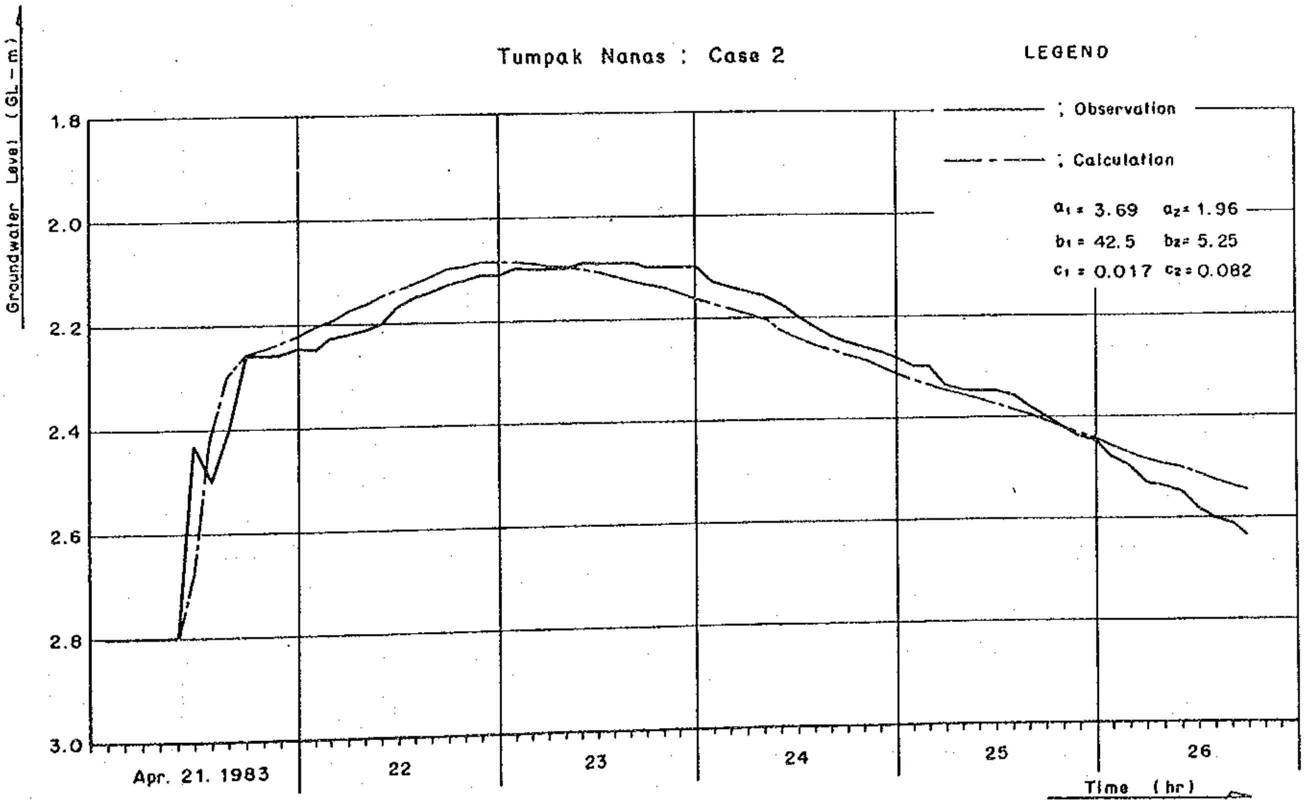


Fig.-8(12) Calculation Result of Asymptotic Function

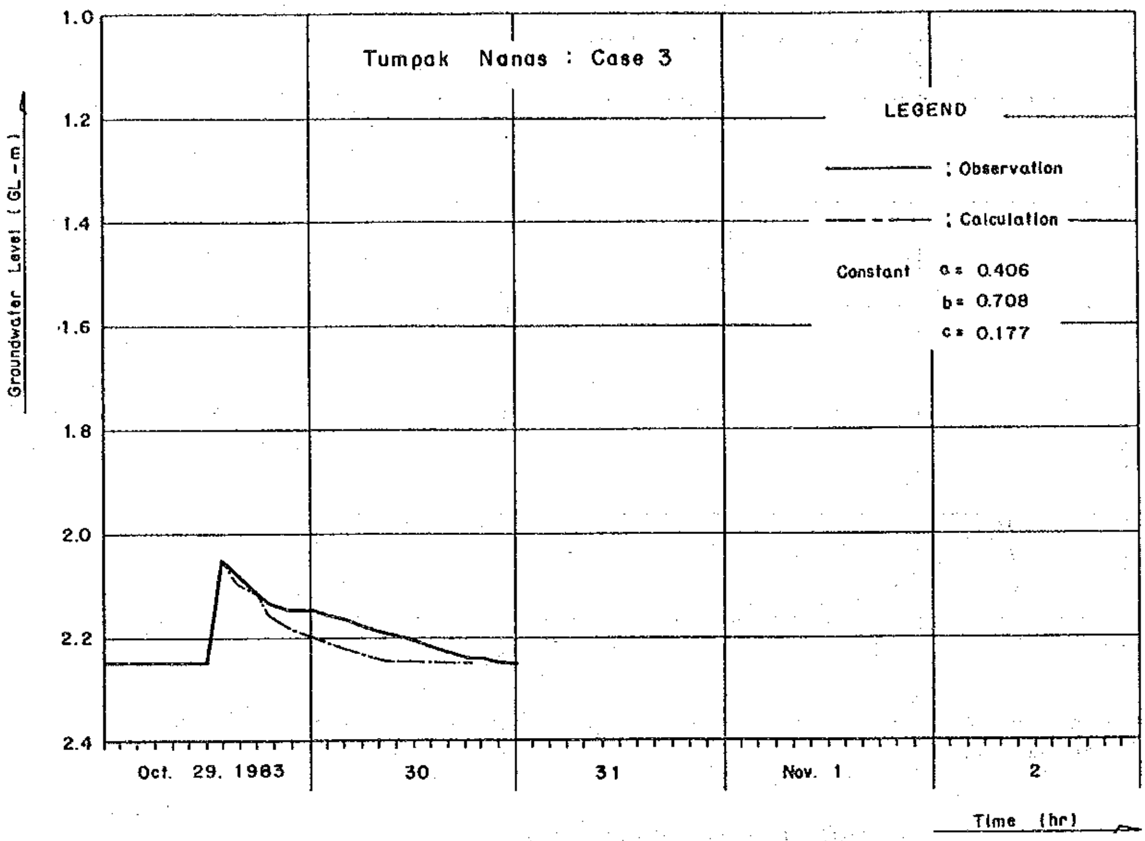


Fig.-8(13) Calculation Result of Asymptotic Function

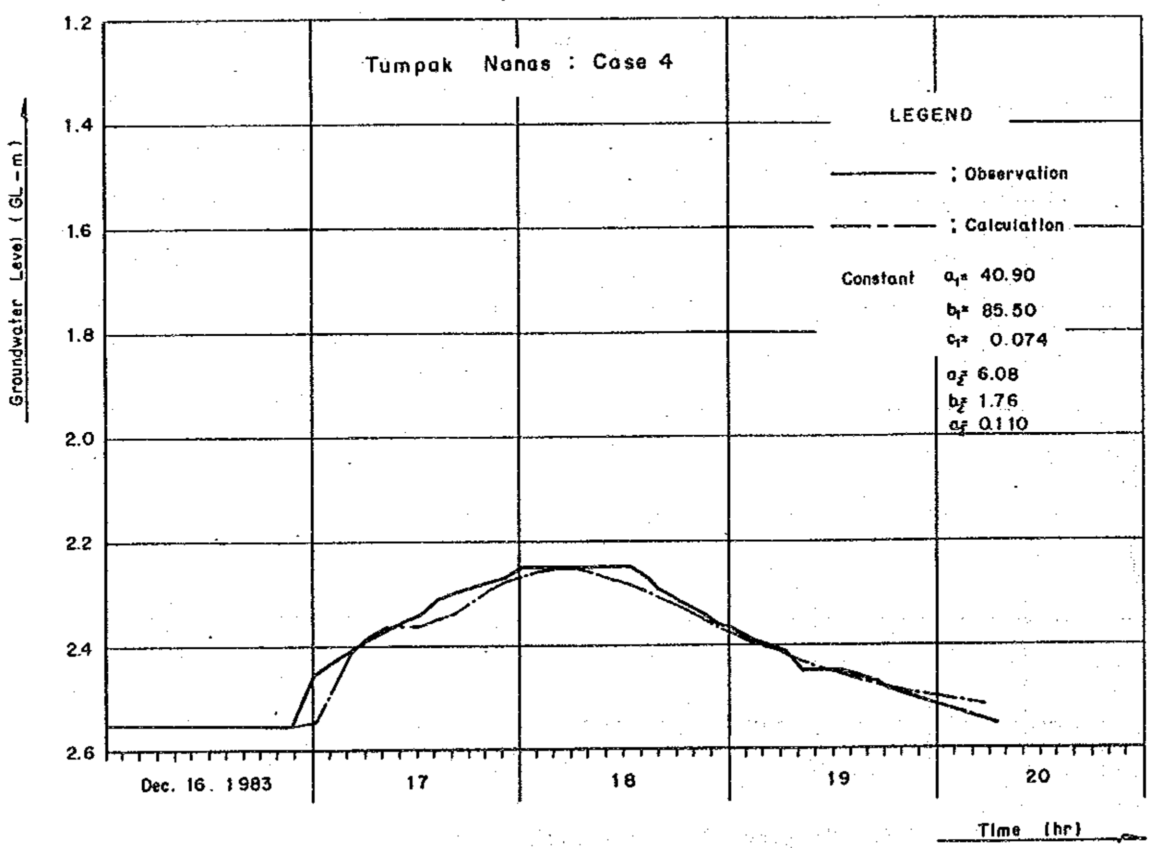


Fig.-8(14) Calculation Result of Asymptotic Function

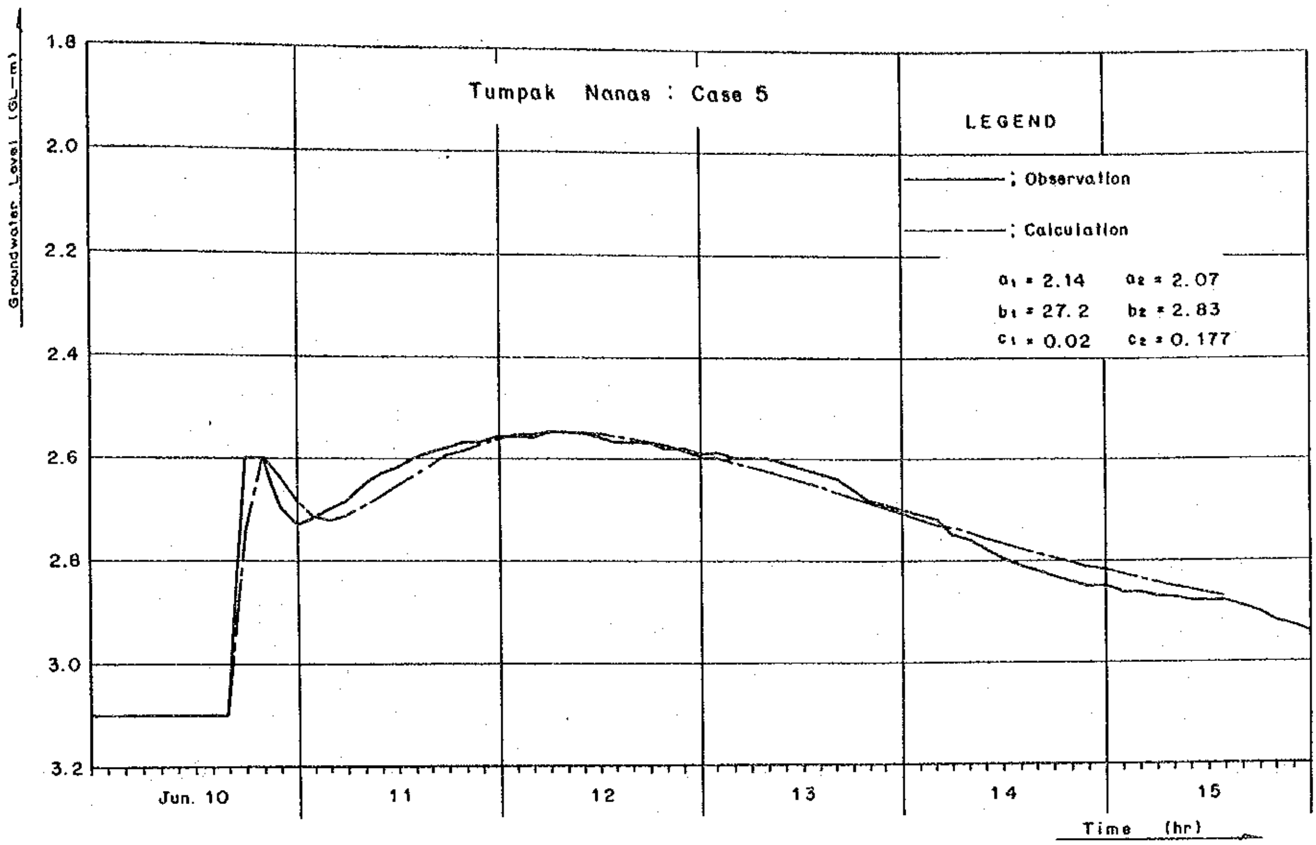


Fig.-8(15) Calculation Result of Asymptotic Function

Table-3 Relationship between Groundwater Recharge Potential Index and Rainfall Intensity

Case	Recharge Potential Index (a/b)		Rainfall (mm)		
	S.U. Krajan	Reksan	Pronojiwo	Supit Urang	Curah Kobo'an
1	0.39	1.01	49.1	87.0	-
2	0.28	1.23	18.2	0.0	2.0
3	0.42	0.44	-	22.2	40.8
4	0.32	0.98	-	44.0	22.8
5	0.52	0.71	61.8	3.0	26.6

② Decrease Ratio of the Groundwater Level

The decrease ratio of the groundwater level represented by constant c has an exponential relationship with time, as shown in Fig.-9. Constant c varies with the groundwater level, it has a large value in high groundwater level while having a small value in low groundwater level.

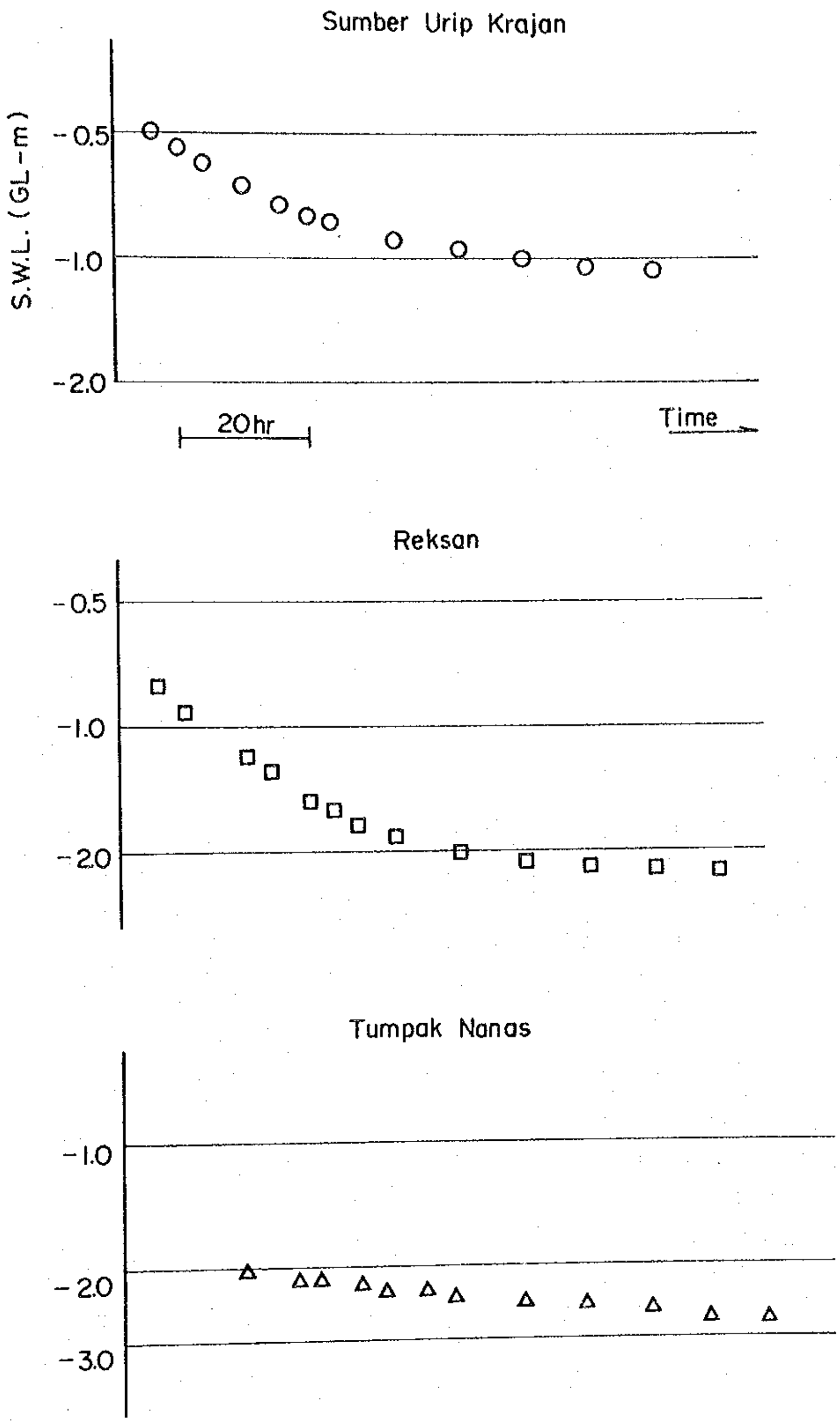


Fig.-9 Decrease Curve of the Groundwater

2.3 HOURLY RAINFALL AMOUNT ANALYSIS

(1) Location of Rainfall Observation Stations

There are four rainfall observation stations in the K. Lengkong basin and its vicinity, as shown in Table-4 and Fig.-10. Data on these four stations is available for analysis of the hourly rainfall amount.

Table-4 Rainfall Observation Stations

NO.	STATION	LOCATION		EL. (m)	BELONGING	TYPE OF EQUIPMENT	INSTALLED DAY
		LATITUDE	LONGITUDE				
32	KAMAR A	S8° 8'56"	E112°57'10"	+1300	PROYEK G. SEMERU	AUTOMATIC	2 FEB '82
34	PRONOJIWO	S8°12'47"	E112°56'18"	+ 600	- DITTO -	- DITTO -	JAN '79
38	CURAH KOBO'AN	S10°0'16"	E113° 0'10"	+ 734	- DITTO -	- DITTO -	JAN '78
42	SUPIT URANG	S8°13'11"	E112°58' 6"	+ 675	- DITTO -	- DITTO -	21 JUN '82

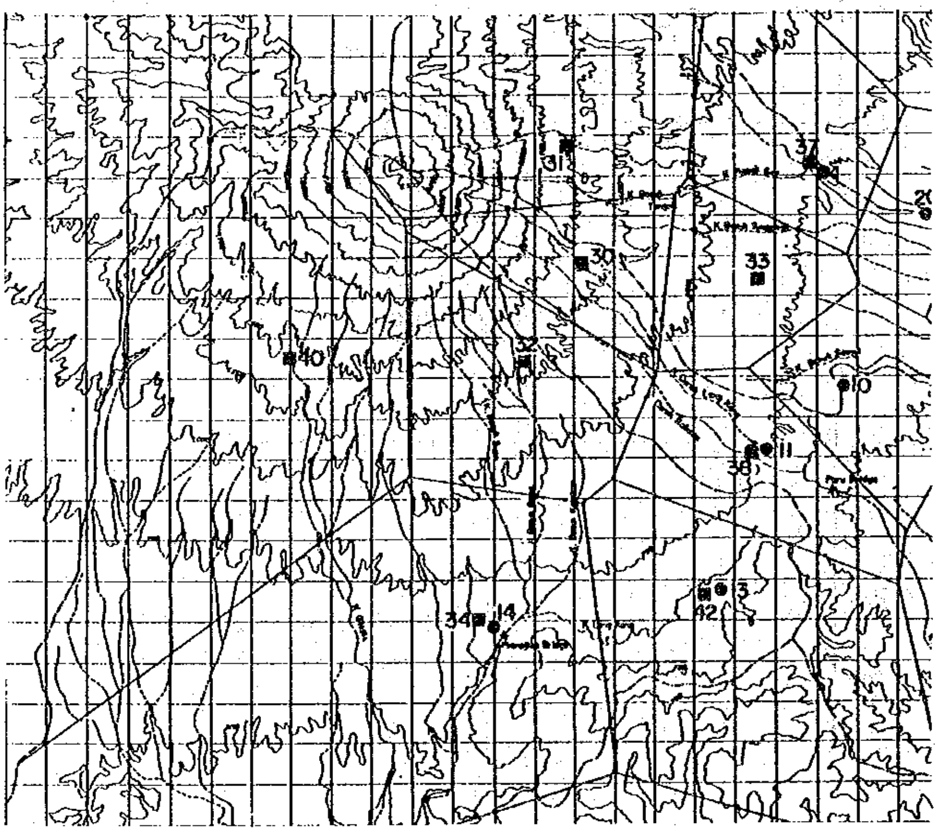


Fig.-10 Location of Rainfall Observation Stations

(2) Methodology

The hourly rainfall characteristics in the K. Lengkong basin will be discussed here, using the calculation of correlation coefficient expressed as follows:

$$r = \frac{cov(X,Y)}{\sqrt{var(X)var(Y)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

where, r: Correlation coefficient

$$cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})$$

$$var(X) = \frac{1}{n}\sum_{i=1}^{n}(X_i-\bar{X})^2$$

$$var(Y) = \frac{1}{n}\sum_{i=1}^{n}(Y_i-\bar{Y})^2$$

X,Y: Serial hourly rainfall data

In order to understand the time lag of rainfall occurrence, the correlationship between observation staions and so on, serial rainfall data is taken in the following way:

$$X: \; x_1, x_2, \ldots, x_m, x_{m+1}, \ldots, x_n, 0, \ldots\ldots\ldots, 0$$

$$Y: \; 0, 0, \ldots., y_1, y_2, \ldots., y_{n-m-1}, y_{n-m}, \ldots, y_n$$

(m-1)hr
Lag time

The correlation coefficient varies with the time lag and has an extreme value representing the maximum correlation coefficient between two rainfall observation stations, as shown in Fig.-11.

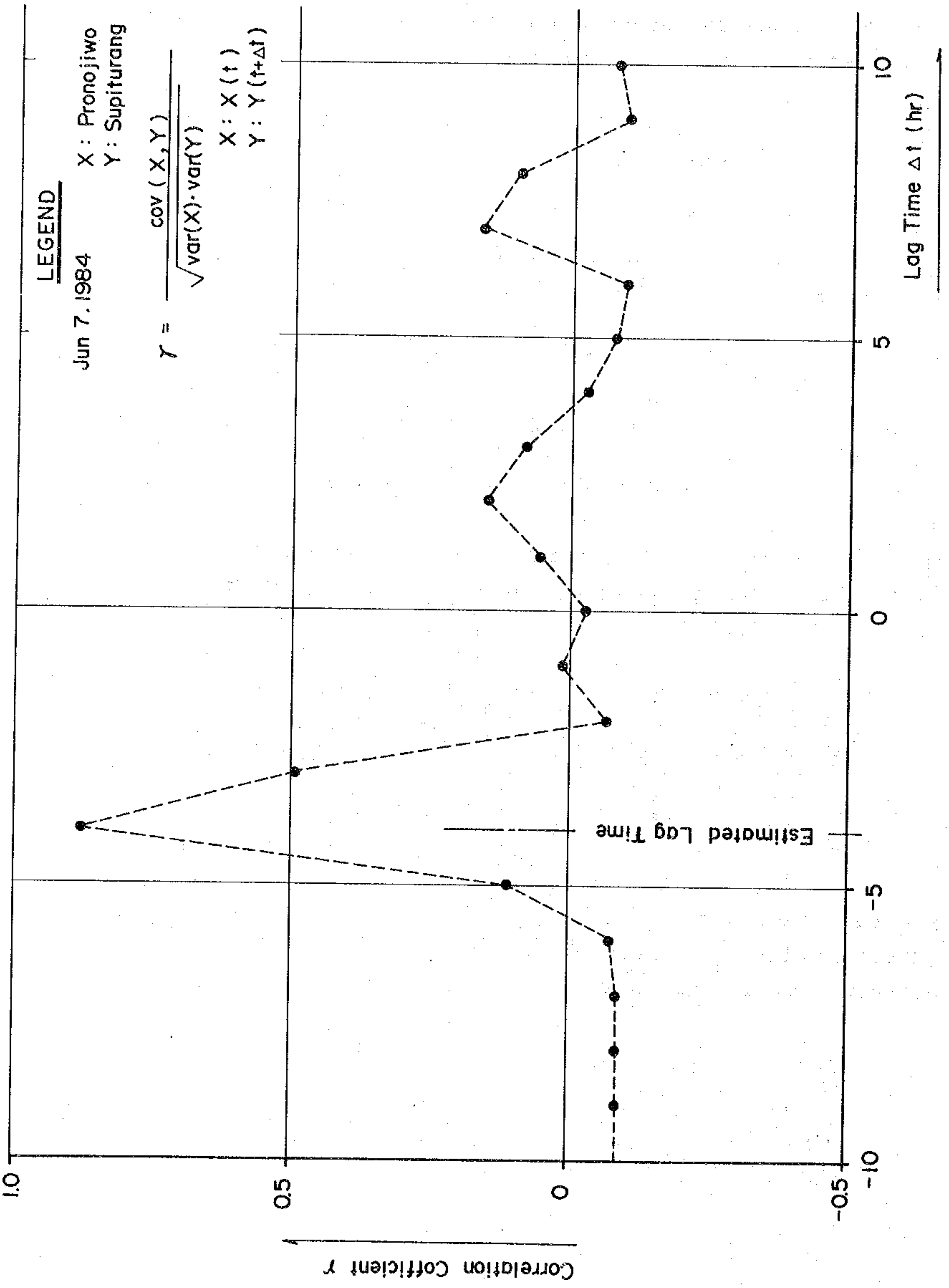


Fig-11 Variation of Correlation Coefficient related to Lag Time

(3) Calculation Results

Calculation of the correlation coefficient based on the time lag concept is carried out on the serial hourly rainfall data, corresponding to the selected typical fluctuation of the groundwater level. The periods of rainfall data are as follows:

Case 1:	14:00, 17 Jan. to 22:00, 20 Jan., 1983
2:	14:00, 6 Feb. to 21:00, 10 Feb., 1983
3:	12:00, 25 Feb. to 6:00, 1 Mar., 1983
4:	11:00, 21 Apr. to 24:00, 27 Apr., 1983
5:	11:00, 29 Apr. to 21:00, 3 May, 1983
6:	15:00, 5 May to 8:00, 10 May, 1983
7:	1:00, 12 May to 21:00, 16 May, 1983
8:	19:00, 25 May to 1:00, 31 May, 1983
9:	19:00, 30 Jun. to 14:00, 6 Jul., 1983
10:	14:00, 27 Oct. to 18:00, 29 Oct., 1983
11:	22:00, 16 Dec. to 1:00, 17 Dec., 1983
12:	12:00, 3 Feb. to 19:00, 6 Feb., 1984
13:	11:00, 1 Mar. to 19:00, 4 Mar.. 1984
14:	8:00, 4 Apr. to 6:00, 7 Apr., 1984
15:	17:00, 27 Apr. to 22:00, 30 Apr., 1984
16:	16:00, 10 Jun. to 24:00, 11 Jun., 1984

Calculation results of correlation coefficients are represented in Table-5 and these graphical representations related to the time lag and rainfall intensity are as shown in Fig.-12 and Fig.-13.

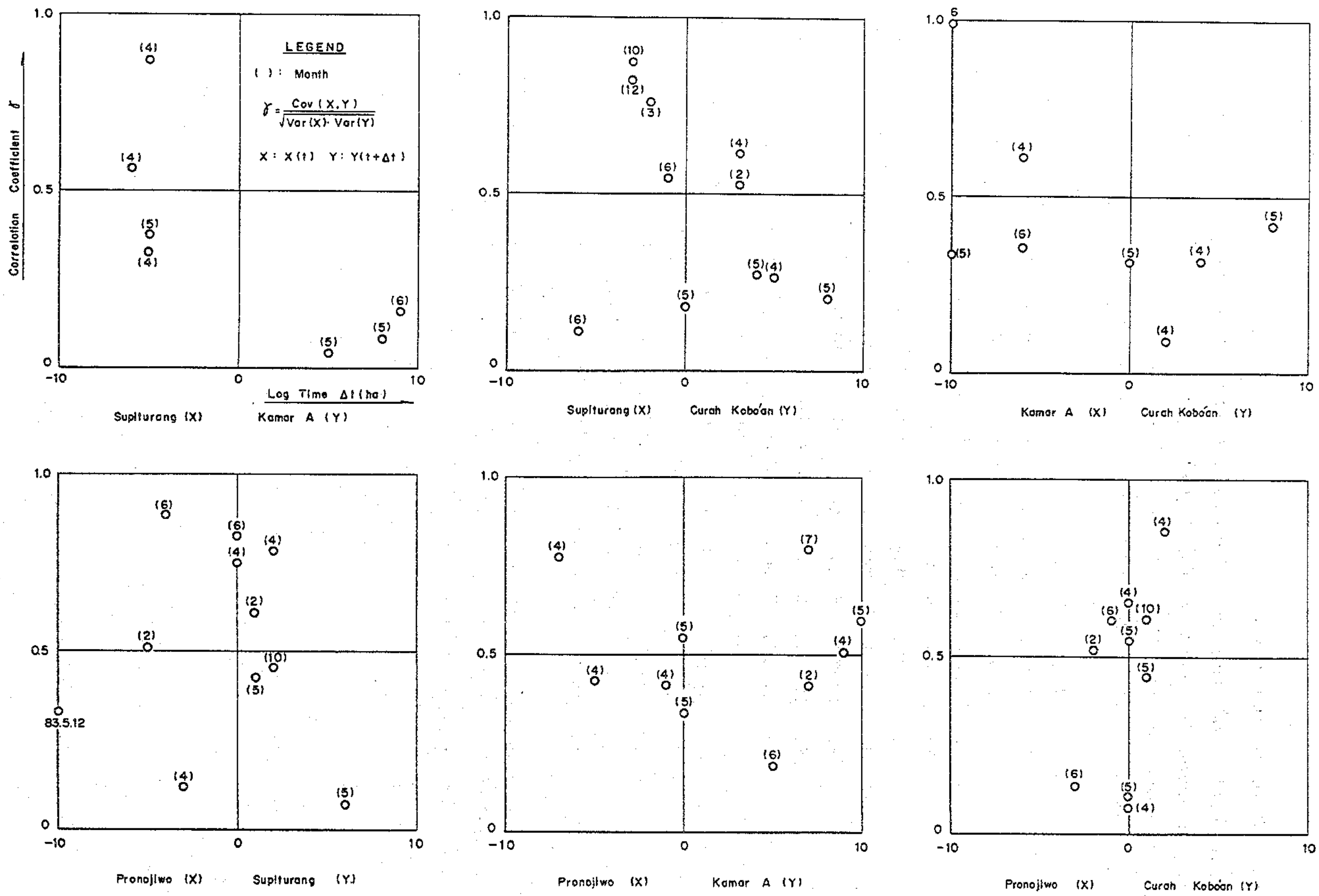


Fig.- 12 Relationship between Correlation Coefficient and log Time

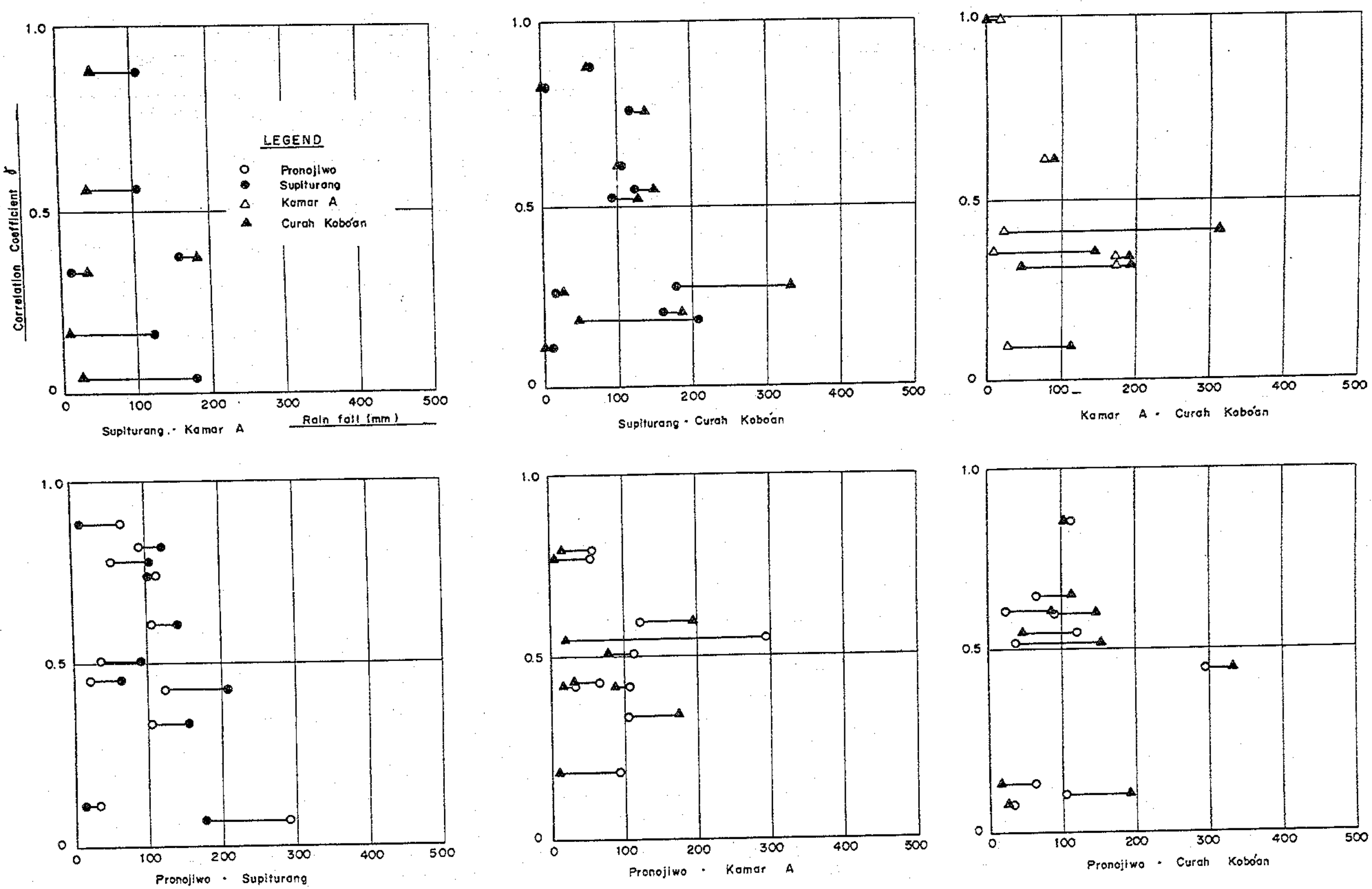


Fig.- 13 Relationship between Correlation Coefficient and Rainfall Intensity

Table-5 Extreme Value of Correlation Coefficient

No.	Station / Beginning Date	X=Pronojiwo Y=Supit Urang	X=Pronojiwo Y=Kamar A	X=Pronojiwo Y=C. Kobo'an	X=Supit Urang Y=Kamar A	X=Supit Urang Y=C. Kobo'an	X=Kamar A Y=C. Kobo'an	Period (hr)
1	17 Jan. 1983	-	-	-	-0.069 (0)	-	-	81
2	6 Feb. 1983	-	-	-	-	-	-	104
3	25 Feb. 1983	0.609 (1)	0.415 (7)	-	-0.084 (0)	-	-	91
4	21 Apr. 1983	0.115 (-3)	0.411(-1)	0.076 (0)	0.327(-5)	0.268 (5)	0.097 (2)	158
5	29 Apr. 1983	-0.055 (-8)	0.429(-5)	0.650 (0)	-0.019 (0)	-0.051 (0)	0.315 (4)	106
6	5 May 1983	0.429 (1)	0.593(10)	0.543 (0)	-0.085 (8)	0.186 (0)	0.338(-10)	114
7	12 May 1983	0.333(-10)	0.333 (0)	0.106 (0)	0.371(-5)	0.206 (8)	0.317 (0)	117
8	25 May 1983	0.070 (6)	0.546 (0)	0.448 (1)	0.047 (5)	0.277 (4)	0.412 (8)	127
9	30 Jun. 1983	0.824 (0)	0.186 (5)	0.600(-1)	0.161 (9)	0.545(-1)	0.352 (-6)	140
10	27 Oct. 1983	0.457 (2)	-	0.605 (1)	-	0.872(-3)	-	53
11	15 Dec. 1983	-	-	-	-	0.827(-3)	-	4
12	3 Feb. 1984	0.504 (-5)	-	0.518(-2)	-	0.523 (3)	-	80
13	1 Mar. 1984	-	-	-	-	0.769(-2)	-	78
14	4 Apr. 1984	0.748 (0)	0.506 (8)	0.853 (2)	0.568(-6)	0.618 (3)	0.611 (-6)	71
15	27 Apr. 1984	0.782 (2)	0.771(-7)	-0.054 (0)	0.879(-5)	-0.047(-2)	-0.048 (-9)	54
16	10 Jun. 1984	0.882 (-4)	0.799 (7)	0.139(-3)	-0.073 (0)	0.111(-6)	0.997(-10)	33

Note: Numbers described in parenthesis represent lag time at which appears the extreme value of correlation coefficient.

(4) Consideration

The calculation results can be summarized as follows:

① The rainfall pattern and distribution in the K. Lengkong basin are considered to be complex phenomena due to meteorological and topographical conditions.

② High correlation relationship among 4 rainfall observation stations shows that the corresponding movement of rainfall is successive and that rainfall distribution is large and almost uniform.

③ Low correlation relationship shows that the corresponding rainfall occurrence has strong locality and/or its turbulence of rainfall intensity develops in the movement of rain clouds.

④ Correlation relationship among 4 rainfall stations gives the qualitative aspect of each rainfall distribution and intensity. It seems, however, to be insufficient to build up a quantitative aspect at the observation well field.

From the view point of microscopic analysis on the groundwater level fluctuation, the reliability of groundwater level observation occurrence can by estimated to be higher than that of rainfall. It depends on the time-spacial difference of observation network in the K. Lengkong Basin; observation wells are located very near from each other and the time check is effectuated every week; on the contrary, rainfall observation stations are far from each other and the time check is only every month.

3. GROUNDWATER RESOURCES DEVELOPMENT POTENTIAL

The solutions for the preliminary groundwater resources development dealt with here include those which require studies to be conducted in the future.

The following two solutions are considered in respect of the hydrogeological structure of the study area.

① Underground Dam/Reservoir
② Drilled Wells

Groundwater resources development by means of an underground dam/reservoir, schematically shown in Fig.-14, has the following merits;

ⓐ As water to be utilized can be stored underground, the land acquisition area for dam/reservoir maintenance purposes will be extremely small in comparison with the surface water development.

ⓑ This solution will not cause large changes in land use.

ⓒ Disasters occurring due to dam destruction, operation misconduct, etc. can be avoided. This solution thus will have sufficient safety in operation.

Although groundwater resources development by means of drilled wells has not yet been applied to the study area, it is also a feasible solution.

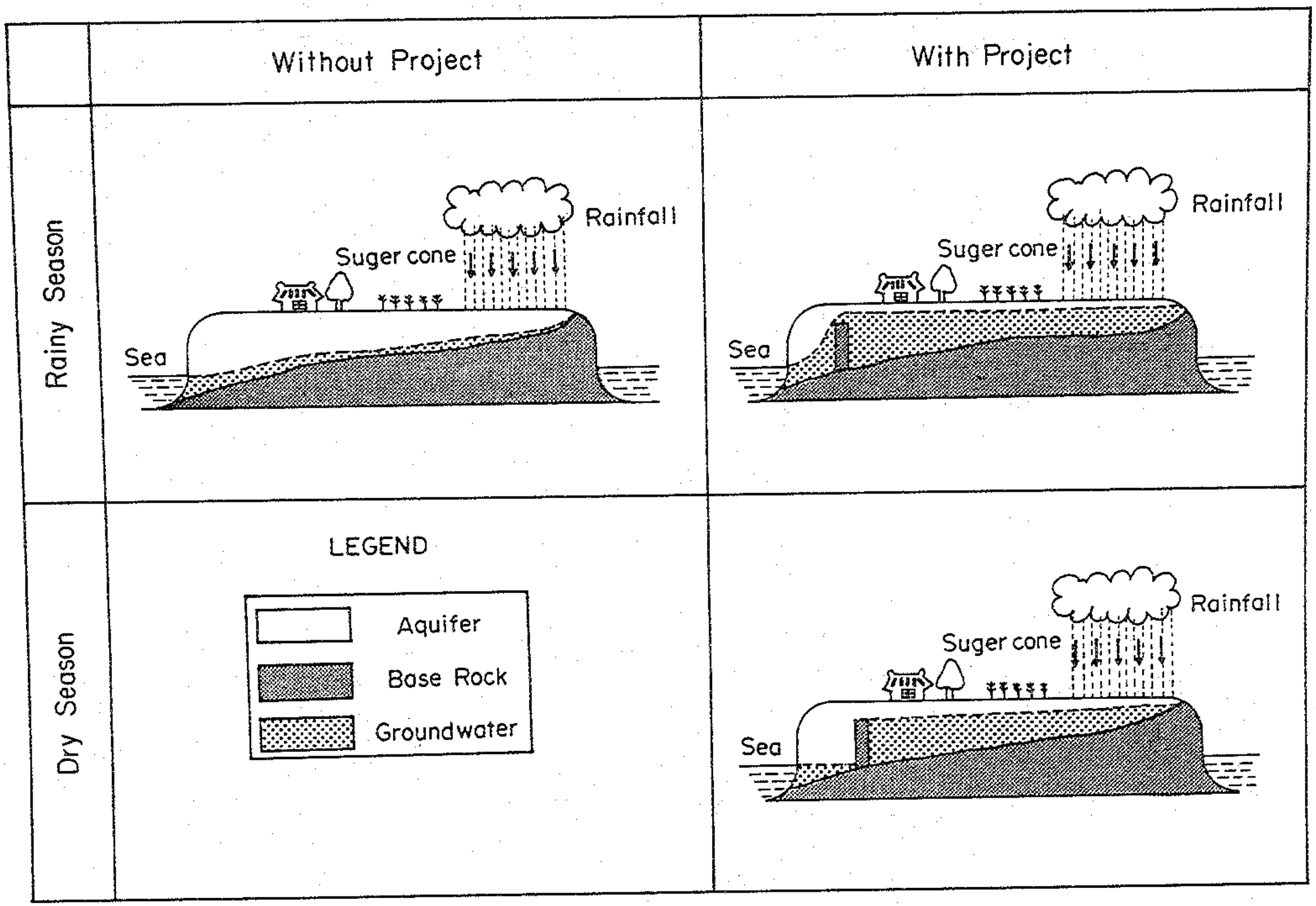


Fig.-14 Schematic Represeation of Underground Dam/Recervoir

3.1 DEVELOPMENT SOLUTION BY MEANS OF AN UNDERGROUND DAM/RESERVOIR

(1) Prospective Site

Electric sounding executed in the K. Lengkong Fan shows the existence of a long narrow ridge of Tertiary formations, of which the weathered surface layer is thought to be an impermeable layer and which is identified as a groundwater basin. The existence of this ridge was confirmed by the drilling work B-11.

The ridge, situated in the vicinity of the Tumpak Nanas sabo dam site, extends from south to north and is partially exposed to the ground surface, as shown in Fig.-15. This impermeable ridge is considered to form a natural underground dam and main subsurface channels of the water-vein system are expected to run through the lower part of this ridge.

Furthermore, diversion channel work from K. Rejali to K. Lengkong is under consideration and the hinterland of the Tumpak Nanas sabo dam will contribute to the augmentation of the groundwater recharge amount by this construction of debris control facilities.

Therefore, the prospective site at Tumpak Nanas is thought to satisfy the necessary conditions for underground dam/reservoir construction.

(2) Rough Estimation of Groundwater Recharge Amount

The groundwater recharge amount (Gr) supplied from the ground surface to the underground by rainfall, is roughly calculated by the product of the recharge area (A), the mean annual rainfall amount (Rm) and the groundwater recharge ratio (r_g), and is expressed as follows:

$$Gr = A.Rm.r_g \quad \cdots\cdots\cdots\cdots \quad (10)$$

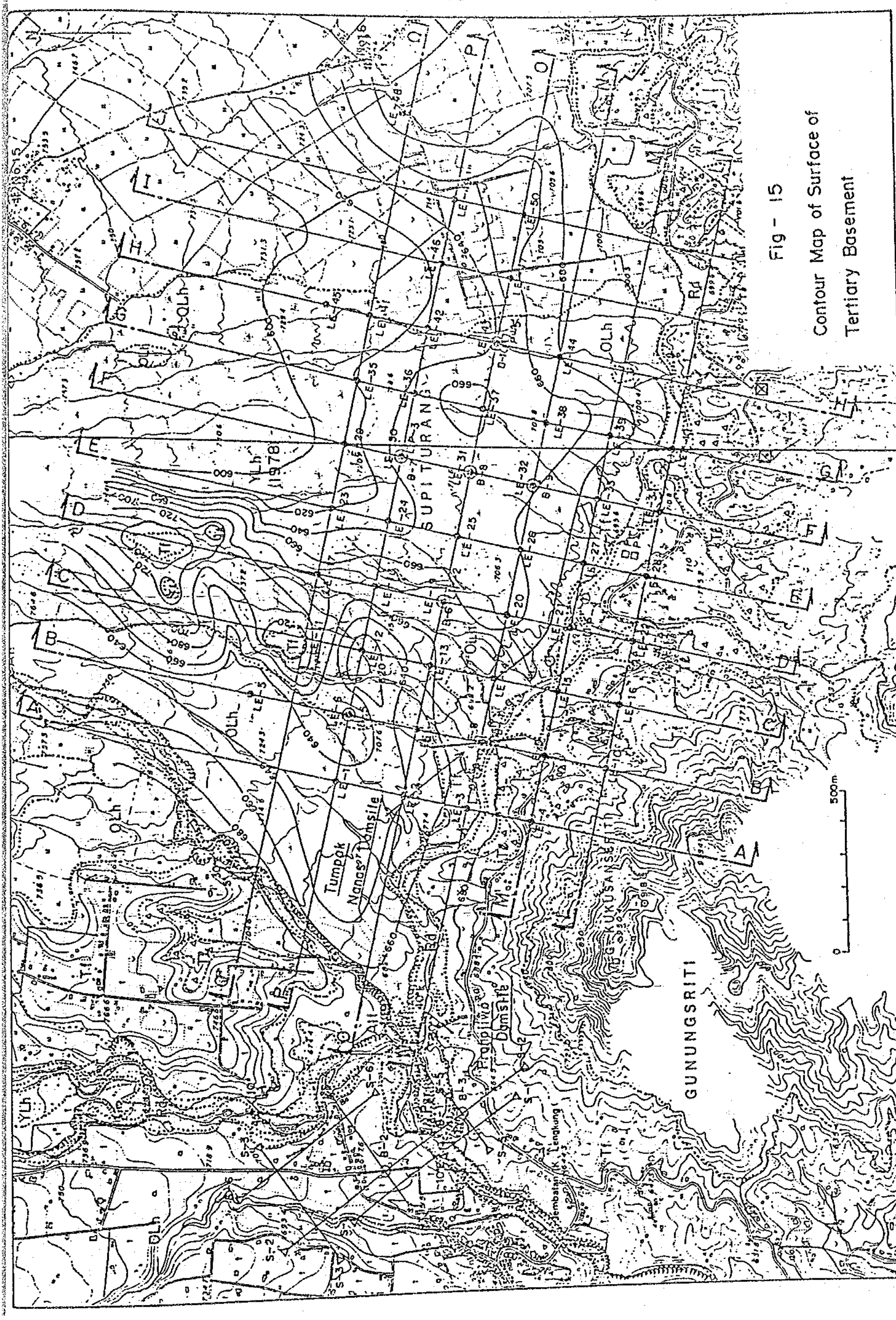


Fig - 15
Contour Map of Surface of Tertiary Basement

The parameters in Eq.(10) are estimated as follows:

a. The recharge area is considered to be the same as the catchment area of the Tumpak Nanas sabo dam, and is about $29.5 km^2$.

b The mean annual rainfall amount for the 28 years from 1951/52 to 1979/80 at Gudung Sawur is about 3,400 mm/year.

c The groundwater recharge ratio is about 30% from the water balance calculation sheet in the area of K. Bondyudo, near K. Lengkong, as shown in Table-6.

The groundwater recharge amount is as follows;

$$\begin{aligned} Gr &= A.Rm.r_g \\ &= 29.5 \times 10^6 \times 3.4 \times 0.30 \\ &= 30 \times 10^6 \; m^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11) \end{aligned}$$

The value of 30×10^6 m^3 is the upper limit of the groundwater resources development potential and a feasible potential will be a certain fraction of the above-mentioned value.

Table-6 Water Balance Calculation Sheet of K. Bondyudo Basin

MONTH \ ITEM \ YEAR	1979/80					1980/1981				
	RAINFALL R(mm)	RUNOFF $Q(\times 10^6 m^3)$	RUNOFF q(mm)	EVAPORATION E(mm)	G.W. RECHARGE (mm)	RAINFALL R(mm)	RUNOFF $Q(\times 10^6 m^3)$	RUNOFF q(mm)	EVAPORATION E(mm)	G.W. RECHARGE (mm)
SEP.	25	9.292	23	72	- 72	0	10.931	26	78	- 104
OCT.	101	7.773	19	75	7	406	11.514	28	77	301
NOV.	624	10.038	24	(70)	530	0	26.818	65	45	- 110
DEC.	283	13.336	32	74	177	499	(26.701)	65	39	395
JAN.	249	14.907	36	67	146	161	(23.726)	57	60	44
FEB.	317	14.927	36	51	230	138	19.886	48	61	29
MAR.	36	24.762	60	71	- 95	0	47.156	114	73	- 187
APR.	175	23.010	56	73	46	52	16.695	40	62	- 50
MAY	8	15.300	37	82	- 111	162	8.408	20	74	68
JUN.	0	19.882	48	91	- 129	210	9.277	22	75	113
JUL.	50	21.309	52	71	- 73	124	10.209	25	76	23
AUG.	108	14.134	34	86	- 12	54	2.448	6	77	- 29
Total	1,976	-	457	873	646	1,806	-	516	797	493
RATIO	1.00	-	0.23	0.44	0.33	1.00	-	0.29	0.44	0.27

Note: STATION: RAINFALL ; Gugialit
RUNOFF ; Dam Umbul (CA = 412.75 km)
EVAPORATION; Gebuk Dams Hillin

$$f_{rg} = \frac{\text{Groundwater Recharge}}{\text{Rainfall}} = \frac{0.33 + 0.27}{2} = 0.30$$

(3) Estimated Extraction Volume from Underground Dam/Reservoir

The developable volume to be extracted from underground dam/reservoir is roughly estimated by the following equation:

$$Q = \int \lambda e . d_r \, dA \quad \ldots\ldots \quad (12)$$

where, Q: Developable volume
λe: Effective porosity
d_r: Drawdown due to extraction
A: Catchment area

Eq.(12) can be also expressed by;

$$Q = \int \lambda e . dr . f(H) \, dH \quad \ldots\ldots \quad (13)$$

where, H: Height representing the elevation
f(H): Function determinated from H-A curve
$dA = f(H) dH$

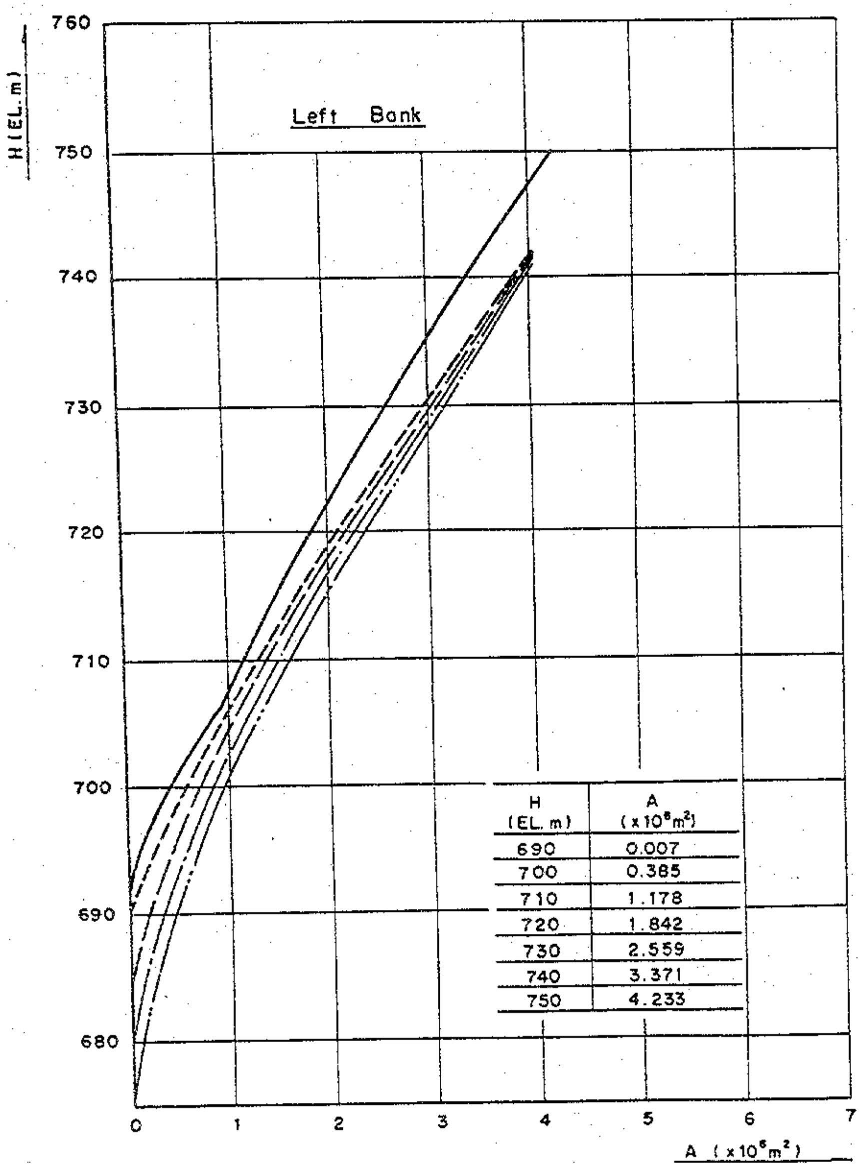
In order to evaluate the developable volume, the following drawdown conditions in the hinterland of the underground dam/reservoir should be considered:

Case 1: Drawdown of 5m
Case 2: Drawdown of 10m
Case 3: Drawdown of 15m

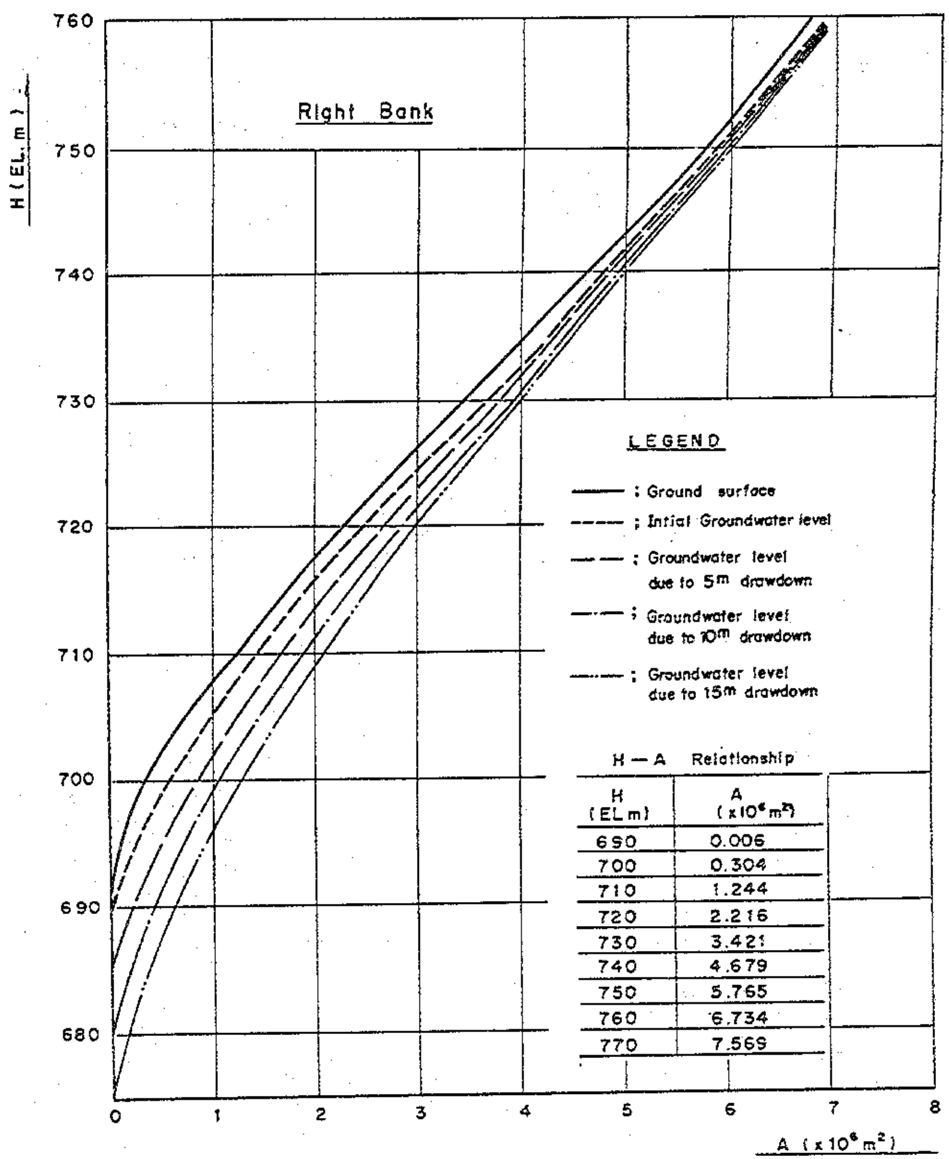
The graphical evaluation of drawdown is made in the following procedures;

① H-A curve (left bank, right bank)
② Actual groundwater table on the H-A curve
③ Drawdown evaluation on the H-A curve
④ Calculation of developable volume

The relationship between the catchment area and the groundwater table in elevation is as shown in Fig.-16.



H (EL.m)	A ($\times 10^6 m^2$)
690	0.007
700	0.385
710	1.178
720	1.842
730	2.559
740	3.371
750	4.233



H — A Relationship

H (EL m)	A ($\times 10^6 m^2$)
690	0.006
700	0.304
710	1.244
720	2.216
730	3.421
740	4.679
750	5.765
760	6.734
770	7.569

Fig.- 16 Catchment Area and Groundwater Level in Elevation

The developable volume of groundwater resources will be calculated as shown in Table-7.

Table-7 Developable Volume of Groundwater Resources

Case		Developable Volume (10^6 m^3)		Total (10^6 m^3)
		Right Bank	Left Bank	
1	Drawdown of 5m	2.1	1.4	3.5
2	Drawdown of 10m	4.8	2.4	7.2
3	Drawdown of 15m	6.2	3.7	9.9

Note: Effective Porosity = 0.20

(4) Facilities of Underground Dam/Reservoir

The Facilities of an underground dam/reservoir consist of;

① Cutoff (grout, walls, piles)

② Intake facilities (extraction of groundwater)
- Pump wells
- Conduits

③ Water conveyance facilities

④ Farm ponds

⑤ Observation wells

⑥ Control house

The conceptual distribution of these facilities is as shown in Fig.-17.

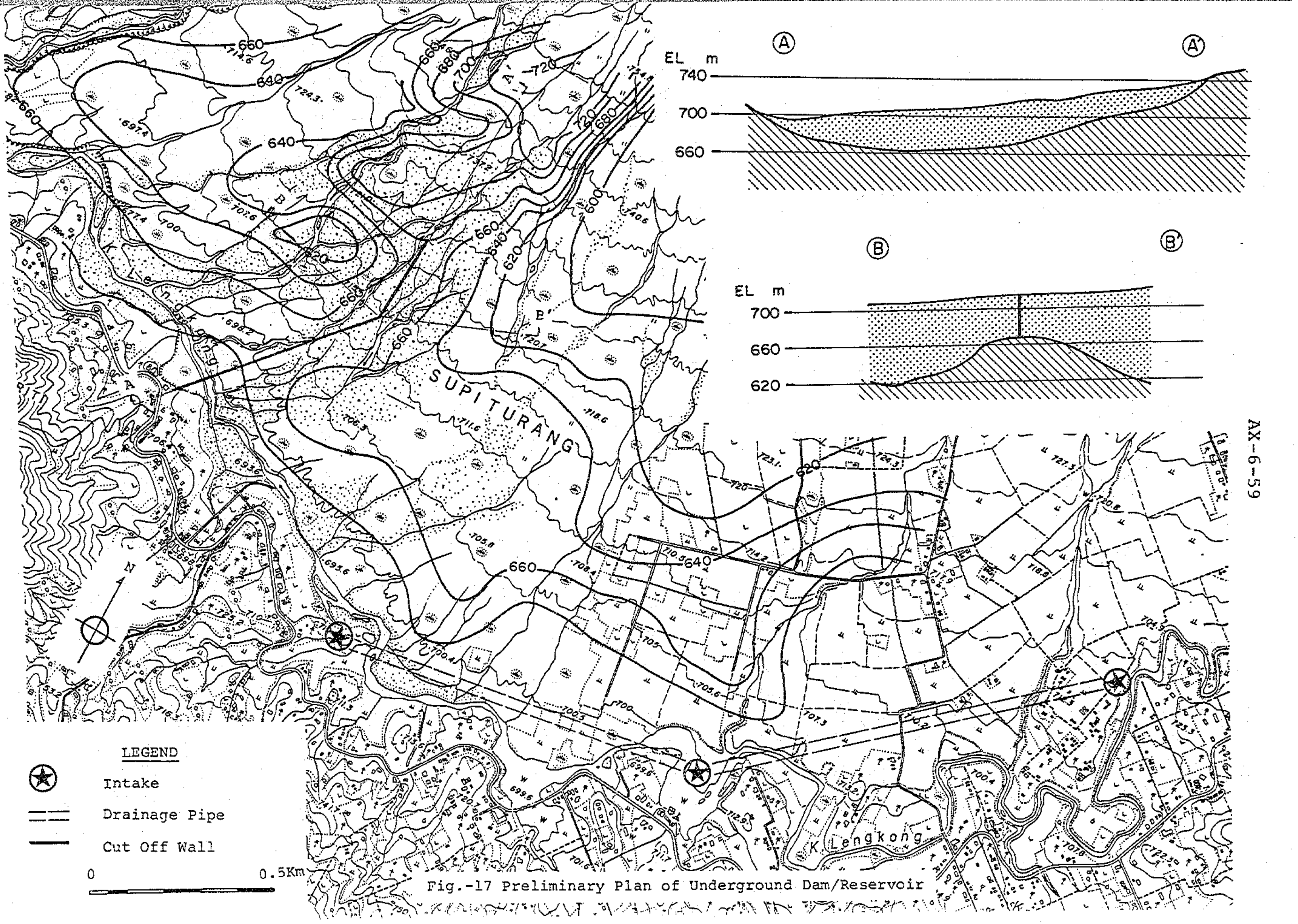


Fig.-17 Preliminary Plan of Underground Dam/Reservoir

3.2 DEVELOPMENT SOLUTION BY MEANS OF DRILLED WELLS

The groundwater resources development potential by means of drilled wells will be dealt with here, based on the tentative numerical analysis on the extraction and recovery processes of groundwater in the prospective well field in the K. Lengkong fan.

(1) Calculation Method

ⓐ Basic equation

In order to avoid non-lineality of the equation governing the unconfined aquifer system, the following equation is applied to the calculation;

$$S.\frac{\partial H}{\partial t} = k.b.\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right) + q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where, H = Groundwater level (El. m)
k = Permeability (m/day)
q = Groundwater recharge or pumping volume
S = Coefficient of storage
b = Thickness of aquifer (m)
x,y = Distance
t = Time

ⓑ Simulation method

The unsteady finite difference method is applied to solve the equation (14).

(2) Calculation Conditions

ⓐ Boundaries

The prospective well field is surrounded by the following boundaries with an approximate area of 10 km^2.

- North boundary;
  EL. 800m contour line of Mt. Semeru
- South boundary;
  National road along K. Lengkong
- West boundary;
  Impervious underground ridge of tuff
- East boundary:
  K. Curah Kobo'an

ⓑ Elements and nodal points

Elements and nodal points of the simulation model, as shown in Fig.-18, is made from the topographical and hydraulic conditions.

ⓒ Parameters

Permeability coefficient: k = 10^{-3} cm/s
(0.86 m/day)

Thickness of aquifer : b = 150m

Coefficient of storage : S = 0.2

ⓓ Groundwater recharge amount

The groundwater recharge amount by rainfall is estimated to be 30% of the mean monthly rainfall amount for the 28 years from 1951/52 to 1979/80 at Gudung Sawur.

Table-8 Mean Monthly Rainfall (1951/52-1979/80)

Item \ Month	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Monthly Rainfall (mm/month)	206	286	270	340	366	327	334	258	283	258	289	207

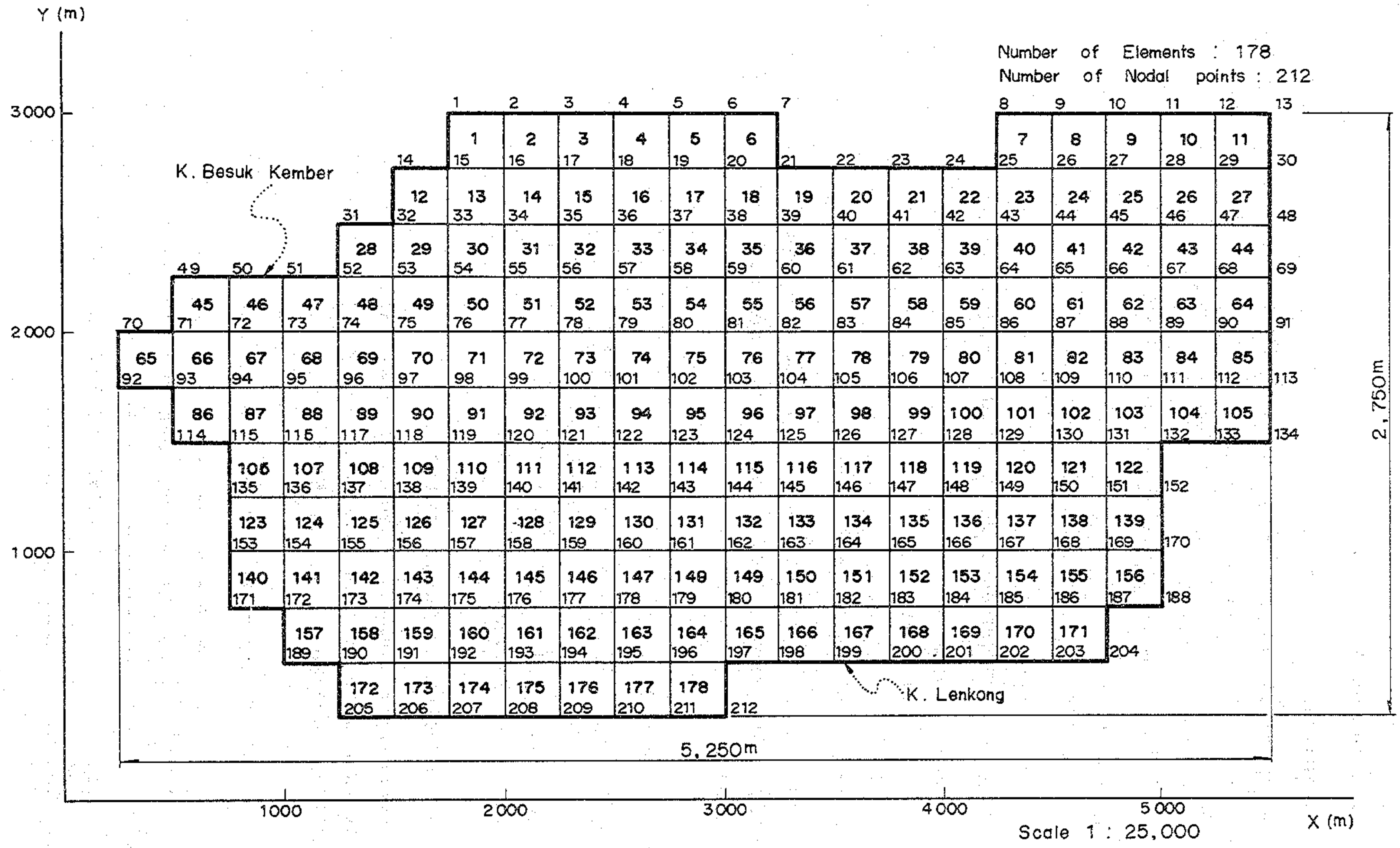


Fig. – 18 Elements and Nodal Points

(e) Pumping volume

Drilled well points; 20 points
Pumping period ; 180 days (dry season)
Discharge Case 1; $q = 1.0\ m^3/s$
(=0.05 m^3/s/point x 20 points)
Case 2; $q = 0.5\ m^3/s$
(=0.025 m^3/s/point x 20 points)

(f) Boundary conditions and time step

The groundwater level at the boundary of K. Lengkong, K. Besuk Kembar and piedmonts of Mt. Semeru should be kept constant.
The time step of the numerical calculation is 10 days.

(3) Calculation Results

The calculation results, as shown in Fig.-19 to Fig.-21, can be summarized as follows;

(1) Drawdown of groundwater level

Maximum drawdown of the groundwater level (d_r) appears at Nodal Point 127 at 755 to 765m in elevation.

- Case 1 $q = 0.5\ m^3/s$; d_r = 10m
- Case 2 $q = 1.0\ m^3/s$; d_r = 21m

(2) Recovery of groundwater level

After the end of extraction by pumping during the dry season (180 continuous days), the recovery height (hr) from the lowest level of groundwater during the rainy season at Nodal Point 127 is estimated as follows;

- Case 1 $q = 0.5\ m^3/sec$; hr = 5m
- Case 2 $q = 1.0\ m^3/sec$; hr = 9m

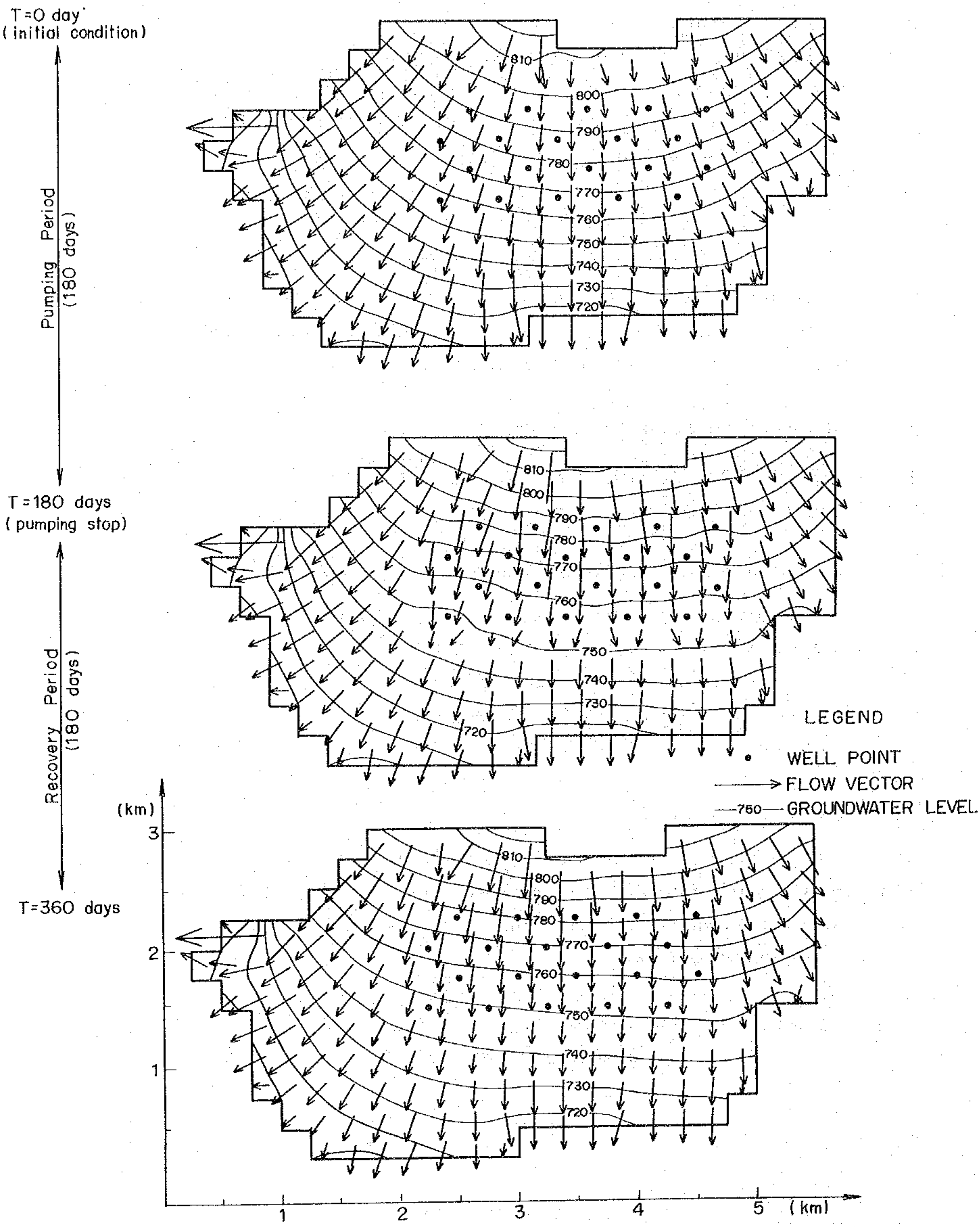


Fig.—19 Groundwater Level Fluctuations
(Pumping Discharge ; 0.5 m^3/s)

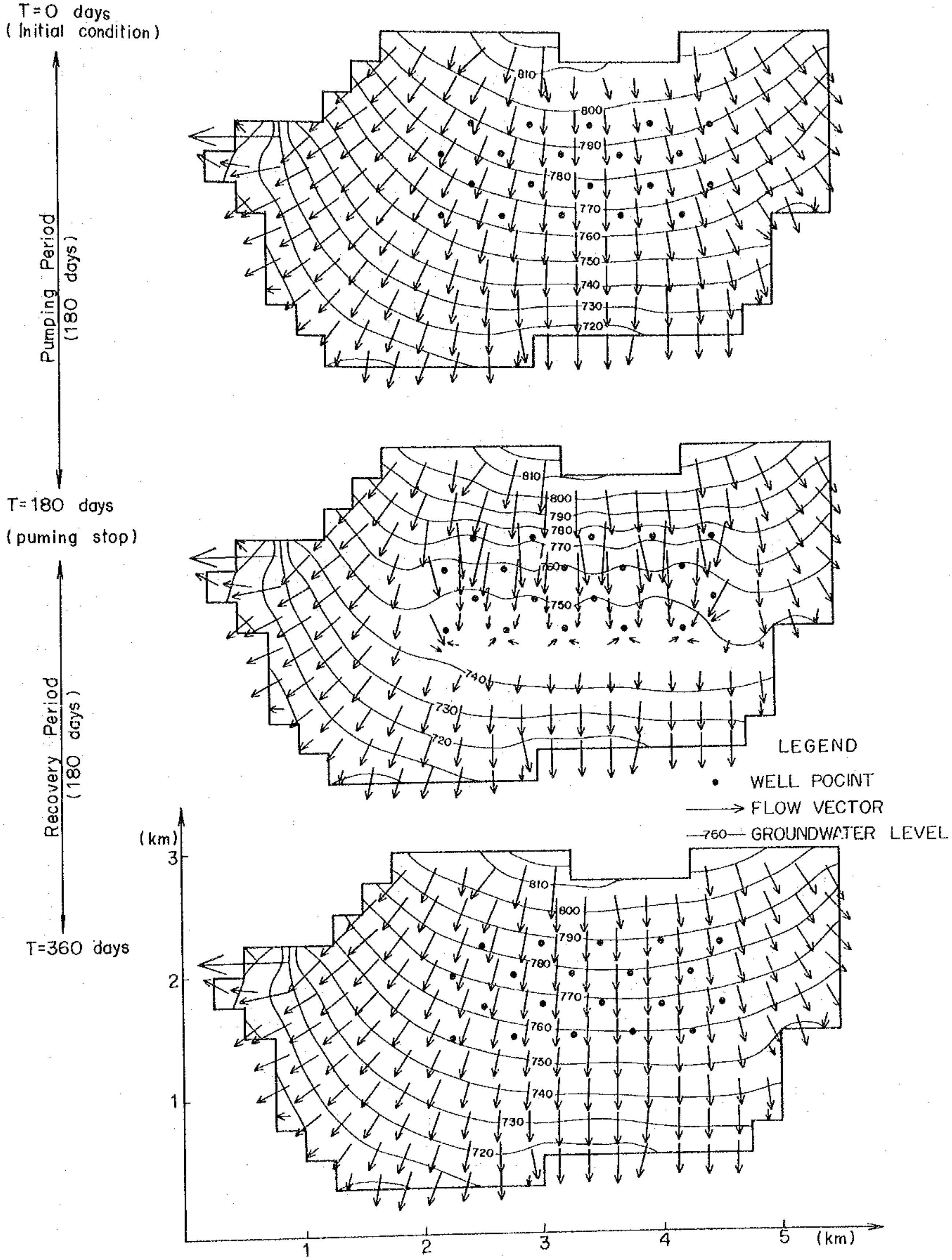


Fig. -20 Groundwater Level fluctuations
(Pumping Discharge ; 1.0 m^3/s)

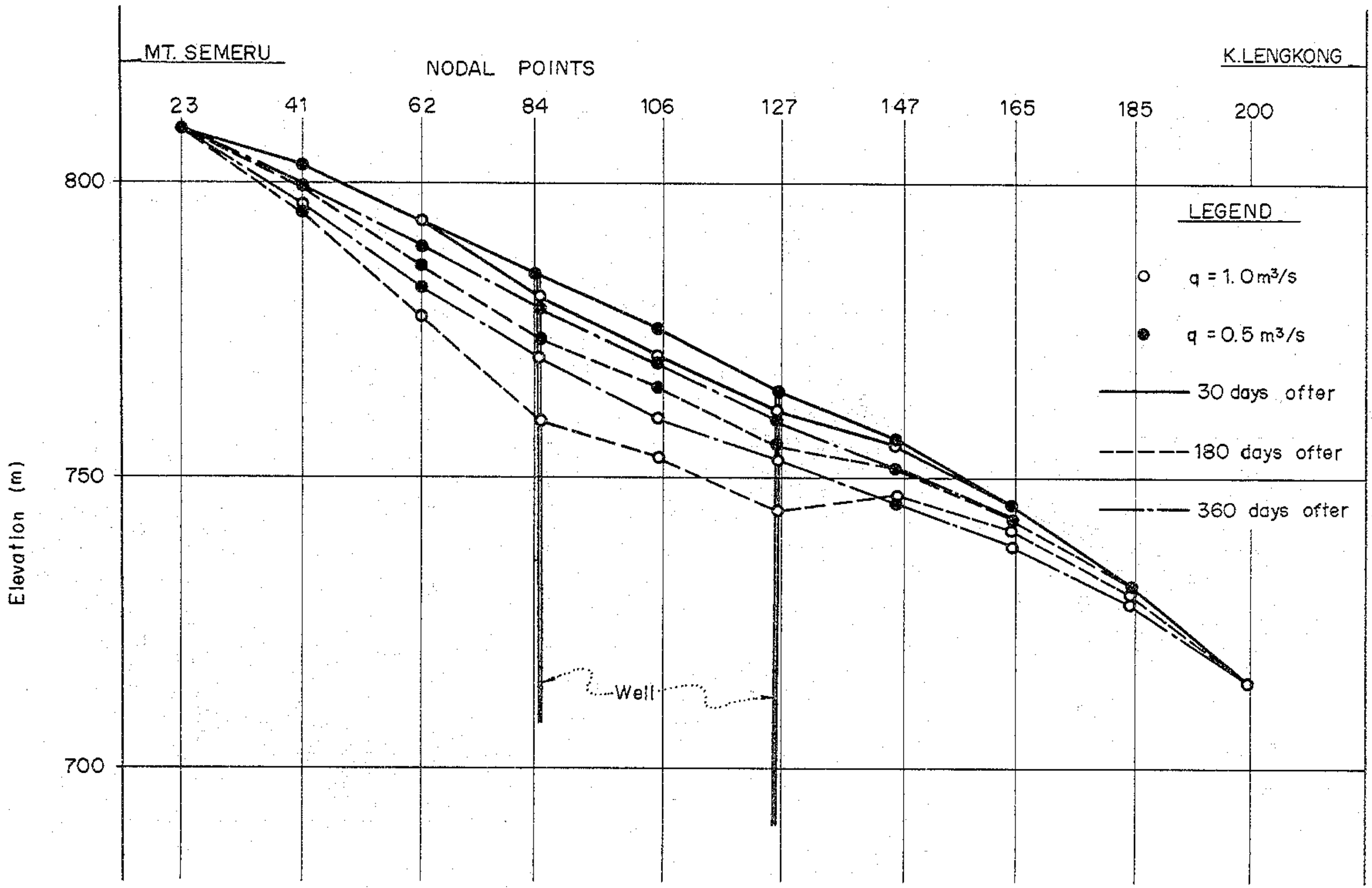


Fig-21 Fluctuations in the Groundwater Level due to pumping

(4) Developable Volume of Groundwater Resources

Based on the equilibrium condition between the extraction amount by pumping and the natural recharge amount by rainfall, the extraction discharge should be less than 0.5 m^3/s.

The range of suitable extraction discharge is thought to be between 0.1 to 0.3 m^3/s and its developable volume of groundwater resources will be 1.6×10^6 m^3 to 4.7×10^6 m^3 during dry season.

3.3 STUDY ITEMS FOR FURTHER STUDY

In order to discuss in more detail the groundwater resources development, the following items should be carried out;

① Rainfall observation in the prospective development site

② Drilling and pumping tests

③ Groundwater level observation, covering the whole area of the K. Lengkong groundwater basin

④ Water quality analysis of deep aquifer

⑤ Grout test

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