MALAYSIA

MINISTRY OF AGRICULTURE
DRAINAGE AND IRRIGATION DEPARTMENT

PERAI BARRAGE GATE OPERATION STUDY IN SEBERANG PERAI PULAU PINANG

FINAL REPORT

VOLUME II

ANNEX A - HYDROLOGY
ANNEX B - MATHEMATICAL MODEL SIMULATION OF UNSTEADY FLOW IN OPEN CHANNEL
ANNEX C - COMPUTATION RESULT ON GATE OPERATION AND FLOW CONDITION OF PERAI RIVER

DECEMBER 1988

JAPAN INTERNATIONAL COOPERATION AGENCY

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Annex A

Annex A

Annex A is the reference of Chapter IV

(Hydrological Analysis on Sg.Perai Basin)

A-1 Multiple Regression Model & Numerical Estimation of Water Balance

A-2 Iwai-Kadoya's Method

A-3 Kinematic Wave Method

A-4 Monthly rainfall at each rainfall gauging station (1958 ~ 1987)

A-5 Changes of discharge at ARA KUDA (1978 ~ 1987)

A-6 Changes of daily rainfall (Back-data to obtain the base flow and relation between $\Sigma R\ell$ and ΣR)

A-7 Changes of observed hourly discharge and estimated base flow based on Annex A-6

A-8 Hourly fluctuation of discharge (Hydrograph)

Annex A-1

Third International Symposium on Stochastic Hydraulics
August 5-7, 1980, Tokyo, Japan

A STATISTICAL APPROACH TO RAINFALL RUNOFF PROCESS BY MULTIPLE REGRESSION ANALYSIS

By

Y. Ito

H. Shiraishi

R. Oonishi

3rd Laboratory of Water Management,
National Research Institute of Agricultural Engineering,
Ministry of Agriculture, Forestry and Fishery
Tsukuba, Ibaraki, Japan

SYNOPSIS

In order to identify runoff kernels of generalized impulse response function based on the theory of nonlinear response system, various techniques have been proposed recently in our country.

A multiple regression analysis is presented in this paper as a powerful method.

In solving the integral equation (i.e., the generalized impulse response function) shown by Wiener (12), this paper presents a method of statistical system analysis utilizing the multiple regression analysis to investigate runoff mechanism.

INTRODUCTION

So far, the unit hydrograph procedure has been widely utilized to estimate the rainfall runoff.

It is reasonable to employ this procedure in cases in which the runoff phenomena are linear. However, in general cases, the runoff phenomena are considered to be nonlinear. Consequently, the unit hydrograph procedure must be improved so that it can represent the nonlinearity of runoff phenomena.

Now, if the relationship between rainfall (input) and runoff (output) can be treated as a linear system, the relationship can be expressed by the following well-known functional series called the convolution integral, that is;

$$y(t) = \int_{-\infty}^{t} h(t-\tau) \cdot X(\tau)\,d\tau \qquad (1)$$

or

$$y(t) = \int_{0}^{\infty} h(\tau) \cdot X(t-\tau)\,d\tau \qquad (2)$$

where y(t) is the value of runoff at time t. The runoff kernel $h(\tau)$, which characterizes the system, is refered to as impulse response. The input $X(\tau)$ is rainfall intensity and the letter τ is a variable showing time-lag.

The nonlinear system can be expressed by general functional series where the first term is the same as Eq. (1) or (2) and the successive terms as similar equations of higher degrees. This functional series can be called Volterra (11) series and presented by use of the same form as Eq. (2), thus;

$$y(t) = \sum_{n=1}^{\infty} \int_{(n)} \cdots \int_{0}^{\infty} h_n(t; \tau_1, \tau_2, \cdots\cdots, \tau_n) \cdot \prod_{i=1}^{n} X(t-\tau_i) \cdot d\tau_1 \cdot d\tau_2 \cdots\cdots d\tau_n \qquad (3)$$

where $X(t-\tau_i)$ is the rainfall intensity at time $t-\tau_i$ (τ_i is time-lag in case the present time t is taken as the origin). $h\,(t; \tau_1, \tau_2, \cdots\cdots, \tau_n)$ is the runoff kernel of the nth degree.

From the end of 1960's to the begining of 1970's, the various solutions to this functional series were introduced by Amorocho and Brandstetter (3), Bidwell (4), Kuchment and Borshchevsky (7) and Hino (5).

Taking the accuracy of observed data into consideration, Eq. (3) is approximated by using the following formula obtained by truncating the terms of higher order than the third degree of moment from practical view point. That is;

$$y(t)=h_0+\int_0^{\infty} h(\tau)\cdot X(t-\tau)d\tau+\iint_0^{\infty} h_1(t;\tau_1,\tau_1)X(t-\tau_1)X(t-\tau_1)\cdot d\tau_1\cdot d\tau_1 \qquad (4)$$

When Eq. (4) is expressed by a discrete form, the multiple regression analysis can be employed to solve the equation. By using the best unbiased estimate of partial regression coefficients A_0, A_i, B_{ij} and expressing the estimation of y(t) by Y(t), this equation is changed into the following form

$$Y(t)=A_0+\sum_{i=1}^{m} A_i X(t-\tau_i)+\sum_{i=1}^{m}\sum_{j=1}^{m} B_{ij} X(t-\tau_i) X(t-\tau_j) \qquad (5)$$

The parameters A_0, A_i, and B_{ij} are determined by the method of least squares.

In this case, though the coefficients A_i of the linear term and B_{ij} of the nonlinear term can be simultaneously determined, two methods in which the coefficients A_i and B_{ij} are identified separately are proposed here because of the strong mutural relation between the variables $X(t-\tau_i)$ and $X(t-\tau_i)X(t-\tau_j)$; that is, an optimum linear runoff model having the coefficients A_i of the linear term is first determined and then the nonlinear effect is taken into consideration. Two methods of F.M.R. (Fixed Maximum Rainfall) and F.M.D. (Fixed Maximum Discharge), which are utilized to extract the linear components from observed data, are proposed in this paper to construct of the optimum linear model. As an evaluating index for estimating optimum parameters, the following multiple correlation coefficient R_{log} is employed

$$R_{\log}=\frac{\sum_{i=1}^{n}(\log y_i-\frac{1}{n}\sum_{j=1}^{n}\log y_j)(\log Y_i-\frac{1}{n}\sum_{j=1}^{n}\log Y_j)}{\sqrt{\sum_{i=1}^{n}(\log y_i-\frac{1}{n}\sum_{j=1}^{n}\log y_j)^2\sum_{i=1}^{n}(\log Y_i-\frac{1}{n}\sum_{j=1}^{n}\log Y_j)^2}} \qquad (6)$$

where Y_i is the estimated value, y_i is the observed value, and n is the number of data.

Thus, by using R_{log}, the linear model for estimating low water discharge, which shows strong linearity, is determined as accurately as possible.

MULTIPLE REGRESSION ANALYSIS

Now, when the observed value (discharge time series, for example) y_i is expressed by the variables (rainfall time series, for example) X_{1i}, X_{2i}, X_{3i}, ... , X_{pi}, the multiple regression model can be expressed by the following linear combinating equation

$$\begin{aligned} y_i &= a_0 + a_1X_{1i} + a_2X_{2i} + \dots + a_pX_{pi} + e_i \\ &= a_0 + \sum_{j=1}^{p} a_jX_{ji} + e_i \quad (i=1,2,3,\ \dots\ ,n) \end{aligned} \qquad (7)$$

where e_i is the residuals (errors) that is contained in the variations of y_i, which cannot be expressed by X_{ji} ($j=1,2,3,\ \dots\ ,p$). a_j ($j=0,1,2,\ \dots\ ,p$) are called partial regression coefficients, which are all unknown parameters. y_i and X_{ji} ($j=1,2,3,\ \dots\ ,p$) are actual observed data.

In order to determine the values of a_0, a_1, a_2, ... , a_p, the least square method is used by the following procedure

$$Y_i = a_0 + a_1x_{1i} + a_2x_{2i} + \dots + a_px_{pi} \qquad (8)$$

where Y_i is the estimated value of y_i.

Therefore the difference between the observed and the estimated output is

$$e_i = y_i - Y_i \tag{9}$$

and the integral square error E, which is given by the sum of the squares of these differences, is

$$\begin{aligned} E &= \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - Y_i)^2 \\ &= \sum_{i=1}^{n} \{ y_i - (a_0 + a_1 x_{1i} + \dots + a_p x_{pi}) \}^2 \longrightarrow \text{Min.} \end{aligned} \tag{10}$$

The solution of this equation can be obtained by satisfying the following conditions;

$$\partial E / \partial a_j = 0 \qquad (j = 0, 1, 2, \dots, p) \tag{11}$$

The above conditions correspond to the following simultaneous equations of the order of p+1, thus;

$$\left.\begin{aligned} a_0 n + a_1 \sum_{i=1}^{n} X_{1i} + a_2 \sum_{i=1}^{n} X_{2i} + \dots\dots\dots\dots + a_p \sum_{i=1}^{n} X_{pi} &= \sum_{i=1}^{n} y_i \\ a_0 \sum_{i=1}^{n} X_{1i} + a_1 \sum_{i=1}^{n} X_{1i}^2 + a_2 \sum_{i=1}^{n} X_{1i} X_{2i} + \dots + a_p \sum_{i=1}^{n} X_{1i} X_{pi} &= \sum_{i=1}^{n} X_{1i} y_i \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ a_0 \sum_{i=1}^{n} X_{pi} + a_1 \sum_{i=1}^{n} X_{1i} X_{pi} + a_2 \sum_{i=1}^{n} X_{2i} X_{pi} + \dots + a_p \sum_{i=1}^{n} X_{pi}^2 &= \sum_{i=1}^{n} X_{pi} y_i \end{aligned}\right\} \tag{12}$$

Generally, the simultaneous equations are mathematically called "Normal Equation". Though there are several different methods in solving this simultaneous equations, Eq. (12) is solved here by the method of Gauss-Jordan.

In order to obtain the more physically significant partial regression coefficients a_j ($j = 0, 1, 2, \dots, p$), it is desirable that the predictor variables X_{ji} ($j = 1, 2, 3, \dots, p$) are statistically independent of each other. In estimating runoff by the use of the multiple regression analysis, the predictor variables coincide with the intensities of rainfall with time variables (time-lag). Therefore, the following autocorrelation coefficients r(k) can be employed to examine the probabilistic independency of rainfall sequence

$$r(k) = \frac{1}{n-k} \left\{ \sum_{i=1}^{n-k} (x_i - \bar{x}_1)(x_{i+k} - \bar{x}_2) / S_1 S_2 \right\} \tag{13}$$

where $\bar{x}_1 = \sum_{i=1}^{n-k} x_i / (n-k)$, $\bar{x}_2 = \sum_{i=1}^{n-k} x_{i+k} / (n-k)$

$$S_1 = \sqrt{\sum_{i=1}^{n-k} (x_i - \bar{x}_1)^2 / (n-k)} \qquad S_2 = \sqrt{\sum_{i=1}^{n-k} (x_{i+k} - \bar{x}_2)^2 / (n-k)}$$

x_i and x_{i+k} are the observed time series of rainfall, $\bar{x}_1$ and $\bar{x}_2$ are the sample means, S_1 and S_2 are the standard deviations, n is the number of data, and k is the time-lag.

To facilitate the analysis of the structure of time series, the autocorrelation diagram can be drawn with r(k) as the ordinate and k as the abscissa.

This graphical representation is called a correlogram. If r(k) = 0 for all k ≠ 0, the observed values are independently distributed in time, and the time series is said to be purely random one. In runoff analysis using daily discharge and where Y_i is the estimated value of y_i.

Therefore the difference between the observed and the estimated output is

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$$r(k) = \frac{1}{n-k} \left\{ \sum_{i=1}^{n-k} (x_i - \bar{x}_1)(x_{i+k} - \bar{x}_2) / S_1 S_2 \right\} \tag{13}$$

where $\bar{x}_1 = \sum_{i=1}^{n-k} x_i / (n-k)$, $\bar{x}_2 = \sum_{i=1}^{n-k} x_{i+k} / (n-k)$

$$S_1 = \sqrt{\sum_{i=1}^{n-k} (x_i - \bar{x}_1)^2 / (n-k)} \qquad S_2 = \sqrt{\sum_{i=1}^{n-k} (x_{i+k} - \bar{x}_2)^2 / (n-k)}$$

x_i and x_{i+k} are the observed time series of rainfall, $\bar{x}_1$ and $\bar{x}_2$ are the sample means, S_1 and S_2 are the standard deviations, n is the number of data, and k is the time-lag.

To facilitate the analysis of the structure of time series, the autocorrelation diagram can be drawn with r(k) as the ordinate and k as the abscissa.

This graphical representation is called a correlogram. If r(k) = 0 for all $k \neq 0$, the observed values are independently distributed in time, and the time series is said to be purely random one. In runoff analysis using daily discharge and rainfall, the actual time series of rainfall can be considered to be independent.

The general pattern of the correlogram in our country is shown in Fig. 1.

Therefore, the increase in the predictor variables X_{ji} ($j = 1,2,3, \ldots, p$) makes only slight changes in the values of the partial regression coefficients obtained by multiple regression analysis. This fact is shown in Fig. 2.

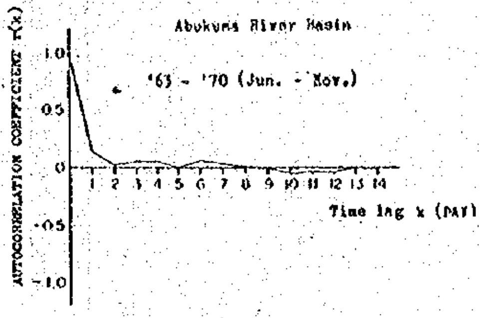

Fig. 1 Pattern of the correlogram in our country

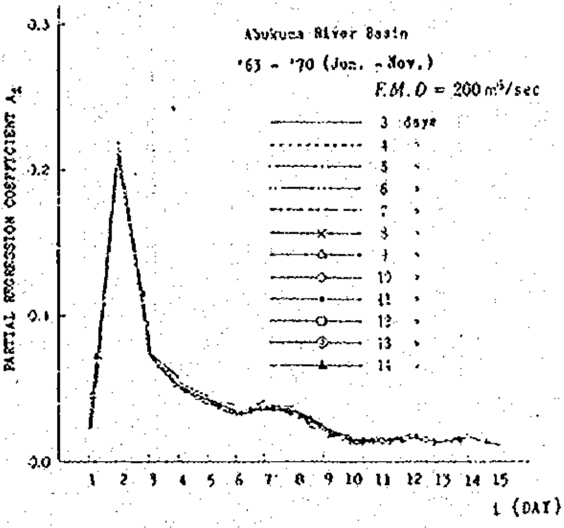

Fig. 2 Example of the change of linear partial regression coefficients under the influence of the number of predictor variables

ANALYSIS OF THE LINEAR RUNOFF MODEL AND THE NONLINEAR RUNOFF MODEL

The runoff is affected by rainfall intensity and rainfall distribution, so the runoff is not linearly related to the rainfall. Therefore, it is effective to employ the nonlinear runoff model shown by Eq. (5) including the nonlinear term.

By replacing each nonlinear variable of Eq. (5) by a newly defined linear variable, a normal equation as shown by Eq. (12) is obtained. However, if the normal equation (12) is directly solved to obtain simultaneously the coefficients A_i of linear term and B_{ij} of nonlinear term of Eq. (5), the obtained partial regression coefficients A_i seem to be insignificant from physical view point as shown in Fig. 3. It is considered that such a distortion is due to the presence of strong correlation between linear and nonlinear variables.

On the other hand, when the normal equation is solved by temporarily neglecting nonlinear term, the obtained partial regression coefficients A_i become physically significant as shown in Fig. 4.

From this reason, the desirable procedure is, at first, to determine the linear runoff model (called the statistical unit hydrograph) by separating the linear component from the observed runoff data, and then, to determine the nonlinear runoff model from residual component.

In more detail, an attempt is made to remove the linear component from the observed runoff values in order to determine the linear multiple regression model, which is expressed by neglecting nonlinear term of Eq. (5).

On the other hand, nonlinear part which cannot be expressed by the linear model (i.e., the residual differences between the observed values and the estimated values by the linear model) is treated separately by the nonlinear term of Eq. (5).

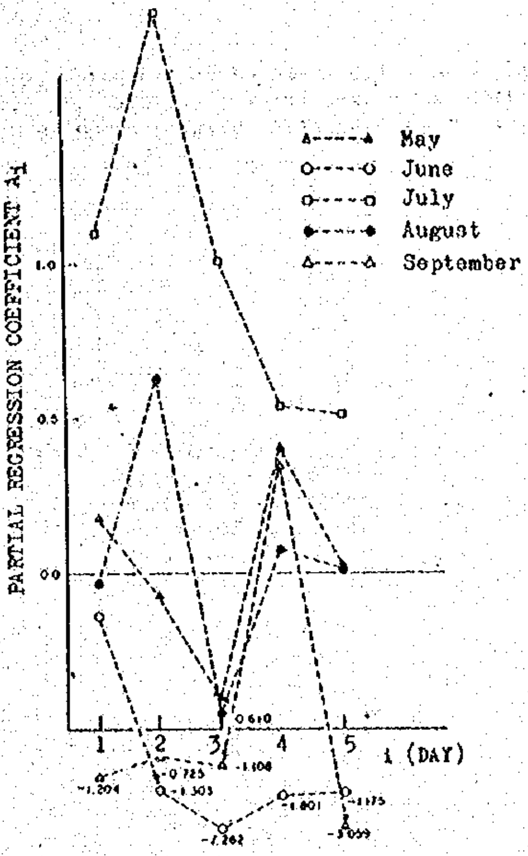

Fig. 3 Linear partial regression coefficients calculated together with linear and nonlinear predictor variables

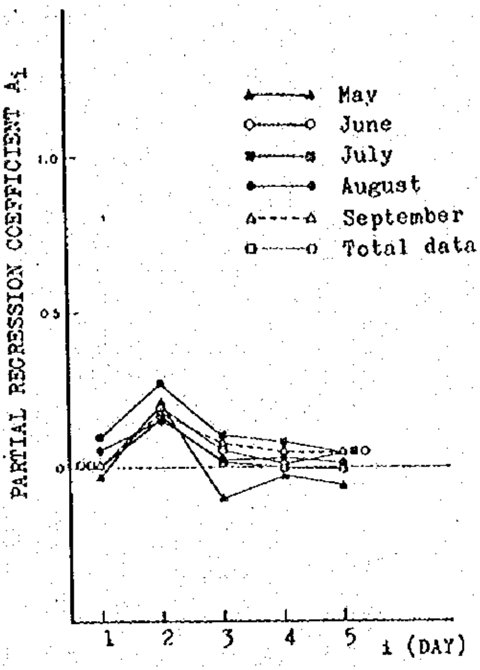

Fig. 4 Linear partial regression coefficients calculated only with linear predictor variables

Therefore, the linear runoff model is expressed as follows;

$$Y_1(t) = A_0 + \sum_{i=1}^{n} A_i X(t - \tau_i) \tag{14}$$

where $Y_1(t)$ is the linear runoff component, and A_i are the partial regression coefficients of the linear runoff. Then, it is necessary that the partial regression coefficients A_0 and A_i ($i = 1,2,3, \ldots ,n$) are positive, while A_0 means base flow discharge. And, time-lag τ_i (i.e., $\tau_i = (i-1)\Delta t$, $\Delta t = 1$ (day) in this paper) should be given as long as possible. However, if A_0 or A_i change into a negative value, the calculation has to be discontinued.

General patterns of A_0 and A_i are shown in Fig. 5 and Fig. 6 in connection with the influence of the number of predictor variables.

These figures also present the effect of time-lag. On the other hand, the nonlinear runoff model is expressed as follows;

$$Y_2(t) = B_0 + \sum_{i=1}^{n}\sum_{j=i}^{n} B_{ij}\, X(t - \tau_i)\, X(t - \tau_j) \tag{15}$$

where $Y_2(t)$ is the nonlinear runoff component and is the residual difference between the observed and estimated value by Eq. (14). B_0 is the mean value of the errors, which cannot be expressed even by Eq. (15). In general, it is nearly zero. B_{ij} are the partial regression coefficients, and they mean the unit hydrograph of second degree. An actual example is shown in Fig. 7.

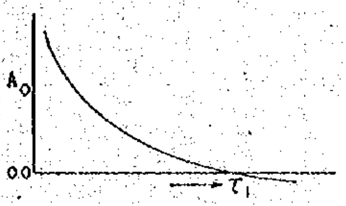

Fig. 5 Change of constant partial regression coefficient A_0 under the influence of the number of predictor variables

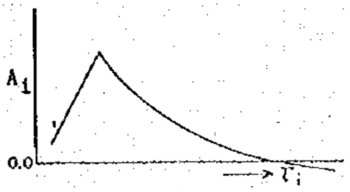

Fig. 6 Change of linear partial regression coefficients under the influence of the number of predictor variables

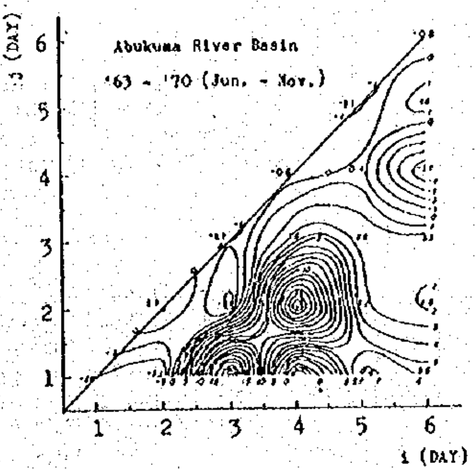

Fig. 7 An example of the quadratic partial regression coefficients B_{ij}

It is considered that the values of the partial regression coefficients B_{ij} for $i=j$ represent the degree of nonlinearity caused by the intensity of rainfall itself, and B_{ij} for $i \neq j$ represent the degree of nonlinearity caused by the distribution of rainfall. Hence, the estimated total runoff $Y(t)$ is expressed as follows;

$$Y(t) = Y_1(t) + Y_2(t) \tag{16}$$

The observed runoff hydrograph is considered to consist of surface, subsurface and ground-water runoff components. The subsurface and ground-water runoff components can be represented by the linear runoff model (Eq. (14)), and the surface runoff component can be represented by the nonlinear model (Eq. (15)). Therefore, in order to separate smoothly and systematically the linear componont from observed values, the method of F.M.R. (the Fixed Maximum Rainfall) and the method of F.M.D (the Fixed Maximum Discharge) are devised. These methods are detailed as follows:

METHOD OF F.M.R.

As previously mentioned, the nonlinearity of runoff is influenced by rainfall intensity. Therefore, the rainfall data less than a fixed value of rainfall intensity (i.e.,F.M.R.) are chosen from the observed data and used in obtaining the corresponding statistical unit hydrograph. In more detail, the procedure of F.M.R. are expounded by using actual data in Table 1.

DATE i	DISCHARGE y_i (mm/day) or (m^3/sec)	RAINFALL (mm/day)							
		X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	....	X_{pi}
1	20.5	50	1	0	3	0	2	. . .	.
2	15.3	2	50	1	0	3	0	. . .	.
3	3.3	11	2	50	1	0	3	. . .	.
4	2.1	0	1	2	50	1	0	. . .	.
5	1.0	0	0	1	2	50	1	. . .	.
6	15.2	30	0	0	1	2	50	. . .	.
7	16.3	25	30	0	0	1	2	. . .	.
8	10.2	5	25	30	0	0	1	. . .	.
9	5.3	0	5	25	30	0	0	. . .	.
10	4.5	10	0	5	25	30	0	. . .	.
11	6.1	1	10	0	5	25	30	. . .	.
12	2.0	0	1	10	0	5	25	. . .	.
13	1.0	0	0	1	10	0	5	. . .	.
14	0.5	0	0	0	1	10	0	. . .	.
15	4.3	20	0	0	0	1	10	. . .	.
16	10.9	0	20	0	0	0	1	. . .	.
17	3.2	1	0	20	0	0	0	. . .	.
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 1 Example of the time series data

For simplicity, if the predictor variables X_{ji} ($j=1,2,\ldots,6$) (i.e., $X(t-\tau)$ ($i=1,2,\ldots,6$) in Eq. (14)) are used in calculating the value of y_i, the time series of X_{ji} is expressed as shown in Table 1. In case of F.M.R.=10 (mm/day), the statistical unit hydrograph is obtained for the data satisfying the following condition;

$$0 \leqq X_{ji}\ (j=1,2,\ldots,6) \leqq 10 = \text{F.M.R.} \quad (i=1,2,\ldots,n) \tag{17}$$

That is to say, the sets of adoptable data must be limited to y_i and X_{ji} ($j=1,2,\ldots,6$) for $i=13,14$, etc. as shown by the dotted line in Table 1. And, the sets of time series data of y_i and X_{ji} shown in a row in Table 1 increases according as the value of F.M.R. increases by introducing the effect of large rainfall intensity.

Each of statistical unit hydrographs obtained by using various values of F.M.R. is shown in Fig. 8. These hydrographs show the characteristics of the linear runoff in the basin of the Abukuma River. The abscissa shows the time-lag of rainfall (i.e., the predictor variables) and the ordinate shows the partial regression coefficients of the predictor variables. The rainfall with the intensity beyond the value of F.M.R. for the most suitable unit hydrograph representing the linear component causes the nonlinear runoff.

METHOD OF F.M.D.

It is assumed, in general, that subsurface and ground-water runoff mainly influence on low or ordinary discharge, and that surface runoff on high or flood discharge. Consequently, it may be considered that the formers are linear and the latter is nonlinear. Therefore, in this analysis, another procedure is devised as follows.

That is, the discharge data less than a fixed value of discharge (i.e., F.M.D.) are chosen from the observed data. In case of F.M.D.=5 (mm/day or m^3/sec) in Table 1, the statistical unit hydrograph is obtained for the data satisfying the following condition;

$$0 \leqq y_i \leqq 5 = \text{F.M.D.} \quad (i=1,2,\ldots,n) \tag{18}$$

That is to say, a lot of sets among the data can be adopted as shown by the broken line in Table 1 (i.e., y_i and X_{ji} ($j= 1,2, \ldots ,6$) of $i= 3,4,5,10,12,13,14,15$th row). By increasing the values of F.M.D. at suitable intervals, different statistical unit hydrographs are computed. The results of this method applied to the basin of the Abukuma River are shown in Fig. 9.

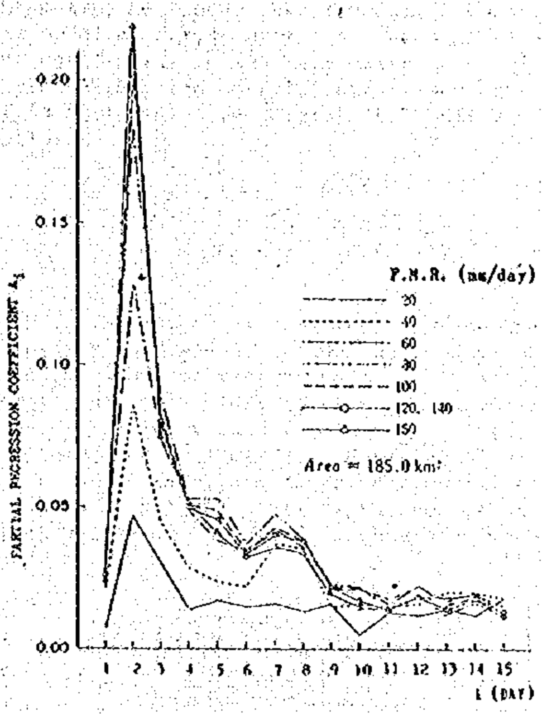

Fig. 8 Characteristics of linear runoff for each of F.M.R. at Moniwa of the Abukuma River Basin

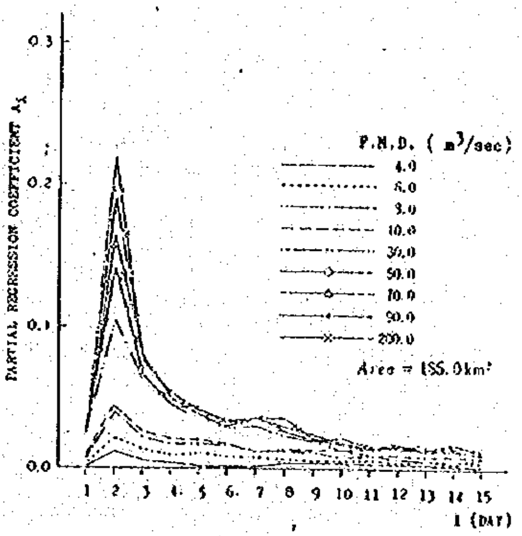

Fig. 9 Characteristics of linear runoff for each of F.M.D. at Moniwa of the Abukuma River Basin

For practical use, the method of F.M.D. is more convenient than the method of F.M.R. because the number of available data in the computation by the method of F.M.D. is greater than that by the method of F.M.R. as shown in Table 1. In particular, when the time-lag is extremely long, in other words the number of the predictor variables increases, the adoptable data tend to decrease significantly.

So, the procedure of F.M.D. is generally more excellent than that of F.M.R.. The runoff beyond the value of F.M.D. for the most suitable unit hydrograph representing the linear component shows the nonlinear runoff. And, taking note of the same peak value of partial regression coefficients determined by each procedure, the relation between F.M.R. and F.M.D. is obtained as shown in Fig. 10.

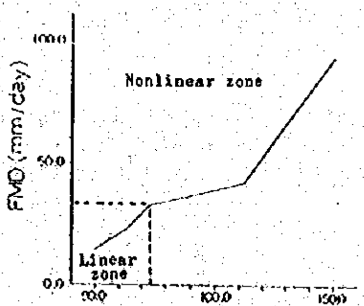

Fig. 10 Relation between F.M.R. and F.M.D.

APPLICABLE LIMIT OF LINEAR RUNOFF MODEL

According as the data of higher discharges presenting stronger nonlinearity are utilized in determining statistical unit hydrograph, the distortion of approximation may arise in the linear model. This distortion affects on the multiple correlation coefficient of the linear model. That is, the value of multiple correlation coefficient varies with the adopted F.M.D. or F.M.R value. So, the value of F.M.D. or F.M.R. corresponding to the maximum value of multiple correlation coefficient are chosen. Data which are far greater than this F.M.D. or F.M.R. value shows the remarkable nonlinearity and give the strong destortion to the estimated linear runoff model. Consequently, it is desirable to employ the linear model of F.M.D. or F.M.R. which gives a maximum value of the multiple correlation coefficient as the most suitable model for linear runoff. Therefore, the multiple correlation coefficient as the index of applicable limit of linear runoff model is employed. In general, the multiple correlation coefficient R is expressed as follows;

$$R = \frac{\sum_{i=1}^{k} (y_i - \bar{y})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{k}(y_i - \bar{y})^2 \sum_{i=1}^{k}(Y_i - \bar{Y})^2}} \qquad (19)$$

where k is the number of data less than each F.M.D. or F.M.R. used in estimating the linear runoff model, y_i the observed values, Y_i the estimated values, and $\bar{y}$ and $\bar{Y}$ the mean values of k observed and estimated data.

Particularly, in order to select a linear runoff model which gives better fitness especially for lower runoff part, R_{log} in Eq. (6), which emphasize the lower part more than R, can be adopted. Some actual examples of R and R_{log} for the river basins of our country are shown in Figs. 11 and 12 respectively. Generally, the peak values of R tend to vary with each of the river basin. On the other hand, the peak values of R_{log} tend to show a value of F.M.D. ranging from about 10 to 30 (mm/day).

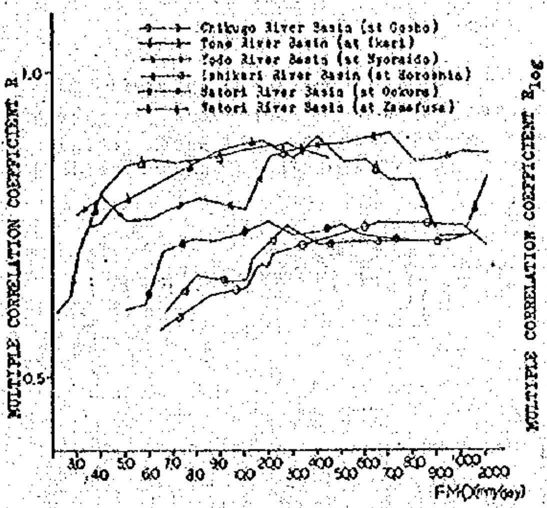

Fig. 11 Examples of the change of R for each of F.M.D. in the river basin of our country

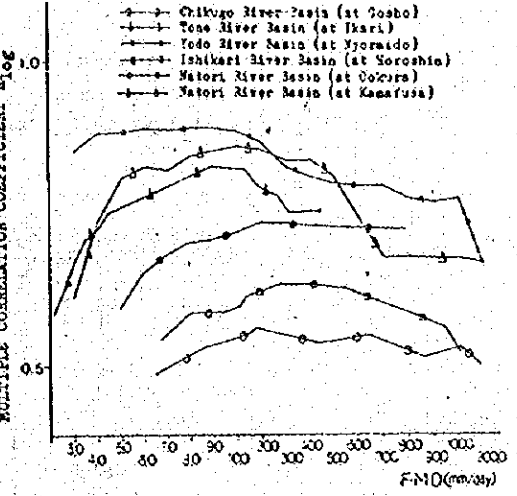

Fig. 12 Examples of the change of R_{log} for each of F.M.D. in the river basin of our country

EXAMPLES OF ANALYSIS

In order to verify the effectiveness of the above mentioned procedures of runoff analysis, some results are obtained from actual data in our country. Fig. 13 shows the statistical unit hydrographs (i.e., the linear runoff models by the method of F.M.D.) for the Echi River basin. The catchment area is 110 km^2, and daily data of the discharge and rainfall (mm/day) from June to November of 1967, 1968 and 1969, when there is no influence of snowfall, are used in the analysis. Fig. 12 shown previously is the actual example of R_{log}, and in this figure, the peak of R_{log} arises in the case of F.M.D.=9 (mm/day). Therefore, the model of F.M.D.=9 (mm/day) is selected as the most suitable statistical unit hydrograph representing the linear runoff component.

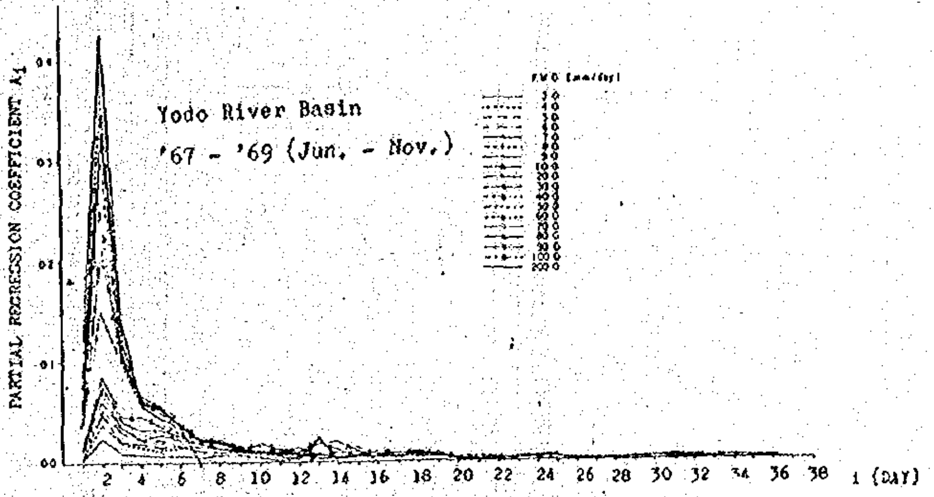

Fig. 13 Characteristics of linear runoff for each of F.M.D. at Nyoraido of the Yodo River Basin

Fig. 14 shows the estimated result for the checking and droughty year 1964 by applying the above model, which are identified using the data from 1967 to 1969.

Fig. 14 shows that the linear model constructed by this procedure is very suitable for the low discharge.

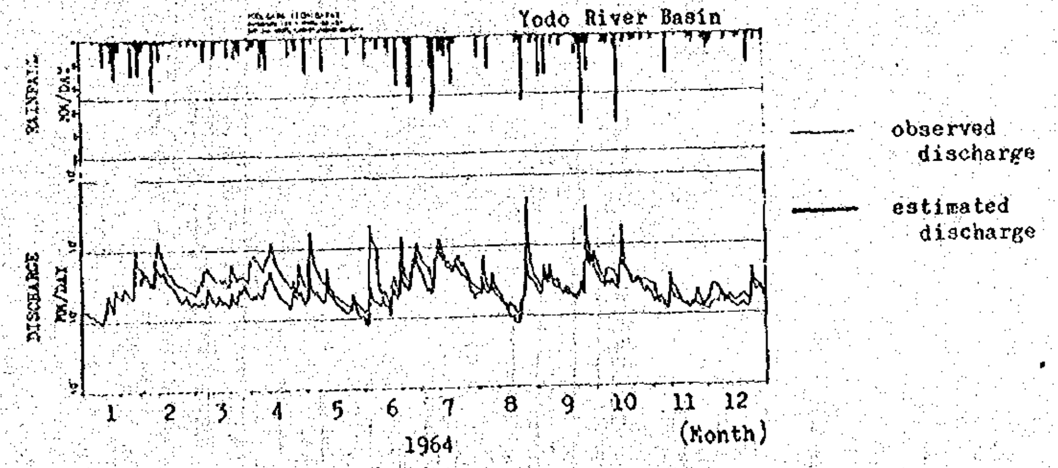

Fig. 14 Comparison between the observed discharges and estimated ones by the linear model at Nyoraido of the Yodo River Basin

Figs. 15 and 16 are the examples for another river basin (Egawa, the Chikugo River basin, 39 km^2). Fig. 15 shows the estimated result by the linear runoff model, and Fig. 16 by the nonlinear runoff model.

The linear model is very suitable for the observed low discharge and the nonlinear one for the observed high discharge.

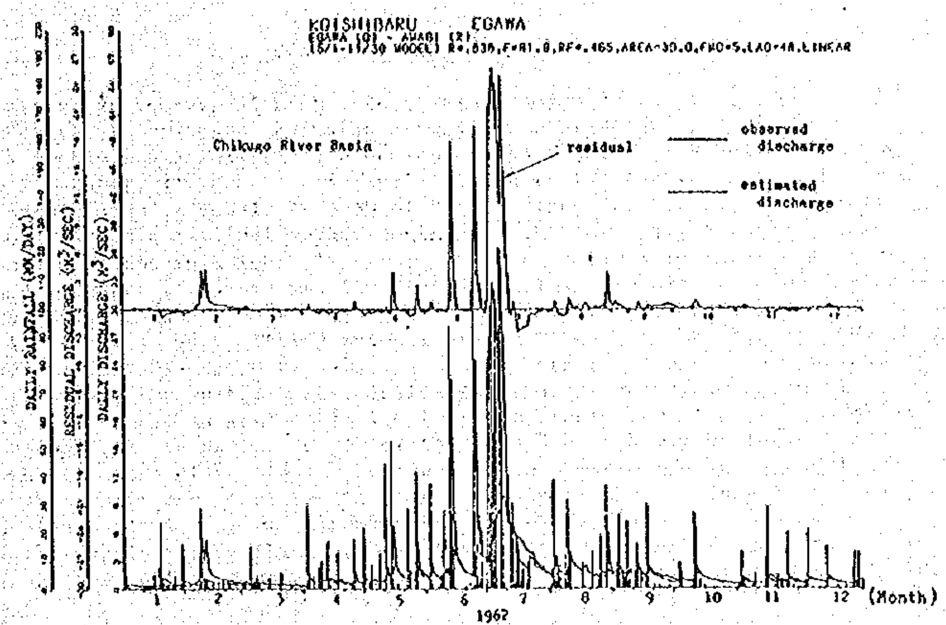

Fig. 15 Comparison between the observed discharges and estimated ones by the linear model at Egawa of the Chikugo River Basin

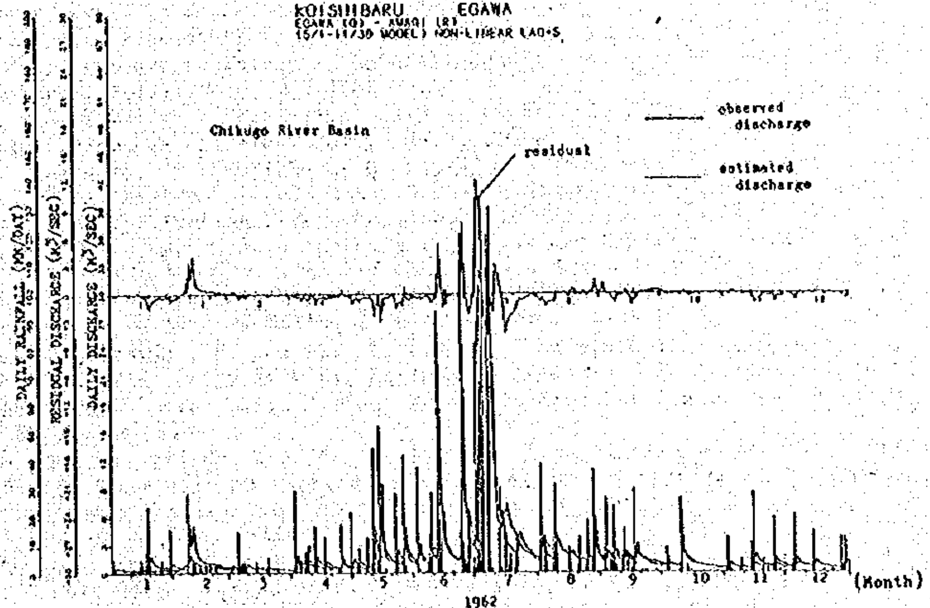

Fig. 16 Comparison between the observed discharges and estimated ones by introducing the nonlinear model at Egawa of the Chikugo River Basin

CONCLUSION AND SUMMARY

In this paper, an analytical method to obtain a solution to Eq. (4) containing a term of 2nd-degree is presented by using a multiple regression analysis.

Up to the present, the multiple regression analysis has been widely utilized in this field. However, there is a practical difficulty in treating the linear and nonlinear factors simultaneously because of the existance of the high correlation between them. As an analytical method containing the term of 2nd-degree, this paper presents a method in which a linear prediction is first performed and then the residuals between its values and the observed values are explained by the nonlinear factors (i.e., the term of 2nd-degree). The limit of adopting the linear prediction is investigated by taking account of the Fixed Maximum Rainfall (F.M.R.) and the Fixed Maximum Discharge (F.M.D.). And, in order to determine a suitable linear runoff model, the multiple correlation coefficient calculated from Eq. (6) or Eq. (19) are proposed as applicable limit of the linear runoff model. For all practical purposes, it is useful to employ the method of F.M.D. and the multiple correlation coefficient of Eq. (6). As the results of this procedure, it is presented that the runoff can be estimated more accurately using the nonlinear model shown by Eq. (15) than the simple linear one shown by Eq. (14).

By using this analytical method, authors have been investigating many basins in our country and have obtained satisfactory results for not only daily data but also hourly ones.

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ORIGINAL PAPER

Numerical Estimation of Water Balance in a River Basin

Hajime Tanji,* Ryoichi Oonishi,*
and Kazumi Iwasaki**

* *Third Water Management Unit, Water Management Department, National Research Institute of Agricultural Engineering (NRIAE)*
** *Second Hydraulic Research Unit, Department of Hydraulic Engineering (NRIAE)*

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SUMMARY

A multiple regression analysis, one of the statistical numerical estimation methods of water balance in a basin, is introduced with an example basin in this paper. This method can be used easily by means of a digital computer. The mathematical bases of the method are given here. As for the runoff model by this method, the whole basin consists of two kinds of areas. One is a non-irrigated area, the other is an irrigated area. An example of an estimation of water balance of multiple regressional models is given for the Yashiro river basin in Fukushima prefecture. The prominent character of this method is that the models simulate very well the low flow and the return flow of the river at the checking points. Some results of the simulation are shown in several figures. From these results, this method simulates totally water balance well.

I. FOREWORD

Recently the effective utilization of water resources has become an important theme not only for domestic and industrial use but also for irrigation. The demand for water has been changing and spreading. Water usage has extended with the advance of urbanization and industrialization. The demand for water for irrigation is not decreasing because of the expansion of irrigation and changes in farm management.

With the development of dams and the expansion of irrigation and water supply facilities, the amount of water controlled by such facilities in catchment basins has been increasing. To sum up, while the water management problem, the effective utilization of water in a whole catchment basin, has long been present, there are increasing numbers of facilities which can be used for water control. Therefore it is necessary to clarify by what method and on what data the water balance of a basin can be controlled.

Data on water utilization have been obtained from the various points in a river basin. Kaneko[6] studied the water balance of a whole catchment basin on the basis of data obtained by different methods and in different periods. The authors have improved on Kaneko's method of arranging disparate data, and established a method of a numerical analysis of the water balance in a basin, by using a multiple regression analysis to build a model in a computer. This method clarifies the total water balance situation in a basin up to the present and will estimate the water balance in the near future. A multiple regressional model will facilitate the evaluation of the amount of water recycled through irrigation. Appropriate evaluation of recycled water makes it possible to adequately control the water in a basin.

The authors have been putting such a systematic analysis method of water balance to practical use widely and have made proposals for better water control methods in Japan. This analysis method utilizes a multiple regression analysis, the principle of which is based on a solution of integral equations given by Weiner. The authors have applied this analysis method to many irrigated and non-irrigated areas in Japan. After making improvements, they have confirmed that the method can be used at low water level, and that it permits an accurate estimate of the discharge of returned flow from irrigation. In this paper, first the method of water balance in a river basin is roughly explained; then the characteristics of this numerical estimation method are presented in detail, with examples of a water balance analysis in some areas where the methods were recently applied.

II. METHOD OF ANALYSIS

1. Basic Equation

If the relationship between rainfall and runoff conforms to Weiner's nonlinear system theory, the relationship can be generally expressed by the Volterra series in which the present time 't' is taken as the origin:

$$Y(t)=\sum_{n=0(n)}^{\infty}\int\cdots\int_0^{\infty}h_n(\tau_1,\tau_2,\cdots,\tau_n)\prod_{k=1}^{n}X(t-\tau_k)d\tau_1 d\tau_2\cdots d\tau_n \qquad (1)$$

where $X(t-\tau_k)=A_r\cdot R(t-\tau_k)$

A_i: acreage of the area in a basin. $R(t-\tau k)$: intensity of rainfal in an area. $Y(t)$: the value of the watershed runoff at the time t. h_n: runoff kernel of the nth degree. τ_k: integral variable showing time-lag of runoff.
t: time.

Approximating equation (1) by taking the terms up to the second degree of moment (i.e., $n=2$) and using the multiple regression analysis (one of the discrete forms), the equation can be solved. The following equation is obtained by expressing the best objective estimates of the partial regression coefficients of the multiple regressional model as A_o, A_i, and B_{ij} and the estimatd runoff discharge as $Y(t)$:

$$Y(t)=A_o+\sum_{i=1}^{n}A_i\cdot X(t-\tau_i)+\sum_{i=1}^{n}\sum_{j=1}^{n}B_{ij}\cdot X(t-\tau_i)\cdot X(t-\tau_j) \qquad (2)$$

The parameters A_o, A_i, and B_{ij} are determined by the method of least squares. If the linear terms A_i, and the nonlinear terms B_{ij} of the equation (2) are solved simultaneously, the independence of predictor variables cannot be maintained. Therefore, the authors first extract the linear components from the observed values $Y(t)$, and then a multiple regressional model as shown in linear terms A_i, alone is applied to the linear components and a nonlinear multipl regressional model as shown in the nonlinear terms B_{ij} is applied to the residual difference (nonlinear components) between the observed values and the estimated values by the linear model. It is considered that the value of the partial regression coefficients B_{ij} for $i=j$ expresses the degree of nonlinearity to be caused by the distribution of rainfall.

2. Runoff model for a paddy-field area

In the multiple regression analysis for rainfall-runoff relations, as the first step, characteristics of runoff in a basin can be expressed by one of two models. One is a mountain area model which takes into consideration rainfall alone, and the other is a paddy-field area model which takes into consideration both rainfall and diversion of water, as shown in **Figure 1**.

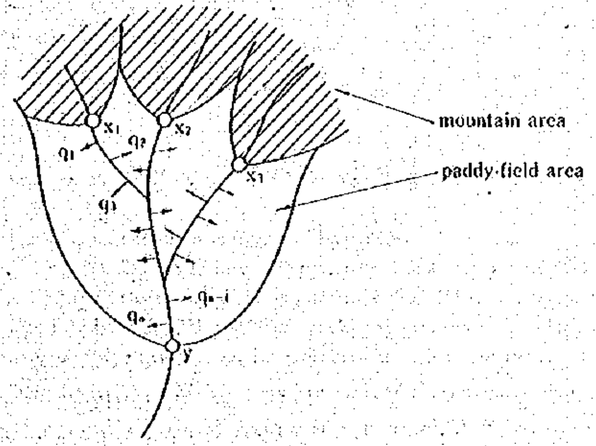

Figure 1 Outline of a river basin

In other words, the mountain area model can apply to a non-irrigated area and the paddy-field area model can apply to an irrigated area. For the mountain area model, the basic equation can be used directly. But for the paddy-field area model, the basic equation must be corrected as follows.

When equation (2) is applied to the runoff of a paddy-field area which contains a cycling process of repeated water use, the equation can be expressed as (3) and (4) below:

$$Y'(t)=F(t)+A_o+\sum_{i=1} A_i\cdot Z_i+\sum_{i=1}^{n}\sum_{j=1}^{m} B_{ij}\cdot Z_i\cdot Z_j \tag{3}$$

$$F(t)=\sum_{p=1}^{d}\left(Q(t)_p-\sum_{k=1} q(t)_{kp}\right) \tag{4}$$

where $Z_i=X(t-\tau_i)+q(t-\tau_i)+q'(t-\tau_i)-q''(t-\tau_i)X(t-\tau_i)=Ar\cdot R(t-\tau_i)$

$\tau_i=(i-1)\Delta t$

(j in Z_j and $X(t-\tau)$ is the same as in i)

$Y(t)$: estimated runoff rate at the base point of the paddy-field area.

$Q(t)_p$: the rate of flow of tributaries. $q(t)_{kp}$: diversion from rivers in an area. A_o: regression coefficient. A_i: partial regression coefficients for linear runoff. B_{ij}: partial regression coefficients for nonlinear runoff. $R(t-\tau_i)$: intensity of rainfall in an area. $q(t-\tau_i)$: total amount of diversion in an area. $q'(t-\tau_i)$: water supplied by areas. $q''(t-\tau_i)$: component runoff from the area to the outside (including evapo-transpiration). A: acreage of the area. Δt: time increment. t: time.

$F(t)$ in equation (4) is a function which expresses the water balance system, taking into consideration the repeated utilization of water, and indicates the residual flow rate of the river.

That is, the river water decreases in flow rate as it irrigates and supplies water to the paddy-field area, but at a certain point, the amount of possible diversion on the basis of water rights may exceed the amount of river discharge. In this case, the actual diversion is total and the deficit is considered to be made up by seepage and return flow. This relationship is expressed by the following equation:

$$\begin{array}{lll} Q \geq q & q' = q & F = Q - q \\ Q < q & q' = Q & F = 0 \end{array} \qquad (5)$$

where Q: the rate of river flow. q: the rate of diversion authorized under water rights. F residual discharge of river.

q': possible diversion (actual amount of diversion).

An equation such as (5) calculates the water balance at various tributaries and main streams, and the residual flow rate $F(t)$ at the base point (i.e., the downstream end of a paddy-field area) can also be obtained. When $F(t)$ of the equation (4) is obtained, the unknown runoff kernel parameters A_o, A_l and B_{ij} can be determined as a function of equation (2).

In addition, the returning ratio of linear runoff is expressed by $\sum_{j=1} A_i$; this is utilized as $\gamma = D_1/D_2$, and means the ratio of return runoff amount D_2 to the outside compared with amount of water of diversion D_1 in the area. As returning runoff caused by water taken in a paddy field generally shows an intense linearity, it may be said that the returning ratio is considered as $\sum_{i=1} A_i$. Further, if this returning ratio is expressed by $\gamma(=\sum_{i=1} A_i)$, the average number repeats ω of water utilization in an area can be expressed by the following formula:

$$\omega = 1/(1-\gamma) \qquad (6)$$

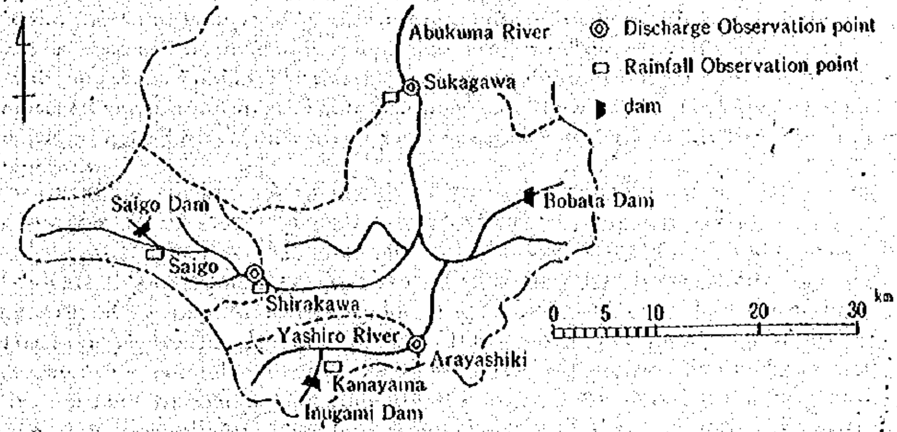

Figure 2 Observation points and dams

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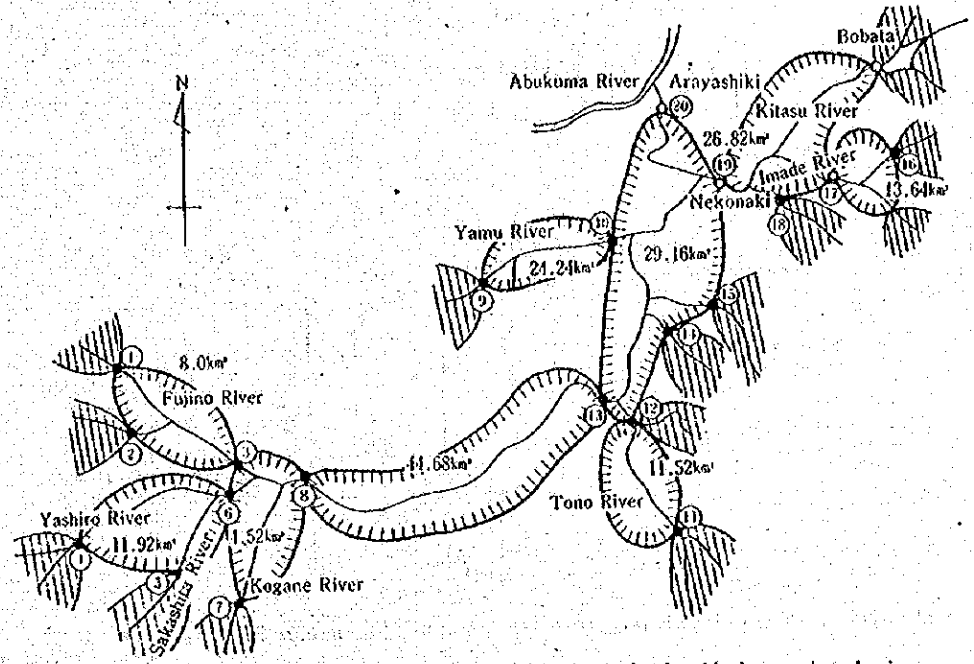

Figure 3 Water balance model of the Yashiro River basin in the Abukuma river basin (conceptional figure)

III. RESULTS OF ANALYSIS

Figure 4 shows the water balance system of the Yashiro river basin in the Abukuma river basin (**Figures 2** and 3). An example of the analytical method of water balance follows using the multiple regressional analysis in the Yashiro river basin.

In this basin, there are two periodic measuring points of the flow volumes, Bobata and Arayashiki. The basin can be divided into mountain areas with no water intake and paddy-field areas with some water intakes. The interface points of mountain and paddy-field areas are the base points of the mountain areas. These base points are shown by “.”s in **Figure 4**. Thus **Figure 4** shows the boundaries of the water balance system between the paddy-field areas and the mountain areas.

The linear runoff model was made up of only the first two terms of equation (2), adopting Bobata as a base point for the mountain areas. When coefficients of equation (2) are determined, the value called F.M.D. (the Fixed Maximum linear Discharge) is introduced, and data class and model class are divided in linearity. That is to say, when the intensity of rainfall is high, the nonlinearity of runoff is strong. And when the intensity of rainfall is low, the linearity of runoff is strong. This principle can be applied to the flow. It is assumed, in general, that subsurface and ground-water runoff mainly influence low or ordinary discharge, and that surface runoff influences high or flood discharge. Consequently, it may be considered that the former are linear and the latter are nonlinear. Therefore, in this analysis, another procedure is devised as follows.

It is proposed to separate the discharge data within an F.M.D. from the observed data. If F.M.D.=5 mm/d (or m^3/s), in **Table 1**, is taken, the following condition must be satisfied:

$$0 \leq Y_i \leq 5 = \text{F.M.D.} \quad (i=1,2,\cdots\cdots,n) \tag{7}$$

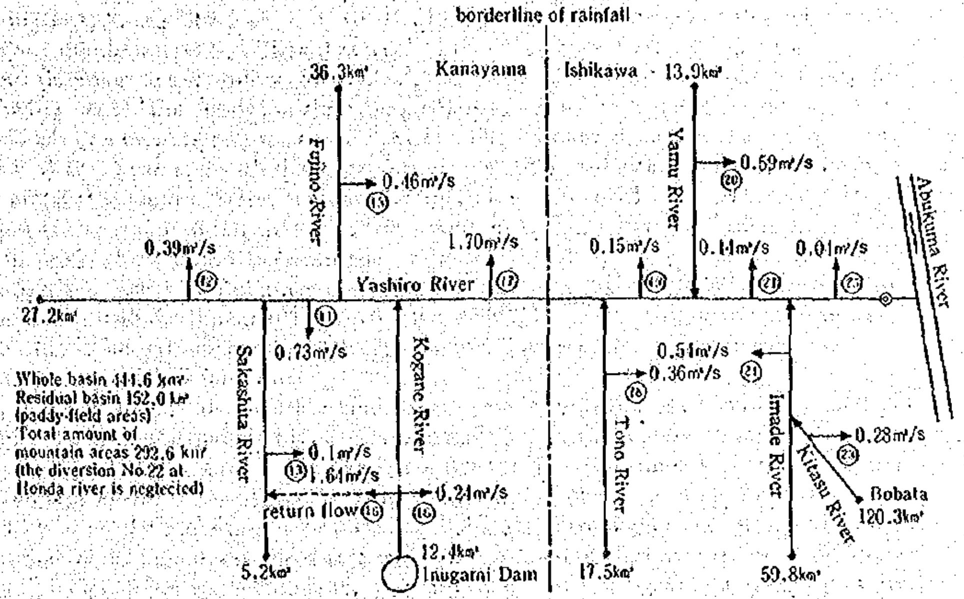

Figure 4 Systematic diagram of water balance analysis in the Yashiro river basin

Table 1 Examples of the time series data

DATE i	DISCHARGE y_i (mm/d) or (m³/s)	RAINFALL (mm/d)							
		X_{1i}	X_{2i}	X_{3i}	X_{4i}	X_{5i}	X_{6i}	…	X_{pi}
1	20.5	50	1	0	3	0	2	…	·
2	15.3	2	50	1	0	3	0	…	·
3	3.3	11	2	50	1	0	3	…	·
4	2.1	0	1	2	50	1	0	…	·
5	1.0	0	0	1	2	50	1	…	·
6	15.2	30	0	0	1	2	50	…	·
7	16.3	25	30	0	0	1	2	…	·
8	10.2	5	25	30	0	0	1	…	·
9	5.3	0	5	25	30	0	0	…	·
10	4.5	10	0	5	25	30	0	…	·
11	6.1	1	10	0	5	25	30	…	·
12	2.0	0	1	10	0	5	25	…	·
13	1.0	0	1	1	10	0	5	…	·
14	0.5	0	0	0	1	10	0	…	·
15	4.3	20	0	0	0	1	10	…	·
16	10.9	0	20	0	0	0	1	…	·
17	3.2	1	0	20	0	0	0	…	·
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	·	·	·	·	·	·	·	…	·

That is to say, a number of sets among the data can be adopted as shown by the broken line, i.e., among $i=1, 2, \ldots, n$ for $i=3, 4, 5, 10, 12, 13, 14, 15$, etc. By making values of F.M.D. increase at suitable intervals, different statistical unit hydrographs are computed.

Various time-lags are examined for each F.M.D. The maximum time-lag is adopted for every F.M.D. under the condition that the partial regression coefficients are not negative. Then, models can be obtained for every F.M.D. The number of models is as many as the number F.M.D. The model with the largest autocorrelation coefficient is adopted as the most suitable among the models. Here, in order to estimate low water discharge, not the model with the largest autocorrelation but that with the largest logarithmic autocorrelation is adopted. **Figure 6** shows the relation between the estimated runoff by the mountain area model (**Figure 5**) of the basin with Bobata as the base point and the actual runoff. When the intensity of the rainfall is high, nonlinearity of the runoff is strong. Hence the estimated value does not coincide with the actual value at the peak of the runoff. But the estimated runoff coincides with the actual value at a low flow rate.

Next, a runoff model for a paddy-field area is made with the base point of runoff at Arayashiki. To build the model, it is necessary to have full data on the runoff rate at the point which is expressed as the mark "." in **Figure 4**. But the observed runoff value was obtained only at Bobata in this study. Thus, for points other than Bobata, the runoff flow rates are estimatd by using the mountain area model at Bobata and employing the estimated values $Y(t)$, a runoff model for a paddy-field area which is expressed by the linear terms of equations (3) and (4). The data on water intake for agricultural use are utilized after making a pattern based on the data obtained from four actual observations.

Figure 7 shows a statistical unit hydrograph of a linear runoff model by the above-mentioned method.

Figure 8 shows a comparison of the estimated runoff obtained by the model with the observed runoff. **Figure 8** shows that the estimated runoff by the obtained model coincides well with the observed runoff.

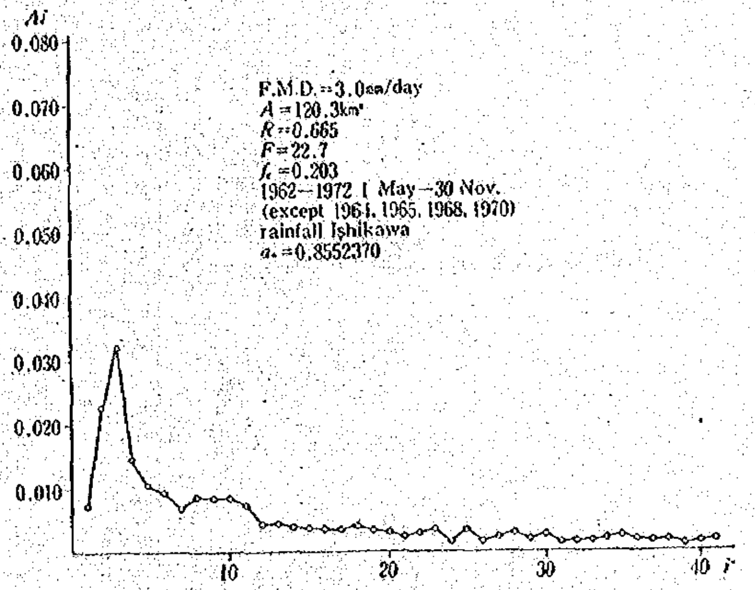

Figure 5 Statical unit hydrograph at Bobata in the Abukuma river basin

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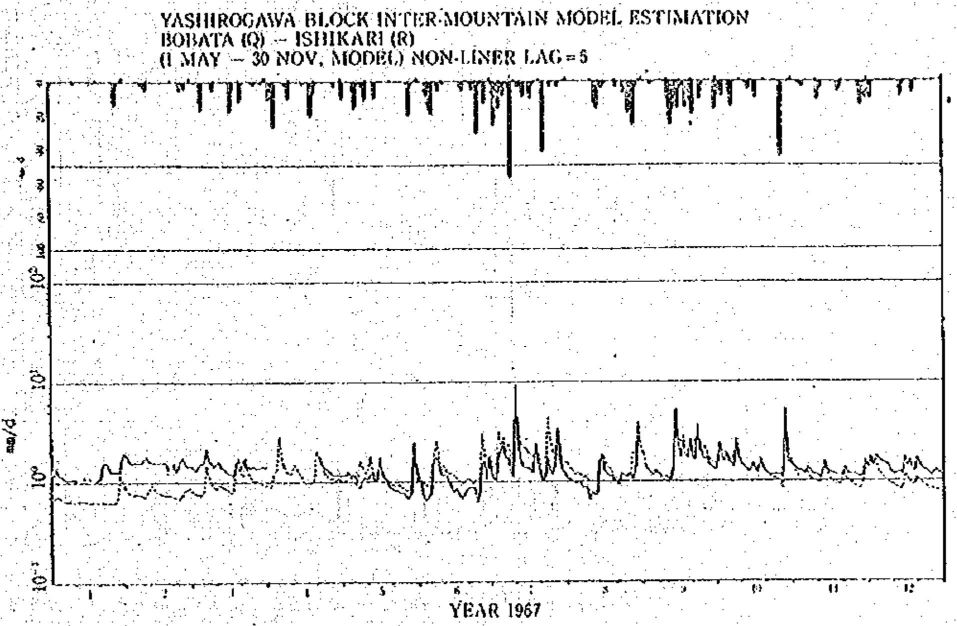

Figure 6 Estimation of river flow at Bobata (linear model)

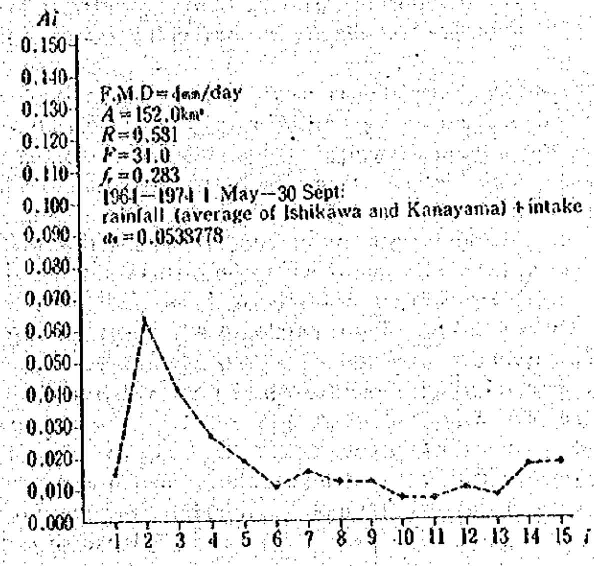

Figure 7 Statistical unit hydrograph at Arayashiki in the Yashiro river basin

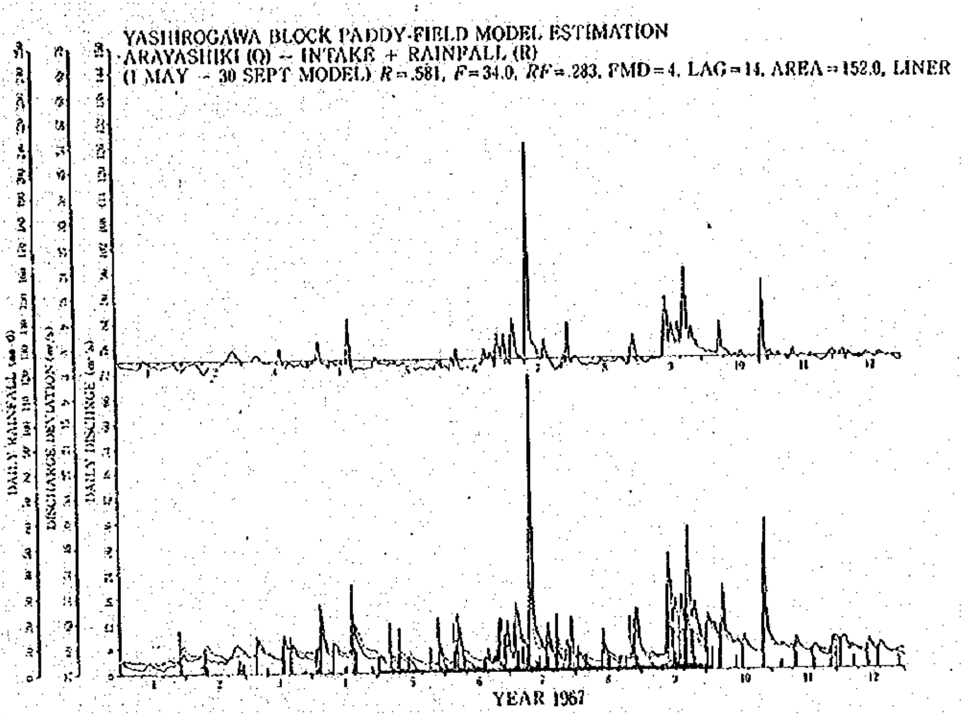

Figure 8 Estimation of river flow at Arayashiki (linear model)

As mentioned above, a model is prepared based on data obtained from actual observations. It is desirable that these observations should be made as often as possible over a long continuous period of time. At present the number of regular observaion points is limited due to the costs involved. To make up for the deficiency of data, simultaneous observations of flow rates were conducted at the Yashiro river basin four times a year on July 24th, August 5th and 11th (in periods of irrigation), and on October 3rd (in a non-irrigation period) in 1981. The simultaneous observation of flow rates was conducted regarding the flow rate of rivers and the diversions.

As previously mentioned, the periodic pattern of the diversions is determined based on the data. The data on the river flow rates are utilized in checking models — that is to say, the daily flow rate at the point can be estimated by fitting the point of the simultaneous flow rate observation to the runoff point of the basin in the model, and an examination of the water balance model can be conducted.

The examinations will be done as follows. In the case of the mountain area of the river basin where the model cannot be made independently, and where two or more models of mountain area are given near this area, the choice of the better model of the mountain area should be made by comparison between the simulated runoff and the simultaneous observed runoff. However, in the observation under discussion, only one mountain area model is obtained in the areas of the basin, and there is no chance to make a choice among models. Instead, a choice of rainfall datum locations is made. The paddy-field area model utilizes the data from Ishikawa at the lower reaches of the Yashiro river and Kanayama in the upper reaches of the Yashiro river. But the estimated runoff value of the paddy-field area did not coincide well with the observed runoff values as it did with the mountain area runoff. Judging from the result, the rainfall at Kanayama has the character not of a paddy-field area but of a mountain area.

Accordingly, the data on Shirakawa (**Figure 2**), which is somewhat distant from the Yashiro river, but where the correlation with Ishikawa is better than that of Kanayama, were adopted instead of the data of Kanayama. In addition, the flow data at Inugami dam was utilized. As a result, the estimated runoff values of paddy-field area runoff coincided with simultaneous flow rate observation to a higher degree than before.

Figure 9 shows the estimated amount of the return flow of intake water by the linear runoff model. In this way, the repeated use of water for irrigation is estimated by the multiple regression model. The fluctuation of repeated water is less than that of rainfall, and the repeated water could be utilized as a suitable water source for the lower reaches.

As shown in the comparison between estimation and actual observaion, it becomes clear that both in the paddy-field areas and in the mountain areas of this catchment basin, considerable nonlinear components are contained in the actual runoff. Accordingly, a model which contains nonlinear terms was prepared (**Figures 10** and **11**). In these figures the numbers of the days of the time-lags are taken as axes. For every partial coefficient i is taken as X-axis and j is taken as Y-axis here. **Figures 11** and **12** show the comparison between estimation and actual runoff. These estimations were done by the mountain area model based on the nonlinear runoff model and by the paddy-field area model based on the linear runoff model. The figures coincided well with the actual observations by adding nonlinear terms to the estimation' even in the case of intensive rainfall.

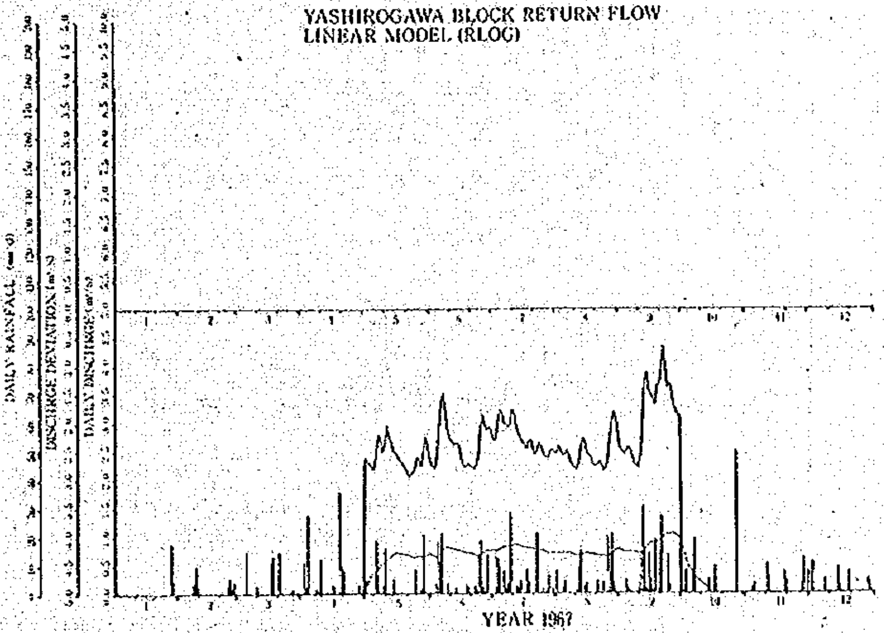

Figure 9 Estimation of return flow at Arayashiki (linear model)

	1	2	3	4	5	6
1	−16.13	23.69	24.20	−0.76	36.21	−3.97
2		80.14	5.10	87.63	−22.54	106.14
3			16.19	42.64	0.34	16.25
4				4.97	−6.68	14.08
5					3.98	9.05
6						1.60

×10^{-5}

$b = -15.56 \times 10^{-5}$

Figure 10 Nonlinear component of runoff at Bobata b_{11} - b_{66}

	1	2	3
1	3.66	0.26	6.50
2		25.03	3.50
3			6.08

×10^{-4}

$b = -1.217068$

Figure 11 Nonlinear component of runoff at Arayashiki b_{11} - b_{33}

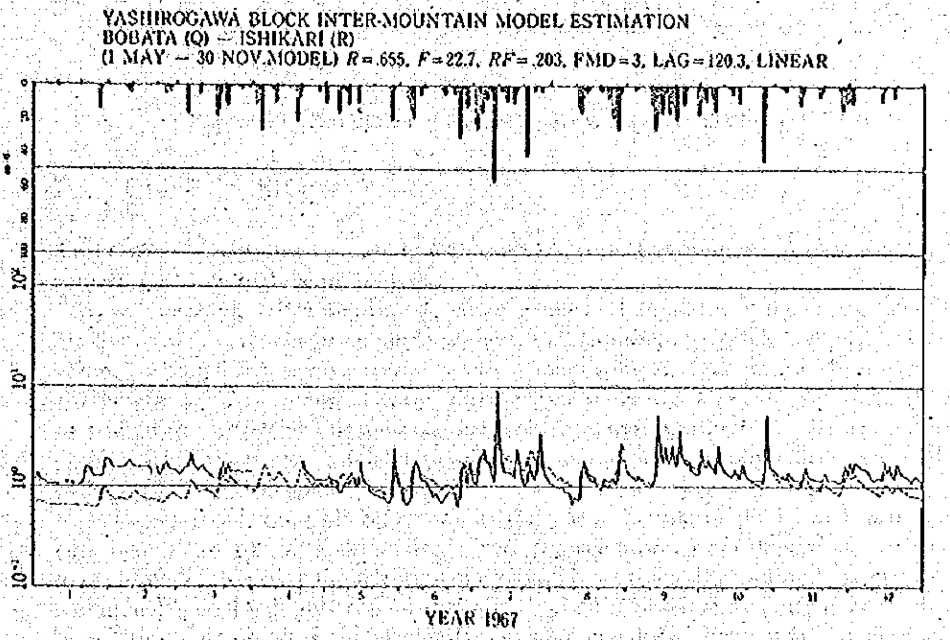

Figure 12 Estimation of river flow at Bobata (nonlinear model)

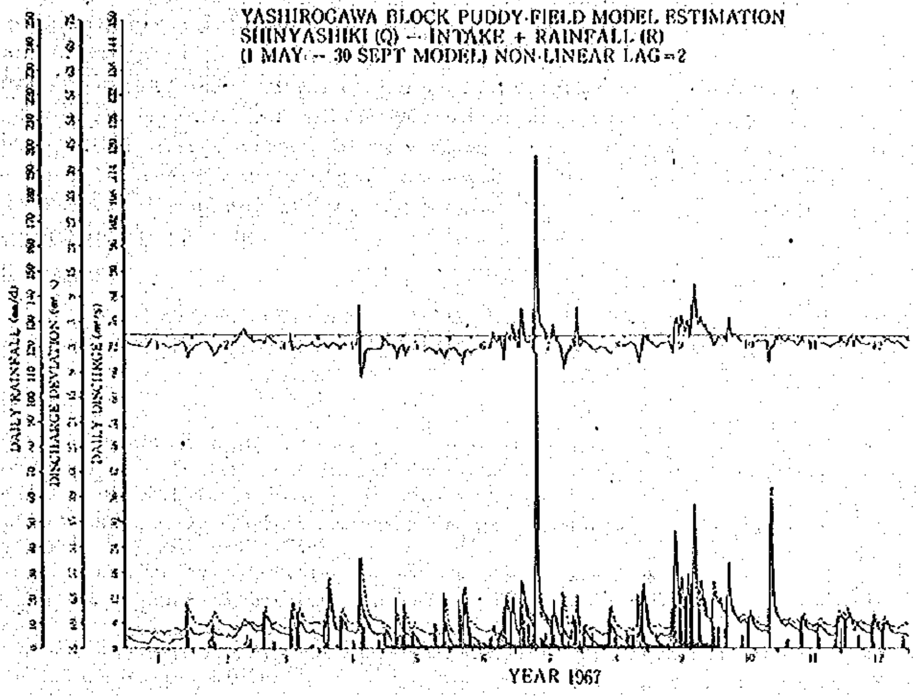

Figure 13 Estimation of river flow at Arayashiki (non-linear model)

IV. CONCLUSION

This paper has presented an analytical method for determining water balance of river basin using a multiple regression analysis.

By this method, if data on rainfall, water intake and discharge at the base point of the river are available, a model can be made without determining separately the physical parameter values which represents complicated topographical, geographical and geological characteristics of a catchment basin. Further, the returnig water from a paddy field area can be estimated effectively. The most serious problem is that the number of discharge observation points are few. But in this model data on simultaneous flow rate observation are used and can make up for the deficiency.

As stated above, multiple regression analysis is a statistic method which is utilized more effectively in an area where data are scarce. A large number of calculations are necessary to make a model, but once the selection of a model is completed, very simple calculations in the completed model will give the estimation of runoff. Consequently, and in contrast with the calculation by a physical model, smaller computers will be sufficient for calculation of water control in a small river basin by this method. At present, practical applications to this aspect are being carried out.

The numerical estimation method of water balance introduced in this paper has been widely utilized in representative river basins in Japan. Needless to say, the accuracy of data influences the results. Nevertheless, satisfactory results have been obtained in many types of river basins.

In conclusion, the role of the multiple regressional model was made clear in this paper. The ultimate purpose of the authors is the appropriate utilization of water in a river basin, i.e., adequate transportation and distribution of water. For this purpose, it is necessary to analyze low flow and to estimate returned flow.

With regarded to individual water management and drainage, the authors have applied separately mathematical methods based on hydraulics. But for the overall and appropriate management of these individual facilities, it is necessary to determine the correct water balance in a river basin. The multiple regression analysis method has been improved in order to determine the appropriate scale of dams and canals as well as to ascertain the best way of managing water in a river basin.

Acknowledgement

The authors are pleased to acknowledge the considerable assistance of Dr. Hidehiko Shiraishi. The authors also would like to express their appreciation to Dr. Michio Nakahara.

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Annex A-2

Iwai - Kadoya's method for the calculation of probable dairly rainfall

In most cases, the frequency curve for the maximum daily rainfall per year indicates an asymmetric distribution. Extensive studies have been made on application of this distribution in order to find a method with justified reliance, which may roughly be classified into the following categories; the method to utilize the characteristics of "Normal Distribution" (Logarithm-Normal Distribution) and the method to directly apply "Asymmetric-Distribution Function" (Distribution of Extreme Values). In order to identify whether these rainfalls are forming the log - normal distribution or not, the Hazen's probability paper is used.

The theory of "Log-Normal Distribution Function" is as follows:

$$F(x) = \frac{1}{\sqrt{\pi}}\int_{-\infty}^{\xi} e^{-\xi^2}d\xi$$

$$\xi = a\log_{10}\frac{x+b}{x_0+b}, \quad (-b<x<\infty)$$

where a, b and x_0 are constants. There are various types of method to determine these constants based on empirical distribution functions. Here, Iwai's method may be adopted. which is widely used in Japan.
-Kadoya

$$x_g : \log_{10}x_g = \frac{1}{N}\sum_{i=1}^{N}\log_{10}x_i$$

$$b_s \fallingdotseq \frac{x_i x_s - x_g^2}{2x_g-(x_i+x_s)}, \quad (s=N-i+1)$$

$$b = \frac{1}{m}\sum_{i=1}^{m} b_s, \quad \left(m \fallingdotseq \frac{N}{10}\right)$$

Where N is number of samples.

$$\log_{10}(x_0+b) = \frac{1}{N}\sum_{i=1}^{N}\log_{10}(x_i+b)$$

$$\frac{1}{a} = \sqrt{\frac{2}{N-1}\sum_{i=1}^{N}\left(\log_{10}\frac{x_i+b}{x_0+b}\right)^2} = \sqrt{\frac{2N}{N-1}}S_x$$

$$S_x = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\{\log_{10}(x_i+b)\}^2-\{\log_{10}(x_0+b)\}^2}$$

For the estimation of probable daily rainfall, the following formula is used;

$$\log_{10}(x+b) = \log_{10}(x_0+b)+\frac{1}{a}\xi$$

Where ξ is the normal variable in relation to return period T,

$$\frac{100}{W(\%)} \fallingdotseq T \to \xi$$

T (year)	ξ	T (year)	ξ	T (year)	ξ	T (year)	ξ	T (year)	ξ
2	0.0000	37	1.3622	72	1.5560	107	1.6629	260	1.8847
3	0.3045	38	1.3702	73	1.5597	108	1.6654	270	1.8936
4	0.4769	39	1.3782	74	1.5635	109	1.6678	280	1.9022
5	0.5951	40	1.3860	75	1.5672	110	1.6701	290	1.9105
6	0.6858	41	1.3932	76	1.5709	111	1.6725	300	1.9184
7	0.7547	42	1.4008	77	1.5745	112	1.6749	310	1.9260
8	0.8134	43	1.4079	78	1.5780	113	1.6772	320	1.9335
9	0.8634	44	1.4146	79	1.5815	114	1.6795	330	1.9407
10	0.9062	45	1.4213	80	1.5849	115	1.6818	340	1.9476
11	0.9442	46	1.4276	81	1.5883	116	1.6841	350	1.9542
12	0.9780	47	1.4342	82	1.5917	117	1.6863	360	1.9606
13	1.0084	48	1.4404	83	1.5950	118	1.6885	370	1.9672
14	1.0361	49	1.4464	84	1.5982	119	1.6907	380	1.9733
15	1.0614	50	1.4520	85	1.6014	120	1.6929	390	1.9792
16	1.0848	51	1.4578	86	1.6046	125	1.7034	400	1.9850
17	1.1065	52	1.4634	87	1.6077	130	1.7135	410	1.9906
18	1.1263	53	1.4693	88	1.6108	135	1.7232	420	1.9961
19	1.1455	54	1.4746	89	1.6138	140	1.7324	430	2.0014
20	1.1630	55	1.4798	90	1.6168	145	1.7414	440	2.0067
21	1.1798	56	1.4849	91	1.6198	150	1.7499	450	2.0118
22	1.1955	57	1.4901	92	1.6228	155	1.7582	460	2.0166
23	1.2102	58	1.4952	93	1.6257	160	1.7662	470	2.0213
24	1.2246	59	1.4999	94	1.6285	165	1.7739	480	2.0260
25	1.2380	60	1.5047	95	1.6314	170	1.7814	490	2.0305
26	1.2509	61	1.5094	96	1.6342	175	1.7885	500	2.0350
27	1.2639	62	1.5141	97	1.6369	180	1.7955	550	2.0565
28	1.2749	63	1.5180	98	1.6396	185	1.8023	600	2.0757
29	1.2861	64	1.5231	99	1.6423	190	1.8089	650	2.0931
30	1.2967	65	1.5274	100	1.6450	195	1.8153	700	2.1094
31	1.3069	66	1.5317	101	1.6476	200	1.8215	750	2.1242
32	1.3170	67	1.5359	102	1.6502	210	1.8332	800	2.1375
33	1.3270	68	1.5400	103	1.6528	220	1.8446	850	2.1506
34	1.3359	69	1.5441	104	1.6554	230	1.8554	900	2.1630
35	1.3453	70	1.5481	105	1.6579	240	1.8656	950	2.1750
36	1.3537	71	1.5521	106	1.6604	250	1.8753	1000	2.1850

DRAINAGE ANALYSIS FOR PLANNING OF MAIN FACILITIES IN AGRICULTURAL FIELDS

Ryoichi Oonishi, Hajime Tanji
Hiromichi Toyoda and Munehide Ishiguro
National Research Institute of
Agricultural Engineering, MAFF
JAPAN

2. ANALYSIS OF RAINFALL-RUNOFF

The method of tracing the rainfall-runoff from a certain drainage basin to a drainage canal, which are required in order to carry out drainage analysis during a storm, is presented in this section. Hourly data on rainfall, flow rates and others are assumed to be available for this analysis. This analysis can be divided into four major components of runoff, as next:

(1) effective rainfall;
(2) base flow;
(3) subsurface runoff, and
(4) surface runoff.

More explanations on each of these are given in following subsections, but it is specially noted that the direct runoff is treated with a form of a hydrograph, because it consists of surface runoff and subsurface one and as it changes hourly.

(a) Effective rainfall

The authors have used the method to separate the surface runoff and subsurface runoff plus base flow by connecting two points of intersection on a runoff curve as shown in Fig. 1. After getting the surface runoff (the area above the dotted line on Fig. 1), the effective rainfall is given by the follwing equation.

$$\Sigma Rr = (\Sigma Q \cdot \Delta t)/A \qquad (1)$$

where, Q: discharge to the drainage canal;
A: area of the basin;
Δt: time increment and
Rr: total rainfall.

The total loss of rainfall, Rl, is expressed as follows:

$$\Sigma Rl = \Sigma R - \Sigma Rr \qquad (2)$$

where, R: rainfall.

(b) Base Flow

Fig. 2 shows the curves of the diminishing runoff after a rainfall. The base flow is defined as the constant discharge after the diminution. The two values of base flow are shown on Fig.2. One is for an irrigation period, and the other is for a non-irrigation period. It is considered that the two values revealed are due to the influence of irrigation.

(c) Subsurface Runoff

The subsurface flow passes usually through pervious strata. Consequently, the subsurface flow tends to have strong linearity. Therefore, it is possible to employ the unit hydrograph analysis for examination of this part of runoff. The subsurface runoff shown in Fig. 1 is defined to be the discharge between surface runoff and base flow.

(d) Surface Runoff

There are two methods to solve the problem of surface flow. They are to put into a model either of a flow on the uniform slope (as shown in Fig. 3) or of a flow over a notch (in Fig. 4).

The momentum equation of the flow is expressed in accordance with the Manning formula, when one considers the flow on the uniform slope, as follows:

$$Q = v \cdot A = \frac{1}{N} \cdot h \cdot h^{\frac{2}{3}} \cdot I^{\frac{1}{2}} \qquad (3)$$

where, v: average velocity of flow on the slope;
I: slope;
A: cross-sectional area of flow (for unit width, A = 1.0 x h); and
N: roughness coefficient.

The equation of continuity is expressed as follows:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_x \qquad (4)$$

where, q_x: side inflow.

After getting the logarithm of the equation (3) and the partial-difference by t, then putting the result into the equation (4), the characteristic curve is obtained and solved as follows:

$$Q = \left\{ (1-\delta) \cdot K^{r} \cdot \left(\frac{1}{\alpha}\right)^{\delta} \cdot \left(1 + \frac{2}{3}\beta\right) \cdot \int_{\tau}^{t} q_x \cdot dt + Q_{\tau}^{1-\delta} \right\}^{\frac{1}{1-\delta}} \qquad (5)$$

The relation between x and t is modified as follows:

$$x = \int_{\tau}^{t} \left\{ K^{r} \cdot \left(\frac{Q}{\alpha}\right)^{\delta} \left(1 + \frac{2}{3}\beta\right) \right\} dt + x_{\tau} \qquad (6)$$

where, $K = I^{\frac{1}{2}}/N$, $r = 3\beta/(2+3\beta)$,
$\delta = 2/(2+3\beta)$, τ: time ($t=\tau$)
t: time, Q_{τ}, x_{τ}: discharge and location at $t = \tau$

N: equivalent roughness coefficient

here,

$$\left.\begin{array}{l} R = h \\ A = \alpha \cdot h^{\beta} \end{array}\right\}$$

α, β: constants derived from the results of survey

The equations (5) and (6) are calculated with a time interval of about 10 minutes by a computer.

As the flow in a drainage canal is often affected by backwater effect, the equations of continuity and of the momentum for nonsteady flow are used for solution.

$$\frac{1}{g}\cdot\left(\frac{\partial v}{\partial t}\right)+\frac{1}{g}\cdot\frac{\partial}{\partial x}\left(\frac{v^2}{2}\right)+i+\frac{\partial h}{\partial x}+\frac{n^2|v|v}{R^{4/3}}=0 \quad (7)$$

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}-q_x=0 \quad (8)$$

where, g: acceleration of gravity (m/sec²);
i: slope of canal;
h: depth of water (m);
R: hydraulic radius (m);
n: Manning's roughness coefficient;
A: cross-sectional area of flow (m²);
Q: discharge passes through (m³/sec);
q_x: side inflow (m³/sec) per unit width;
x: distance, and
t: time.

In this method of analysis, the equation (7) and (8) have been once transformed into equation of difference style and solved by numerical integration. The difference increment, ⊿x, expresses the length of a mesh in the model. The time increment, t, should be chosen so as to satisfy the requirements of the following formula.

$$\Delta t < \frac{\Delta x}{V_{max} \pm \sqrt{g \cdot h_{max}}} \quad (9)$$

where, V_{max} :maximum of velocity v, and
h_{max} :maximum of water depth, h.

Various types of flow from paddy fields, dry fields and mountainous parts of the basin are analyzed by combined use of models of rainfall-runoff as outlined in the paragraph above.

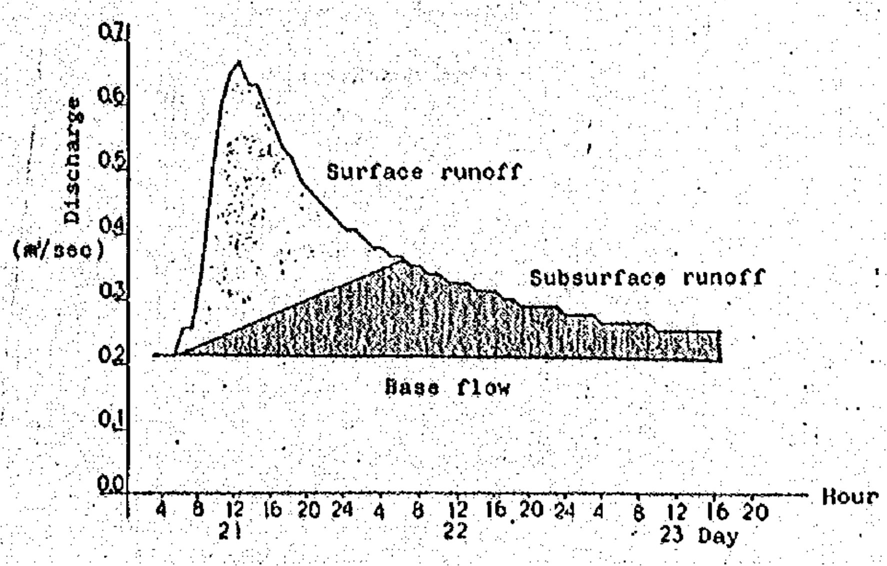


Fig.1:Separation of surface runoff, subsurface runoff and base flow

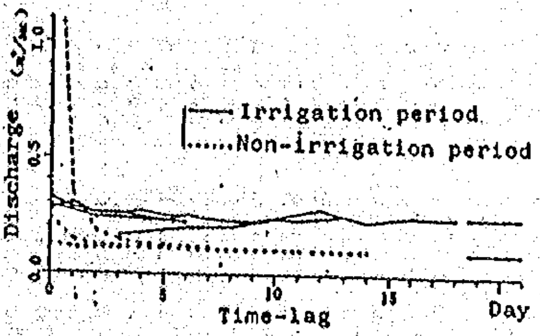


Fig.2:The curve of diminishing runoff after a rainfall (an example in the Ishikari River basin)

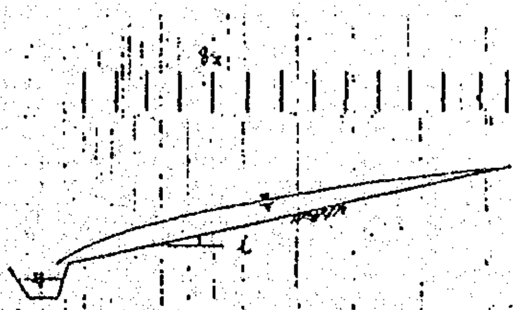


Fig.3:Uniform slope model of rainfall and runoff

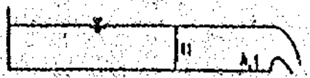


Fig.4:Notch model

Annex A-4

Table 1 Monthly rainfall at LAHAR IKAN MATI (A)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	195.3	-99.9	278.1	240.8	-99.9
1966	105.9	125.2	334.3	238.3	193.8	245.4	272.8	238.8	182.4	-99.9	-99.9	-99.9	-99.9
1967	-99.9	64.8	75.7	117.9	98.6	200.2	86.9	292.9	187.1	338.6	212.1	27.9	-99.9
1968	34.8	37.8	48.8	242.8	138.9	165.1	454.9	230.9	190.8	367.8	182.6	237.7	2332.9
1969	65.3	59.2	130.8	58.4	143.3	148.8	38.9	224.8	249.7	392.7	229.1	101.3	1842.3
1970	183.4	0.0	168.9	207.0	219.5	86.9	329.4	109.2	285.5	480.3	213.6	227.1	2510.8
1971	29.7	250.7	151.6	58.4	279.4	252.7	76.5	202.2	680.0	611.4	38.6	237.5	2868.7
1972	25.1	48.0	52.8	241.8	71.4	243.3	71.9	36.6	334.0	294.1	83.6	173.2	1675.8
1973	20.1	27.2	90.7	193.0	139.2	277.1	222.0	288.3	152.1	295.4	272.0	180.6	2157.7
1974	23.1	258.6	89.7	238.5	196.1	98.0	87.1	186.7	256.3	271.0	158.2	17.5	1880.8
1975	186.4	147.3	83.3	115.6	273.1	64.5	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	102.0	-99.9
1978	24.5	133.0	123.0	77.5	389.0	272.5	156.5	143.0	238.5	185.5	201.5	18.0	1962.5
1979	33.5	35.5	6.5	176.0	196.5	216.5	280.5	112.5	198.5	165.5	364.5	34.0	1820.0
1980	2.5	40.0	61.0	142.5	165.5	125.5	135.5	308.0	548.5	348.0	231.5	86.5	2195.0
1981	45.0	112.0	36.5	139.0	270.5	117.5	62.0	157.5	376.0	234.0	146.0	8.5	1634.5
1982	0.0	10.0	175.5	264.5	234.5	64.0	184.5	90.0	414.0	352.0	209.0	102.0	2100.0
1983	3.0	48.0	34.5	130.0	433.5	207.5	102.5	81.0	392.0	191.0	81.5	60.5	1765.0
1984	218.0	130.0	89.0	386.0	166.5	161.0	266.0	108.5	179.0	159.0	118.0	126.0	2107.0
1985	51.0	103.5	111.0	188.5	251.0	33.0	77.5	149.0	352.5	440.5	236.0	81.5	2075.0
1986	4.0	9.5	74.5	126.5	244.0	62.0	135.0	264.5	431.0	707.5	199.0	60.5	2318.0
1987	11.5	0.0	51.0	147.5	163.0	68.2	98.5	316.5	442.5	177.5	444.5	183.5	2104.2
MEAN	45.6	76.6	83.0	177.5	214.8	152.9	163.5	177.0	336.5	332.5	209.5	113.9	2079.4

Table 2 Monthly rainfall at PARIT LAGAN (B)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1966	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	79.0	72.5	72.5	215.0	183.5	110.5	61.5	167.0	461.0	109.5	175.5	7.0	1714.5
1982	0.0	26.0	78.0	113.5	87.5	13.5	78.5	41.5	141.5	163.5	164.5	35.5	943.5
1983	17.5	9.0	3.5	50.0	198.0	75.0	54.0	29.0	227.0	88.5	32.0	34.5	818.0
1984	83.0	49.0	42.0	240.5	36.0	56.0	92.5	68.0	92.0	69.0	60.0	56.5	944.5
1985	21.5	83.5	83.0	156.0	96.5	18.0	49.5	80.5	151.0	223.0	108.5	35.0	1106.0
1986	5.0	0.0	38.0	60.0	114.5	38.5	47.5	119.0	200.0	271.5	104.5	30.0	1028.5
1987	8.0	0.0	32.5	81.0	70.0	39.0	62.0	101.0	166.0	68.0	163.0	57.5	848.0
MEAN	30.6	34.3	49.9	130.9	112.3	50.1	63.6	86.6	205.5	141.9	115.4	36.6	1057.6

Table 3 Monthly rainfall at MALKOFF ESTATE (C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	73.9	150.6	119.6	103.6	454.9	139.7	88.4	237.0	136.7	316.5	467.6	18.3	2306.8
1959	24.1	124.0	83.3	188.7	331.5	310.1	108.2	225.3	210.6	367.5	204.0	181.1	2358.4
1960	97.0	0.3	73.7	206.8	162.1	188.5	229.4	154.7	256.0	161.0	230.1	220.2	1979.3
1961	108.7	163.3	363.2	345.7	228.6	202.2	212.1	151.4	143.0	434.1	333.5	223.0	2908.8
1962	121.9	5.1	68.8	170.4	173.2	205.5	256.3	235.0	222.9	603.5	190.5	152.9	2405.9
1963	125.7	41.4	204.7	12.2	154.2	144.8	101.9	186.9	234.4	370.6	604.5	163.3	2344.6
1964	100.6	73.2	67.1	205.0	350.5	89.4	252.7	158.5	604.8	430.0	425.7	90.3	2856.8
1965	9.7	98.6	246.6	216.7	135.9	40.4	159.8	388.6	296.2	473.5	316.5	405.1	2787.6
1966	141.5	111.3	256.5	252.0	246.1	149.4	382.8	219.7	247.4	307.3	182.6	114.3	2610.9
1967	162.1	47.5	55.9	282.2	191.0	181.1	98.8	212.3	224.8	325.6	344.7	56.4	2182.4
1968	44.7	11.9	105.9	326.9	118.9	151.4	371.6	385.8	341.9	318.8	206.8	293.1	2677.7
1969	140.0	61.7	112.3	89.9	127.0	165.4	99.1	285.2	208.3	404.4	225.3	112.0	2030.6
1970	171.5	0.0	90.2	195.1	196.1	79.8	335.0	108.2	265.9	535.9	231.1	232.2	2441.0
1971	39.7	129.3	185.4	131.8	200.9	212.1	71.4	276.4	763.8	555.9	138.4	225.8	2922.8
1972	52.6	141.5	96.8	297.2	59.4	119.6	62.2	33.0	498.9	453.6	265.4	147.3	2227.5
1973	26.2	25.6	103.1	241.8	211.1	171.7	236.0	189.7	144.0	338.1	361.4	177.0	2225.7
1974	14.5	92.2	42.9	222.0	214.6	78.5	136.6	120.7	272.5	197.9	165.7	24.6	1582.7
1975	185.9	151.4	142.0	146.1	196.9	148.1	225.5	187.0	230.5	353.0	248.0	234.5	2448.9
1976	0.0	12.5	138.5	136.0	242.5	134.0	107.5	155.5	425.0	377.5	221.5	152.5	2103.0
1977	38.0	148.5	0.0	126.5	335.0	174.5	50.5	242.0	380.0	447.0	152.0	138.5	2232.5
1978	68.0	45.5	131.5	58.0	283.0	509.0	192.5	245.0	281.5	327.5	250.5	14.5	2406.5
1979	36.0	15.0	54.0	255.0	172.5	150.0	451.0	78.0	377.0	234.0	322.5	28.5	2173.5
1980	0.0	112.0	109.0	98.0	143.5	74.0	120.5	331.5	630.0	354.5	404.5	114.5	2492.0
1981	23.0	96.0	79.5	234.5	154.0	109.5	68.0	194.5	327.0	133.5	96.0	4.5	1520.0
1982	0.0	17.5	118.5	129.0	306.0	55.0	123.0	85.0	322.0	326.5	334.0	107.0	1923.5
1983	37.0	48.0	38.0	62.0	381.0	219.0	138.0	81.0	444.0	181.0	92.0	112.0	1833.0
1984	183.5	147.0	92.5	518.5	66.0	62.5	216.5	149.0	99.0	151.5	159.5	186.0	2031.5
1985	53.0	140.5	155.0	204.0	190.0	78.5	94.0	178.5	249.0	248.0	134.0	51.0	1775.5
1986	5.0	0.0	74.5	59.0	156.0	56.0	70.0	203.5	347.5	319.0	212.0	65.0	1568.5
1987	0.0	0.0	61.0	78.0	196.0	124.5	117.0	214.0	260.5	165.5	286.0	167.5	1670.0
MEAN	69.2	73.7	115.7	186.4	212.6	150.8	172.5	197.1	314.8	340.4	260.2	140.7	2234.3

Table 4 Monthly rainfall at METELOGICAL STATION,BUTTERWORTH (D)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	20.8	162.1	97.8	136.1	125.0	339.6	77.7	155.2	211.8	304.8	189.2	125.7	1945.8
1960	39.1	46.7	166.4	181.9	142.2	245.1	182.1	136.7	329.9	-99.9	241.8	178.3	-99.9
1961	117.9	145.8	183.4	190.0	252.0	265.9	74.9	136.9	329.9	141.5	254.5	109.5	2202.2
1962	76.7	3.5	127.5	170.2	216.4	271.3	225.3	184.9	255.0	536.4	86.1	116.8	2270.2
1963	73.7	100.1	255.8	3.8	192.3	173.7	74.4	221.0	198.4	253.5	290.3	72.9	1910.9
1964	191.0	36.1	113.9	196.9	394.5	102.1	270.3	169.4	577.6	604.0	348.5	77.0	3086.3
1965	0.0	111.8	242.8	103.9	64.5	82.8	211.1	283.5	324.1	196.3	488.7	280.7	2390.2
1966	211.1	283.5	324.1	196.3	488.7	280.7	188.0	257.3	174.8	258.3	87.6	167.1	2917.5
1967	188.0	257.3	174.8	258.3	87.6	167.1	43.7	196.3	195.8	282.7	211.8	29.5	2092.9
1968	43.7	196.3	195.8	282.7	211.8	29.5	308.9	419.1	281.4	269.7	174.5	214.4	2627.8
1969	308.9	419.1	281.4	269.7	174.5	214.4	65.5	246.9	363.0	376.4	367.3	153.7	3240.8
1970	65.5	246.9	363.0	376.4	367.3	153.7	397.5	202.9	258.3	613.7	257.0	218.7	3520.9
1971	38.9	93.2	92.5	74.7	214.9	189.5	72.1	272.3	581.7	488.2	77.7	231.4	2427.1
1972	27.9	103.4	54.1	278.4	110.7	159.3	48.3	56.6	611.4	238.0	159.3	124.5	1971.9
1973	51.8	7.5	106.4	200.7	262.6	288.3	233.9	155.7	105.9	184.7	420.9	91.2	2109.2
1974	9.7	267.0	50.5	190.2	143.5	131.3	116.1	161.8	299.2	331.5	161.0	13.2	1875.0
1975	127.0	116.3	215.2	169.9	191.3	130.3	231.0	130.0	267.0	411.5	188.0	128.0	2305.5
1976	0.5	25.0	115.5	238.0	285.1	151.1	114.7	208.1	530.0	394.9	199.0	94.5	2356.4
1977	25.5	102.5	11.5	203.0	388.0	92.9	67.0	164.9	490.0	455.5	162.2	40.0	2207.0
1978	-99.9	35.2	30.8	109.4	184.0	253.2	186.7	275.6	218.9	463.2	138.5	13.5	-99.9
1979	34.0	87.2	82.0	377.7	90.7	136.2	341.4	103.9	237.2	262.9	317.0	38.0	2108.2
1980	20.2	86.4	189.0	127.4	116.9	57.2	125.0	319.5	602.0	273.0	173.6	126.5	2216.7
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
MEAN	81.6	142.5	164.1	202.2	218.9	170.8	164.1	202.3	345.2	343.8	230.7	122.7	2389.1

Table 5 Monthly rainfall at Sg. DUA (E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	94.5	73.7	104.6	123.4	536.4	116.6	50.0	211.6	193.8	248.4	465.1	38.4	2256.5
1959	215.7	150.0	225.3	194.3	220.5	369.1	62.2	140.5	221.0	476.8	188.2	147.3	2611.9
1960	44.2	37.6	214.9	242.1	169.9	246.1	282.7	80.5	313.9	131.1	321.1	206.0	2290.1
1961	103.4	102.4	219.5	158.2	317.8	197.1	97.0	79.2	234.4	285.8	222.3	140.5	2157.6
1962	92.5	19.1	81.8	179.1	256.3	272.3	205.0	170.7	198.9	544.3	186.4	179.6	2386.0
1963	81.0	127.5	307.3	33.5	194.8	136.1	93.0	258.1	239.8	251.2	365.5	81.0	2168.8
1964	79.0	62.7	31.8	246.6	340.1	83.8	217.4	115.1	559.1	456.9	310.6	77.7	2580.8
1965	0.5	127.5	184.9	120.7	86.6	60.7	203.7	378.5	293.1	8.0	298.5	322.3	2085.9
1966	78.7	120.9	182.4	198.1	179.1	102.9	257.6	275.6	218.9	206.2	182.4	148.8	2151.6
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	39.0	110.5	39.5	246.0	138.0	98.0	60.5	208.0	298.5	69.0	154.0	1.0	1453.0
1982	2.5	10.0	73.0	85.0	124.5	2.0	92.0	60.5	152.5	165.5	165.5	20.5	953.5
1983	12.0	1.0	14.0	60.5	122.5	87.5	57.0	27.5	220.0	86.5	49.0	11.5	749.0
1984	62.0	99.5	111.0	284.0	89.0	52.0	144.0	140.0	97.5	66.0	40.5	53.5	1239.0
1985	33.0	72.0	107.0	96.5	94.0	9.5	59.0	107.0	160.5	264.0	188.5	35.0	1226.0
1986	2.5	0.0	74.0	37.5	160.0	40.0	59.0	119.5	218.0	256.0	96.5	28.5	1082.5
1987	2.5	0.0	55.5	59.0	108.5	80.0	69.5	98.0	167.0	108.5	185.5	57.5	992.5
MEAN	59.0	69.5	126.2	147.8	196.1	172.1	125.0	154.4	236.7	226.6	213.7	96.8	1774.0

Table 6 Monthly rainfall at MAYFIELD ESTATE (F)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SFP	OCT	NOV	DEC	TOTAL
1958	102.9	64.3	84.8	134.4	274.1	115.3	42.4	225.8	160.3	198.1	438.2	57.4	1898.0
1959	3.6	198.6	129.3	169.4	263.1	237.5	59.9	126.7	167.9	344.7	157.5	217.7	2075.9
1960	100.3	2.5	166.6	279.7	159.5	159.8	265.4	121.9	166.1	166.4	205.2	177.3	1970.7
1961	148.1	105.7	254.3	233.2	163.8	144.0	154.7	93.5	186.9	259.8	282.4	314.5	2340.9
1962	314.5	3.8	146.3	185.9	219.7	185.4	223.5	183.6	199.9	504.4	122.2	123.2	2412.4
1963	164.3	48.0	126.2	16.0	277.6	80.0	98.0	114.8	167.6	320.3	523.7	92.5	2029.0
1964	152.7	74.7	26.7	266.7	354.1	131.3	235.5	101.6	622.8	272.3	251.5	132.1	2622.0
1965	21.6	31.0	141.0	156.5	80.8	17.0	98.8	361.2	324.9	373.9	339.1	322.1	2267.9
1966	126.2	91.7	149.6	251.2	144.5	85.6	264.7	212.6	200.7	370.8	221.2	280.7	2399.5
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
MEAN	126.0	68.9	136.1	188.1	215.2	128.4	160.3	171.3	244.1	312.3	282.3	190.8	2224.0

Table 7 Monthly rainfall at Sg.KULIM HEADWORK (G-H)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	140.7	136.1	115.1	180.1	455.2	160.5	48.0	284.2	240.0	151.9	476.0	39.9	2427.7
1959	5.4	173.2	198.1	216.9	310.6	230.6	67.3	135.1	197.1	332.7	261.4	185.4	2314.3
1960	65.8	57.2	193.0	186.2	160.5	175.0	283.7	99.1	225.0	135.6	285.2	206.5	2072.8
1961	76.5	120.1	179.8	221.0	131.8	186.4	208.8	105.4	189.2	321.8	229.9	173.0	2143.7
1962	74.4	14.0	147.3	123.7	219.7	285.2	171.7	167.4	144.0	527.3	168.1	143.3	2186.1
1963	91.4	68.8	253.0	10.9	135.9	135.9	141.0	416.1	198.6	329.7	461.3	100.1	2342.7
1964	38.6	139.4	25.4	277.6	384.3	81.3	242.3	84.6	654.6	342.4	338.1	74.4	2684.0
1965	9.9	28.2	192.0	251.7	133.9	54.9	125.5	326.4	325.9	226.3	370.8	320.8	2366.3
1966	70.4	80.3	178.3	182.9	159.5	82.0	316.0	206.8	182.1	277.1	182.1	256.5	2174.0
1967	253.7	22.1	115.8	254.5	277.9	173.5	36.3	152.4	163.6	374.1	387.6	29.2	2241.7
1968	21.1	29.0	171.2	286.5	101.1	110.2	231.1	374.1	111.3	289.6	260.4	292.4	2278.0
1969	208.3	21.6	179.8	32.5	219.7	87.9	99.3	142.0	174.2	351.3	271.3	179.6	1967.5
1970	269.2	17.3	80.8	308.6	214.1	92.7	304.0	164.3	373.4	768.4	249.7	189.2	3031.7
1971	42.2	204.2	127.3	204.0	136.9	205.7	67.1	260.6	369.8	514.4	120.4	257.8	2510.4
1972	53.6	77.5	71.4	336.3	57.7	79.2	63.8	31.8	370.1	344.4	239.3	199.9	1925.0
1973	44.5	27.4	148.1	207.8	360.9	209.0	139.7	177.5	153.2	293.1	373.1	209.0	2342.8
1974	10.9	83.8	39.4	250.4	224.8	61.7	150.6	102.4	325.6	305.3	201.4	72.1	1828.4
1975	125.0	161.3	202.4	180.8	184.7	90.9	226.0	150.0	222.0	298.0	226.0	172.5	2239.6
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	16.5	107.0	97.0	154.0	319.0	286.5	186.0	252.5	258.5	346.0	115.0	18.5	2156.5
1979	29.5	23.0	57.0	409.0	202.5	136.5	248.5	108.0	185.5	266.0	441.0	29.0	2135.5
1980	18.0	116.0	143.0	218.5	152.5	91.0	136.0	330.0	449.0	381.0	328.0	196.0	2559.0
1981	2.0	101.0	103.0	354.0	176.0	109.0	66.0	257.0	415.0	177.0	134.0	29.0	1923.0
1982	17.0	54.0	165.0	203.0	405.0	4.0	152.0	104.0	308.0	346.0	418.0	143.0	2319.0
1983	81.0	33.0	115.0	202.0	387.0	223.0	103.0	167.0	421.0	157.0	158.0	138.0	2185.0
1984	229.0	222.0	299.0	489.0	143.0	76.0	208.0	177.0	184.0	194.0	331.0	154.0	2706.0
1985	61.0	167.0	279.0	232.0	296.0	82.0	142.0	243.0	226.0	436.0	318.0	87.0	2569.0
1986	9.0	9.0	88.0	114.0	246.0	92.0	67.0	219.0	435.0	361.0	256.0	112.0	2008.0
1987	0.0	0.0	193.0	143.0	249.0	173.0	85.0	179.0	310.0	410.5	360.0	106.5	2209.0
MEAN	73.8	81.9	148.5	222.5	230.2	134.8	154.1	193.5	279.0	330.6	284.3	146.9	2280.2

Table 8 Monthly rainfall at BUKIT MERAH PADI STATION (I)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	15.0	131.1	133.6	217.2	177.5	223.5	110.7	180.6	200.7	418.3	114.6	113.5	2036.3
1960	24.6	63.2	150.9	225.0	94.0	218.2	219.5	125.7	258.6	157.7	393.7	211.3	2142.4
1961	179.3	73.9	184.9	127.0	90.9	173.5	182.9	83.1	198.9	385.3	367.5	159.8	2207.0
1962	67.6	34.0	137.2	89.2	169.4	303.0	159.3	216.2	125.5	520.7	181.9	227.1	2231.1
1963	58.4	46.2	190.8	11.2	137.2	154.9	80.8	239.3	209.6	282.2	412.5	79.2	1902.3
1964	51.6	59.9	58.9	235.2	403.9	89.4	274.3	96.3	582.2	367.0	284.5	84.6	2587.8
1965	2.5	38.6	155.7	173.0	113.8	91.7	144.0	347.0	246.1	269.0	238.0	350.8	2171.2
1966	105.9	152.4	118.9	113.8	117.9	71.4	311.2	318.0	133.9	132.6	69.9	159.0	1804.9
1967	191.5	36.8	90.4	92.7	190.5	123.2	37.1	133.9	147.3	386.8	267.2	34.3	1731.7
1968	21.1	40.4	128.3	173.5	80.0	200.9	238.8	247.1	175.3	310.1	116.6	231.4	1963.5
1969	102.6	86.6	85.6	51.6	244.1	170.4	37.6	227.8	155.2	321.6	284.7	71.9	1840.7
1970	224.8	1.8	55.6	211.1	227.8	81.0	311.4	174.2	270.8	664.7	158.2	194.1	2575.5
1971	79.1	50.3	74.2	112.3	54.6	149.9	67.3	264.7	404.9	389.5	50.8	165.4	1845.0
1972	19.6	77.2	33.3	389.1	78.0	51.3	30.2	35.6	376.2	213.6	156.5	194.8	1655.4
1973	36.6	24.6	119.6	230.1	216.4	221.5	141.7	127.0	85.9	260.4	380.7	129.3	1973.8
1974	2.0	20.6	37.8	192.8	142.0	69.1	112.3	54.9	201.7	337.1	162.1	42.9	1375.3
1975	156.7	140.5	173.0	148.6	61.7	95.3	78.5	152.5	222.5	328.0	240.5	161.0	1958.8
1976	0.0	42.0	200.0	104.0	200.0	45.0	112.5	66.5	357.0	257.5	160.5	93.5	1638.5
1977	22.0	60.0	9.5	243.0	189.0	69.0	58.0	214.5	444.0	446.5	100.5	147.0	2003.0
1978	23.5	30.0	71.5	125.5	329.5	231.5	174.5	239.0	227.0	373.0	36.0	12.0	1873.0
1979	26.0	38.5	55.0	337.0	103.0	154.5	203.5	161.0	185.5	279.0	318.0	54.5	1865.5
1980	9.5	145.5	124.0	155.5	197.5	76.5	66.5	369.0	570.0	270.0	196.5	103.0	2283.5
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
MEAN	64.1	63.4	108.7	170.8	164.5	139.3	143.3	185.2	262.7	332.3	213.2	137.3	1984.8

Table 9 Monthly rainfall at BUKIT MERTAJAM ESTATE (J-K)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	95.5	68.6	180.1	185.2	378.0	224.3	112.0	321.3	238.8	256.3	487.2	42.7	2590.0
1959	22.6	170.9	359.7	270.3	235.5	329.7	141.0	193.0	302.8	496.1	247.4	271.3	3040.3
1960	81.0	87.4	184.4	241.3	154.4	-99.9	313.2	165.1	279.7	251.0	245.1	217.7	-99.9
1961	134.6	267.5	435.4	284.7	140.2	280.2	245.4	48.0	176.5	499.4	302.3	285.2	3099.4
1962	132.6	33.5	165.1	326.4	357.6	232.4	258.1	122.4	237.5	870.2	254.5	152.9	3143.2
1963	155.4	125.5	172.5	69.3	277.9	114.6	233.9	159.5	194.3	388.1	521.5	315.0	2727.5
1964	165.6	107.7	83.3	291.6	393.4	74.2	434.8	157.2	624.8	368.8	254.0	91.7	3048.1
1965	7.6	41.7	248.7	219.5	145.5	50.3	188.7	314.2	284.7	584.2	349.3	380.5	2814.9
1966	118.9	117.9	267.0	278.6	136.4	175.5	238.8	206.8	248.9	566.9	459.7	365.8	3181.2
1967	230.6	146.1	49.3	355.6	419.6	241.0	207.8	188.5	254.8	555.8	447.5	66.0	3162.6
1968	47.8	52.8	136.7	349.3	172.7	199.4	215.6	299.0	92.2	437.9	186.4	169.9	2359.7
1969	99.8	135.9	143.5	109.0	347.2	241.8	114.3	317.0	146.1	596.9	318.3	164.6	2734.4
1970	155.2	5.3	183.6	301.0	319.5	117.6	180.3	99.8	349.8	593.6	570.0	323.1	3198.8
1971	59.9	180.8	150.6	92.2	156.0	189.5	109.0	320.8	468.6	414.3	177.8	451.6	2771.1
1972	60.2	202.7	98.3	530.4	145.5	172.5	134.1	63.5	304.0	380.5	463.3	270.0	2825.0
1973	67.6	74.4	342.4	470.7	437.1	210.6	236.5	286.5	180.3	534.4	434.1	258.6	3533.2
1974	79.5	171.5	97.5	333.5	292.4	103.4	135.4	108.7	281.2	198.6	295.4	69.1	2166.2
1975	199.9	196.9	302.3	443.7	217.9	56.6	259.0	149.0	286.0	255.0	297.0	313.0	2976.3
1976	2.0	42.0	181.0	285.0	196.0	125.0	197.5	153.5	340.0	467.0	398.0	71.0	2458.0
1977	75.0	124.0	49.0	157.0	254.0	183.0	87.0	332.0	372.0	623.0	201.0	131.0	2579.0
1978	42.0	92.0	114.0	219.0	307.0	164.0	114.0	203.0	234.0	339.0	99.0	25.0	1952.0
1979	34.0	31.0	69.0	351.0	93.0	235.0	171.0	301.0	328.0	311.0	590.0	65.0	2579.0
1980	35.0	119.0	113.0	207.0	240.0	170.0	179.0	432.0	476.0	360.0	450.0	253.0	3040.0
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.0	-99.9	-99.9	-99.9
MEAN	92.0	114.0	179.0	278.6	257.4	176.8	190.6	217.1	291.9	459.0	354.7	206.2	2817.3

Table 10 Monthly rainfall at BUKIT BERAPIT RESERVOIR (L)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	2.5	90.2	153.7	229.9	160.0	171.5	74.9	124.5	243.8	468.6	181.6	129.5	2030.7
1960	109.2	40.6	145.1	181.6	133.4	120.7	242.6	104.1	99.1	163.8	278.1	191.8	1811.1
1961	72.4	115.6	162.6	203.5	122.7	118.1	141.2	106.7	266.7	287.5	429.5	196.1	2222.6
1962	123.2	17.8	96.0	144.0	192.0	107.7	133.6	193.0	110.0	522.7	112.0	79.8	1831.8
1963	76.5	41.9	182.9	46.2	192.8	173.4	62.0	120.7	133.9	416.3	526.8	128.3	2051.7
1964	33.0	100.3	41.9	133.4	259.1	142.2	188.5	41.9	482.6	273.8	154.7	64.3	1915.7
1965	5.1	17.8	144.8	124.7	74.9	36.1	125.0	217.4	237.7	273.8	276.9	324.6	1858.8
1966	113.3	112.3	132.8	201.9	78.7	81.8	207.0	214.4	96.3	302.3	228.9	188.2	1957.9
1967	236.2	56.4	47.0	210.1	398.0	120.9	85.1	88.1	115.6	388.4	251.0	32.3	2029.1
1968	11.4	32.3	101.9	295.1	108.0	81.3	168.1	181.9	98.3	397.3	167.6	171.2	1814.4
1969	96.5	85.1	331.0	106.2	194.6	121.9	85.9	155.4	147.6	463.3	292.6	135.4	2215.5
1970	394.5	3.0	142.7	243.1	172.5	90.7	224.0	83.8	329.9	544.3	402.8	160.3	2791.6
1971	22.9	159.5	133.6	159.0	138.4	135.6	102.4	278.9	283.5	445.8	159.5	301.0	2320.1
1972	68.3	89.9	33.0	310.9	25.4	82.3	44.5	47.8	370.6	392.4	297.9	223.0	1986.0
1973	63.5	30.0	195.8	195.3	197.6	121.9	94.0	133.4	86.4	465.3	283.5	238.8	2105.5
1974	39.4	74.9	130.8	296.4	230.1	71.9	141.2	84.1	330.7	264.4	210.8	51.6	1926.3
1975	149.6	143.0	181.4	243.6	163.8	95.8	186.5	117.5	138.0	225.0	239.5	213.0	2096.7
1976	4.0	49.5	215.5	117.5	163.0	78.0	78.0	207.5	414.5	248.0	147.5	116.0	1839.0
1977	32.5	32.0	5.0	130.0	109.5	114.5	31.0	200.5	297.0	406.5	172.0	59.0	1589.5
1978	14.0	145.0	133.0	176.0	263.0	95.0	151.5	179.5	259.0	278.5	91.0	19.0	1809.5
1979	19.0	12.5	172.0	239.5	135.0	79.5	139.5	207.0	322.5	185.0	410.5	45.5	1967.5
1980	30.5	116.0	65.0	175.0	138.0	55.5	112.0	273.0	422.5	351.0	319.5	216.5	2274.5
1981	3.0	77.0	115.0	178.5	191.5	88.5	45.0	142.5	280.5	136.5	107.5	12.5	1378.0
1982	17.5	34.0	71.0	148.5	270.0	1.5	147.0	85.0	255.0	443.5	284.0	169.5	1926.5
1983	72.5	66.0	47.0	40.5	299.0	119.5	65.5	73.5	388.5	182.5	108.0	158.5	1621.0
1984	222.5	202.0	146.5	336.0	116.5	33.5	270.0	66.5	89.0	200.0	219.0	165.0	2066.5
1985	61.5	176.0	302.5	191.0	193.5	28.5	110.0	104.0	192.5	286.0	399.5	119.0	2164.0
1986	64.0	22.5	75.0	120.0	212.5	125.0	117.5	130.0	451.5	313.0	231.0	102.5	1964.5
1987	5.0	6.0	112.0	61.5	138.5	150.0	77.5	189.0	311.0	241.5	182.0	129.5	1693.5
MEAN	74.6	74.1	131.8	180.7	174.9	96.3	125.9	143.2	250.1	329.9	247.1	142.8	1971.4

Table 11 Monthly rainfall at PWD office KULIM (M)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1966	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
MEAN	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9

Table 1Z Monthly rainfall at BUKIT BESAR RESERVOIR (N)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	176.5	117.9	193.5	204.2	374.7	263.1	84.6	325.6	209.3	369.3	443.7	50.3	2812.7
1959	39.9	136.4	293.4	321.3	340.1	128.0	129.8	310.4	252.5	435.6	258.6	225.3	2871.3
1960	168.7	165.6	260.9	377.2	233.4	141.5	280.7	134.1	243.6	281.9	429.5	279.9	2997.0
1961	101.6	154.9	238.0	371.3	113.5	112.3	308.9	108.2	268.7	405.9	579.4	337.6	3100.3
1962	188.0	45.2	196.6	365.3	238.3	191.0	153.4	188.0	188.7	734.3	274.8	210.3	2973.9
1963	122.9	168.4	204.7	112.3	185.9	109.0	175.8	160.8	206.2	455.2	612.1	147.1	2660.4
1964	172.0	101.3	99.3	336.0	262.6	127.3	327.2	166.9	608.3	219.2	287.5	163.1	2870.7
1965	7.6	86.4	241.0	178.6	172.2	80.0	196.9	256.5	319.5	433.1	338.1	441.2	2751.1
1966	138.4	111.3	203.2	264.2	154.7	153.7	231.1	111.8	151.1	262.9	249.4	240.8	2272.6
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1982	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1983	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1984	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1985	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1986	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1987	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
MEAN	124.0	120.8	214.5	281.2	230.6	145.1	209.8	195.8	272.0	399.7	385.9	232.8	2812.2

Table 13 Monthly rainfall at PERMATANG RAWA (O)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1966	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	5.5	141.0	389.5	392.5	265.5	181.5	93.0	128.5	435.0	226.5	246.5	62.0	2567.0
1982	18.0	46.0	94.0	172.0	221.0	5.0	161.5	96.5	349.0	398.0	414.0	164.0	2139.0
1983	11.0	85.0	8.5	125.0	372.0	132.0	153.0	107.5	306.5	219.0	58.0	140.5	1718.0
1984	267.5	198.5	162.5	561.0	128.5	67.5	318.0	95.5	188.5	235.0	355.5	181.5	2759.5
1985	94.0	137.0	340.5	214.0	173.5	75.0	140.0	154.0	293.5	410.0	285.5	103.5	2420.5
1986	96.0	4.5	106.5	116.5	284.5	146.0	150.0	118.0	423.0	322.5	144.0	117.5	2029.0
1987	0.0	0.0	111.5	156.5	263.0	110.5	103.5	186.5	305.0	290.0	324.5	110.0	1961.0
MEAN	70.3	87.4	173.3	248.2	244.0	102.5	159.9	126.6	328.6	300.1	261.1	125.6	2227.7

Table 14 Monthly rainfall at KOLAMAIR CEROK TO'KUN (P)

YEAR	JAN	FER	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	95.5	68.6	180.1	185.2	378.0	224.3	112.0	321.3	238.8	256.3	487.2	42.7	2590.0
1959	34.3	89.7	204.5	289.6	208.3	227.3	105.4	201.9	332.7	510.5	179.1	161.3	2544.6
1960	130.8	77.5	185.7	271.8	128.3	146.1	254.0	90.2	144.8	186.7	376.9	226.8	2220.6
1961	69.9	134.6	223.5	278.9	138.9	187.7	191.8	117.3	295.4	379.2	381.8	202.7	2601.7
1962	134.1	45.7	200.7	213.9	204.7	168.9	213.9	174.5	201.9	605.5	207.0	109.2	2480.0
1963	147.1	73.7	212.1	78.7	212.1	135.9	78.7	118.1	154.4	408.9	517.4	195.6	2332.7
1964	26.9	176.8	75.5	179.1	345.7	203.2	252.7	70.9	612.4	309.1	176.0	32.3	2461.6
1965	0.0	45.7	125.7	95.3	85.9	58.4	122.7	362.2	260.4	507.7	479.3	411.2	2554.5
1966	104.1	212.3	172.7	213.4	73.7	110.0	236.7	367.0	73.7	242.8	311.7	160.8	2278.9
1967	205.7	80.0	66.0	339.1	547.4	122.2	118.6	140.2	118.9	482.1	370.3	20.3	2610.8
1968	8.9	50.8	183.1	339.3	200.7	123.2	187.7	247.7	158.8	458.5	173.5	208.3	2340.5
1969	87.9	120.7	304.3	119.9	281.9	179.1	74.4	223.5	88.9	495.8	267.2	132.1	2375.7
1970	303.8	15.2	134.1	335.8	169.7	86.9	212.1	125.7	306.1	566.4	353.3	187.2	2796.3
1971	45.7	147.3	114.3	120.7	191.8	161.3	100.3	355.6	350.8	407.7	166.6	347.2	2509.3
1972	59.7	97.3	23.6	325.1	11.4	143.5	55.9	67.8	405.1	447.8	369.3	308.9	2315.4
1973	72.9	48.4	235.2	272.5	326.1	162.6	89.9	165.1	90.2	593.3	386.8	287.8	2731.7
1974	80.0	117.9	167.9	331.2	243.3	107.4	119.9	50.3	350.8	205.2	183.1	72.6	2029.6
1975	211.8	172.7	158.0	243.1	154.9	113.3	210.0	137.5	168.5	256.5	256.5	223.5	2306.3
1976	15.0	37.0	230.5	108.5	159.5	83.0	165.0	249.0	318.0	344.0	174.5	100.5	1984.5
1977	95.0	79.5	24.0	114.0	131.0	137.0	31.5	214.0	345.0	459.5	230.0	123.5	1985.0
1978	55.5	138.0	173.5	190.5	127.0	80.5	115.5	176.5	159.0	317.5	125.5	42.5	1701.5
1979	21.5	85.5	152.5	420.5	183.5	94.5	117.5	177.0	305.5	145.0	365.0	48.0	2116.0
1980	7.5	89.5	135.5	157.0	168.5	81.0	139.0	318.5	407.5	278.5	267.0	177.0	2226.5
1981	18.5	98.5	95.5	219.5	217.0	121.5	103.5	124.0	323.5	204.0	124.0	17.0	1666.5
1982	27.5	25.0	64.0	120.0	283.0	2.5	143.0	79.0	256.5	338.0	374.0	170.5	1883.0
1983	86.5	51.0	62.0	80.5	326.5	89.5	56.0	94.5	377.0	197.5	129.0	132.0	1682.0
1984	229.0	274.0	181.5	292.5	136.0	55.0	257.5	85.5	170.5	211.0	245.0	211.5	2349.0
1985	100.0	186.5	352.5	235.0	146.0	45.0	140.0	109.0	216.5	309.0	444.0	164.0	2447.5
1986	61.5	15.0	92.5	186.5	243.5	181.0	167.0	126.0	437.5	277.5	226.0	120.0	2134.0
1987	0.0	10.0	89.0	84.5	183.5	84.0	110.5	182.5	312.0	287.5	283.5	120.0	1747.0
MEAN	84.6	95.5	154.1	214.7	206.9	123.9	142.8	175.7	266.0	356.3	287.7	158.6	2266.8

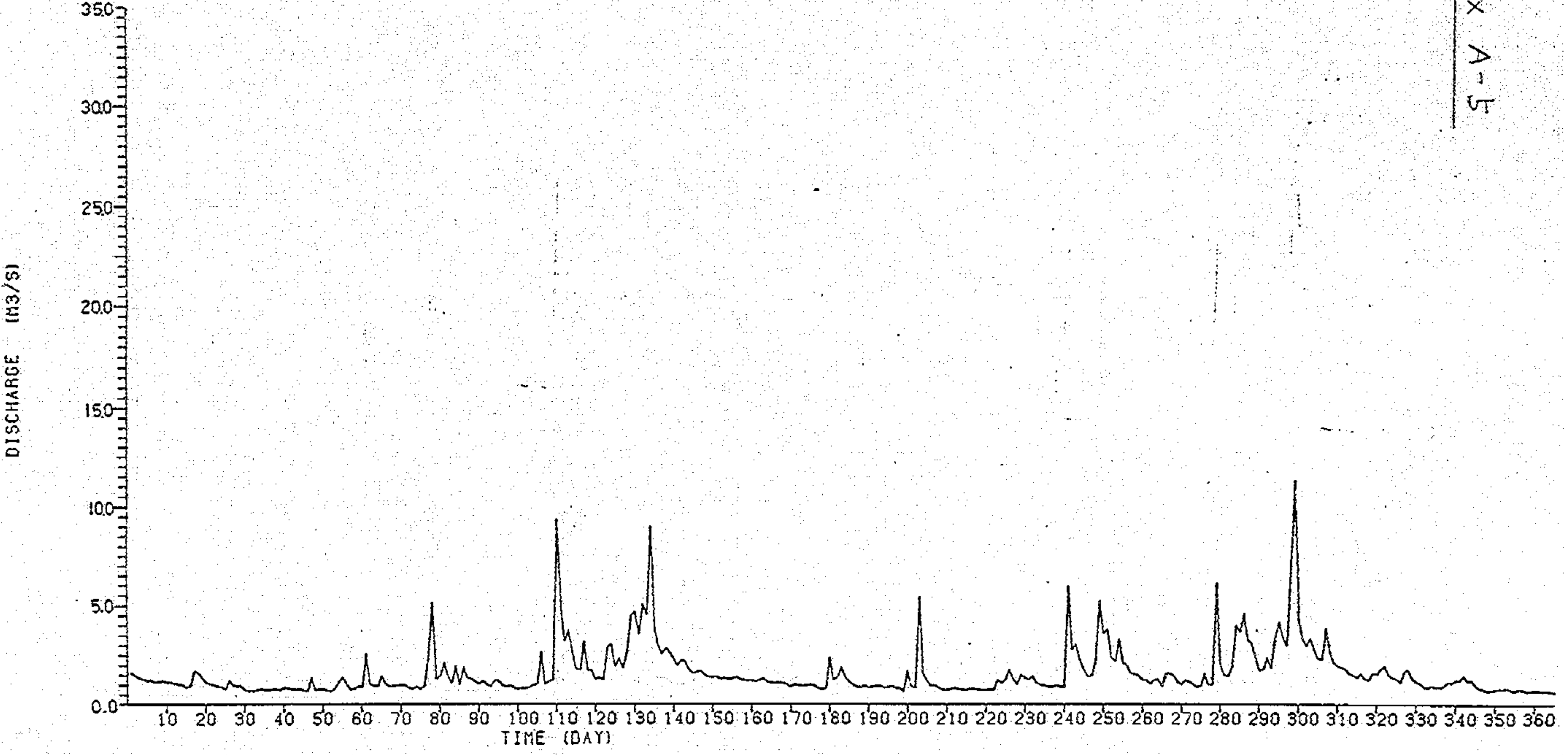
Table 15 Monthly rainfall at KOMPLEK PERAI (Q)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1966	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	67.0	96.5	134.5	245.5	167.5	142.0	98.5	137.5	298.5	79.5	115.0	14.0	1596.0
1982	0.0	14.5	97.5	165.5	213.0	15.0	118.0	196.0	210.5	290.0	260.5	104.5	1685.0
1983	29.5	51.0	7.5	81.5	178.5	81.0	199.0	138.0	305.0	334.5	66.0	126.5	1598.0
1984	215.0	158.0	118.0	414.0	182.5	86.5	167.0	69.5	200.5	186.5	133.5	131.0	2062.0
1985	73.0	102.5	269.5	112.0	200.0	49.0	60.5	94.0	293.0	371.0	170.0	98.0	1892.5
1986	72.0	18.0	75.0	70.0	238.0	136.5	148.0	128.0	363.0	332.0	147.0	85.0	1812.5
1987	18.0	0.0	89.0	155.0	251.0	76.0	136.5	143.0	312.5	357.0	342.5	108.0	1988.5
MEAN	67.8	62.9	113.0	177.6	204.4	83.7	132.5	129.4	283.3	278.6	176.4	95.3	1804.9

Table 16 Monthly rainfall at RUMAH PAM JARAK (R)

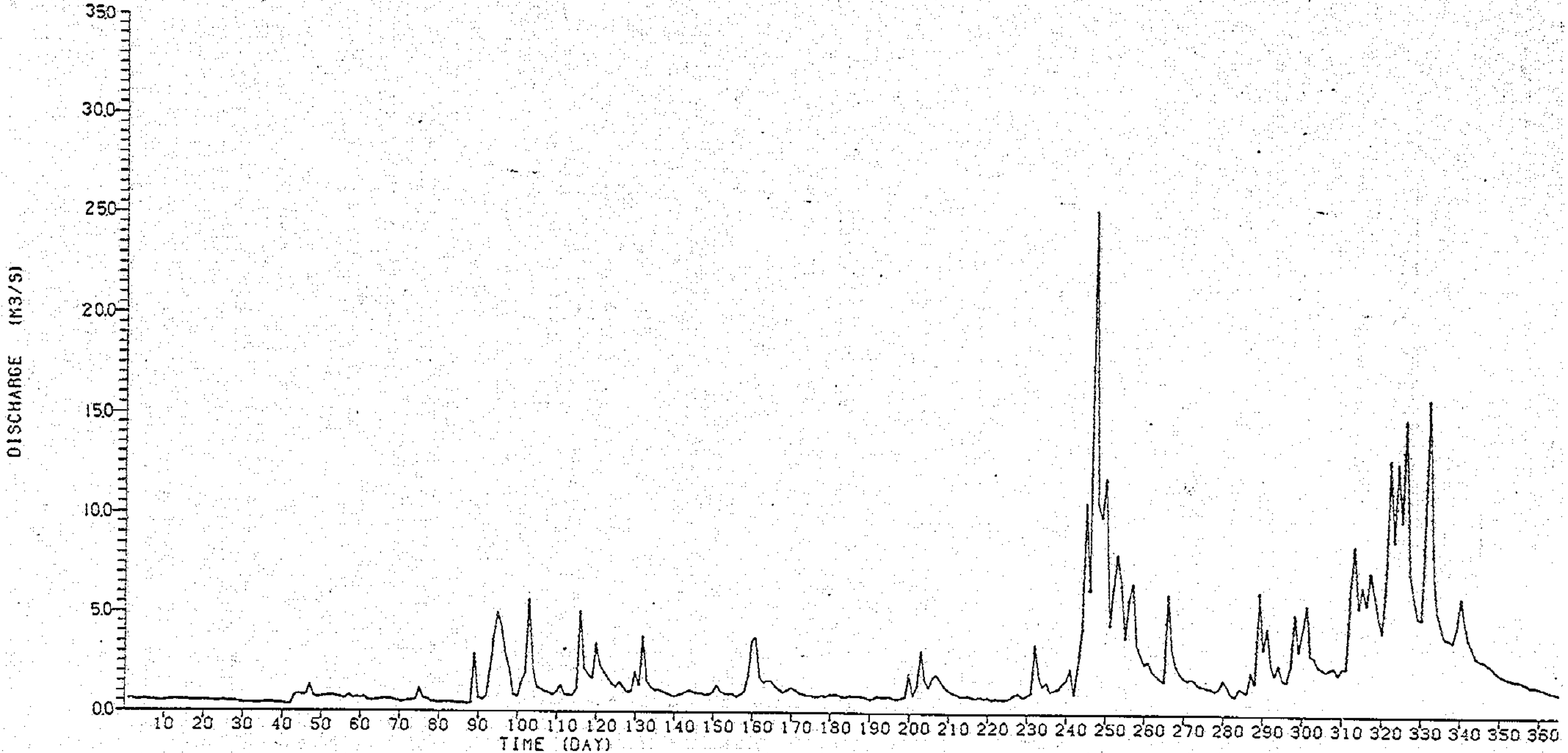
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1958	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1959	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1960	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1961	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1962	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1963	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1964	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1965	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1966	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1967	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1968	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1969	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1970	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1971	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1972	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1973	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1974	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1975	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1976	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1977	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1978	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1979	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1980	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9
1981	2.5	80.0	119.5	275.5	197.5	90.0	57.0	261.5	332.5	188.0	107.0	22.5	1728.5
1982	2.5	30.5	92.5	181.0	325.0	8.5	146.0	126.0	312.0	417.5	506.0	141.5	2289.0
1983	58.5	17.0	99.5	168.0	297.5	225.5	107.0	141.5	395.5	147.0	200.5	128.0	1985.5
1984	224.5	201.5	275.5	499.0	124.5	71.0	228.5	189.0	196.0	161.0	226.5	228.0	2625.0
1985	57.5	173.0	284.5	282.0	280.5	96.5	122.0	230.0	254.0	414.0	369.0	101.0	2664.0
1986	14.5	19.5	135.5	59.0	217.5	122.5	60.0	238.0	441.0	485.0	228.5	127.5	2148.5
1987	1.5	0.0	124.0	188.5	265.0	145.5	100.0	185.5	379.5	384.0	333.5	141.0	2248.0
MEAN	51.6	74.5	161.6	236.1	243.9	108.5	117.2	195.9	330.1	313.8	280.9	127.1	2241.2

Annex A-5

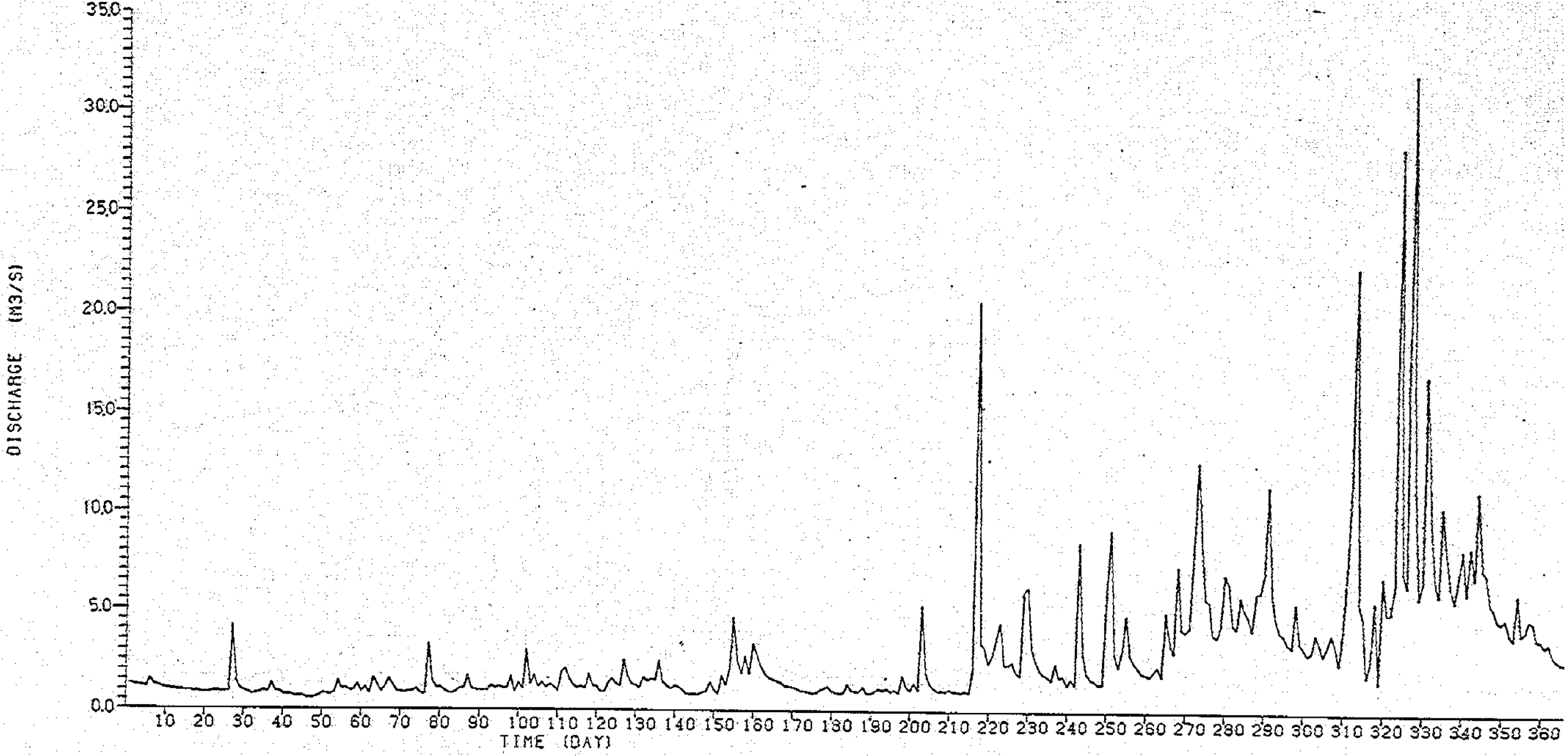


CHANGES OF DISCHARGE (1978)

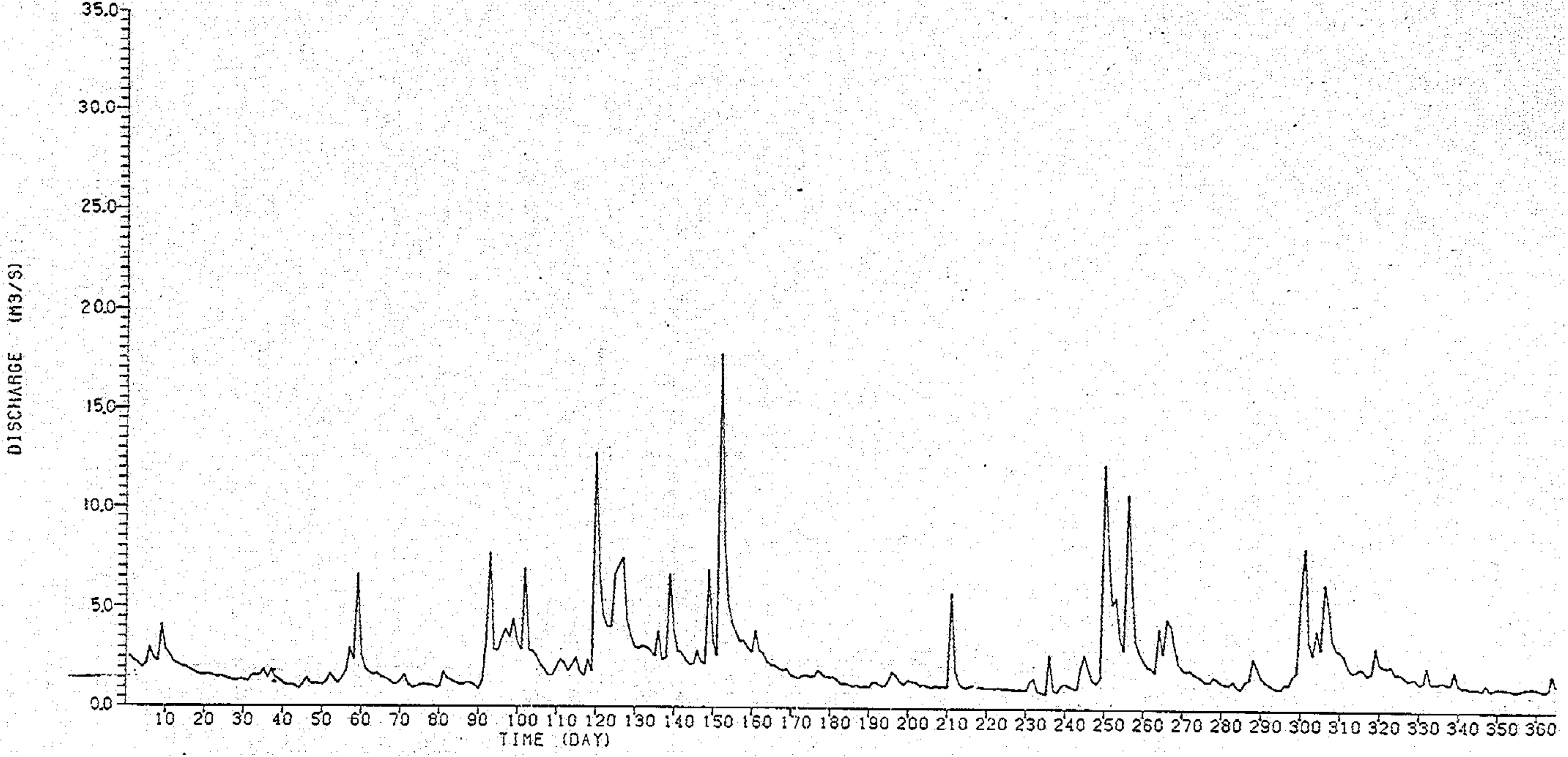
A-50



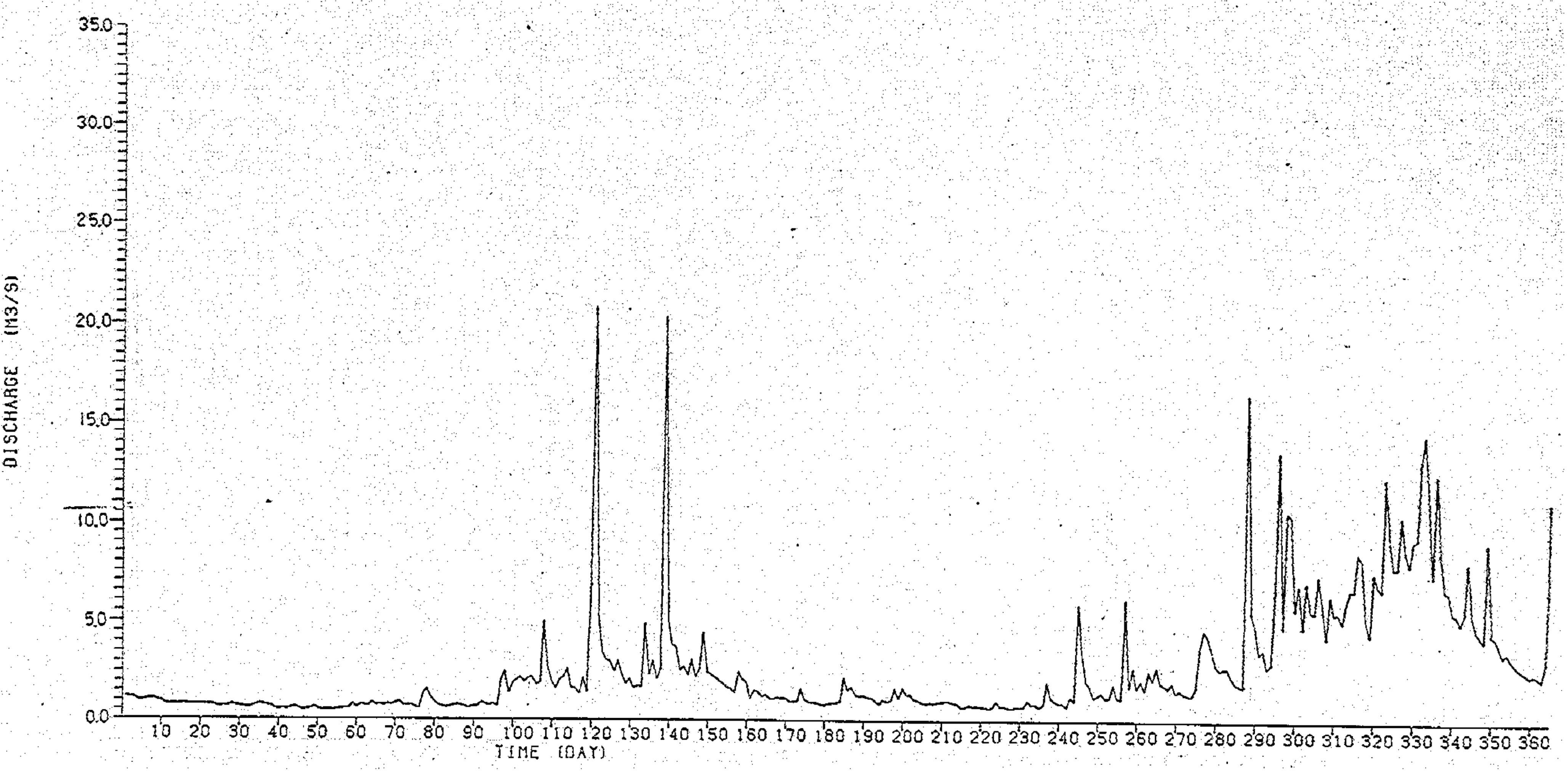
CHANGES OF DISCHARGE (1979)



CHANGES OF DISCHARGE (1980)



CHANGES OF DISCHARGE (1981)



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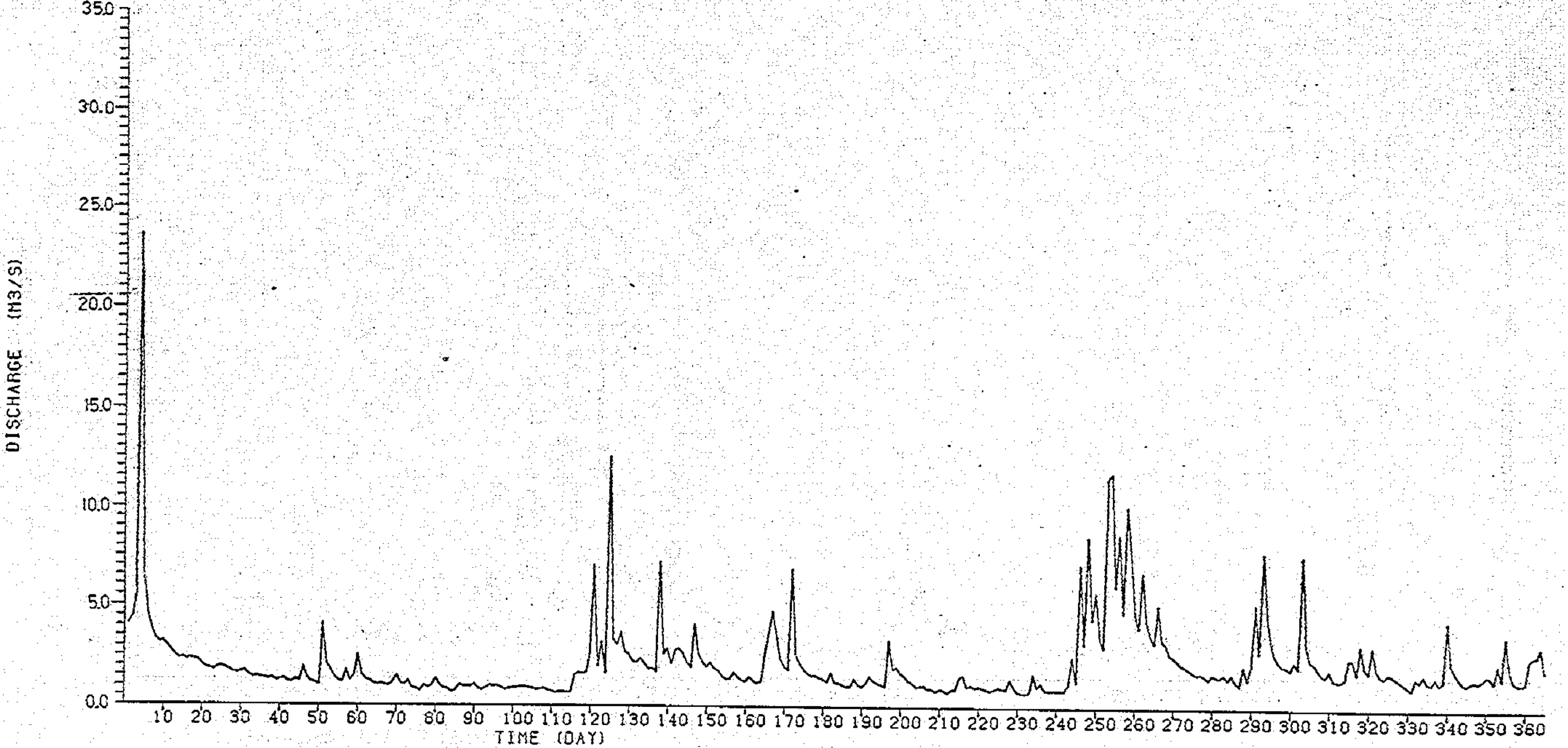

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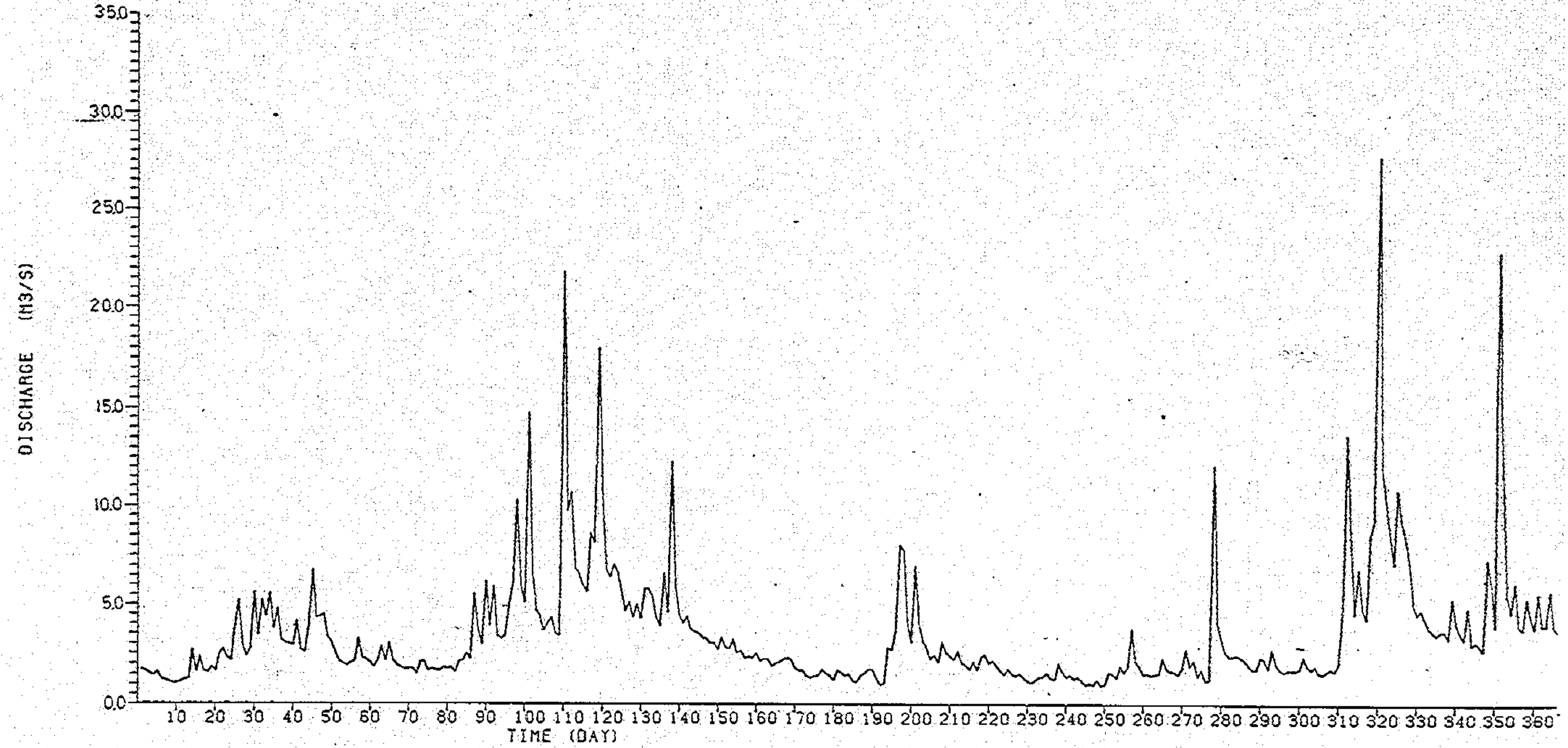

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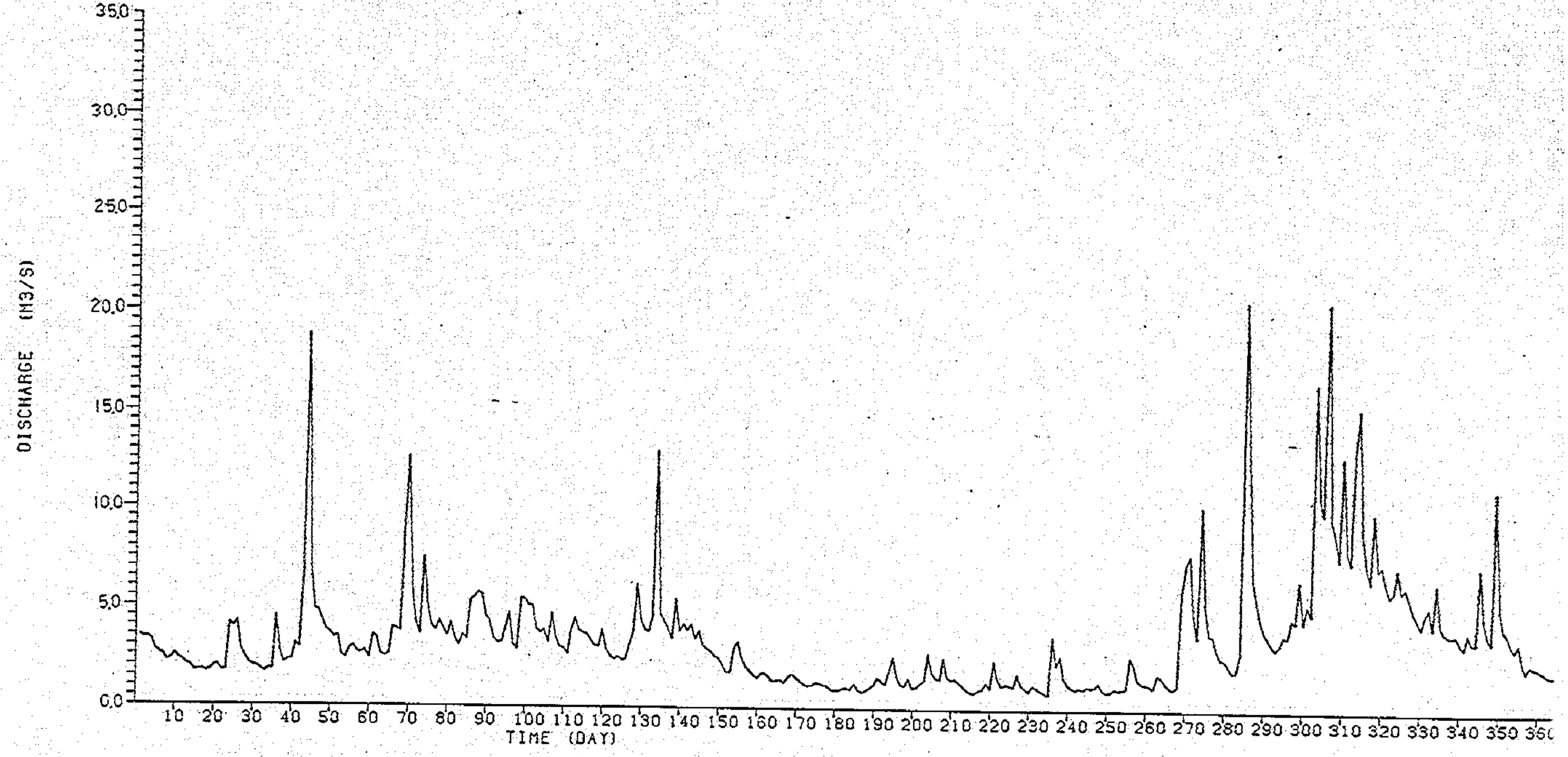

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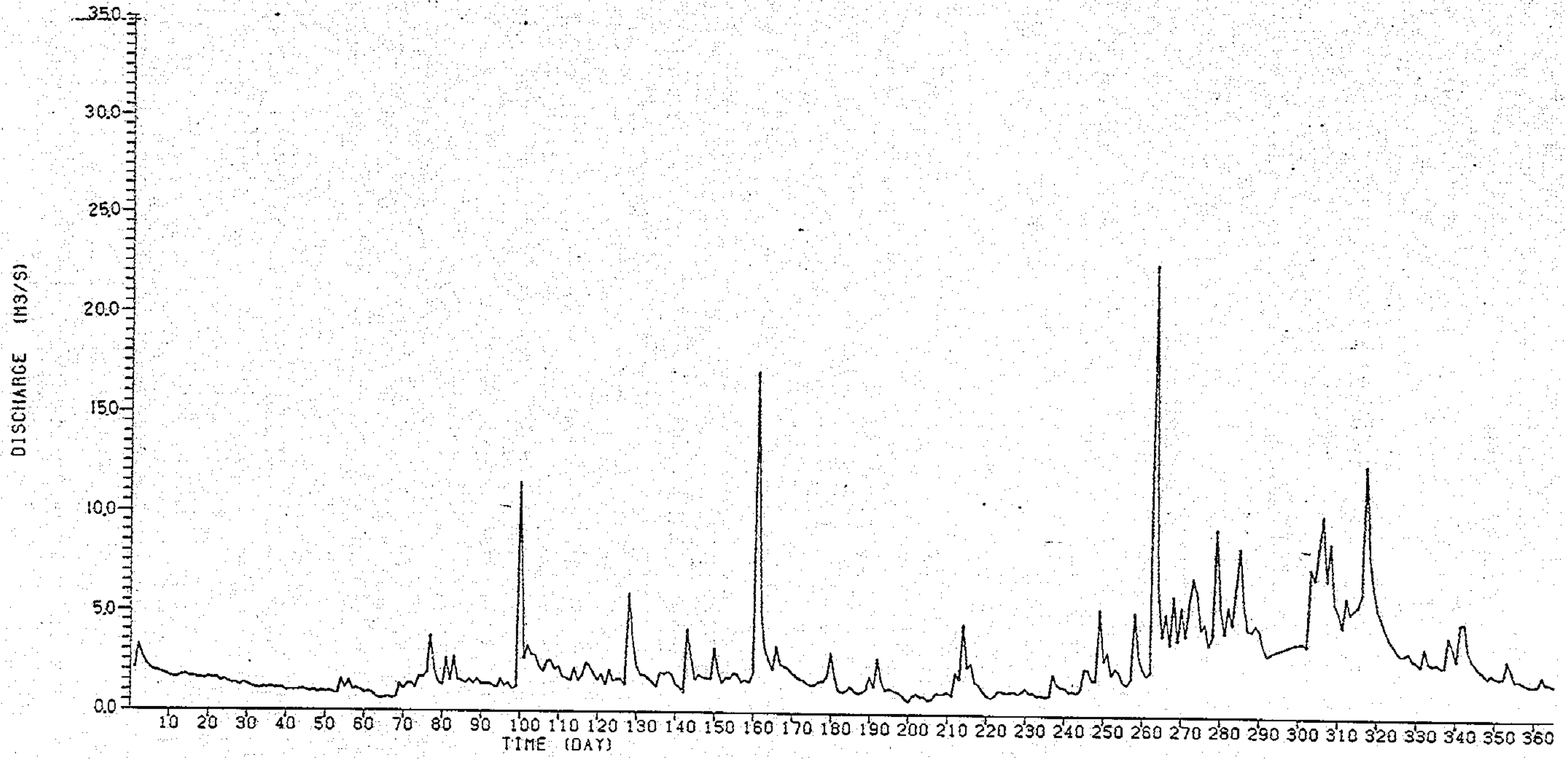
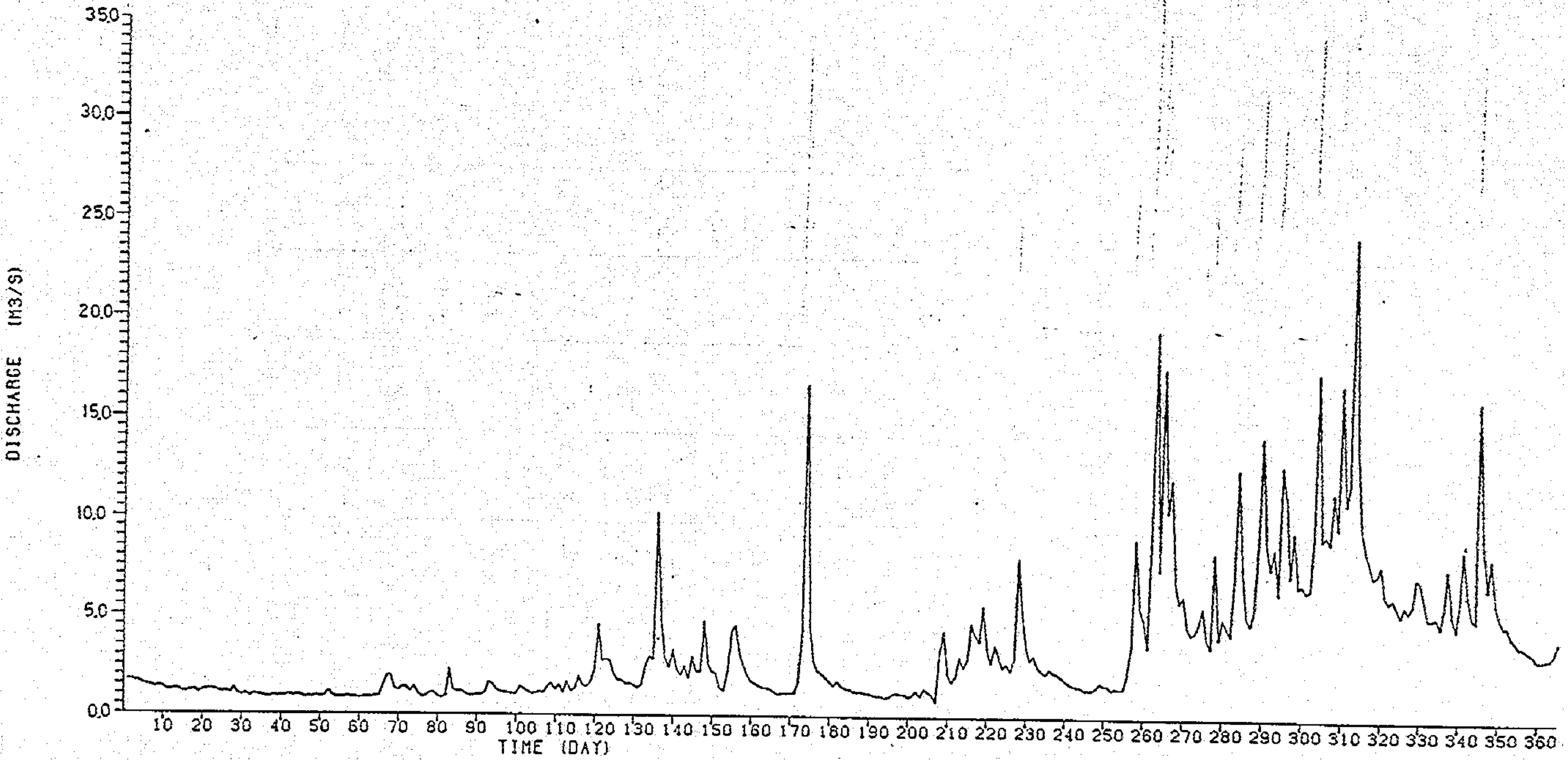


CHANGES OF DISCHARGE (1986)



CHANGES OF DISCHARGE (1987)

Annex A-6

$$R_{(i)} = \frac{R_L(i) + R_P(i) + R_R(i) + R_{G\cdot H}(i)}{4}$$

R_m , m : mark of rainfall gauging station

Table 1 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1981. 4. 22	7.5	13.0	0.0	0.0	—
23	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	3.0	0.0
25	0.0	7.5	0.0	6.0	2.625
26	0.0	0.0	6.5	1.0	1.5
27	5.0	5.0	9.5	21.0	4.375
28	5.0	7.5	0.0	0.0	43.0
29	0.0	0.0	72.5	129.0	0.0
30	20.0	15.0	4.0	1.0	59.125
5. 1	20.0	0.0	9.5	8.0	6.25
2	15.0	2.5	0.0	2.0	8.75
3	0.0	2.5	49.5	20.0	1.125

Table 2 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1981. 5. 26	20.0	20.0	0.0	0.0	–
27	0.0	0.0	0.0	28.0	0.0
28	0.0	0.0	45.5	0.0	7.0
29	25.5	65.5	0.0	2.0	34.125
30	2.5	2.5	2.5	3.0	1.75
31	2.5	2.5	17.0	19.0	2.625
6. 1	10.0	42.5	1.5	5.0	22.125
2	25.5	7.5	0.0	0.0	39.5
3	0.0	0.0	0.0	0.0	0.0
4	20.0	15.0	0.0	0.0	8.75
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0

Table 3 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1981. 8. 13	0.0	0.0	0.0	0.0	–
14	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	53.5	42.0	0.0
18	0.0	0.0	62.5	81.0	23.875
19	25.5	30.5	59.0	29.0	49.875
20	7.5	5.0	0.0	0.0	25.125
21	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	1.0	0.0
23	0.0	0.0	0.0	77.0	0.25
24	51.0	40.5	69.0	0.0	42.125

Table 4 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1981. 9. 1	2.5	0.0	6.0	15.0	–
2	10.5	13.0	3.0	2.0	11.125
3	0.0	0.0	19.5	15.0	1.25
4	0.0	2.5	0.0	0.0	9.25
5	0.0	0.0	2.5	2.0	0.0
6	0.0	0.0	104.0	158.0	1.125
7	71.0	70.5	2.5	2.0	100.875
8	17.5	30.5	26.0	28.0	13.125
9	1.5	0.0	3.0	7.0	13.875
10	25.0	30.5	25.0	28.0	16.375
11	20.0	35.0	4.5	4.0	27.0
12	5.0	7.5	35.0	48.0	5.25

Table 5 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1982. 4. 28	0.0	0.0	0.0	0.0	–
29	0.0	0.0	24.5	24.0	0.0
30	22.5	12.5	62.5	74.0	20.875
5. 1	53.5	25.5	4.5	7.0	53.875
2	22.5	7.5	1.5	3.0	10.375
3	0.0	5.0	0.0	0.0	2.375
4	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	8.0	0.0
6	0.0	0.0	0.0	3.0	2.0
7	17.5	12.5	0.0	0.0	8.25
8	0.0	0.0	10.0	31.0	0.0
9	20.0	35.5	2.5	6.0	24.125

Table 6 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_B(i)$	$R_{G-H}(i)$	R
1982.8.26	0.0	0.0	0.0	0.0	-
27	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	4.0	5.0	0.0
29	2.5	2.5	1.5	2.0	3.5
30	5.0	5.0	7.5	5.0	3.375
31	2.5	3.5	19.0	18.0	4.625
9. 1	2.5	0.0	103.5	110.0	9.875
2	35.0	37.5	41.5	42.0	71.5
3	12.5	8.5	14.0	5.0	26.125
4	5.0	6.5	3.0	4.0	7.625
5	2.5	0.0	0.0	0.0	2.375
6	0.0	0.0	3.0	3.0	0.0

Table 7 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_B(i)$	$R_{G-H}(i)$	R
1982.11.16	25.0	12.5	44.0	38.0	-
17	15.0	12.5	1.0	12.0	27.375
18	2.5	7.5	14.0	11.0	5.75
19	0.0	0.0	17.0	10.0	6.25
20	15.0	10.0	6.0	7.0	13.0
21	15.0	15.0	18.5	2.0	10.75
22	10.0	2.5	27.5	40.0	8.25
23	20.0	50.0	108.0	83.0	34.375
24	10.0	7.5	0.0	0.0	52.125
25	5.0	0.0	8.0	11.0	1.25
26	0.0	1.5	6.0	8.0	5.125
27	36.5	43.5	5.5	15.0	23.5

Table 8 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1982.12.31.	35.0	25.0	0.0	0.0	–
1983. 1. 1	0.0	0.0	17.0	35.0	0.0
2	10.0	11.5	0.0	0.0	18.375
3	5.0	7.5	41.5	42.0	3.125
4	0.0	0.0	0.0	0.0	20.875
5	57.5	67.5	0.0	0.0	31.25
6	0.0	0.0	0.0	4.0	0.0
7	0.0	0.0	0.0	0.0	1.0
8	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0

Table 9 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1983. 9. 1	22.5	25.0	0.0	0.0	–
2	0.0	0.0	39.5	50.0	0.0
3	20.0	22.0	22.0	20.0	32.875
4	5.0	7.5	5.0	5.0	13.625
5	60.0	33.5	10.0	15.0	25.875
6	26.5	10.0	0.0	20.0	15.375
7	12.5	12.5	10.0	2.0	11.25
8	4.0	4.0	2.0	8.0	5.0
9	2.5	2.5	129.0	104.0	3.75
10	70.0	57.5	0.0	0.0	90.0
11	0.0	0.0	3.0	5.0	0.0
12	7.5	12.5	12.0	12.0	7.0

Table 10 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_B(i)$	$R_{G\text{-}H}(i)$	R
1983.10.14	0.0	0.0	9.0	0.0	–
15	7.5	7.5	1.0	7.0	6.0
16	0.0	0.0	15.5	0.0	2.0
17	25.0	20.0	44.5	23.0	15.125
18	39.0	45.0	0.0	45.0	37.875
19	0.0	0.0	17.0	0.0	11.25
20	38.5	37.0	1.5	18.0	23.125
21	5.0	11.5	5.5	3.0	9.0
22	3.5	5.0	0.0	5.0	4.25
23	0.0	0.0	0.0	0.0	1.25
24	0.0	0.0	0.0	0.0	0.0
25	0.0	1.5	2.5	0.0	0.375

Table 11 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_B(i)$	$R_{G\text{-}H}(i)$	R
1984.4.1	10.0	12.5	0.0	0.0	–
2	0.0	0.0	4.0	3.0	0.0
3	0.0	0.0	0.0	2.0	1.75
4	0.0	1.5	0.0	3.0	0.875
5	1.0	6.0	0.0	3.0	2.5
6	0.0	0.0	2.5	2.0	0.75
7	5.0	2.5	12.0	15.0	3.0
8	0.0	0.0	100.0	108.0	6.75
9	35.0	35.0	33.0	45.0	19.5
10	36.5	41.0	0.0	0.0	38.875
11	0.0	0.0	0.0	0.0	0.0
12	2.5	4.0	0.0	0.0	1.625

Table 12 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1984. 4.13	0.0	0.0	0.0	0.0	–
14	0.0	0.0	14.0	23.0	0.0
15	25.0	6.0	0.0	1.0	17.0
16	0.0	0.0	1.0	2.0	0.25
17	0.0	1.5	31.5	24.0	1.125
18	0.0	0.0	135.0	106.0	13.875
19	50.0	70.0	20.0	21.0	90.25
20	45.0	50.0	24.0	36.0	34.0
21	47.0	1.0	0.0	0.0	27.0
22	0.0	0.0	3.5	4.0	0.0
23	2.5	0.0	2.5	12.0	2.5
24	1.0	3.0	0.0	0.0	4.625

Table 13 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1984. 4. 25	0.0	0.0	0.0	3.0	–
26	19.0	11.0	0.0	0.0	8.25
27	1.5	2.5	95.0	54.0	1.0
28	30.0	17.5	21.0	22.0	49.125
29	25.0	27.5	0.0	0.0	23.875
30	0.0	0.0	0.0	0.0	0.0
5. 1	0.0	0.0	0.0	2.0	0.0
2	5.0	1.0	15.0	29.0	2.0
3	0.0	0.0	2.0	4.0	11.0
4	1.5	1.5	0.0	0.0	2.25
5	0.0	0.0	17.5	20.0	0.0
6	10.0	11.0	0.0	0.0	14.625

Table 14 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_P(i)$	$R_{G-H}(i)$	R
1984. 11. 12	7.5	6.5	0.0	2.0	–
13	5.0	17.5	0.0	0.0	6.125
14	0.0	7.5	31.0	40.0	1.875
15	27.5	30.0	2.0	3.0	32.125
16	2.5	16.0	2.0	5.0	5.875
17	0.0	0.0	46.5	74.0	1.75
18	25.0	16.0	7.0	6.0	40.375
19	1.0	1.5	21.5	27.0	3.875
20	2.5	5.0	4.0	5.0	14.0
21	2.5	0.0	18.5	12.0	2.875
22	6.5	2.5	7.5	21.0	9.875
23	0.0	0.0	0.0	0.0	7.125

Table 15 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_P(i)$	$R_{G-H}(i)$	R
1985. 2. 7	0.0	1.5	0.0	0.0	–
8	0.0	2.5	0.0	4.0	0.625
9	2.5	2.5	0.0	0.0	2.25
10	0.0	0.0	12.5	7.0	0.0
11	10.0	15.0	60.5	51.0	44.5
12	33.5	25.0	17.0	23.0	42.5
13	67.5	57.5	14.0	4.0	41.25
14	1.0	0.0	0.0	0.0	4.75
15	0.0	0.0	0.0	4.0	0.0
16	2.5	22.5	6.5	2.0	7.25
17	25.0	16.0	0.0	0.0	12.375
18	0.0	0.0	0.0	0.0	0.0

Table 16 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1985. 3. 4	2.5	2.5	0.0	0.0	—
5	0.0	0.0	4.5	6.0	0.0
6	5.0	6.5	23.5	27.0	5.5
7	2.5	1.0	49.0	29.0	13.5
8	12.5	15.0	0.0	4.0	26.375
9	0.0	0.0	2.5	3.0	1.0
10	2.5	2.5	56.5	60.0	2.625
11	75.0	57.5	21.0	18.0	62.25
12	21.5	22.5	0.0	0.0	20.75
13	0.0	0.0	10.0	13.0	0.0
14	6.0	11.0	13.5	0.0	18.0
15	56.5	75.0	6.5	10.0	36.25

Table 17 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1985. 7. 19	15.0	0.0	0.0	0.0	—
20	1.0	1.0	0.0	0.0	0.5
21	0.0	1.5	0.0	0.0	0.375
22	0.0	1.5	40.0	44.0	0.375
23	0.0	65.0	10.5	7.0	37.25
24	2.5	6.0	5.0	0.0	6.5
25	0.0	0.0	0.0	5.0	1.25
26	27.5	0.0	33.0	34.0	8.125
27	10.0	2.5	2.0	4.0	19.875
28	7.5	0.0	0.0	0.0	3.375
29	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0

Table 18 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1985.10.5	10.0	10.0	0.0	0.0	-
6	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	40.0	23.0	0.0
8	1.0	1.0	0.0	0.0	16.25
9	0.0	0.0	4.0	5.0	0.0
10	2.5	2.5	32.5	45.0	3.5
11	20.0	19.0	139.0	146.0	29.125
12	122.5	100.0	58.0	52.0	126.875
13	25.0	45.0	10.0	5.0	45.0
14	6.0	7.5	0.0	0.0	7.125
15	0.0	0.0	8.5	13.0	0.0
16	0.0	0.0	0.0	0.0	5.375

Table 19 Changes of daily rainfall

date	$R_L(i)$	$R_p(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1985.10.26	7.5	10.0	0.0	0.0	-
27	0.0	0.0	0.0	3.0	0.0
28	17.5	27.5	0.0	2.0	12.0
29	1.0	1.0	28.5	24.0	1.0
30	25.0	19.0	37.0	45.0	24.125
31	9.0	6.5	3.0	7.0	24.375
11. 1	30.0	20.0	44.0	42.0	15.0
2	87.0	75.0	55.0	28.0	62.0
3	5.0	7.0	0.0	3.0	23.75
4	4.0	6.5	4.5	5.0	3.375
5	3.5	6.5	33.5	46.0	4.875
6	22.5	11.0	4.0	3.0	28.25

Table 20 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1985.11.25	0.0	1.0	0.0	0.0	–
26	0.0	0.0	0.0	0.0	0.0
27	0.0	2.5	3.0	3.0	0.625
28	16.5	2.5	1.0	2.0	6.25
29	0.0	0.0	29.5	21.0	0.75
30	27.5	25.0	0.0	3.0	25.75
12. 1	20.0	20.0	0.0	0.0	10.75
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	4.0	9.0	0.0	0.0	3.25
5	0.0	0.0	0.0	0.0	0.0
6	1.0	1.5	0.0	3.0	0.625

Table 21 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G-H}(i)$	R
1986. 7. 29	6.0	12.5	0.0	0.0	–
30	0.0	1.5	6.0	14.0	0.375
31	18.5	30.0	13.5	25.0	17.125
8. 1	7.5	5.0	103.5	89.0	12.75
2	45.0	37.5	6.5	13.0	68.75
3.	7.5	9.0	11.5	12.0	9.0
4.	10.0	15.0	0.0	0.0	12.125
5	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	10.0	0.0	0.0
9	0.0	0.0	11.5	0.0	2.5

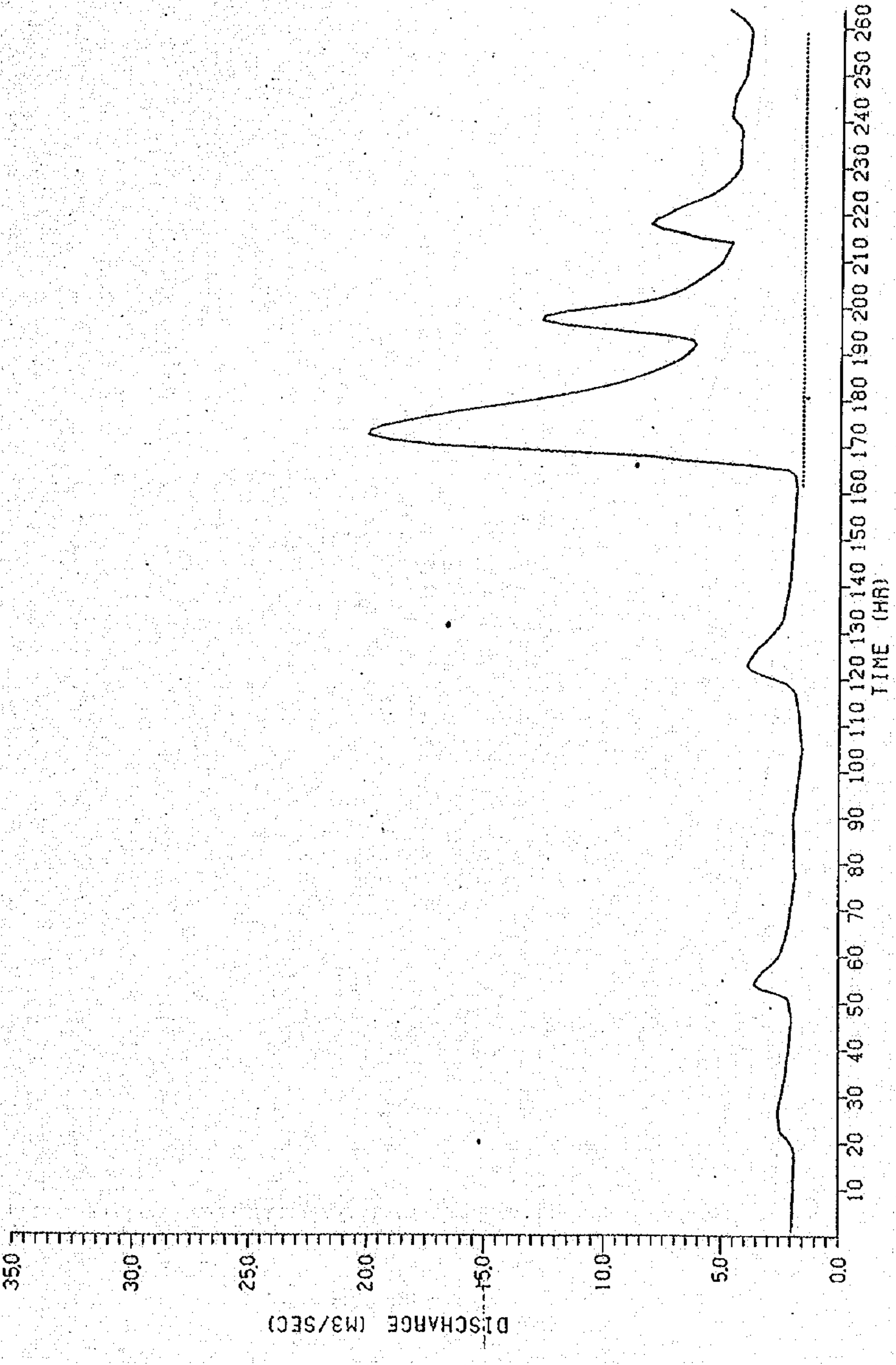
Table 22 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1986. 9. 15	87.5	62.5	16.0	5.0	–
16	2.5	4.0	4.0	5.0	6.875
17	2.5	5.0	12.5	4.0	4.125
18	2.5	5.0	24.0	8.0	6.0
19	6.5	11.5	136.0	143.0	12.5
20	65.0	60.0	29.0	20.0	101.0
21	75.0	30.0	0.0	3.0	38.5
22	4.0	10.0	6.0	8.0	4.25
23	10.0	5.0	0.0	0.0	7.25
24	2.5	5.0	16.0	23.0	1.875
25	17.5	21.0	0.0	0.0	19.375
26	1.0	1.5	9.0	12.0	0.625

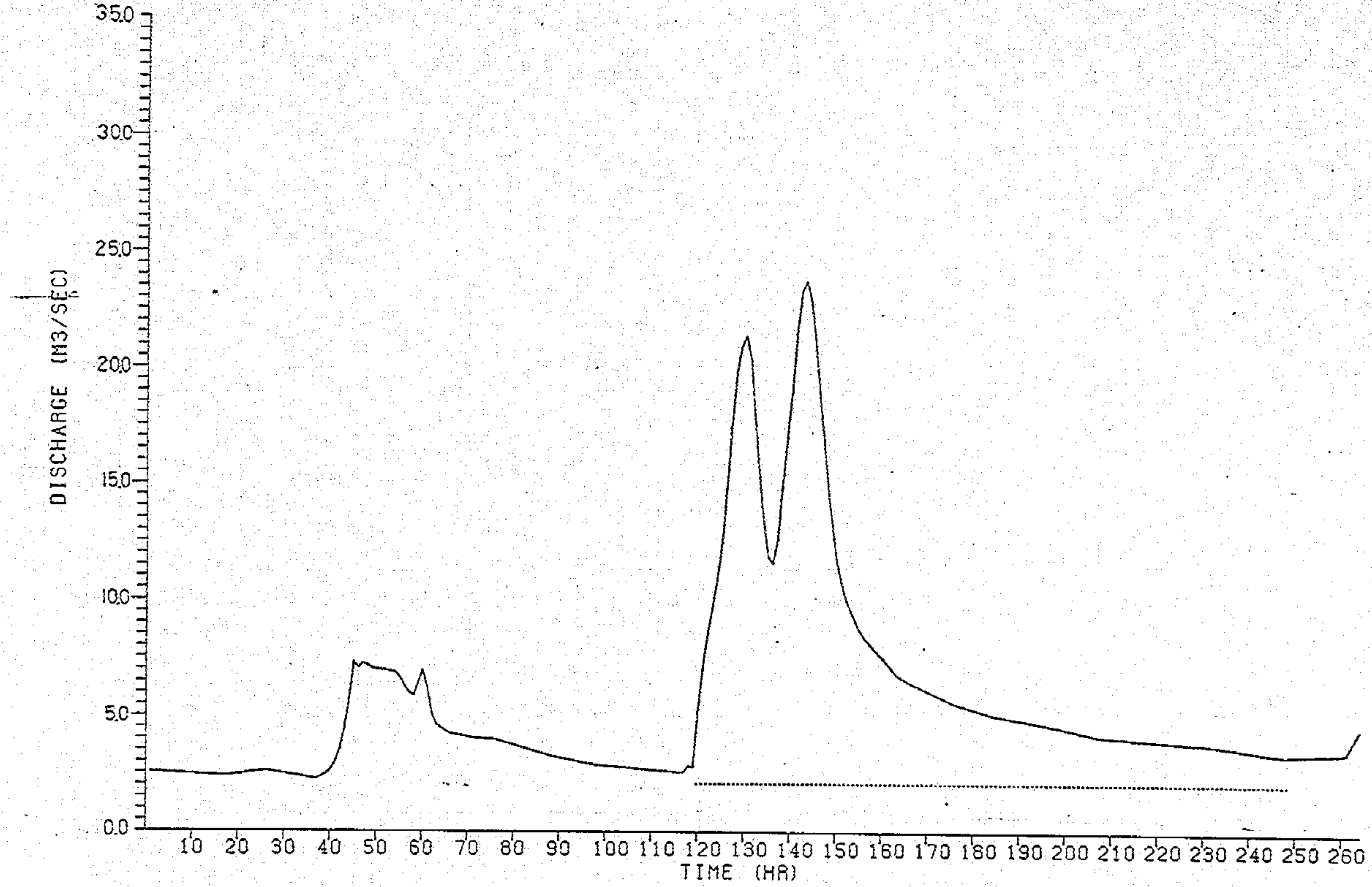
Table 23 Changes of daily rainfall

date	$R_L(i)$	$R_P(i)$	$R_R(i)$	$R_{G\text{-}H}(i)$	R
1986. 10. 1	17.5	25.0	0.0	0.0	–
2	0.0	0.0	6.5	2.0	0.0
3	7.5	5.0	5.0	7.0	5.25
4	5.0	5.0	0.0	2.0	5.5
5	2.5	12.5	111.0	81.0	4.25
6	50.0	30.0	0.0	0.0	68.0
7	0.0	3.5	0.0	0.0	0.875
8	0.0	0.0	15.5	19.0	0.0
9	7.5	1.5	16.0	12.0	10.875
10	2.5	5.0	42.0	31.0	8.875
11	35.5	30.0	28.0	25.0	34.625
12	25.0	30.0	0.0	0.0	27.0

Annex A-7



CHANGE OF DISCHARGE (1981. 4.23 -)



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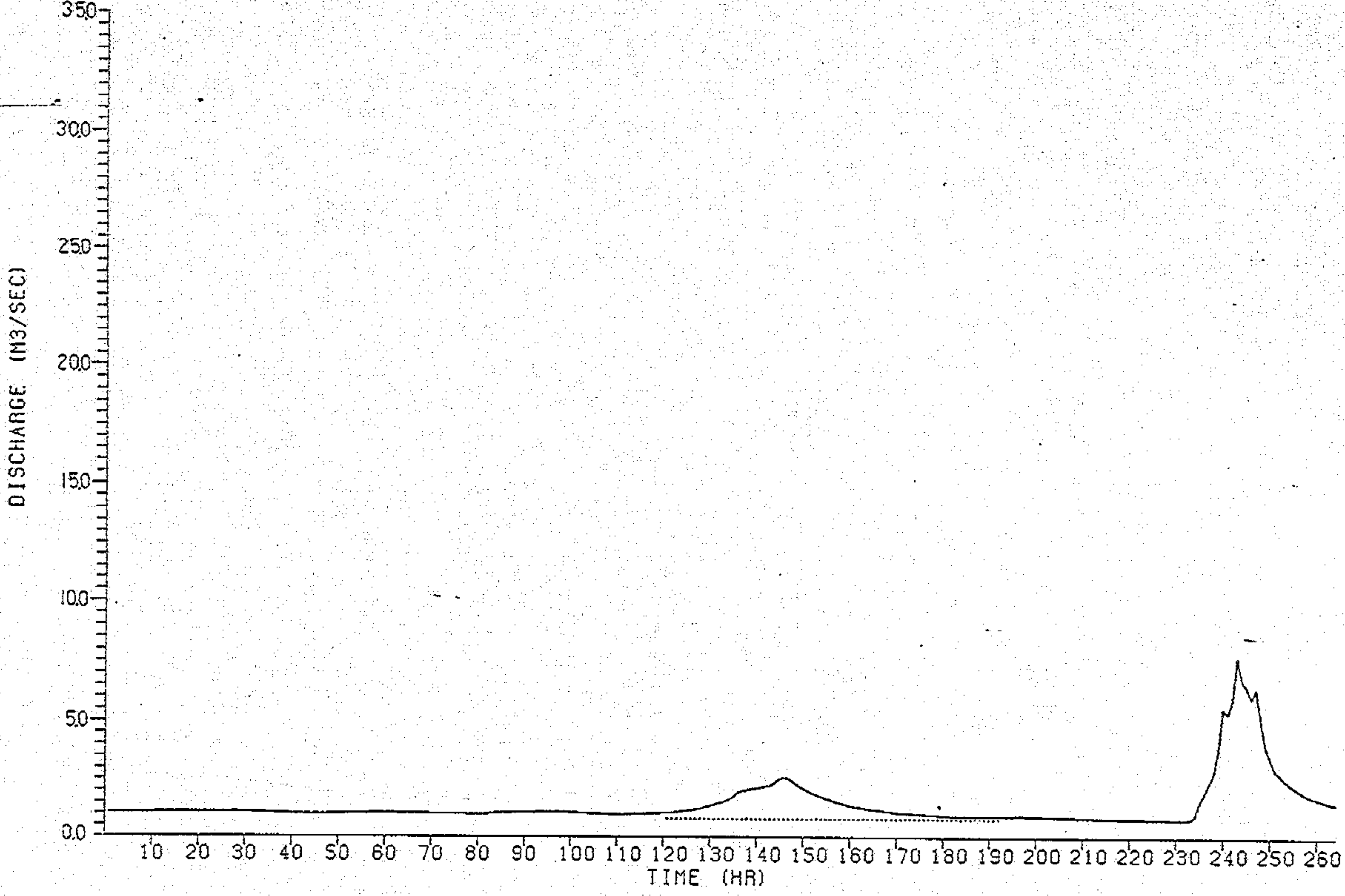

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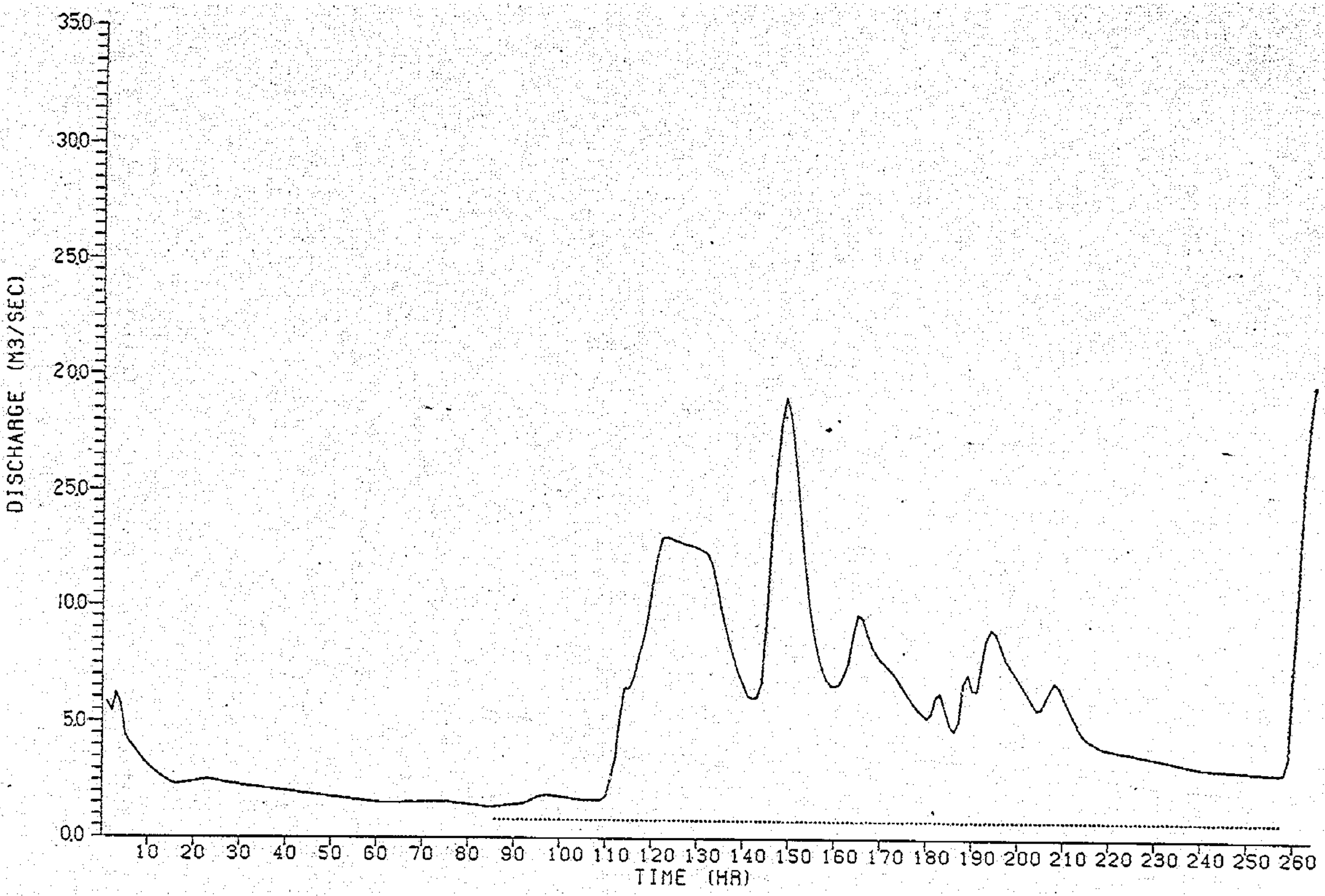
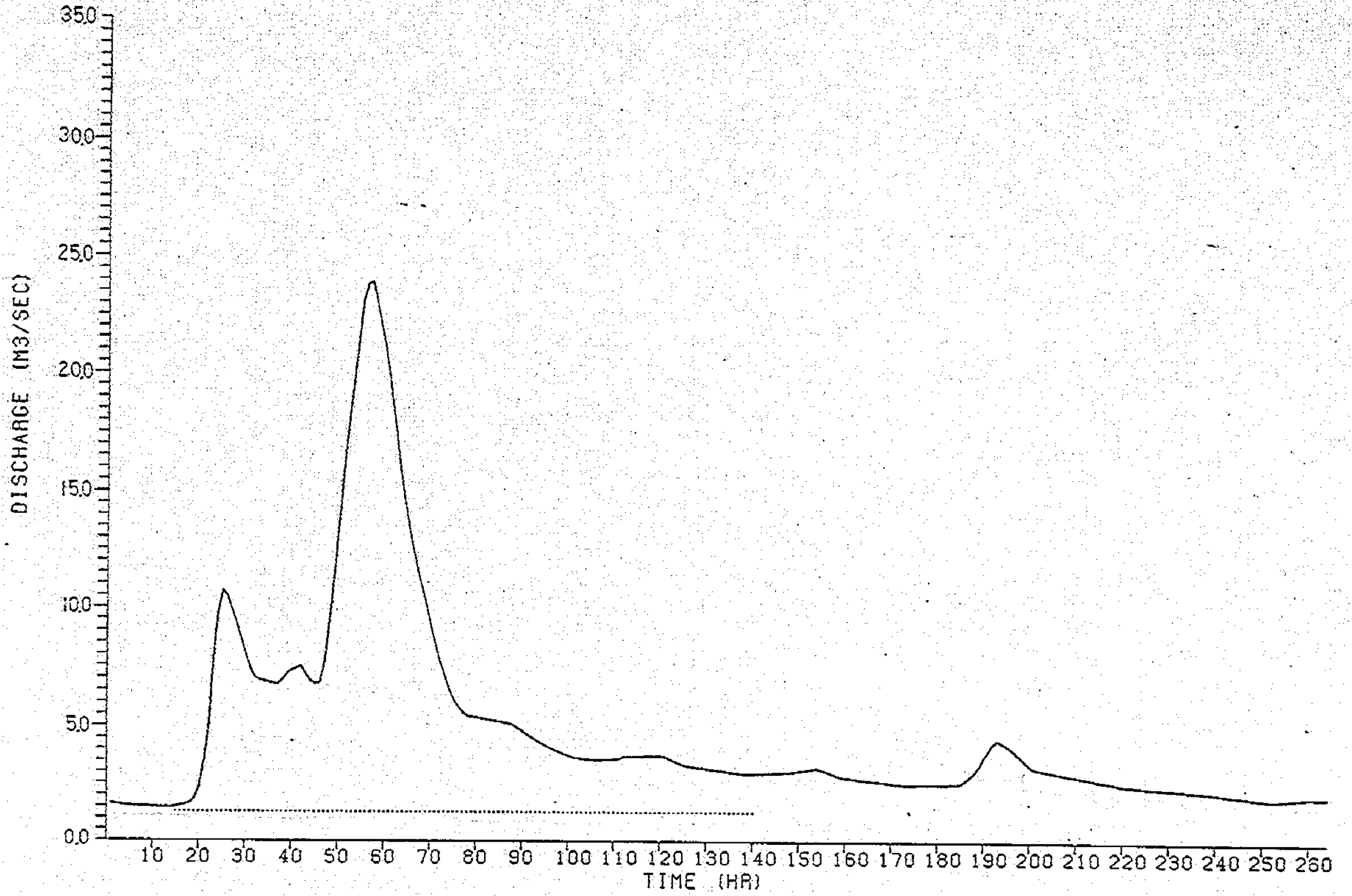


CHANGE OF DISCHARGE (1981. 9. 2 -)



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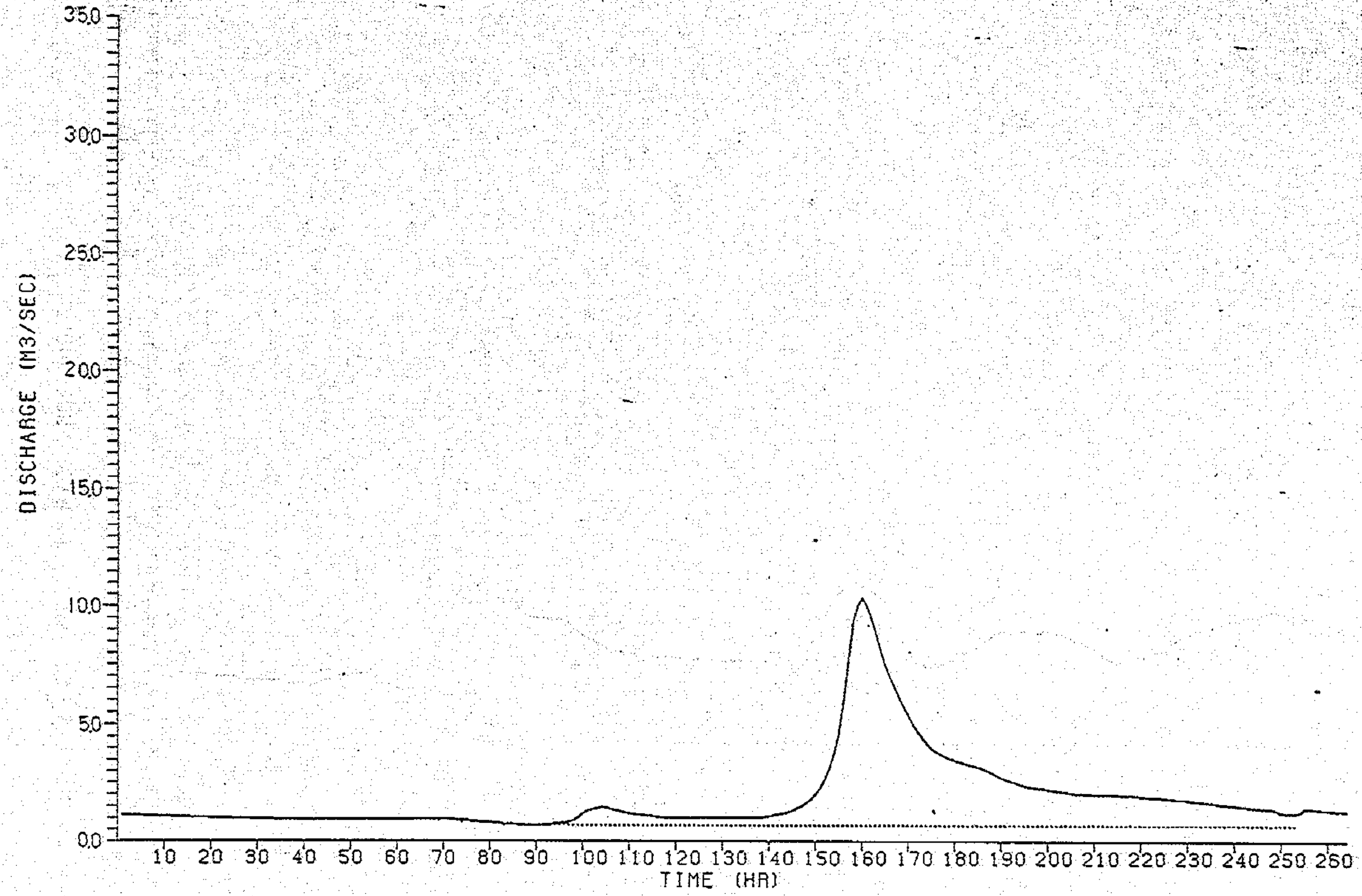

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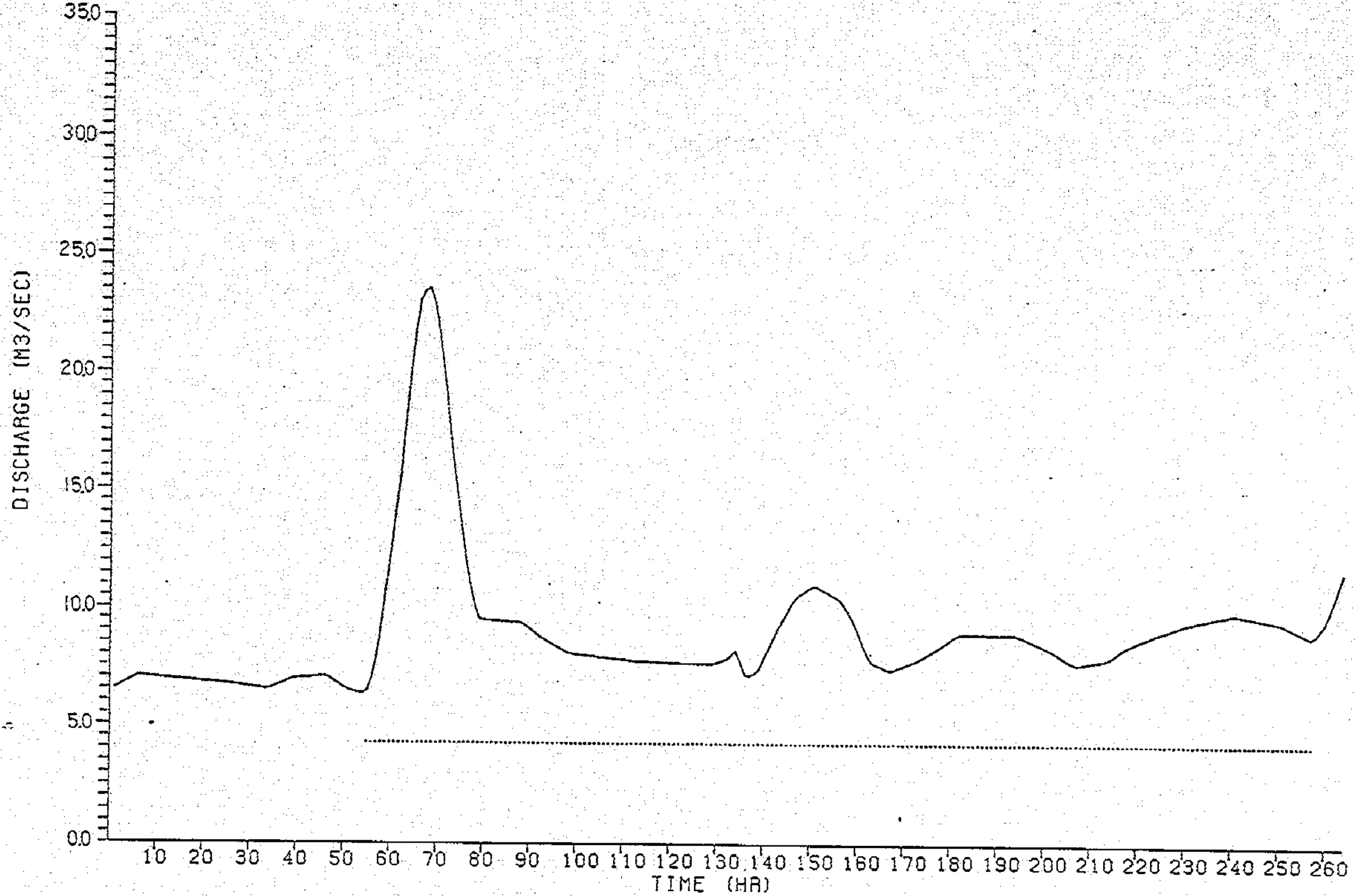
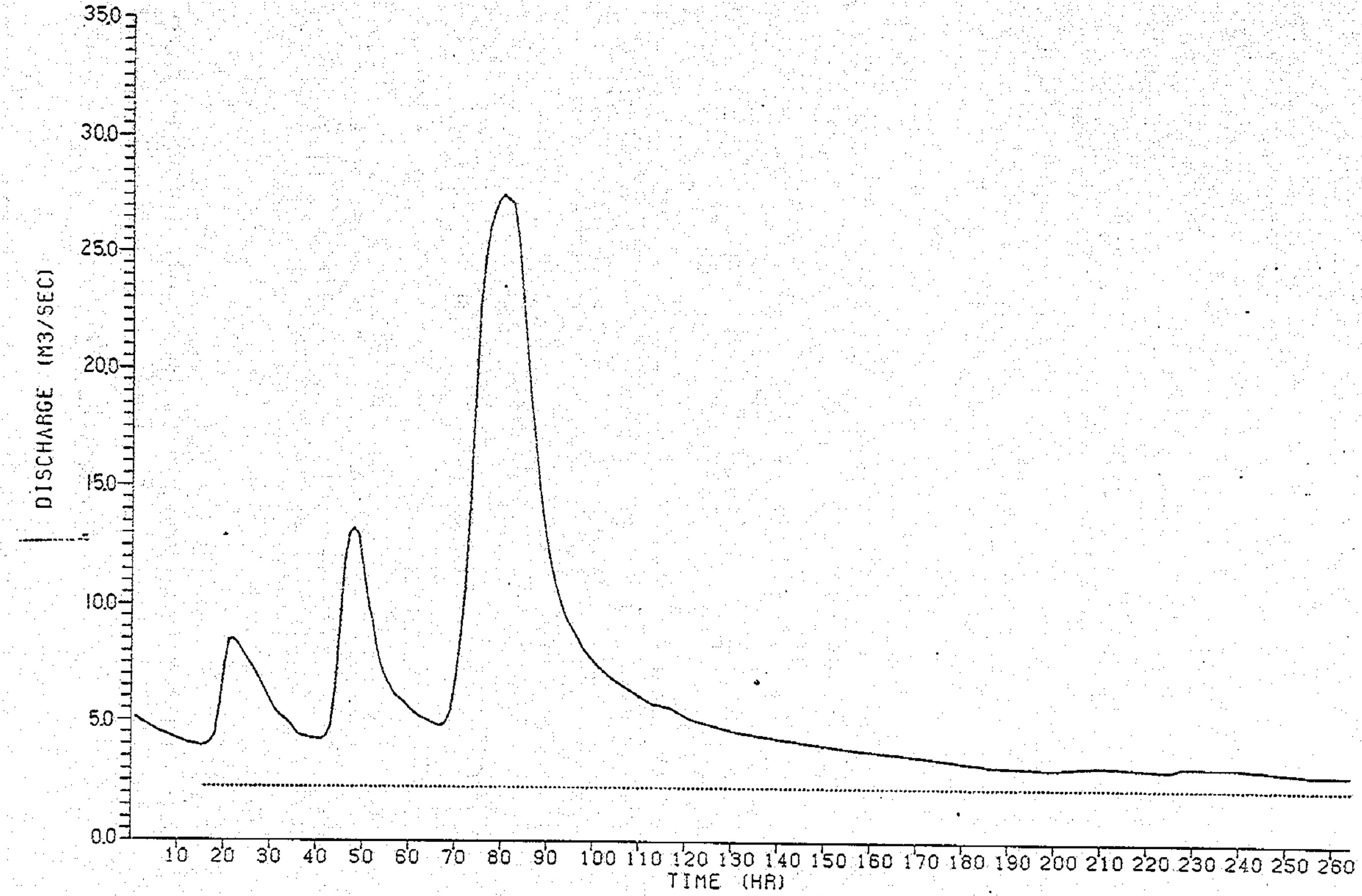


CHANGE OF DISCHARGE (1982. 11. 17 -)



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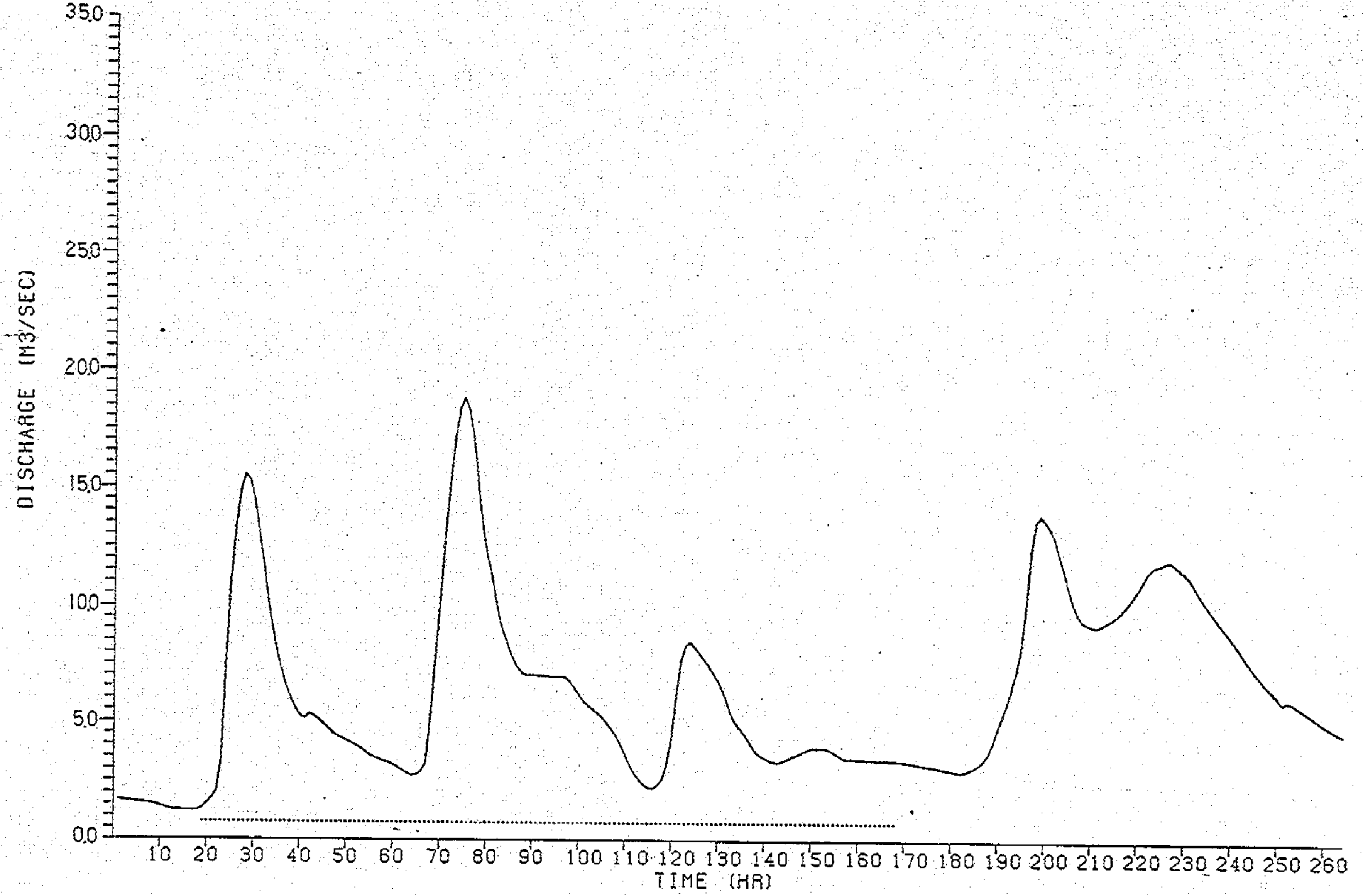
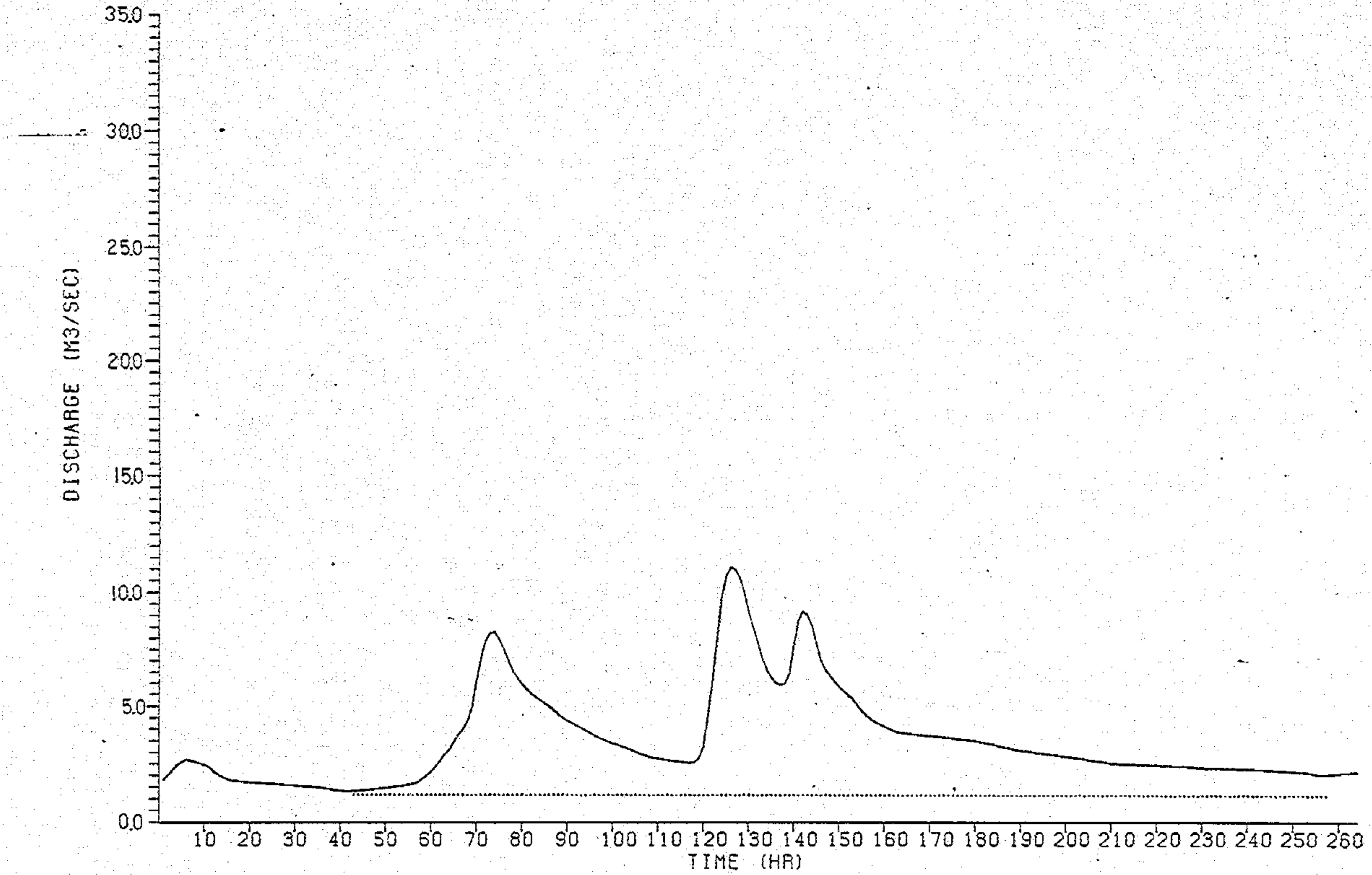


CHANGE OF DISCHARGE (1983. 9. 2 -)



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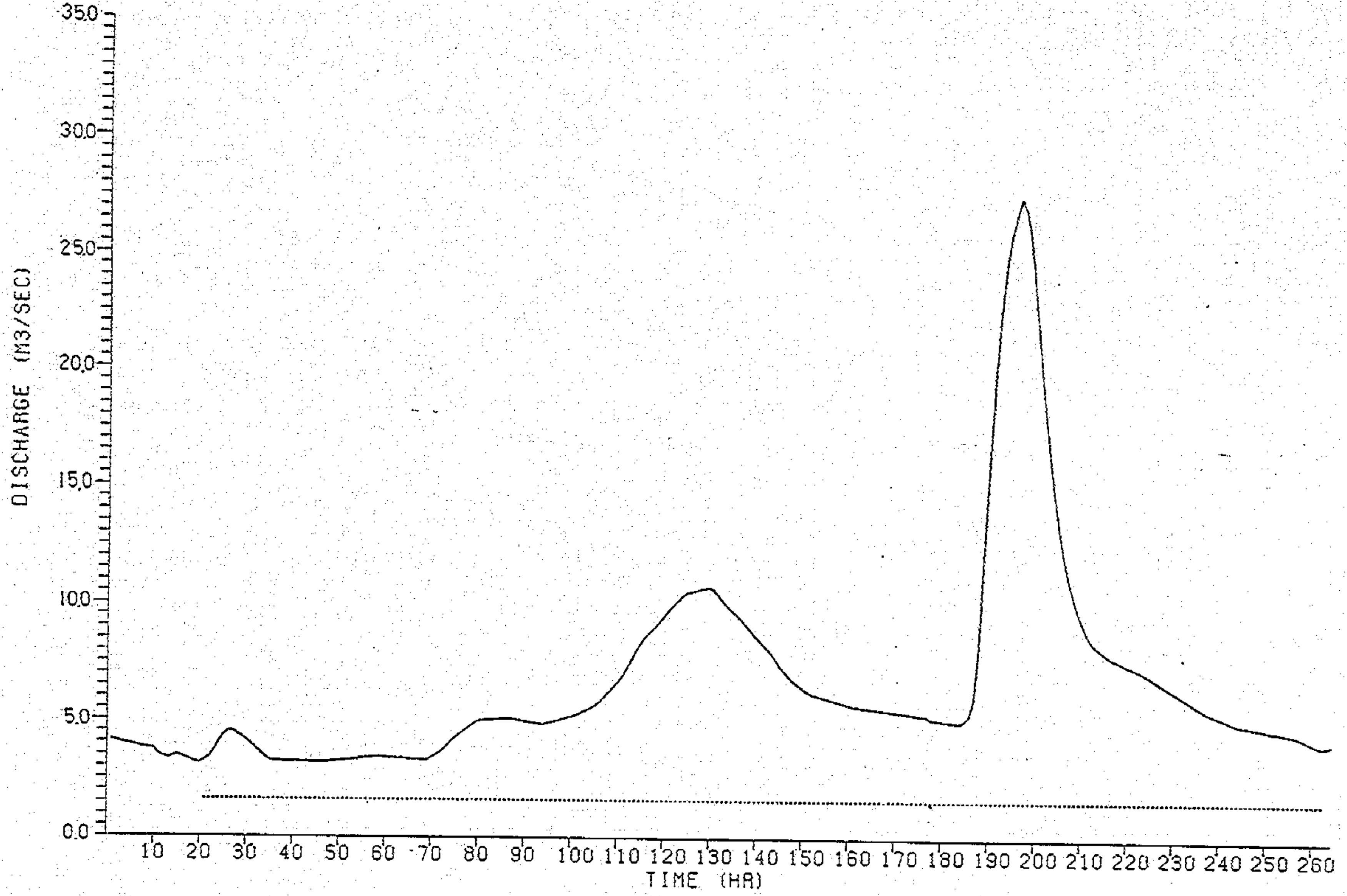

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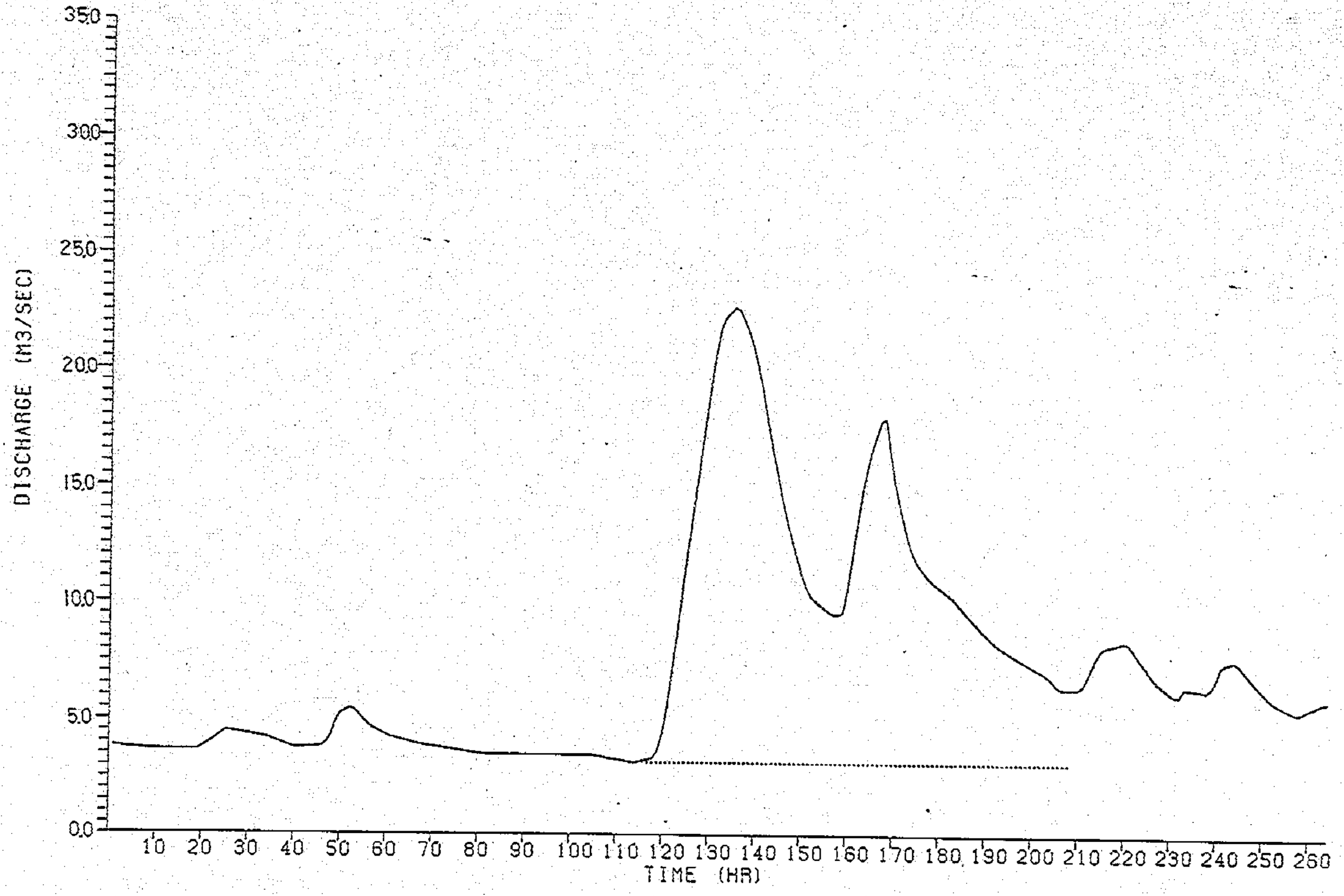
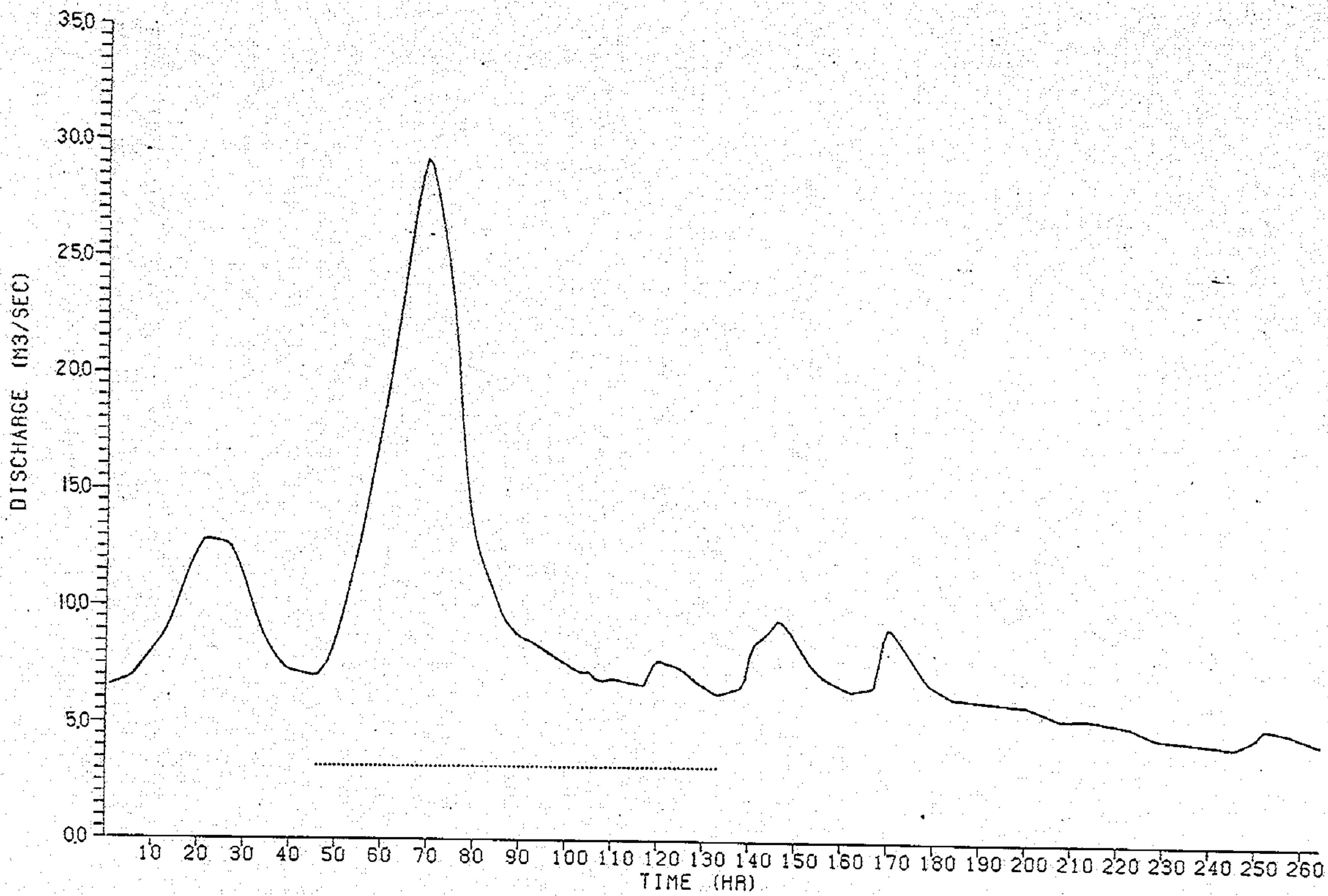
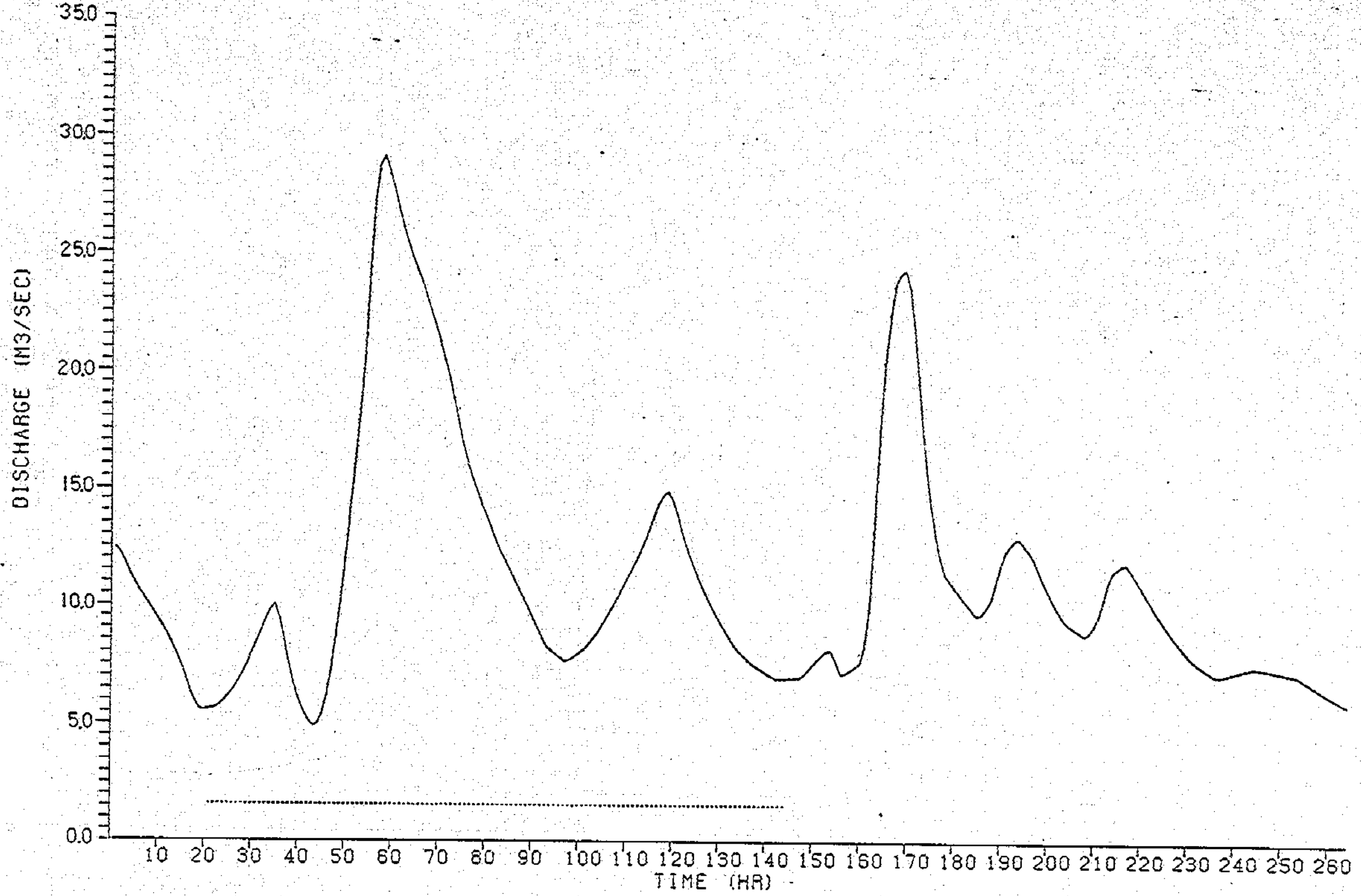


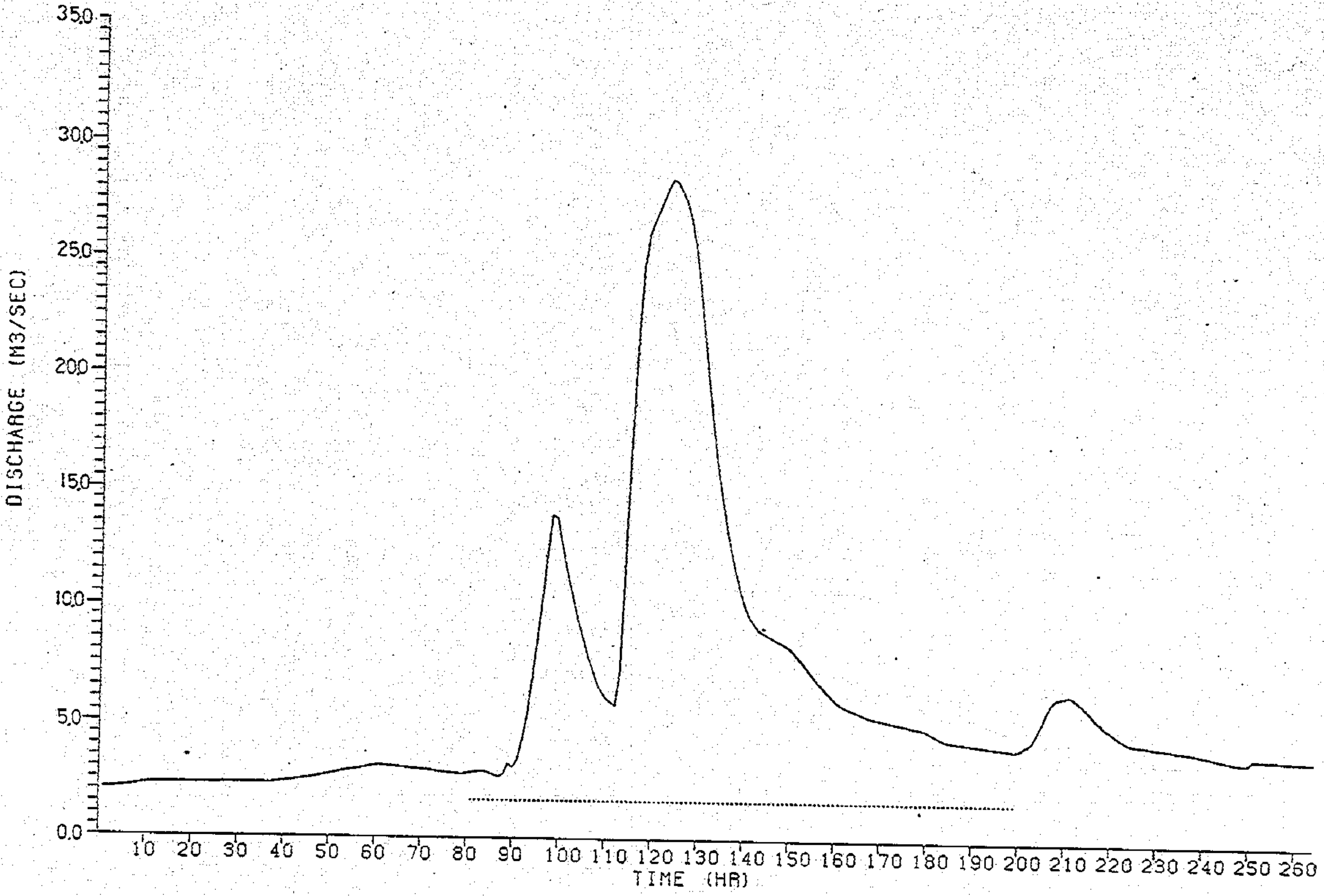
CHANGE OF DISCHARGE (1984. 4. 14 -)



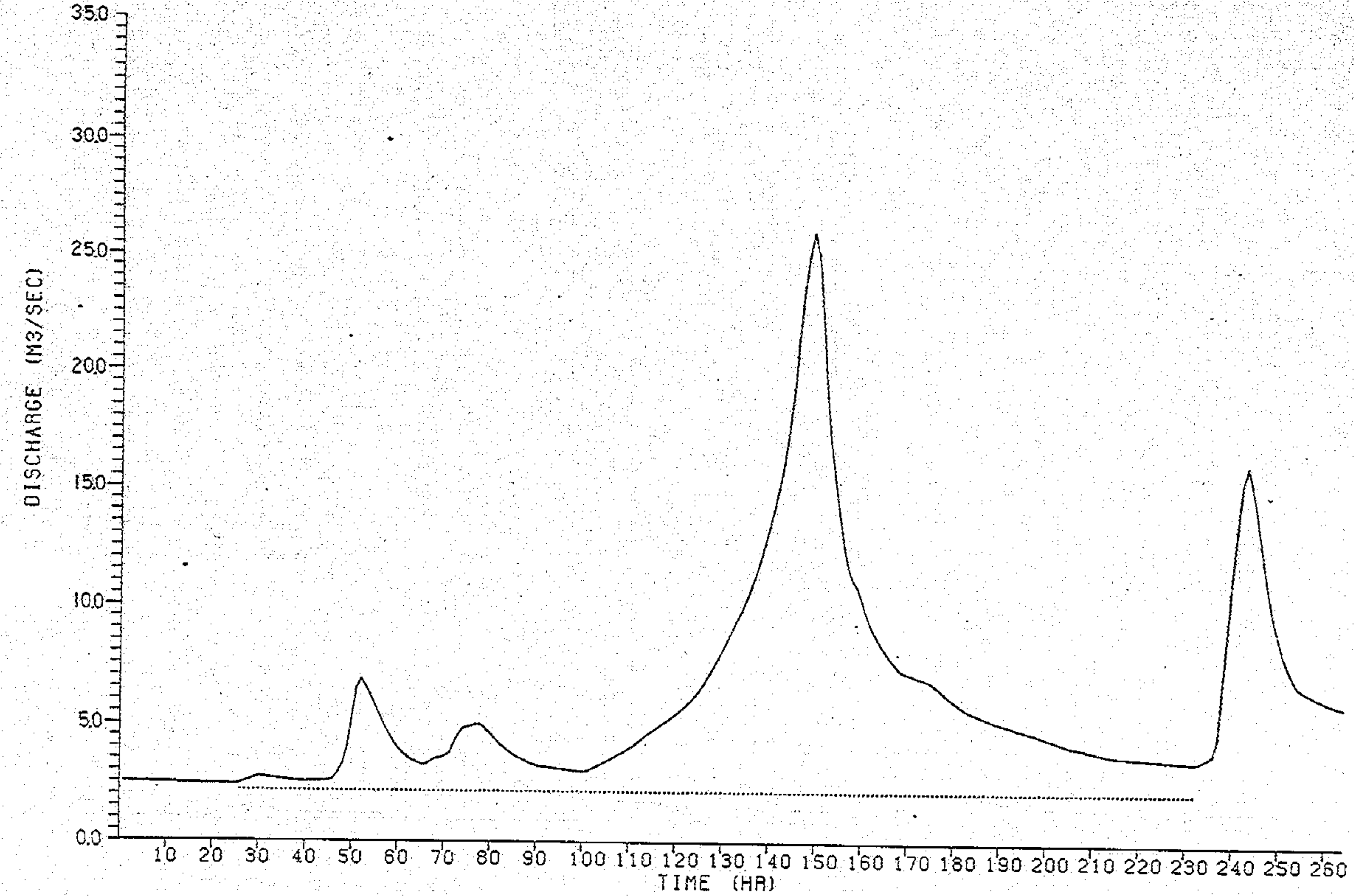
CHANGE OF DISCHARGE (1984. 4. 26 -)



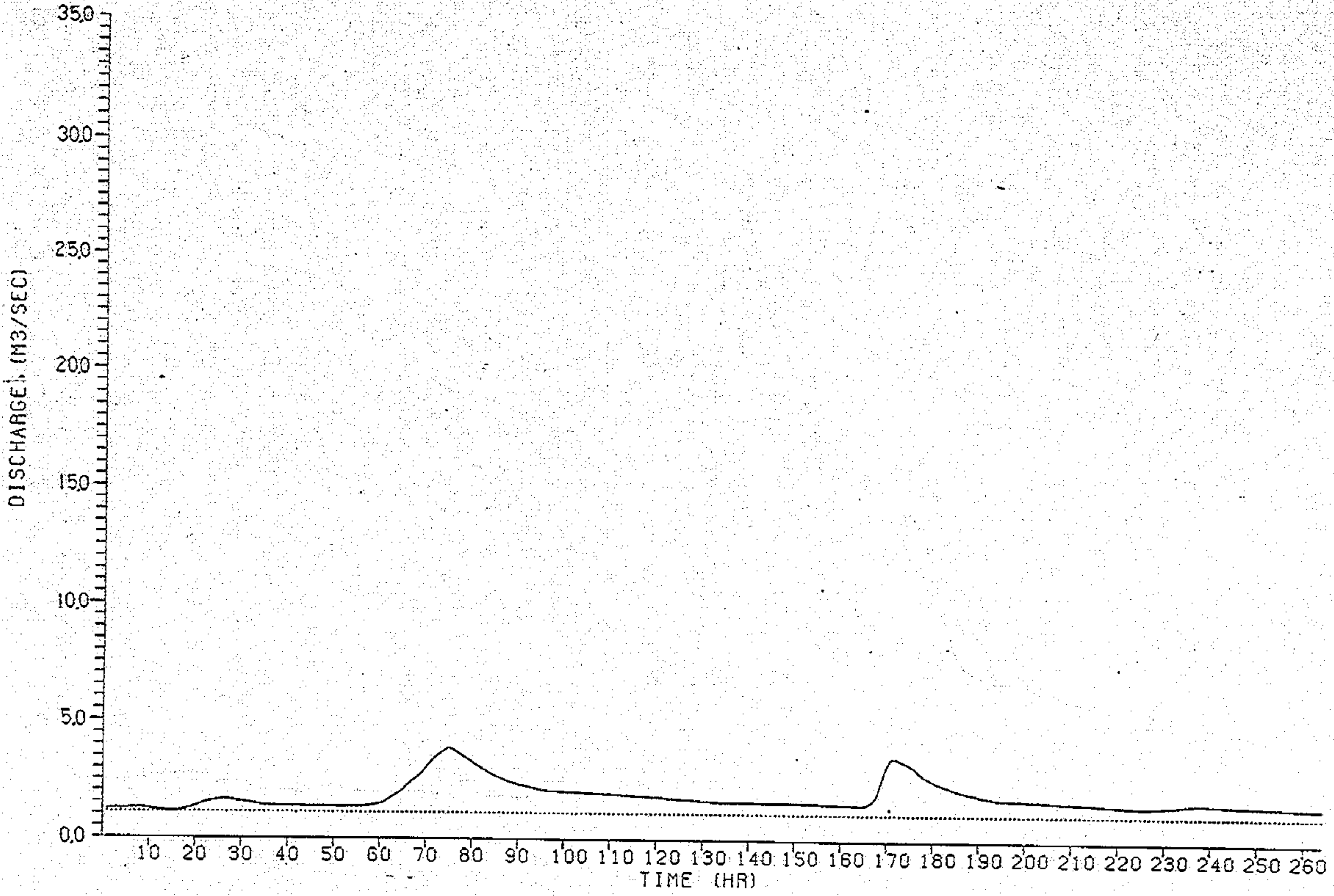
CHANGE OF DISCHARGE (1984.11.13 -)



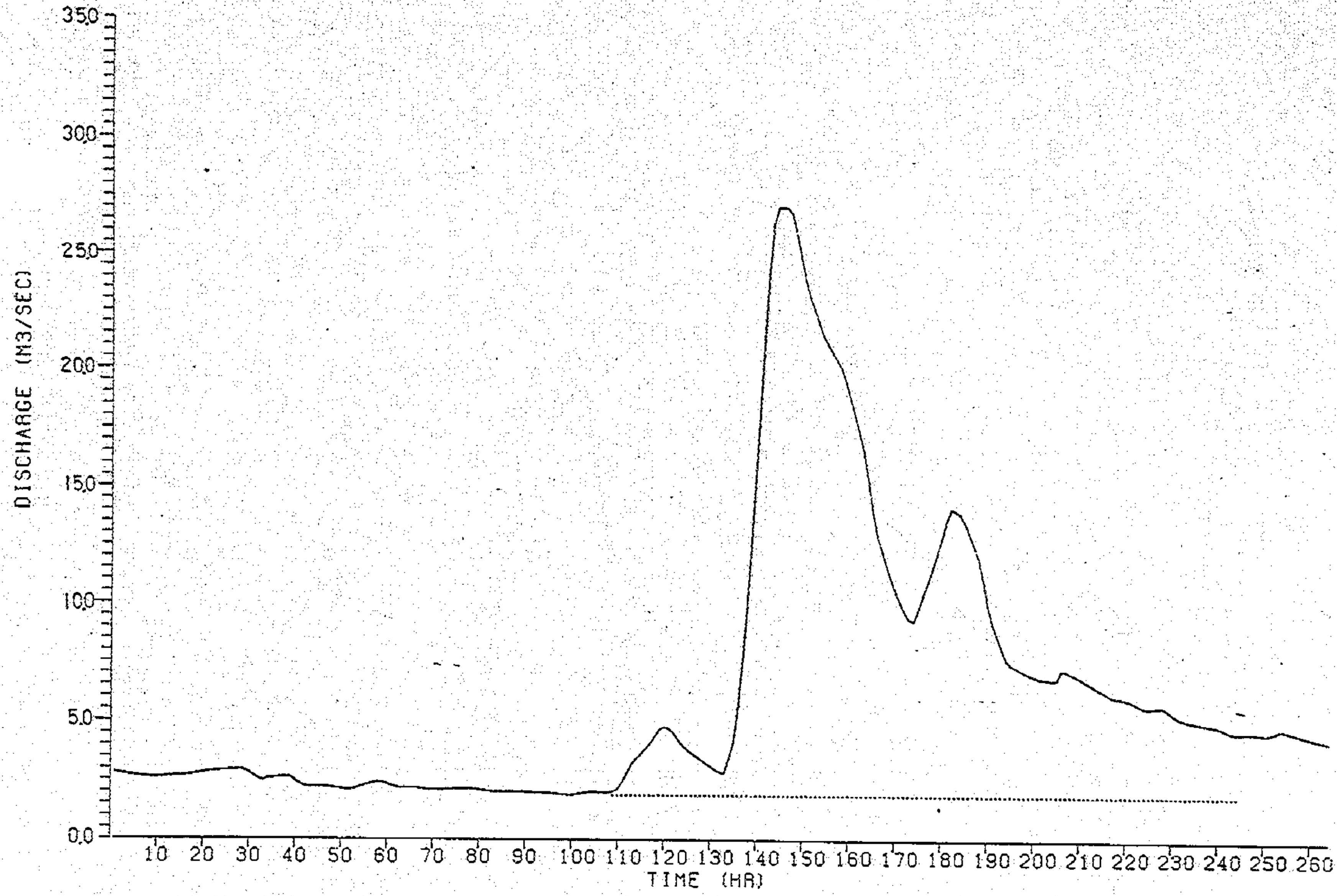
CHANGE OF DISCHARGE (1985. 2. 8 -)



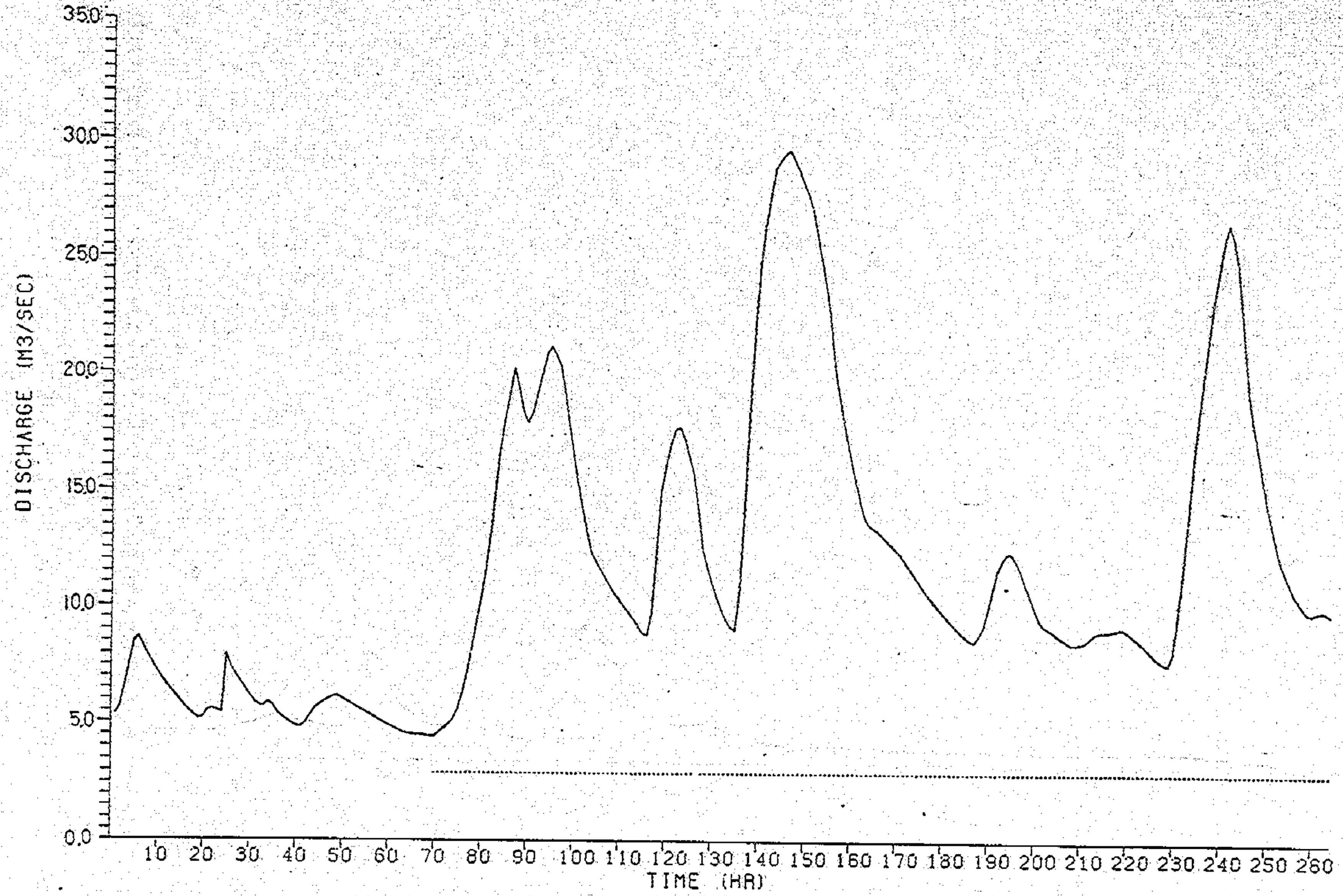
CHANGE OF DISCHARGE (1985. 3. 5 -)



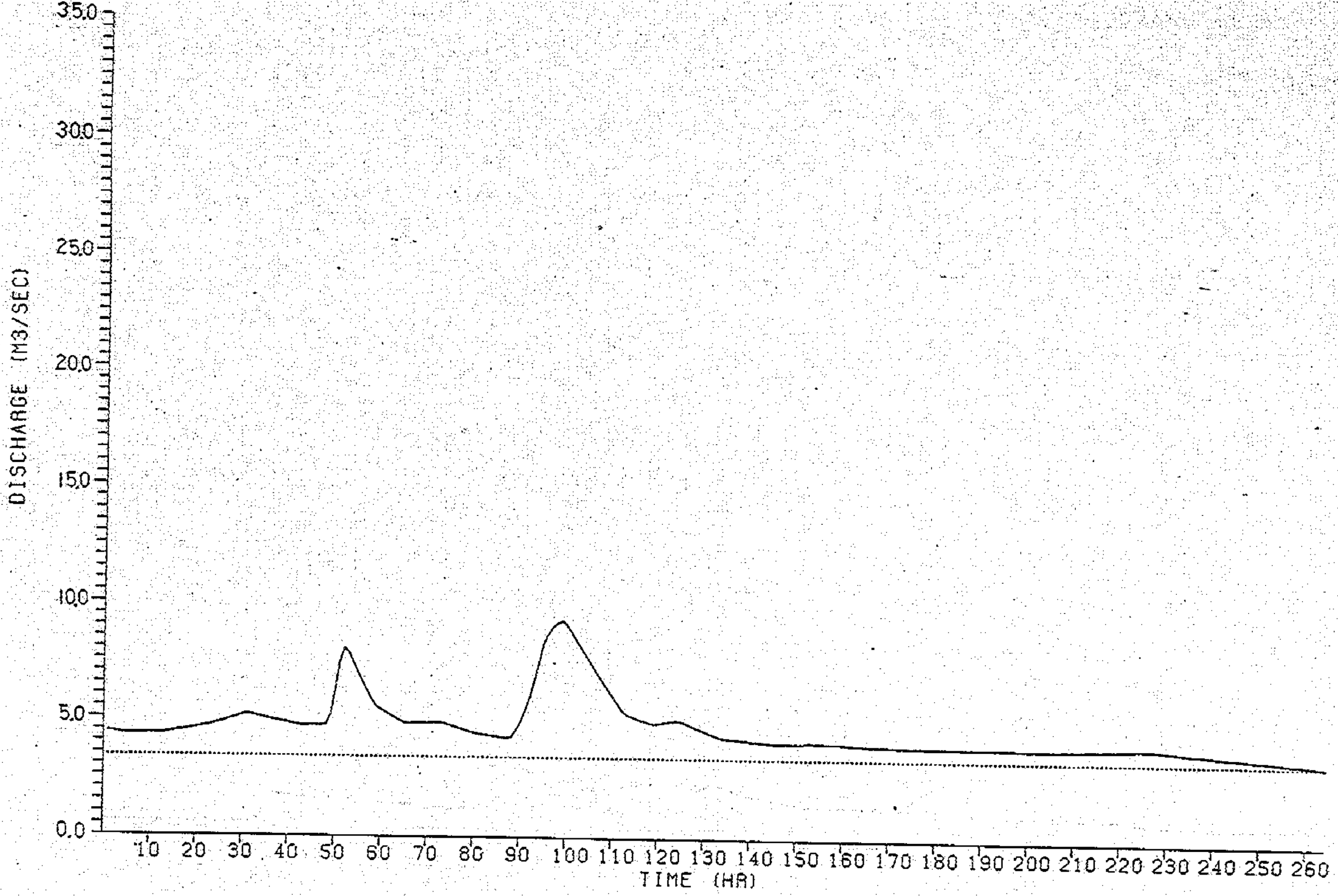
CHANGE OF DISCHARGE (1985. 7. 20 -)



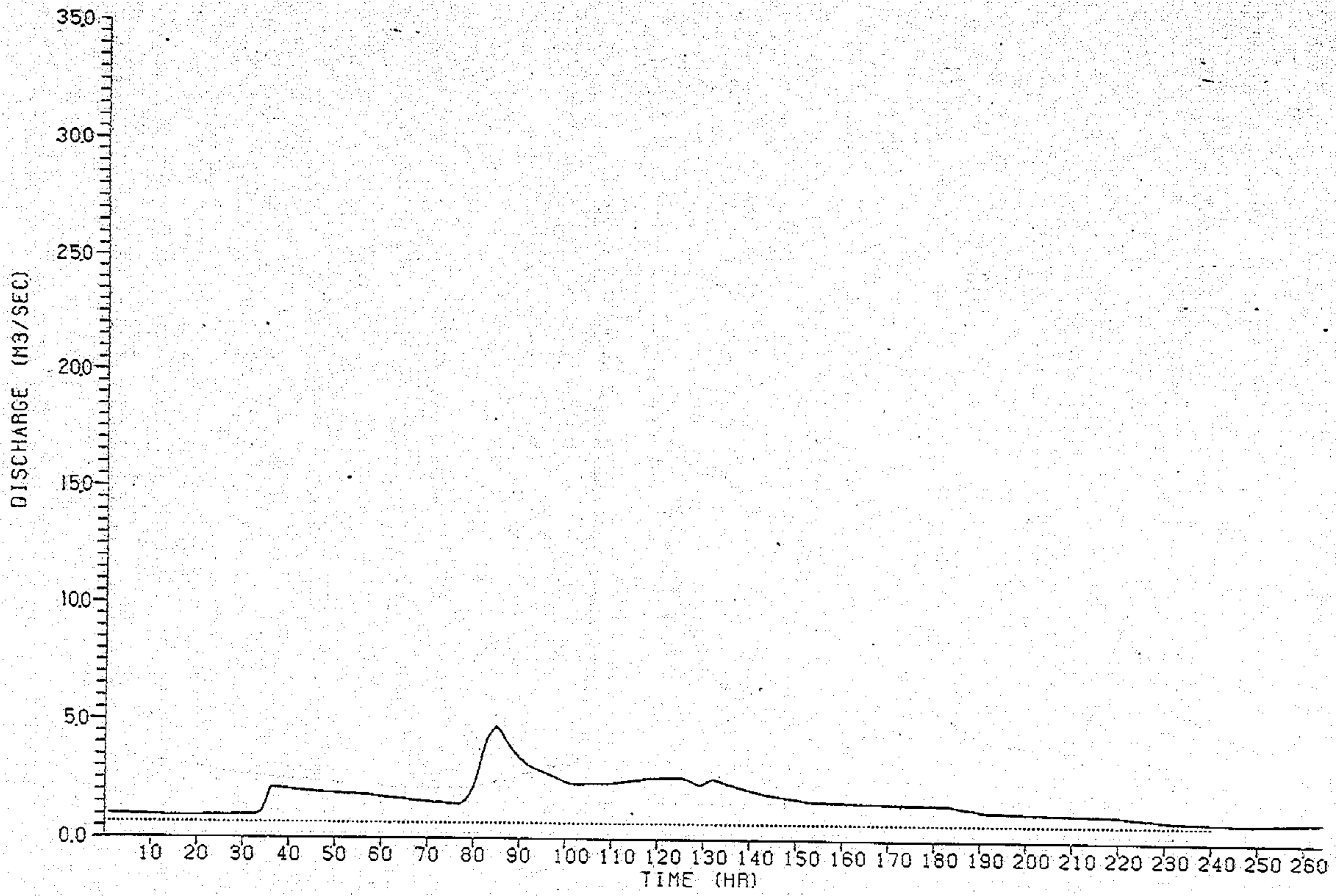
CHANGE OF DISCHARGE (1985. 10. 6 -)



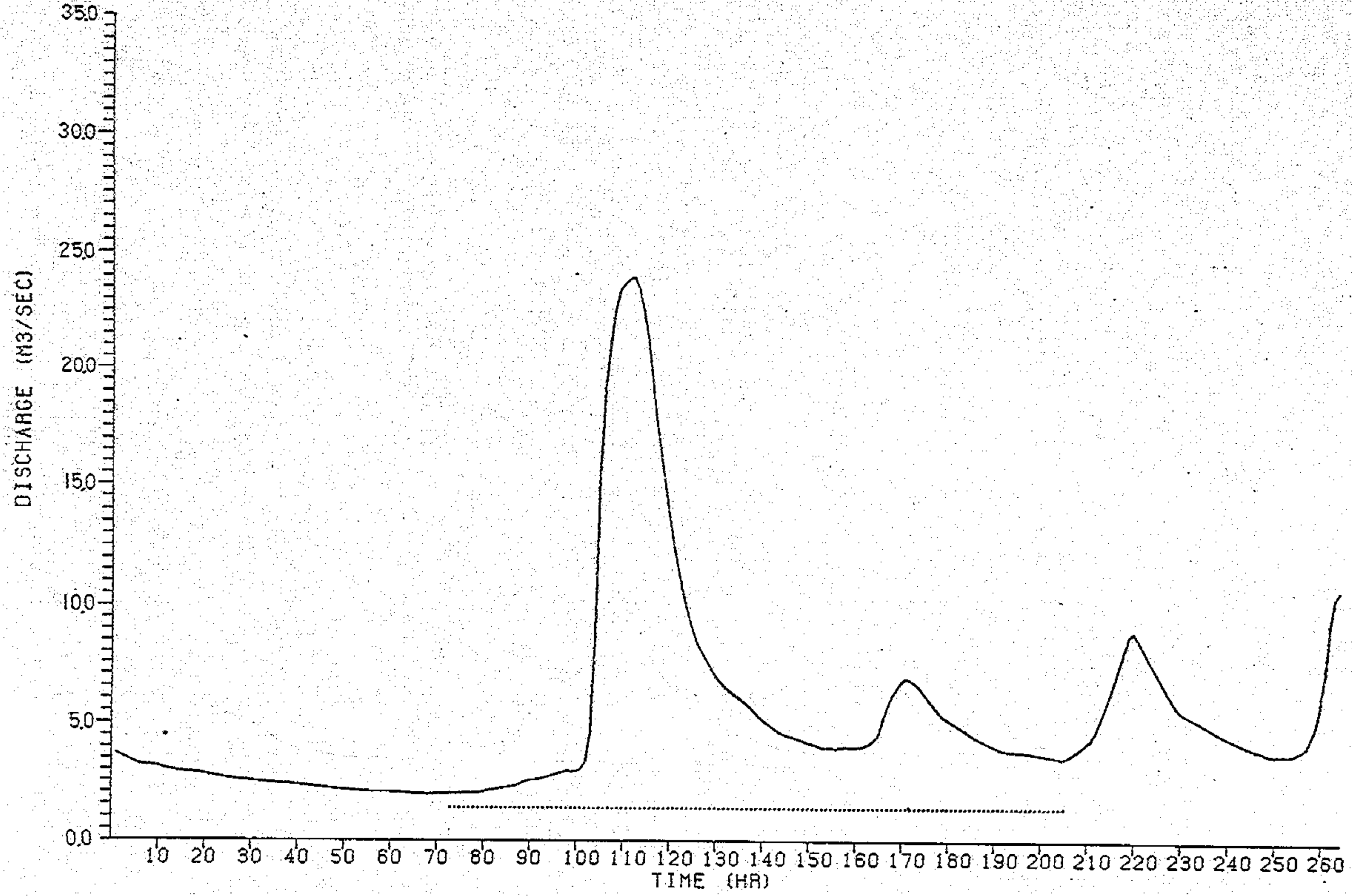
CHANGE OF DISCHARGE (1985.10.27 –)



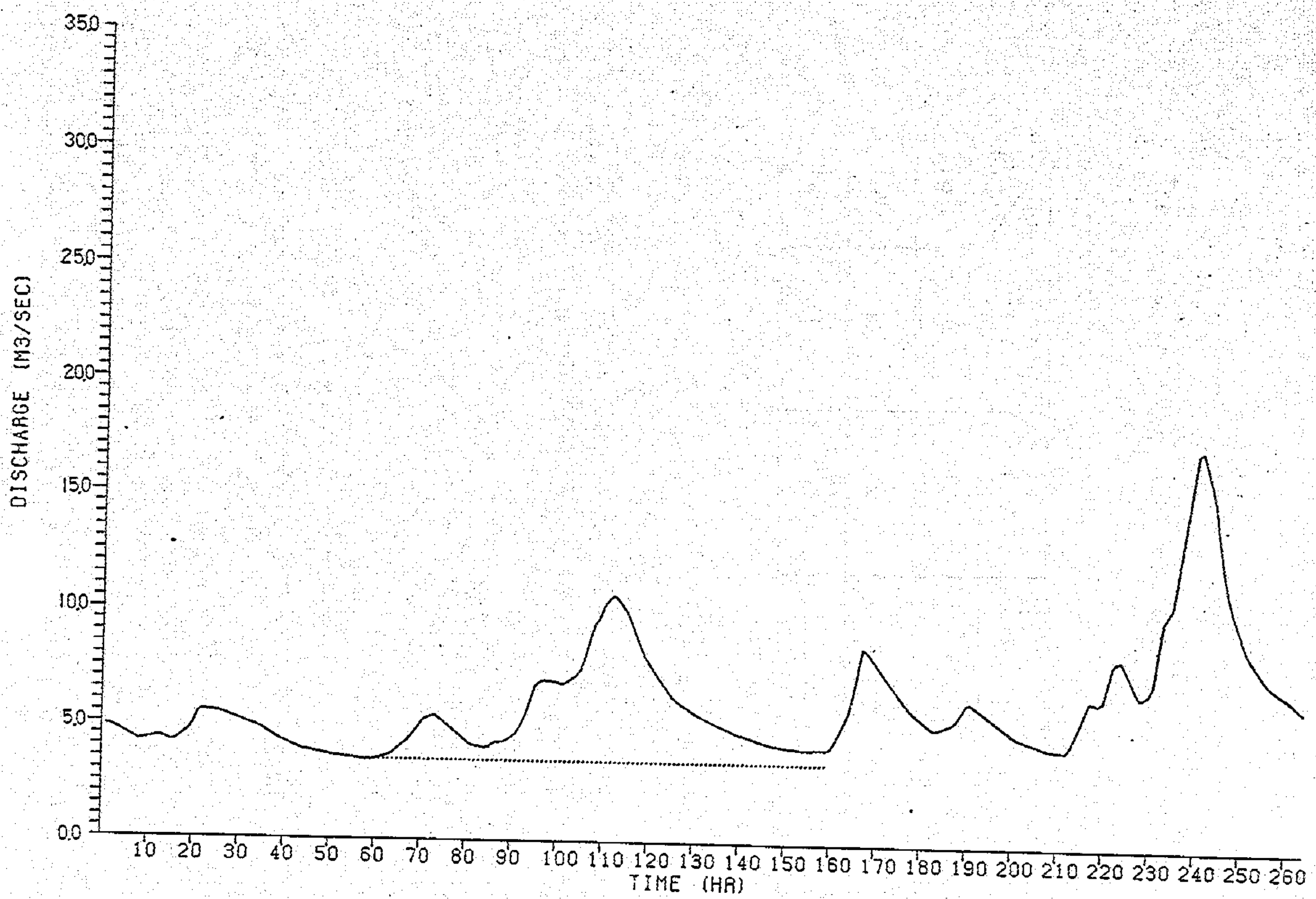
CHANGE OF DISCHARGE (1985. 11. 26 -)



CHANGE OF DISCHARGE (1986. 7.30 -)



CHANGE OF DISCHARGE (1986. 9.16 -)



CHANGE OF DISCHARGE (1986. 10. 2 -)

Annex A-8

The names of case are as follows :

N Rlmax	0.7	1.0	1.5
100	A	B	C
150	D	E	F
200	G	H	I

Table 1 specific discharge

(1/5 : type1) (m^3/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00213	0.00137	0.00075	0.00085	0.00056	0.00041	0.00050	0.00039	0.00034
7	0.00339	0.00244	0.00171	0.00185	0.00137	0.00100	0.00124	0.00094	0.00070
8	0.00398	0.00286	0.00200	0.00216	0.00159	0.00115	0.00144	0.00109	0.00082
9	0.00446	0.00320	0.00222	0.00241	0.00177	0.00127	0.00159	0.00120	0.00089
10	0.00455	0.00327	0.00228	0.00247	0.00181	0.00131	0.00164	0.00123	0.00092
11	0.00459	0.00329	0.00228	0.00248	0.00182	0.00131	0.00164	0.00124	0.00092
12	0.00462	0.00330	0.00229	0.00249	0.00183	0.00131	0.00165	0.00124	0.00092
13	0.00466	0.00332	0.00230	0.00250	0.00183	0.00132	0.00165	0.00124	0.00093
14	0.00469	0.00333	0.00230	0.00252	0.00184	0.00132	0.00166	0.00124	0.00093
15	0.00472	0.00335	0.00231	0.00253	0.00184	0.00132	0.00167	0.00125	0.00093
16	0.00476	0.00336	0.00232	0.00254	0.00185	0.00132	0.00167	0.00125	0.00093
17	0.00479	0.00338	0.00232	0.00255	0.00185	0.00133	0.00168	0.00125	0.00093
18	0.00483	0.00339	0.00233	0.00257	0.00186	0.00133	0.00168	0.00126	0.00093
19	0.00486	0.00341	0.00233	0.00258	0.00187	0.00133	0.00169	0.00126	0.00093
20	0.00489	0.00342	0.00234	0.00259	0.00187	0.00133	0.00170	0.00126	0.00093
21	0.00460	0.00344	0.00235	0.00260	0.00188	0.00133	0.00170	0.00126	0.00094
22	0.00408	0.00345	0.00235	0.00262	0.00188	0.00134	0.00171	0.00127	0.00094
23	0.00360	0.00347	0.00236	0.00263	0.00189	0.00134	0.00171	0.00127	0.00094
24	0.00320	0.00348	0.00237	0.00264	0.00189	0.00134	0.00172	0.00127	0.00094
25	0.00286	0.00350	0.00237	0.00262	0.00190	0.00134	0.00173	0.00128	0.00094
26	0.00257	0.00351	0.00238	0.00244	0.00191	0.00135	0.00173	0.00128	0.00094
27	0.00233	0.00343	0.00239	0.00222	0.00191	0.00135	0.00174	0.00128	0.00094
28	0.00212	0.00318	0.00239	0.00203	0.00192	0.00135	0.00174	0.00128	0.00094
29	0.00194	0.00290	0.00240	0.00186	0.00192	0.00135	0.00174	0.00129	0.00094
30	0.00178	0.00266	0.00240	0.00171	0.00193	0.00136	0.00166	0.00129	0.00095
31	0.00164	0.00244	0.00241	0.00158	0.00193	0.00136	0.00154	0.00129	0.00095
32	0.00152	0.00226	0.00242	0.00147	0.00194	0.00136	0.00143	0.00130	0.00095
33	0.00142	0.00209	0.00242	0.00137	0.00194	0.00136	0.00134	0.00130	0.00095
34	0.00133	0.00194	0.00243	0.00128	0.00187	0.00137	0.00125	0.00130	0.00095
35	0.00124	0.00181	0.00244	0.00120	0.00175	0.00137	0.00118	0.00130	0.00095
36	0.00117	0.00169	0.00244	0.00113	0.00164	0.00137	0.00111	0.00131	0.00095
37	0.00110	0.00159	0.00245	0.00107	0.00154	0.00137	0.00105	0.00131	0.00095
38	0.00105	0.00150	0.00235	0.00101	0.00145	0.00138	0.00099	0.00131	0.00096
39	0.00099	0.00141	0.00222	0.00096	0.00137	0.00138	0.00095	0.00131	0.00096
40	0.00094	0.00133	0.00209	0.00092	0.00130	0.00138	0.00090	0.00127	0.00096
41	0.00090	0.00126	0.00197	0.00088	0.00123	0.00138	0.00086	0.00121	0.00096
42	0.00086	0.00120	0.00186	0.00084	0.00117	0.00139	0.00082	0.00115	0.00096
43	0.00083	0.00114	0.00177	0.00080	0.00112	0.00139	0.00079	0.00110	0.00096
44	0.00079	0.00109	0.00168	0.00077	0.00107	0.00139	0.00076	0.00105	0.00096
45	0.00076	0.00104	0.00159	0.00074	0.00102	0.00139	0.00073	0.00100	0.00096

(m³/sec/ha)

case Time (hr)	A	B	C	D	E	F	G	H	I
46	0.00074	0.00100	0.00152	0.00072	0.00098	0.00140	0.00071	0.00096	0.00097
47	0.00071	0.00096	0.00145	0.00069	0.00094	0.00139	0.00068	0.00092	0.00097
48	0.00069	0.00092	0.00138	0.00067	0.00090	0.00135	0.00066	0.00089	0.00097
49	0.00066	0.00089	0.00132	0.00065	0.00087	0.00129	0.00064	0.00086	0.00097
50	0.00064	0.00086	0.00127	0.00063	0.00084	0.00124	0.00062	0.00083	0.00097
51	0.00063	0.00083	0.00122	0.00061	0.00081	0.00119	0.00061	0.00080	0.00097
52	0.00061	0.00080	0.00117	0.00060	0.00078	0.00115	0.00059	0.00077	0.00097
53	0.00059	0.00077	0.00112	0.00058	0.00076	0.00110	0.00058	0.00075	0.00097
54	0.00058	0.00075	0.00108	0.00057	0.00074	0.00106	0.00056	0.00073	0.00098
55	0.00056	0.00073	0.00105	0.00056	0.00071	0.00103	0.00055	0.00071	0.00098
56	0.00055	0.00071	0.00101	0.00054	0.00069	0.00099	0.00054	0.00069	0.00097
57	0.00054	0.00069	0.00098	0.00053	0.00068	0.00096	0.00053	0.00067	0.00095
58	0.00053	0.00067	0.00095	0.00052	0.00066	0.00093	0.00052	0.00065	0.00092
59	0.00052	0.00065	0.00092	0.00051	0.00064	0.00090	0.00051	0.00064	0.00089
60	0.00051	0.00064	0.00089	0.00050	0.00063	0.00087	0.00050	0.00062	0.00087
61	0.00050	0.00062	0.00086	0.00049	0.00061	0.00085	0.00049	0.00061	0.00084
62	0.00049	0.00061	0.00084	0.00048	0.00060	0.00083	0.00048	0.00059	0.00082
63	0.00048	0.00060	0.00082	0.00048	0.00059	0.00080	0.00047	0.00058	0.00080
64	0.00047	0.00058	0.00079	0.00047	0.00058	0.00078	0.00047	0.00057	0.00078
65	0.00047	0.00057	0.00077	0.00046	0.00056	0.00076	0.00046	0.00056	0.00076
66	0.00046	0.00056	0.00076	0.00046	0.00055	0.00075	0.00045	0.00055	0.00074
67	0.00045	0.00055	0.00074	0.00045	0.00054	0.00073	0.00045	0.00054	0.00072
68	0.00045	0.00054	0.00072	0.00044	0.00053	0.00071	0.00044	0.00053	0.00071
69	0.00044	0.00053	0.00070	0.00044	0.00052	0.00070	0.00044	0.00052	0.00069
70	0.00044	0.00052	0.00069	0.00043	0.00052	0.00068	0.00043	0.00051	0.00068
71	0.00043	0.00051	0.00067	0.00043	0.00051	0.00067	0.00043	0.00050	0.00066

Table 2 specific discharge

(1/10: type I) (m³/sec/ha)

case / Time (hr)	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00323	0.00218	0.00130	0.00151	0.00087	0.00054	0.00074	0.00051	0.00039
7	0.00484	0.00345	0.00238	0.00258	0.00188	0.00134	0.00169	0.00126	0.00092
8	0.00569	0.00405	0.00279	0.00303	0.00220	0.00155	0.00197	0.00146	0.00106
9	0.00637	0.00454	0.00311	0.00338	0.00245	0.00172	0.00219	0.00162	0.00117
10	0.00651	0.00463	0.00318	0.00346	0.00251	0.00177	0.00225	0.00166	0.00121
11	0.00657	0.00466	0.00319	0.00348	0.00252	0.00177	0.00226	0.00167	0.00121
12	0.00663	0.00468	0.00320	0.00350	0.00253	0.00178	0.00227	0.00167	0.00121
13	0.00669	0.00471	0.00321	0.00352	0.00254	0.00178	0.00228	0.00168	0.00121
14	0.00675	0.00474	0.00323	0.00355	0.00255	0.00179	0.00229	0.00168	0.00121
15	0.00681	0.00476	0.00324	0.00357	0.00256	0.00179	0.00230	0.00168	0.00122
16	0.00687	0.00479	0.00325	0.00359	0.00257	0.00179	0.00231	0.00169	0.00122
17	0.00693	0.00482	0.00326	0.00361	0.00258	0.00180	0.00232	0.00169	0.00122
18	0.00699	0.00484	0.00327	0.00363	0.00259	0.00180	0.00233	0.00170	0.00122
19	0.00645	0.00487	0.00328	0.00366	0.00260	0.00181	0.00234	0.00170	0.00122
20	0.00559	0.00490	0.00329	0.00368	0.00261	0.00181	0.00235	0.00171	0.00123
21	0.00484	0.00492	0.00330	0.00370	0.00262	0.00181	0.00236	0.00171	0.00123
22	0.00423	0.00495	0.00331	0.00372	0.00263	0.00182	0.00237	0.00172	0.00123
23	0.00372	0.00498	0.00332	0.00348	0.00264	0.00182	0.00238	0.00172	0.00123
24	0.00330	0.00487	0.00334	0.00312	0.00265	0.00183	0.00239	0.00173	0.00124
25	0.00294	0.00444	0.00335	0.00279	0.00265	0.00183	0.00241	0.00173	0.00124
26	0.00264	0.00399	0.00336	0.00252	0.00266	0.00184	0.00237	0.00174	0.00124
27	0.00239	0.00369	0.00337	0.00228	0.00267	0.00184	0.00220	0.00174	0.00124
28	0.00217	0.00327	0.00338	0.00208	0.00268	0.00184	0.00201	0.00175	0.00124
29	0.00199	0.00298	0.00339	0.00190	0.00269	0.00185	0.00185	0.00175	0.00125
30	0.00182	0.00272	0.00340	0.00175	0.00258	0.00185	0.00170	0.00176	0.00125
31	0.00168	0.00250	0.00341	0.00162	0.00240	0.00186	0.00157	0.00176	0.00125
32	0.00156	0.00230	0.00342	0.00150	0.00222	0.00186	0.00146	0.00177	0.00125
33	0.00145	0.00213	0.00337	0.00140	0.00206	0.00186	0.00136	0.00177	0.00125
34	0.00136	0.00198	0.00318	0.00130	0.00191	0.00187	0.00128	0.00178	0.00126
35	0.00127	0.00185	0.00296	0.00122	0.00179	0.00187	0.00120	0.00173	0.00126
36	0.00120	0.00173	0.00276	0.00115	0.00167	0.00188	0.00113	0.00163	0.00126
37	0.00113	0.00162	0.00257	0.00109	0.00157	0.00188	0.00106	0.00153	0.00126
38	0.00107	0.00152	0.00241	0.00103	0.00148	0.00189	0.00101	0.00145	0.00126
39	0.00101	0.00143	0.00226	0.00098	0.00139	0.00189	0.00096	0.00137	0.00127
40	0.00096	0.00136	0.00213	0.00093	0.00132	0.00189	0.00091	0.00129	0.00127
41	0.00092	0.00129	0.00200	0.00089	0.00125	0.00190	0.00087	0.00123	0.00127
42	0.00088	0.00122	0.00189	0.00085	0.00119	0.00183	0.00083	0.00117	0.00127
43	0.00084	0.00116	0.00179	0.00082	0.00113	0.00174	0.00080	0.00111	0.00127
44	0.00081	0.00111	0.00170	0.00078	0.00108	0.00166	0.00077	0.00106	0.00128
45	0.00077	0.00106	0.00161	0.00075	0.00103	0.00158	0.00074	0.00102	0.00128

(m^3/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00075	0.00101	0.00154	0.00073	0.00099	0.00150	0.00071	0.00097	0.00128
47	0.00072	0.00097	0.00147	0.00070	0.00095	0.00143	0.00069	0.00093	0.00128
48	0.00070	0.00093	0.00140	0.00068	0.00091	0.00137	0.00067	0.00090	0.00128
49	0.00067	0.00090	0.00134	0.00066	0.00088	0.00131	0.00065	0.00087	0.00127
50	0.00065	0.00087	0.00128	0.00064	0.00085	0.00126	0.00063	0.00083	0.00123
51	0.00063	0.00084	0.00123	0.00062	0.00082	0.00121	0.00061	0.00081	0.00119
52	0.00062	0.00081	0.00118	0.00060	0.00079	0.00116	0.00060	0.00078	0.00114
53	0.00060	0.00078	0.00114	0.00059	0.00077	0.00112	0.00058	0.00076	0.00110
54	0.00058	0.00076	0.00110	0.00057	0.00074	0.00107	0.00057	0.00073	0.00106
55	0.00057	0.00074	0.00106	0.00056	0.00072	0.00104	0.00055	0.00071	0.00102
56	0.00056	0.00072	0.00102	0.00055	0.00070	0.00100	0.00054	0.00069	0.00099
57	0.00054	0.00070	0.00099	0.00054	0.00068	0.00097	0.00053	0.00067	0.00096
58	0.00053	0.00068	0.00096	0.00053	0.00066	0.00094	0.00052	0.00066	0.00093
59	0.00052	0.00066	0.00093	0.00051	0.00065	0.00091	0.00051	0.00064	0.00090
60	0.00051	0.00064	0.00090	0.00051	0.00063	0.00088	0.00050	0.00063	0.00087
61	0.00050	0.00063	0.00087	0.00050	0.00062	0.00086	0.00049	0.00061	0.00085
62	0.00049	0.00061	0.00085	0.00049	0.00060	0.00083	0.00048	0.00060	0.00082
63	0.00048	0.00060	0.00082	0.00048	0.00059	0.00081	0.00048	0.00059	0.00080
64	0.00048	0.00059	0.00080	0.00047	0.00058	0.00079	0.00047	0.00057	0.00078
65	0.00047	0.00058	0.00078	0.00046	0.00057	0.00077	0.00046	0.00056	0.00076
66	0.00046	0.00056	0.00076	0.00046	0.00056	0.00075	0.00045	0.00055	0.00074
67	0.00046	0.00055	0.00074	0.00045	0.00055	0.00073	0.00045	0.00054	0.00073
68	0.00045	0.00054	0.00073	0.00045	0.00054	0.00072	0.00044	0.00053	0.00071
69	0.00044	0.00053	0.00071	0.00044	0.00053	0.00070	0.00044	0.00052	0.00069
70	0.00044	0.00053	0.00069	0.00043	0.00052	0.00069	0.00043	0.00052	0.00068
71	0.00043	0.00052	0.00068	0.00043	0.00051	0.00067	0.00043	0.00051	0.00067

4

Table 3 specific discharge

(1/20 : type I) (m^3/sec/ha)

case / Time (hr)	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00031	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00453	0.00312	0.00196	0.00220	0.00143	0.00078	0.00117	0.00071	0.00047
7	0.00660	0.00468	0.00320	0.00347	0.00250	0.00175	0.00223	0.00164	0.00118
8	0.00776	0.00551	0.00375	0.00408	0.00293	0.00204	0.00262	0.00191	0.00136
9	0.00870	0.00617	0.00420	0.00457	0.00328	0.00228	0.00292	0.00213	0.00151
10	0.00889	0.00629	0.00428	0.00467	0.00335	0.00233	0.00299	0.00218	0.00155
11	0.00899	0.00633	0.00430	0.00471	0.00337	0.00234	0.00301	0.00219	0.00156
12	0.00909	0.00638	0.00432	0.00474	0.00338	0.00234	0.00303	0.00220	0.00156
13	0.00919	0.00642	0.00434	0.00478	0.00340	0.00235	0.00304	0.00220	0.00156
14	0.00929	0.00646	0.00435	0.00481	0.00341	0.00236	0.00306	0.00221	0.00157
15	0.00939	0.00651	0.00437	0.00485	0.00343	0.00236	0.00308	0.00222	0.00157
16	0.00949	0.00655	0.00439	0.00488	0.00345	0.00237	0.00309	0.00223	0.00157
17	0.00928	0.00659	0.00441	0.00492	0.00346	0.00238	0.00311	0.00224	0.00158
18	0.00799	0.00664	0.00442	0.00495	0.00348	0.00238	0.00313	0.00224	0.00158
19	0.00677	0.00668	0.00444	0.00499	0.00349	0.00239	0.00315	0.00225	0.00158
20	0.00579	0.00672	0.00446	0.00502	0.00351	0.00240	0.00316	0.00226	0.00158
21	0.00500	0.00676	0.00448	0.00464	0.00353	0.00240	0.00318	0.00227	0.00159
22	0.00435	0.00648	0.00449	0.00409	0.00354	0.00241	0.00320	0.00227	0.00159
23	0.00383	0.00579	0.00451	0.00361	0.00356	0.00242	0.00321	0.00228	0.00159
24	0.00339	0.00513	0.00453	0.00320	0.00357	0.00242	0.00304	0.00229	0.00160
25	0.00302	0.00457	0.00455	0.00286	0.00359	0.00243	0.00276	0.00230	0.00160
26	0.00271	0.00409	0.00456	0.00258	0.00360	0.00244	0.00249	0.00231	0.00160
27	0.00245	0.00369	0.00458	0.00233	0.00346	0.00244	0.00226	0.00231	0.00161
28	0.00223	0.00334	0.00460	0.00212	0.00318	0.00245	0.00206	0.00232	0.00161
29	0.00204	0.00304	0.00462	0.00194	0.00291	0.00246	0.00188	0.00233	0.00161
30	0.00187	0.00278	0.00446	0.00178	0.00266	0.00246	0.00173	0.00234	0.00162
31	0.00172	0.00255	0.00413	0.00165	0.00245	0.00247	0.00160	0.00232	0.00162
32	0.00160	0.00235	0.00380	0.00153	0.00226	0.00248	0.00149	0.00219	0.00162
33	0.00149	0.00217	0.00351	0.00142	0.00209	0.00248	0.00139	0.00204	0.00163
34	0.00139	0.00202	0.00324	0.00133	0.00195	0.00249	0.00130	0.00190	0.00163
35	0.00130	0.00188	0.00301	0.00125	0.00181	0.00250	0.00122	0.00177	0.00163
36	0.00122	0.00176	0.00280	0.00117	0.00170	0.00250	0.00114	0.00166	0.00164
37	0.00115	0.00165	0.00261	0.00111	0.00159	0.00248	0.00108	0.00156	0.00164
38	0.00109	0.00155	0.00245	0.00105	0.00150	0.00236	0.00102	0.00147	0.00164
39	0.00103	0.00146	0.00229	0.00099	0.00141	0.00222	0.00097	0.00138	0.00165
40	0.00098	0.00138	0.00216	0.00095	0.00134	0.00209	0.00093	0.00131	0.00165
41	0.00093	0.00131	0.00203	0.00090	0.00127	0.00197	0.00088	0.00124	0.00165
42	0.00089	0.00124	0.00192	0.00086	0.00120	0.00187	0.00085	0.00118	0.00166
43	0.00085	0.00118	0.00182	0.00083	0.00114	0.00177	0.00081	0.00112	0.00166
44	0.00082	0.00112	0.00172	0.00079	0.00109	0.00168	0.00078	0.00107	0.00163
45	0.00078	0.00107	0.00164	0.00076	0.00104	0.00159	0.00075	0.00103	0.00156

(m³/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00075	0.00103	0.00155	0.00074	0.00100	0.00152	0.00072	0.00098	0.00149
47	0.00073	0.00099	0.00148	0.00071	0.00096	0.00145	0.00070	0.00094	0.00142
48	0.00070	0.00095	0.00142	0.00069	0.00092	0.00138	0.00068	0.00091	0.00136
49	0.00068	0.00091	0.00135	0.00067	0.00089	0.00132	0.00065	0.00087	0.00130
50	0.00066	0.00088	0.00130	0.00065	0.00086	0.00127	0.00064	0.00084	0.00125
51	0.00064	0.00085	0.00124	0.00063	0.00083	0.00122	0.00062	0.00081	0.00120
52	0.00062	0.00082	0.00120	0.00061	0.00080	0.00117	0.00060	0.00079	0.00115
53	0.00060	0.00079	0.00115	0.00059	0.00077	0.00113	0.00059	0.00076	0.00111
54	0.00059	0.00077	0.00111	0.00058	0.00075	0.00108	0.00057	0.00074	0.00107
55	0.00057	0.00074	0.00107	0.00056	0.00073	0.00105	0.00056	0.00072	0.00103
56	0.00056	0.00072	0.00103	0.00055	0.00071	0.00101	0.00055	0.00070	0.00100
57	0.00055	0.00070	0.00100	0.00054	0.00069	0.00098	0.00053	0.00068	0.00097
58	0.00054	0.00068	0.00097	0.00053	0.00067	0.00095	0.00052	0.00066	0.00093
59	0.00052	0.00067	0.00093	0.00052	0.00065	0.00092	0.00051	0.00065	0.00091
60	0.00051	0.00065	0.00091	0.00051	0.00064	0.00089	0.00050	0.00063	0.00088
61	0.00050	0.00063	0.00088	0.00050	0.00062	0.00086	0.00049	0.00062	0.00085
62	0.00050	0.00062	0.00085	0.00049	0.00061	0.00084	0.00049	0.00060	0.00083
63	0.00049	0.00061	0.00083	0.00048	0.00060	0.00082	0.00048	0.00059	0.00081
64	0.00048	0.00059	0.00081	0.00047	0.00058	0.00080	0.00047	0.00058	0.00079
65	0.00047	0.00058	0.00079	0.00047	0.00057	0.00078	0.00046	0.00057	0.00077
66	0.00046	0.00057	0.00077	0.00046	0.00056	0.00076	0.00046	0.00056	0.00075
67	0.00046	0.00056	0.00075	0.00045	0.00055	0.00074	0.00045	0.00055	0.00073
68	0.00045	0.00055	0.00073	0.00045	0.00054	0.00072	0.00044	0.00054	0.00071
69	0.00045	0.00054	0.00072	0.00044	0.00053	0.00071	0.00044	0.00053	0.00070
70	0.00044	0.00053	0.00070	0.00044	0.00052	0.00069	0.00043	0.00052	0.00068
71	0.00043	0.00052	0.00069	0.00043	0.00051	0.00067	0.00043	0.00051	0.00067

6

Table 4 specific discharge

(1/40 : type I) (m^3/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00032	0.00031	0.00030	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00609	0.00420	0.00274	0.00302	0.00200	0.00118	0.00180	0.00104	0.00062
7	0.00871	0.00615	0.00417	0.00455	0.00325	0.00225	0.00289	0.00210	0.00148
8	0.01024	0.00724	0.00491	0.00535	0.00382	0.00263	0.00339	0.00245	0.00172
9	0.01149	0.00812	0.00550	0.00599	0.00427	0.00294	0.00380	0.00274	0.00192
10	0.01174	0.00827	0.00560	0.00612	0.00436	0.00300	0.00388	0.00280	0.00197
11	0.01190	0.00834	0.00562	0.00617	0.00438	0.00301	0.00391	0.00281	0.00197
12	0.01206	0.00840	0.00565	0.00623	0.00441	0.00302	0.00393	0.00283	0.00197
13	0.01222	0.00847	0.00568	0.00628	0.00443	0.00303	0.00396	0.00284	0.00198
14	0.01238	0.00854	0.00570	0.00634	0.00446	0.00304	0.00399	0.00285	0.00198
15	0.01253	0.00860	0.00573	0.00639	0.00448	0.00305	0.00401	0.00286	0.00199
16	0.01186	0.00867	0.00576	0.00645	0.00450	0.00306	0.00404	0.00287	0.00199
17	0.00995	0.00874	0.00579	0.00650	0.00453	0.00307	0.00407	0.00288	0.00200
18	0.00830	0.00880	0.00581	0.00655	0.00455	0.00308	0.00409	0.00290	0.00200
19	0.00700	0.00887	0.00584	0.00632	0.00458	0.00309	0.00412	0.00291	0.00201
20	0.00597	0.00873	0.00587	0.00555	0.00460	0.00310	0.00414	0.00292	0.00201
21	0.00514	0.00776	0.00589	0.00481	0.00463	0.00311	0.00417	0.00293	0.00202
22	0.00448	0.00678	0.00592	0.00420	0.00465	0.00312	0.00395	0.00294	0.00202
23	0.00392	0.00595	0.00595	0.00370	0.00467	0.00313	0.00354	0.00296	0.00203
24	0.00347	0.00526	0.00597	0.00328	0.00470	0.00314	0.00315	0.00297	0.00203
25	0.00310	0.00467	0.00600	0.00293	0.00440	0.00315	0.00282	0.00298	0.00204
26	0.00278	0.00418	0.00603	0.00263	0.00397	0.00316	0.00254	0.00299	0.00204
27	0.00251	0.00377	0.00598	0.00238	0.00359	0.00317	0.00230	0.00300	0.00205
28	0.00228	0.00340	0.00554	0.00216	0.00325	0.00318	0.00209	0.00301	0.00205
29	0.00208	0.00309	0.00504	0.00198	0.00296	0.00319	0.00192	0.00285	0.00206
30	0.00191	0.00283	0.00460	0.00182	0.00271	0.00320	0.00176	0.00263	0.00206
31	0.00176	0.00259	0.00421	0.00168	0.00249	0.00321	0.00163	0.00242	0.00207
32	0.00163	0.00239	0.00387	0.00155	0.00230	0.00322	0.00151	0.00223	0.00207
33	0.00152	0.00221	0.00356	0.00145	0.00213	0.00323	0.00141	0.00207	0.00208
34	0.00141	0.00205	0.00330	0.00135	0.00198	0.00314	0.00131	0.00193	0.00208
35	0.00132	0.00191	0.00306	0.00127	0.00184	0.00295	0.00123	0.00180	0.00209
36	0.00124	0.00179	0.00284	0.00119	0.00172	0.00275	0.00116	0.00168	0.00209
37	0.00117	0.00168	0.00265	0.00112	0.00161	0.00256	0.00109	0.00158	0.00210
38	0.00110	0.00157	0.00248	0.00106	0.00152	0.00240	0.00104	0.00148	0.00210
39	0.00105	0.00148	0.00232	0.00101	0.00143	0.00225	0.00098	0.00140	0.00211
40	0.00099	0.00140	0.00218	0.00096	0.00135	0.00212	0.00094	0.00132	0.00205
41	0.00094	0.00133	0.00206	0.00092	0.00128	0.00200	0.00089	0.00126	0.00196
42	0.00090	0.00126	0.00194	0.00087	0.00122	0.00189	0.00085	0.00119	0.00185
43	0.00086	0.00120	0.00184	0.00084	0.00116	0.00179	0.00082	0.00114	0.00175
44	0.00083	0.00114	0.00174	0.00080	0.00111	0.00169	0.00079	0.00108	0.00166
45	0.00079	0.00109	0.00165	0.00077	0.00106	0.00161	0.00076	0.00104	0.00158

(m³/sec/ha),

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00076	0.00104	0.00157	0.00074	0.00101	0.00153	0.00073	0.00099	0.00151
47	0.00073	0.00100	0.00150	0.00072	0.00097	0.00146	0.00071	0.00095	0.00144
48	0.00071	0.00096	0.00143	0.00069	0.00093	0.00140	0.00068	0.00092	0.00137
49	0.00069	0.00092	0.00137	0.00067	0.00090	0.00134	0.00066	0.00088	0.00132
50	0.00066	0.00089	0.00131	0.00065	0.00086	0.00128	0.00064	0.00085	0.00126
51	0.00064	0.00086	0.00126	0.00063	0.00083	0.00123	0.00062	0.00082	0.00121
52	0.00062	0.00083	0.00121	0.00061	0.00081	0.00118	0.00061	0.00079	0.00116
53	0.00061	0.00080	0.00116	0.00060	0.00078	0.00114	0.00059	0.00077	0.00112
54	0.00059	0.00077	0.00112	0.00058	0.00076	0.00109	0.00058	0.00075	0.00108
55	0.00058	0.00075	0.00108	0.00057	0.00073	0.00105	0.00056	0.00072	0.00104
56	0.00056	0.00073	0.00104	0.00056	0.00071	0.00102	0.00055	0.00070	0.00101
57	0.00055	0.00071	0.00101	0.00054	0.00069	0.00098	0.00054	0.00068	0.00097
58	0.00054	0.00069	0.00097	0.00053	0.00068	0.00095	0.00053	0.00067	0.00094
59	0.00053	0.00067	0.00094	0.00052	0.00066	0.00092	0.00052	0.00065	0.00091
60	0.00052	0.00065	0.00091	0.00051	0.00064	0.00090	0.00051	0.00063	0.00088
61	0.00051	0.00064	0.00089	0.00050	0.00063	0.00087	0.00050	0.00062	0.00086
62	0.00050	0.00062	0.00086	0.00049	0.00061	0.00085	0.00049	0.00061	0.00084
63	0.00049	0.00061	0.00084	0.00048	0.00060	0.00082	0.00048	0.00059	0.00081
64	0.00048	0.00060	0.00082	0.00048	0.00059	0.00080	0.00047	0.00058	0.00079
65	0.00047	0.00058	0.00079	0.00047	0.00058	0.00078	0.00047	0.00057	0.00077
66	0.00047	0.00057	0.00077	0.00046	0.00056	0.00076	0.00046	0.00056	0.00075
67	0.00046	0.00056	0.00076	0.00046	0.00055	0.00074	0.00045	0.00055	0.00073
68	0.00045	0.00055	0.00074	0.00045	0.00054	0.00073	0.00045	0.00054	0.00072
69	0.00045	0.00054	0.00072	0.00044	0.00053	0.00071	0.00044	0.00053	0.00070
70	0.00044	0.00053	0.00070	0.00044	0.00053	0.00069	0.00044	0.00052	0.00069
71	0.00044	0.00052	0.00069	0.00043	0.00052	0.00068	0.00043	0.00051	0.00067

Table 5 specific discharge

(1/5 : type II) (m³/sec/ha).

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00032	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00037	0.00033	0.00031	0.00032	0.00031	0.00030	0.00031	0.00030	0.00030
7	0.00044	0.00038	0.00033	0.00034	0.00032	0.00031	0.00031	0.00031	0.00030
8	0.00045	0.00041	0.00037	0.00037	0.00034	0.00032	0.00033	0.00031	0.00031
9	0.00045	0.00041	0.00037	0.00038	0.00035	0.00033	0.00035	0.00032	0.00031
10	0.00045	0.00041	0.00037	0.00038	0.00035	0.00034	0.00035	0.00033	0.00031
11	0.00045	0.00041	0.00037	0.00038	0.00035	0.00034	0.00035	0.00033	0.00032
12	0.00045	0.00041	0.00037	0.00038	0.00035	0.00034	0.00035	0.00033	0.00032
13	0.00045	0.00041	0.00037	0.00038	0.00035	0.00034	0.00035	0.00033	0.00032
14	0.00047	0.00042	0.00038	0.00038	0.00036	0.00034	0.00035	0.00034	0.00032
15	0.00052	0.00045	0.00039	0.00040	0.00037	0.00034	0.00036	0.00034	0.00033
16	0.00060	0.00050	0.00043	0.00044	0.00039	0.00036	0.00038	0.00035	0.00033
17	0.00072	0.00058	0.00048	0.00050	0.00043	0.00038	0.00041	0.00037	0.00034
18	0.00100	0.00077	0.00059	0.00063	0.00051	0.00043	0.00048	0.00042	0.00037
19	0.00224	0.00159	0.00110	0.00119	0.00087	0.00064	0.00079	0.00061	0.00048
20	0.00307	0.00222	0.00157	0.00169	0.00126	0.00093	0.00114	0.00088	0.00067
21	0.00360	0.00260	0.00182	0.00197	0.00146	0.00106	0.00132	0.00100	0.00076
22	0.00405	0.00292	0.00203	0.00220	0.00162	0.00117	0.00146	0.00111	0.00083
23	0.00448	0.00321	0.00223	0.00242	0.00178	0.00128	0.00160	0.00120	0.00090
24	0.00459	0.00328	0.00228	0.00248	0.00182	0.00131	0.00164	0.00124	0.00092
25	0.00465	0.00330	0.00229	0.00250	0.00183	0.00131	0.00165	0.00124	0.00093
26	0.00471	0.00333	0.00230	0.00251	0.00183	0.00132	0.00166	0.00124	0.00093
27	0.00476	0.00335	0.00231	0.00253	0.00184	0.00132	0.00166	0.00125	0.00093
28	0.00482	0.00337	0.00231	0.00255	0.00185	0.00132	0.00167	0.00125	0.00093
29	0.00488	0.00339	0.00232	0.00256	0.00185	0.00133	0.00168	0.00125	0.00093
30	0.00477	0.00341	0.00233	0.00258	0.00186	0.00133	0.00169	0.00126	0.00093
31	0.00455	0.00343	0.00234	0.00260	0.00187	0.00133	0.00170	0.00126	0.00093
32	0.00433	0.00345	0.00234	0.00262	0.00188	0.00133	0.00170	0.00126	0.00093
33	0.00415	0.00347	0.00235	0.00263	0.00188	0.00134	0.00171	0.00127	0.00094
34	0.00399	0.00349	0.00236	0.00264	0.00189	0.00134	0.00172	0.00127	0.00094
35	0.00375	0.00351	0.00237	0.00255	0.00190	0.00134	0.00173	0.00127	0.00094
36	0.00345	0.00348	0.00237	0.00244	0.00190	0.00134	0.00173	0.00128	0.00094
37	0.00314	0.00335	0.00238	0.00234	0.00191	0.00135	0.00174	0.00128	0.00094
38	0.00286	0.00321	0.00239	0.00226	0.00192	0.00135	0.00175	0.00128	0.00094
39	0.00259	0.00308	0.00240	0.00219	0.00192	0.00135	0.00170	0.00129	0.00094
40	0.00236	0.00297	0.00240	0.00208	0.00193	0.00135	0.00164	0.00129	0.00094
41	0.00216	0.00288	0.00241	0.00195	0.00194	0.00136	0.00158	0.00129	0.00095
42	0.00198	0.00273	0.00242	0.00182	0.00194	0.00136	0.00153	0.00130	0.00095
43	0.00182	0.00256	0.00243	0.00170	0.00190	0.00136	0.00148	0.00130	0.00095
44	0.00168	0.00240	0.00243	0.00158	0.00184	0.00137	0.00144	0.00130	0.00095
45	0.00156	0.00224	0.00244	0.00148	0.00177	0.00137	0.00137	0.00131	0.00095

(m^3/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00146	0.00209	0.00245	0.00138	0.00172	0.00137	0.00130	0.00131	0.00095
47	0.00136	0.00195	0.00239	0.00130	0.00167	0.00137	0.00124	0.00131	0.00095
48	0.00128	0.00183	0.00231	0.00122	0.00162	0.00138	0.00117	0.00131	0.00096
49	0.00120	0.00171	0.00224	0.00115	0.00156	0.00138	0.00111	0.00129	0.00096
50	0.00114	0.00161	0.00217	0.00109	0.00149	0.00138	0.00105	0.00125	0.00096
51	0.00108	0.00151	0.00210	0.00103	0.00142	0.00138	0.00100	0.00122	0.00096
52	0.00102	0.00143	0.00204	0.00098	0.00136	0.00139	0.00095	0.00118	0.00096
53	0.00097	0.00135	0.00198	0.00093	0.00129	0.00139	0.00091	0.00115	0.00096
54	0.00093	0.00128	0.00190	0.00089	0.00123	0.00139	0.00087	0.00113	0.00096
55	0.00089	0.00122	0.00182	0.00085	0.00117	0.00139	0.00083	0.00110	0.00096
56	0.00085	0.00116	0.00174	0.00082	0.00112	0.00139	0.00080	0.00106	0.00097
57	0.00082	0.00111	0.00166	0.00079	0.00107	0.00137	0.00077	0.00103	0.00097
58	0.00078	0.00106	0.00159	0.00076	0.00103	0.00133	0.00074	0.00099	0.00097
59	0.00076	0.00102	0.00151	0.00073	0.00098	0.00130	0.00072	0.00095	0.00097
60	0.00073	0.00098	0.00145	0.00071	0.00094	0.00126	0.00069	0.00092	0.00097
61	0.00070	0.00094	0.00139	0.00068	0.00091	0.00123	0.00067	0.00089	0.00097
62	0.00068	0.00090	0.00133	0.00066	0.00088	0.00121	0.00065	0.00086	0.00097
63	0.00066	0.00087	0.00127	0.00064	0.00085	0.00118	0.00063	0.00083	0.00097
64	0.00064	0.00084	0.00122	0.00062	0.00082	0.00115	0.00061	0.00080	0.00098
65	0.00062	0.00081	0.00118	0.00061	0.00079	0.00112	0.00060	0.00078	0.00097
66	0.00061	0.00079	0.00113	0.00059	0.00077	0.00108	0.00058	0.00075	0.00096
67	0.00059	0.00076	0.00109	0.00058	0.00074	0.00105	0.00057	0.00073	0.00094
68	0.00058	0.00074	0.00105	0.00056	0.00072	0.00102	0.00056	0.00071	0.00092
69	0.00056	0.00072	0.00102	0.00055	0.00070	0.00099	0.00054	0.00069	0.00090
70	0.00055	0.00070	0.00099	0.00054	0.00068	0.00096	0.00053	0.00067	0.00088
71	0.00054	0.00068	0.00095	0.00053	0.00067	0.00093	0.00052	0.00066	0.00087

10

Table 6 specific discharge

(1/10 : type II) (m³/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00034	0.00032	0.00031	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030
6	0.00045	0.00037	0.00033	0.00034	0.00032	0.00031	0.00031	0.00031	0.00030
7	0.00052	0.00045	0.00038	0.00039	0.00034	0.00032	0.00033	0.00032	0.00031
8	0.00052	0.00046	0.00040	0.00041	0.00038	0.00033	0.00036	0.00033	0.00031
9	0.00052	0.00046	0.00040	0.00041	0.00038	0.00035	0.00037	0.00035	0.00032
10	0.00052	0.00046	0.00040	0.00041	0.00038	0.00035	0.00037	0.00035	0.00033
11	0.00052	0.00046	0.00040	0.00041	0.00038	0.00035	0.00037	0.00035	0.00033
12	0.00052	0.00046	0.00040	0.00041	0.00038	0.00035	0.00037	0.00035	0.00033
13	0.00052	0.00046	0.00040	0.00041	0.00038	0.00035	0.00037	0.00035	0.00033
14	0.00055	0.00047	0.00041	0.00042	0.00039	0.00036	0.00038	0.00035	0.00033
15	0.00063	0.00052	0.00044	0.00046	0.00041	0.00037	0.00039	0.00036	0.00034
16	0.00075	0.00060	0.00049	0.00051	0.00044	0.00039	0.00042	0.00038	0.00035
17	0.00093	0.00073	0.00057	0.00060	0.00050	0.00043	0.00048	0.00042	0.00037
18	0.00136	0.00101	0.00075	0.00080	0.00063	0.00051	0.00059	0.00049	0.00041
19	0.00323	0.00228	0.00155	0.00169	0.00121	0.00085	0.00108	0.00080	0.00059
20	0.00437	0.00313	0.00217	0.00235	0.00172	0.00123	0.00154	0.00116	0.00086
21	0.00513	0.00367	0.00253	0.00274	0.00200	0.00142	0.00179	0.00134	0.00098
22	0.00578	0.00413	0.00284	0.00308	0.00224	0.00158	0.00201	0.00149	0.00108
23	0.00640	0.00456	0.00313	0.00340	0.00246	0.00173	0.00220	0.00162	0.00118
24	0.00658	0.00466	0.00319	0.00348	0.00252	0.00177	0.00226	0.00167	0.00121
25	0.00671	0.00469	0.00321	0.00351	0.00253	0.00178	0.00227	0.00167	0.00121
26	0.00683	0.00473	0.00322	0.00355	0.00254	0.00178	0.00229	0.00168	0.00121
27	0.00696	0.00477	0.00323	0.00358	0.00255	0.00179	0.00230	0.00168	0.00122
28	0.00678	0.00481	0.00325	0.00361	0.00257	0.00179	0.00231	0.00169	0.00122
29	0.00644	0.00485	0.00326	0.00365	0.00258	0.00180	0.00233	0.00169	0.00122
30	0.00612	0.00489	0.00327	0.00368	0.00259	0.00180	0.00234	0.00170	0.00122
31	0.00584	0.00493	0.00329	0.00371	0.00260	0.00181	0.00236	0.00171	0.00123
32	0.00561	0.00497	0.00330	0.00361	0.00262	0.00181	0.00237	0.00171	0.00123
33	0.00517	0.00494	0.00331	0.00345	0.00263	0.00182	0.00239	0.00172	0.00123
34	0.00468	0.00473	0.00333	0.00329	0.00264	0.00182	0.00240	0.00172	0.00123
35	0.00419	0.00452	0.00334	0.00316	0.00265	0.00183	0.00239	0.00173	0.00123
36	0.00375	0.00433	0.00335	0.00305	0.00267	0.00183	0.00231	0.00174	0.00124
37	0.00335	0.00416	0.00337	0.00288	0.00268	0.00184	0.00221	0.00174	0.00124
38	0.00300	0.00401	0.00338	0.00268	0.00269	0.00184	0.00213	0.00175	0.00124
39	0.00271	0.00376	0.00339	0.00247	0.00264	0.00185	0.00205	0.00175	0.00124
40	0.00246	0.00349	0.00341	0.00227	0.00254	0.00185	0.00199	0.00176	0.00125
41	0.00224	0.00322	0.00342	0.00209	0.00244	0.00185	0.00190	0.00176	0.00125
42	0.00205	0.00297	0.00340	0.00192	0.00235	0.00186	0.00178	0.00177	0.00125
43	0.00189	0.00274	0.00329	0.00177	0.00228	0.00186	0.00167	0.00178	0.00125
44	0.00174	0.00252	0.00316	0.00164	0.00221	0.00187	0.00156	0.00175	0.00125
45	0.00162	0.00233	0.00305	0.00153	0.00211	0.00187	0.00146	0.00169	0.00126

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(m^3/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00151	0.00216	0.00295	0.00142	0.00199	0.00188	0.00137	0.00164	0.00126
47	0.00141	0.00201	0.00285	0.00133	0.00188	0.00188	0.00129	0.00159	0.00126
48	0.00132	0.00188	0.00277	0.00125	0.00177	0.00189	0.00121	0.00154	0.00126
49	0.00124	0.00176	0.00264	0.00118	0.00167	0.00189	0.00114	0.00150	0.00127
50	0.00117	0.00165	0.00250	0.00111	0.00157	0.00190	0.00108	0.00145	0.00127
51	0.00111	0.00155	0.00237	0.00105	0.00148	0.00186	0.00102	0.00140	0.00127
52	0.00105	0.00147	0.00224	0.00100	0.00140	0.00180	0.00097	0.00133	0.00127
53	0.00100	0.00139	0.00212	0.00095	0.00133	0.00175	0.00093	0.00128	0.00128
54	0.00095	0.00131	0.00201	0.00091	0.00126	0.00170	0.00089	0.00122	0.00128
55	0.00091	0.00125	0.00190	0.00087	0.00120	0.00165	0.00085	0.00116	0.00128
56	0.00087	0.00119	0.00180	0.00084	0.00114	0.00161	0.00081	0.00111	0.00128
57	0.00083	0.00113	0.00171	0.00080	0.00109	0.00157	0.00078	0.00106	0.00128
58	0.00080	0.00108	0.00163	0.00077	0.00105	0.00152	0.00075	0.00102	0.00128
59	0.00077	0.00104	0.00155	0.00074	0.00100	0.00146	0.00073	0.00098	0.00125
60	0.00074	0.00100	0.00148	0.00072	0.00096	0.00141	0.00070	0.00094	0.00122
61	0.00072	0.00096	0.00141	0.00069	0.00092	0.00135	0.00068	0.00090	0.00119
62	0.00069	0.00092	0.00135	0.00067	0.00089	0.00130	0.00066	0.00087	0.00116
63	0.00067	0.00089	0.00130	0.00065	0.00086	0.00125	0.00064	0.00084	0.00114
64	0.00065	0.00086	0.00125	0.00063	0.00083	0.00120	0.00062	0.00081	0.00111
65	0.00063	0.00083	0.00120	0.00062	0.00080	0.00116	0.00061	0.00079	0.00109
66	0.00061	0.00080	0.00115	0.00060	0.00078	0.00112	0.00059	0.00076	0.00107
67	0.00060	0.00078	0.00111	0.00059	0.00075	0.00108	0.00058	0.00074	0.00104
68	0.00058	0.00075	0.00107	0.00057	0.00073	0.00104	0.00056	0.00072	0.00101
69	0.00057	0.00073	0.00103	0.00056	0.00071	0.00101	0.00055	0.00070	0.00098
70	0.00055	0.00071	0.00100	0.00055	0.00069	0.00097	0.00054	0.00068	0.00095
71	0.00054	0.00069	0.00097	0.00053	0.00067	0.00094	0.00053	0.00066	0.00092

Table 7 specific discharge

(1/20: type II) (m³/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00037	0.00033	0.00031	0.00032	0.00031	0.00030	0.00031	0.00030	0.00030
6	0.00055	0.00044	0.00036	0.00037	0.00033	0.00031	0.00033	0.00031	0.00031
7	0.00060	0.00051	0.00043	0.00045	0.00039	0.00034	0.00037	0.00033	0.00031
8	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00039	0.00036	0.00032
9	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00040	0.00037	0.00034
10	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00040	0.00037	0.00035
11	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00040	0.00037	0.00035
12	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00040	0.00037	0.00035
13	0.00061	0.00052	0.00044	0.00046	0.00041	0.00037	0.00040	0.00037	0.00035
14	0.00065	0.00054	0.00046	0.00047	0.00042	0.00038	0.00041	0.00037	0.00035
15	0.00076	0.00062	0.00050	0.00052	0.00045	0.00040	0.00043	0.00039	0.00036
16	0.00093	0.00073	0.00058	0.00060	0.00050	0.00043	0.00048	0.00042	0.00037
17	0.00119	0.00091	0.00069	0.00073	0.00059	0.00048	0.00055	0.00047	0.00040
18	0.00180	0.00132	0.00095	0.00102	0.00078	0.00060	0.00072	0.00058	0.00047
19	0.00444	0.00312	0.00211	0.00230	0.00163	0.00112	0.00145	0.00105	0.00075
20	0.00595	0.00423	0.00290	0.00315	0.00228	0.00160	0.00204	0.00150	0.00109
21	0.00699	0.00497	0.00340	0.00369	0.00266	0.00186	0.00238	0.00174	0.00125
22	0.00789	0.00560	0.00382	0.00416	0.00299	0.00208	0.00267	0.00195	0.00139
23	0.00874	0.00620	0.00422	0.00459	0.00329	0.00229	0.00294	0.00214	0.00152
24	0.00907	0.00633	0.00430	0.00471	0.00337	0.00234	0.00301	0.00219	0.00156
25	0.00934	0.00640	0.00432	0.00477	0.00339	0.00235	0.00303	0.00220	0.00156
26	0.00945	0.00647	0.00434	0.00483	0.00341	0.00235	0.00306	0.00221	0.00156
27	0.00897	0.00654	0.00437	0.00489	0.00343	0.00236	0.00308	0.00222	0.00157
28	0.00849	0.00661	0.00439	0.00495	0.00345	0.00237	0.00311	0.00223	0.00157
29	0.00808	0.00668	0.00441	0.00501	0.00347	0.00238	0.00313	0.00224	0.00157
30	0.00774	0.00674	0.00443	0.00486	0.00349	0.00238	0.00316	0.00225	0.00158
31	0.00719	0.00665	0.00446	0.00462	0.00351	0.00239	0.00318	0.00226	0.00158
32	0.00647	0.00634	0.00448	0.00441	0.00354	0.00240	0.00321	0.00227	0.00159
33	0.00573	0.00604	0.00450	0.00422	0.00356	0.00241	0.00313	0.00228	0.00159
34	0.00505	0.00577	0.00452	0.00407	0.00358	0.00242	0.00300	0.00229	0.00159
35	0.00444	0.00555	0.00455	0.00379	0.00360	0.00242	0.00287	0.00229	0.00160
36	0.00392	0.00527	0.00457	0.00347	0.00354	0.00243	0.00276	0.00230	0.00160
37	0.00349	0.00487	0.00459	0.00316	0.00340	0.00244	0.00266	0.00231	0.00160
38	0.00313	0.00446	0.00461	0.00287	0.00325	0.00245	0.00254	0.00232	0.00161
39	0.00282	0.00407	0.00454	0.00260	0.00313	0.00245	0.00238	0.00233	0.00161
40	0.00255	0.00371	0.00436	0.00237	0.00302	0.00246	0.00220	0.00233	0.00162
41	0.00232	0.00338	0.00418	0.00216	0.00291	0.00247	0.00204	0.00226	0.00162
42	0.00212	0.00308	0.00402	0.00198	0.00275	0.00248	0.00189	0.00218	0.00162
43	0.00195	0.00283	0.00388	0.00183	0.00258	0.00249	0.00175	0.00210	0.00163
44	0.00180	0.00260	0.00376	0.00169	0.00241	0.00249	0.00162	0.00203	0.00163
45	0.00167	0.00240	0.00358	0.00157	0.00225	0.00250	0.00151	0.00197	0.00163

(m³/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
46	0.00156	0.00223	0.00338	0.00146	0.00210	0.00249	0.00141	0.00190	0.00164
47	0.00145	0.00207	0.00318	0.00137	0.00196	0.00242	0.00132	0.00182	0.00164
48	0.00136	0.00193	0.00298	0.00128	0.00183	0.00234	0.00124	0.00172	0.00165
49	0.00128	0.00180	0.00279	0.00121	0.00171	0.00226	0.00117	0.00163	0.00165
50	0.00120	0.00169	0.00262	0.00114	0.00161	0.00219	0.00110	0.00155	0.00165
51	0.00113	0.00159	0.00246	0.00108	0.00152	0.00213	0.00104	0.00146	0.00166
52	0.00107	0.00150	0.00231	0.00102	0.00143	0.00207	0.00099	0.00139	0.00166
53	0.00102	0.00142	0.00218	0.00097	0.00136	0.00200	0.00094	0.00132	0.00164
54	0.00097	0.00135	0.00205	0.00093	0.00129	0.00191	0.00090	0.00125	0.00160
55	0.00092	0.00128	0.00194	0.00089	0.00122	0.00183	0.00086	0.00119	0.00155
56	0.00088	0.00122	0.00184	0.00085	0.00116	0.00174	0.00083	0.00113	0.00151
57	0.00085	0.00116	0.00174	0.00082	0.00111	0.00166	0.00080	0.00108	0.00147
58	0.00081	0.00111	0.00166	0.00079	0.00106	0.00159	0.00077	0.00104	0.00143
59	0.00078	0.00106	0.00158	0.00076	0.00102	0.00152	0.00074	0.00099	0.00140
60	0.00075	0.00102	0.00151	0.00073	0.00098	0.00145	0.00071	0.00095	0.00137
61	0.00072	0.00097	0.00144	0.00070	0.00094	0.00139	0.00069	0.00092	0.00132
62	0.00070	0.00094	0.00138	0.00068	0.00090	0.00133	0.00067	0.00088	0.00128
63	0.00068	0.00090	0.00132	0.00066	0.00087	0.00128	0.00065	0.00085	0.00123
64	0.00066	0.00087	0.00127	0.00064	0.00084	0.00123	0.00063	0.00082	0.00119
65	0.00064	0.00084	0.00122	0.00062	0.00081	0.00118	0.00061	0.00080	0.00115
66	0.00062	0.00081	0.00117	0.00061	0.00079	0.00113	0.00060	0.00077	0.00111
67	0.00060	0.00079	0.00113	0.00059	0.00076	0.00109	0.00058	0.00075	0.00107
68	0.00059	0.00076	0.00109	0.00058	0.00074	0.00106	0.00057	0.00073	0.00103
69	0.00057	0.00074	0.00105	0.00056	0.00072	0.00102	0.00056	0.00071	0.00100
70	0.00056	0.00072	0.00101	0.00055	0.00070	0.00099	0.00054	0.00069	0.00097
71	0.00055	0.00070	0.00098	0.00054	0.00068	0.00095	0.00053	0.00067	0.00094

14

Table 8 specific discharge

(1/40 : type II) (m³/sec/ha)

Time (hr) \ case	A	B	C	D	E	F	G	H	I
1	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
2	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
3	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
4	0.00031	0.00031	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030	0.00030
5	0.00043	0.00036	0.00033	0.00033	0.00031	0.00031	0.00031	0.00031	0.00030
6	0.00065	0.00053	0.00041	0.00043	0.00036	0.00033	0.00035	0.00032	0.00031
7	0.00071	0.00058	0.00048	0.00050	0.00044	0.00037	0.00042	0.00036	0.00032
8	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00035
9	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00036
10	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00036
11	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00036
12	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00036
13	0.00071	0.00059	0.00049	0.00051	0.00045	0.00040	0.00043	0.00039	0.00036
14	0.00078	0.00063	0.00051	0.00054	0.00046	0.00041	0.00044	0.00040	0.00036
15	0.00093	0.00073	0.00058	0.00061	0.00051	0.00043	0.00048	0.00042	0.00038
16	0.00115	0.00088	0.00068	0.00072	0.00058	0.00048	0.00054	0.00046	0.00040
17	0.00151	0.00113	0.00084	0.00089	0.00070	0.00055	0.00065	0.00053	0.00045
18	0.00234	0.00169	0.00120	0.00129	0.00096	0.00072	0.00088	0.00068	0.00054
19	0.00589	0.00413	0.00278	0.00303	0.00214	0.00146	0.00190	0.00136	0.00094
20	0.00784	0.00555	0.00378	0.00411	0.00295	0.00205	0.00263	0.00191	0.00136
21	0.00922	0.00653	0.00443	0.00482	0.00345	0.00239	0.00307	0.00223	0.00158
22	0.01041	0.00736	0.00499	0.00544	0.00388	0.00268	0.00346	0.00250	0.00176
23	0.01154	0.00815	0.00552	0.00601	0.00429	0.00295	0.00381	0.00275	0.00193
24	0.01221	0.00834	0.00562	0.00618	0.00438	0.00301	0.00391	0.00281	0.00197
25	0.01232	0.00846	0.00566	0.00629	0.00442	0.00302	0.00395	0.00283	0.00198
26	0.01166	0.00858	0.00569	0.00640	0.00445	0.00303	0.00399	0.00284	0.00198
27	0.01103	0.00870	0.00573	0.00651	0.00448	0.00305	0.00403	0.00286	0.00199
28	0.01049	0.00882	0.00576	0.00647	0.00452	0.00306	0.00407	0.00287	0.00199
29	0.01005	0.00884	0.00580	0.00616	0.00455	0.00307	0.00412	0.00289	0.00200
30	0.00910	0.00843	0.00584	0.00585	0.00459	0.00308	0.00416	0.00290	0.00201
31	0.00805	0.00800	0.00587	0.00558	0.00462	0.00310	0.00408	0.00292	0.00201
32	0.00702	0.00763	0.00591	0.00536	0.00466	0.00311	0.00389	0.00294	0.00202
33	0.00608	0.00731	0.00594	0.00502	0.00469	0.00312	0.00372	0.00295	0.00202
34	0.00529	0.00695	0.00598	0.00459	0.00455	0.00313	0.00356	0.00297	0.00203
35	0.00463	0.00639	0.00601	0.00413	0.00435	0.00314	0.00343	0.00298	0.00203
36	0.00408	0.00580	0.00602	0.00371	0.00416	0.00316	0.00325	0.00300	0.00204
37	0.00363	0.00523	0.00579	0.00332	0.00399	0.00317	0.00301	0.00301	0.00205
38	0.00324	0.00471	0.00554	0.00298	0.00385	0.00318	0.00276	0.00293	0.00205
39	0.00292	0.00424	0.00531	0.00269	0.00367	0.00319	0.00253	0.00281	0.00206
40	0.00264	0.00384	0.00510	0.00244	0.00343	0.00320	0.00231	0.00270	0.00206
41	0.00240	0.00348	0.00493	0.00222	0.00318	0.00322	0.00212	0.00260	0.00207
42	0.00220	0.00318	0.00470	0.00204	0.00294	0.00323	0.00194	0.00252	0.00207
43	0.00202	0.00291	0.00441	0.00188	0.00271	0.00318	0.00179	0.00243	0.00208
44	0.00186	0.00267	0.00411	0.00173	0.00251	0.00307	0.00166	0.00231	0.00209
45	0.00172	0.00247	0.00383	0.00161	0.00232	0.00296	0.00154	0.00217	0.00209

(m³/sec/ha)

case Time (hr)	A	B	C	D	E	F	G	H	I
46	0.00160	0.00228	0.00356	0.00150	0.00215	0.00285	0.00144	0.00204	0.00210
47	0.00149	0.00212	0.00331	0.00140	0.00200	0.00276	0.00134	0.00191	0.00210
48	0.00139	0.00198	0.00308	0.00131	0.00187	0.00268	0.00126	0.00180	0.00211
49	0.00131	0.00185	0.00287	0.00124	0.00175	0.00259	0.00119	0.00169	0.00208
50	0.00123	0.00173	0.00268	0.00117	0.00164	0.00247	0.00112	0.00159	0.00202
51	0.00116	0.00163	0.00251	0.00110	0.00155	0.00234	0.00106	0.00150	0.00195
52	0.00109	0.00154	0.00236	0.00105	0.00146	0.00222	0.00101	0.00141	0.00189
53	0.00104	0.00145	0.00222	0.00099	0.00138	0.00210	0.00096	0.00134	0.00184
54	0.00099	0.00137	0.00209	0.00095	0.00131	0.00199	0.00092	0.00127	0.00179
55	0.00094	0.00130	0.00198	0.00090	0.00124	0.00189	0.00088	0.00121	0.00175
56	0.00090	0.00124	0.00187	0.00086	0.00118	0.00179	0.00084	0.00115	0.00169
57	0.00086	0.00118	0.00178	0.00083	0.00113	0.00170	0.00081	0.00110	0.00162
58	0.00082	0.00113	0.00169	0.00080	0.00108	0.00162	0.00078	0.00105	0.00155
59	0.00079	0.00108	0.00161	0.00077	0.00103	0.00155	0.00075	0.00101	0.00149
60	0.00076	0.00103	0.00153	0.00074	0.00099	0.00147	0.00072	0.00097	0.00143
61	0.00073	0.00099	0.00146	0.00071	0.00095	0.00141	0.00070	0.00093	0.00137
62	0.00071	0.00095	0.00140	0.00069	0.00092	0.00135	0.00068	0.00090	0.00131
63	0.00068	0.00091	0.00134	0.00067	0.00088	0.00129	0.00066	0.00086	0.00126
64	0.00066	0.00088	0.00129	0.00065	0.00085	0.00124	0.00064	0.00083	0.00121
65	0.00064	0.00085	0.00123	0.00063	0.00083	0.00119	0.00062	0.00081	0.00117
66	0.00062	0.00082	0.00119	0.00061	0.00080	0.00115	0.00060	0.00078	0.00112
67	0.00061	0.00079	0.00114	0.00060	0.00077	0.00111	0.00059	0.00076	0.00108
68	0.00059	0.00077	0.00110	0.00058	0.00075	0.00107	0.00057	0.00074	0.00105
69	0.00058	0.00075	0.00106	0.00057	0.00073	0.00103	0.00056	0.00072	0.00101
70	0.00056	0.00073	0.00103	0.00055	0.00071	0.00100	0.00055	0.00070	0.00098
71	0.00055	0.00070	0.00100	0.00054	0.00069	0.00097	0.00054	0.00068	0.00095

ANNEX B

MATHEMATICAL MODEL SIMULATION OF UNSTEADY FLOW IN OPEN CHANNELS, CLOSED CONDUITS, LAKES, ESTUARIES AND BAYS

by

HIDEHIKO SHIRAISHI

Chief, 4th Laboratory of Hydraulics

National Research Institute of Agricultural Engineering

Ministry of Agriculture and Forestry

CONTENTS

VIII. UNSTEADY FLOW IN CLOSED CONDUIT

IX. TWO-DIMENSIONAL UNSTEADY FLOW

REFERENCES

I. ROLE OF MATHEMATICAL MODEL SIMULATION FOR IRRIGATION AND DRAINAGE SYSTEMS ANALYSIS

Irrigation and drainage systems planning involves many complex conditions, and a variety of schemes is presented for consideration. Among them the most suitable one is to be chosen. In this course, speculation of the vital role of actual hydraulic phenomena is taken up. For this purpose, a hydraulic model with similarities to a prototype is conventionally prepared, and water is allowed to flow through it to observe the flow phenomena under various conditions. In the circumstances where the area concerned covers the whole basin or a fairly extensive region, it is often difficult to represent a prototype by using physical model made of wood and cement. In recent years, the advancement of computer technology has stimulated the development of computer software for representing a prototype. This type of model is called a mathematical model, which is put together by incorporating physical laws and other geometric conditions which govern the hydraulic phenomena.

In the design of irrigation and drainage systems, it is important to remember that the components of facilities are not to be treated as independent, but as a system, and the functions of each component are to be considered as a whole. Accordingly, the hydraulic phenomena in irrigation and drainage systems turns out an unsteady flow, and so the dynamics of flow are taken into full consideration. The physical laws which govern an unsteady flow are the following two; that is, one is the equation of motion which controls the motion of flow, and another is the equation of continuity which represents the change of water level due to the inflow and outflow. These two equations are both partially differential expressions.

For given initial and boundary conditions, the equation are integrated numerically with respect to time and distance by means of a mathematical model. In this course, characteristics such as discharge, stage, velocity and so forth at arbitrary points and times are obtained. These computer-oriented simulation techniques are capable of handling problem of hydraulic phenomena in irrigation and drainage systems in an extremely short time and of choosing an optimum scheme from various alternatives.

In the development of a numerical solution, the method of analysis was first tested, using a system of physical characteristics for which the hydraulic behaviour was known. In Fig. 1, the polygonal lines of stage and velocity were obtained by mathematical model simulation, while the solid circles are by actual measurement at the site. Considering the accuracy of the measurements, the mathematical model seems to well represent the hydraulic behaviour of the prototype.

II. MATHEMATICAL MODEL

The fundamental procedure of mathematical model simulation is described for a one-dimensional unsteady free surface flow for reasons of simplicity.

1. Fundamental Equations

Hydraulic characteristics of an unsteady flow are given by simultaneous solution of both the equation of motion and that of continuity. The fundamental equation of a one-dimensional flow are expressed as follows with the downstream end as the origin.

$$\begin{cases} \frac{1}{g}\left(\frac{\partial v}{\partial t}\right) + \frac{1}{g}\frac{\partial}{\partial x}\left(\frac{v^2}{2}\right) + S + \frac{\partial h}{\partial x} + \frac{n^2|v|}{h^{4/3}}v = 0 & (1) \\ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 & (2) \end{cases}$$

Here,

g: acceleration of gravity,

v: velocity (positive for the upstream direction),

s: bottom slope,

h: water depth,

x: distance in longitudinal directions on a horizontal datum plane,

n: Manning's roughness coefficient,

t: elapsed time,

A: cross-sectional area,

Q: discharge through a section,

q: lateral inflow per unit length (positive for inflow, negative for outflow)

2. Operation Grid Systems

In representation of hydraulic behaviour in a mathematical model, the fundamental equations (1) and (2) are converted into difference expressions. Then, for the given initial, boundary and geometric conditions, the numerical integration is performed. It is desirable to constitute the efficient and economic grid system from the standpoint of computer performance. The calculation proceeds from the downstream to the upstream, with distance interval Δx and time interval Δt as shown in Fig. 2, where i and n indicate distance and time, respectively.

The initial values of water depth are thus set at the points of n=1 and even i's. The initial values of velocity are also set at the points of n=2, which is $\Delta t/2$ in progress to n=1, and odd i's. This means that the water depth and the velocity are set at separate points by $\Delta t/2$ in time and $\Delta x/2$ in distance from one to the other. First, from these initial values, the water depth at the points on n=3 is obtained as follows: The equation of continuity is solved at the points of n=2 or time t by using the values at n=1 and n=2. In this case, however, it is taken that the velocity at n=2 keeps for time interval $(t + \Delta t/2) - (t - \Delta t/2) = \Delta t$; and the equation of continuity is integrated for Δx and the water depth concerned is obtained. Then, to obtain the velocity at the points of n=4, the equation of motion is treated at n=3. The water depth at n=3 is thus maintained for time interval Δt; and the equation of motion is integrated along Δx, to calculate the velocity at n=4 by using the values of n=2 and n=3. In order to retain the computer memory the water depth at n=3 and the velocity at n=4 thus derived are shifted to n=1 and n=2, respectively. These values are set to be the initial values for the following time, and the procedure is repeated on.

The selection of the time interval to be used is not arbitrary. It is well-known that solving by finite differences method will not produce a stable solution unless the distance interval, Δx, and the time interval, Δt, are related to the velocity of the long wave, such that

$$\Delta t < \left| \frac{\Delta x}{V_{max} \pm \sqrt{gh_{max}}} \right| \qquad (3)$$

If the value of Δt exceeds that given above, the transmission of hydraulic phenomena goes beyond the tracing speed in the mathematical model and the solution is led to uncoveragence. The values of Δt and Δx must thus be determined to satisfy the expression (3), by speculating in advance the maximum possible velocity and water depth.

In computer programming, it is convenient to use a two-dimensional array of i and n to express the water depth and velocity at grid points, where n is 4. In this case, the remaining memory of the points of n=1 or n=3 and odd i's, and those of n=2 or n=4 and even i's may be used for other information such as of the geometric conditions and so on.

3. Geometric Conditions

The geometric conditions required in a mathematical model are the cross-sectional area and the bottom slope. The cross-sectional area at point i, Ai, is expressed as

$$A_i = f_i(h) \qquad (4)$$

Here, h is the water depth over the bottom. The cross-sectional area in expression (4) is set at the point of even i's. The log-log plotting of Ai and h_i in Eq. (4) is usually in a straight line, and expressed as

$$A_i = a_i h^{m} \qquad (5)$$

Therefore, the cross-sectional areas are represented by a_i and m_i. In the case of a compound cross section, it is then represented approximately by two straight lines which are connected together at a bending point. An example of this for Ino on the Ishikari River is shown in Fig. 3. If the above procedure is not effective, the Lagrange's interpolation method is available to represent the relationship between water depth and a cross-sectional area. Another geometric condition is the bottom slope. From this and the water depth, the hydraulic gradient can be calculated, which is used to solve the equation of motion. In the equation of motion, the velocity concerned is obtained on the basis of the hydraulic gradient between the adjoining even points with the point of the odd i at the center. The bottom altitude, therefore, is set at the points of even i's.

4. Difference Expression of Fundamental Equations

The accuracy of a mathematical model is determined by the difference expressions of the fundamental equations. In choosing the difference expressions, the scale of the prototype and the computer performance must be taken into consideration. In the present case, the central difference expression with respect to distance x and time t, is employed, which possess relatively high accuracy despite the simplicity in treatment. To show the difference expression, suffix i is used for distance and n for time. The difference center is taken at the point (i, n-1); and the unknown values at the point (i, n) are obtained from the initial and boundary conditions.

1) Difference expressions of the equation motion

In the equation of motion (1), the central differences for respective terms are expressed, as follows.

$$\frac{\partial v}{\partial t} = \frac{{}_{n}V_{i} - {}_{n-2}V_{i}}{\Delta t}$$

$$\frac{\partial h}{\partial x} = \frac{{}_{n-1}h_{i+1} - {}_{n-1}h_{i-1}}{\Delta x}$$

$$\frac{\partial v^2}{\partial x} = \frac{{}_{n-1}V^2_{i+1} - {}_{n-2}V^2_{i-2}}{2\Delta x}$$

$$S = \frac{z_{i+1} - z_{i-1}}{\Delta x}$$

$$h = \frac{{}_{n-1}h_{i+1} + {}_{n-1}h_{i-1}}{2}$$

$$V = \frac{{}_{n}V_{i} + {}_{n-2}V_{i}}{2}$$

$$|V| = |\, {}_{n-2}V_{i} \,|$$

Here, z is the bottom altitude.

In the above difference expressions, the value of $\partial v^2/\partial x$ is backward in time. Since this term is mainly due to the change of the cross-sectional area with respect to distance, its central value for Δx has a sufficient accuracy. The value of $|v|$ is also backward. Theoretically, $|v|$ must be expressed in difference form which includes the unknown value of ${}_nV_i$. It is, however, highly complicated in calculating the unknown ${}_nV_i$. The term of v is thus included in the value of ${}_nV_i$, and for the value of $|V|$ the known value of $|{}_{n-2}V_i|$ is used instead.

The value of ${}_nV_i$ is obtained by substituting the difference expressions (6) into the equation of motion (1). This procedure is shown in Fig. 4. The value of ${}_nV_i$ is thus derived from two values of water depth at time n-1 and three values of velocity at n-2.

2) Difference expressions of the equation of continuity

The following treatment is made to increase the accuracy in continuity condition between the distance interval Δx of an open channel of irregular shape as shown in Fig. 5. To obtain the water depth at distance grid i and time t, the cross-sectional areas at the points 1, 2 and 3 are first obtained, where the water depth at time t - Δt is already assigned.

(i) Treatment of $\partial A/\partial t$

$$\frac{\partial A}{\partial t} = \frac{\partial A}{\partial h}\frac{\partial h}{\partial t} = (\text{channel width}) \times \frac{\partial h}{\partial t} \qquad (7)$$

Here, the width of an open channel is the average over the interval Δx. The cross-sectional area expressed by Eq. (5) is assigned at points 1, 2 and 3 in Fig. 5. The channel width, w, between ℓ and m, is thus averaged as follows, at the points 1, 2 and 3.

$$Wi = \frac{\partial Ai}{\partial h} \qquad i = 1, 2, 3 \qquad (8)$$

Substituting Eq. (5) into (8),

$$Wi = \frac{\partial Ai}{\partial h} = a_i m_i h^{mi-1} \qquad i = 1, 2, 3 \qquad (9)$$

and hence $W\ell$ and Wm are given

$$W\ell = \frac{W1 + W2}{2}, \quad Wm = \frac{W2 + W3}{2} \qquad (10)$$

Therefore, the surface area, As, at the interval between points ℓ and m, is given by

$$As = (3W_2 + \frac{W_1 + W_3}{2})\frac{\Delta x}{4} \qquad (11)$$

The average channel width, W, between points ℓ and m, is given as

$$W = \frac{As}{\Delta x} = \frac{1}{4}(3W_2 + \frac{W_1 + W_3}{2}) \qquad (12)$$

Upon substitution of this expression into Eq. (7),

$$\frac{\partial A}{\partial t} = \frac{1}{4}(3W_2 + \frac{W_1 + W_3}{2})(\frac{{}^{n}h_i - {}^{n-2}h_i}{\Delta t}) \qquad (13)$$

(ii) Treatment of $\partial Q/\partial x$

In Fig. 5, the cross-sectional area at point m is given by $(A_2 + A_3)/2$, and that at point ℓ is $(A_1 + A_2)/2$. The velocity at points m and ℓ, Vm and $V\ell$, respectively, are already obtained from the equation of motion. Hence the discharge through point m is given by $(A_2 + A_3)Vm/2$ and that through point ℓ is $(A_1 + A_2)\ V\ell/2$.

Therefore

$$\frac{\partial Q}{\partial x} = \frac{1}{\Delta x}\left(\frac{A_2 + A_3}{2}\ Vm - \frac{A_1 + A_2}{2}\ V\ell \right) \qquad (14)$$

To obtain the cross-sectional area in the above difference expressions (13) and (14), the backward water depth is used. The reason for it is that if a forward unknown value is used, the calculation becomes fairly complicated. Moreover, the central difference expression with respect to distance gives sufficient accuracy, because the change in cross-sectional area with respect to distance is far larger than that with respect to time.

(iii) Treatment of q

The inflow to and outflow from the open channel concerned are treated by the term q. The inflow or outflow by pumping are the examples of this.

To obtain the value of $_nh_i$, the equation of continuity is converted into difference expressions, incorporating the difference terms (13), (14) and q.

5. Roughness Coefficient

In the mathematical model, hydraulic behaviour is simulated without reducing the scale of the prototype and involving the law of similitude unlike the hydraulic model test. In the fundamental equations, however, the constant such as Manning's roughness coefficient, which is inherent to the prototype, is included. The treatment of this constant, determines the similarity of the mathematical model to the prototype. A procedure for determining Manning's roughness coefficient is described below:

In the section of an open channel where the roughness coefficient is to be determined, the water stage, h_o, is measured around the midpoint when the boundary conditions are actually observed. By mathematical model simulation under the same boundary conditions as the prototype, the stage h_d, at the time and distance concerned is obtained. In this procedure, several different values of the roughness coefficient are given and followed by simulation. The relationship between the given roughness coefficient and h_c/h_o is shown in Fig.7. In the figure, simulation is made for two values, n=0.025 and 0.045. The value of n of the prototype and that of the mathematical model agree with each other when h_c/h_o is equal to unity. The roughness coefficient in this case can be determined to be n=0.035.

III. INITIAL CONDITIONS

The procedure for setting the initial conditions is described as follows: When the discharge-time relationship is relatively constant, the initial storage in a channel is not much of a problem, and the average water depth may be taken. The velocity in this case is taken