Research Notes of the N. R. C. D. P., No.24, July 1976

551.579.1 551.482.2(282.2)

ON A METHOD OF FORECASTING THE DAILY DISCHARGE OF THE MAE NAM CHAO PHRAYA AND ITS TRIBUTARIES AT SEVERAL POINTS BY MEANS OF TANK MODEL

By

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1. The purpose and outline of the present report

1.1 The purpose of the present report is to calculate the daily discharge of the Mae Nam Chao Phraya at Nakhon Sawan (catchment area being 110,569 km^2) and its tributaries, i.e. the Mae Nam Ping at Wang Kra Chao (26,369 km^2), the Mae Nam Yom at Kaeng Luang (12,658 km^2) and the Mae Nam Nan at Tha Pla (13,086 km^2), from the daily precipitation observed in or near the respective basins.

1.2 The locations of river gauges and rainfall stations are shown in Fig. 1.

1.3 The tank model which is used for the calculation of daily discharge will be briefly described in the next section.

1.4 The obtained results are fairly good for Nakhon Sawan and Tha Pla, but are not so good for Wang Kra Chao and Kaeng Luang, because of the large areal fluctuation of precipitation which will be described in section 3.

2. Tank model

2.1 Simple tank model for humid regions

2.1.1 In humid regions, where it rains all the year round and

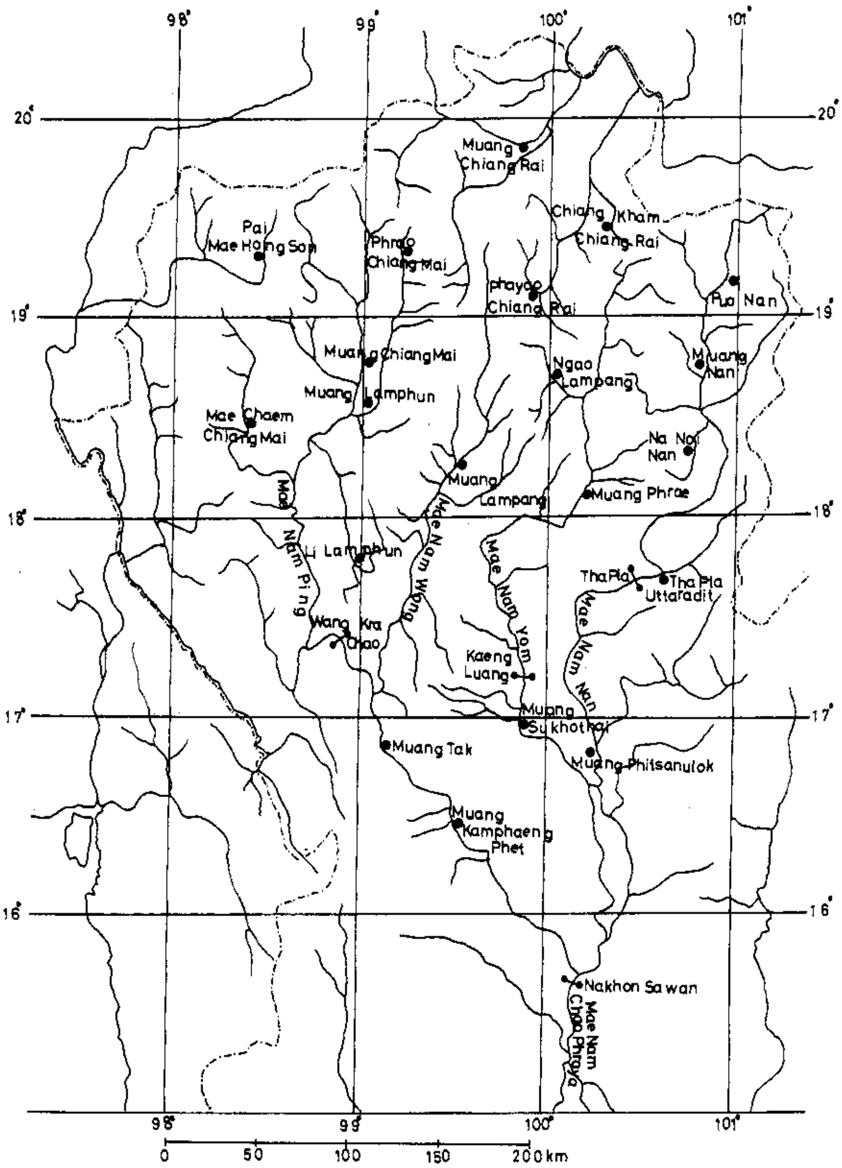
98°
99°
100°
101°
20°
19°
18°
17°
16°
Muang Chiang Rai
Chiang Kham Chiang Rai
Pai Mae Hong Son
Phrao Chiang Mai
Phayao Chiang Rai
Pua Nan
Muang Chiang Mai
Ngao Lampang
Muang Nan
Muang Lamphun
Mae Chaem Chiang Mai
Na Noi Nan
Muang Lampang
Muang Phrae
Mae Nam Ping
Li Lamphun
Mae Nam Wang
Mae Nam Yom
Tha Pla
Tha Pla Uttaradit
Mae Nam Nan
Wang Kra Chao
Kaeng Luang
Muang Sukhothai
Muang Tak
Muang Phitsanulok
Muang Kamphaeng Phet
Nakhon Sawan
Mae Nam Chao Phraya
0
50
100
150
200 km

Fig. 1

where the soil is always wet owing to rainfall or water supply from ground water, we can simulate the runoff structure of river basins fairly well by the simple tank model schematically shown in Fig. 2. It is composed of several tanks laid vertically in series where each of the tanks has one or several outlets in its side wall and one outlet in its bottom. Rainwater is put into the top tank, and water in each tank partly goes down to the next tank through the outlet in the bottom and partly goes out through the outlet(s) in the side wall. The sum of the outputs through the side outlet(s) of each of the tanks forms the river discharge.

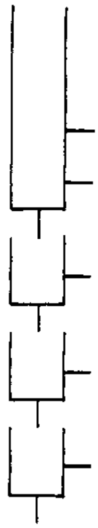

Fig. 2

2.1.2 In spite of its simple appearance, the tank model has several advantages as follows:

1) It has reasonable physical meanings corresponding to the zonal structure of ground water schematically shown in Fig. 3. Of course, real basins cannot be so simple as this but there must be far more complicated conditions; so we think that the tank model somewhat resembles the finite elements method.

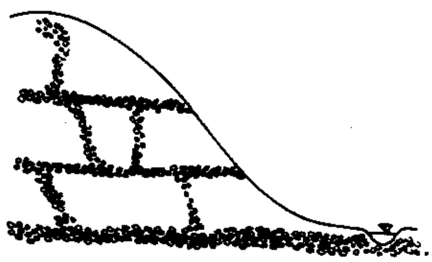

Fig. 3

2) It can represent the nonlinear character of surface runoff.

3) Each tank corresponds to runoff component having its own half period or time constant in approximation. Strictly speaking, from their nonlinear character, the value of the half period of each tank is not definite.

4) Input (rainwater) is distributed to each of the components automatically.

5) Runoff components from lower tanks are smoothened in shape and the time lags are given to them automatically.

2.1.3 A difficult problem about the tank model comes from its non-linear character which makes it impossible for us to find parameters mathematically or by some objective method. The only way is the method of trials and errors. We put a set of numerical values to the unknown parameters, and after numerical calculation we compare the calculated hydrograph with the observed one. By subjective judgement after careful observation and comparison of both hydrographs, we arrange the values of parameters for the next trial. There must be some reasonable and objective way of judgement and a method of finding optimum parameters, but we think, trials and errors guided by subjective judgement of those who have experiences will be far more efficient. It may somewhat resemble the driving of a motor car on the street. It will be very difficult and even impossible to make an automatic machine that can drive a car on the street; yet many people actually can drive easily.

2.2 Composite tank model for nonhumid regions

2.2.1 In nonhumid regions or in the regions with an arid season, we must consider the effect of soil moisture for which we must add a structure at the bottom of the top tank. But it is not good enough to explain the runoff structure of nonhumid basin.

2.2.2 In a nonhumid basin, where some part is wet and the remaining part dry, the surface runoff occurs only in the wet area while in the dry area all the rainfall is absorbed as soil moisture. As the rainy season goes on, the wet area grows larger, starting from a small area along the river.

To approximate the continuous change of wet area, we divide the basin into several zones $S_1, S_2, \cdots, S_m$ as shown in Fig. 4 where $m = 4$. It resembles the approximation of smooth curve by step function.

2.2.3 After the division into m zones, each zone is represented for simulation by a simple tank model with soil moisture structure in the top tank. Thus we get a composite tank model, composed of n x m tanks as shown in Fig. 5, where n = 4, m = 4 and the left side is the mountain side and the right side is the river side. The top tank, the second tank, ··· and the n-th tank of different zones are of identical structures, respectively.

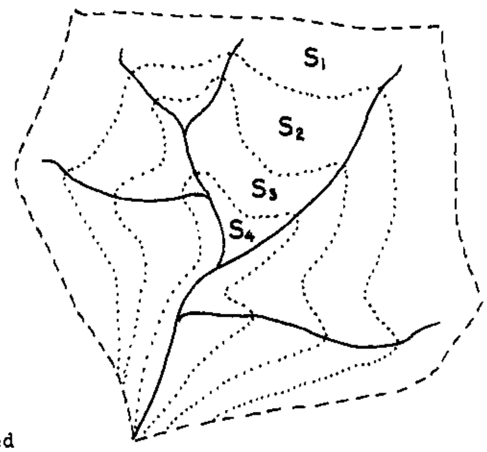

Fig. 4

2.2.4 Hereafter, the water contained as soil moisture is called confined water, and the other water free water. In this model, free water moves in two directions, horizontal and vertical. Each tank receives water from the upper tank of the same zone or from the mountain side tank of the same stratum, and transfers water to the lower tank of the same zone or to the river-side tank of the same stratum. There is another important transfer of water, that is, the water supply to soil moisture from lower free water by capillary action.

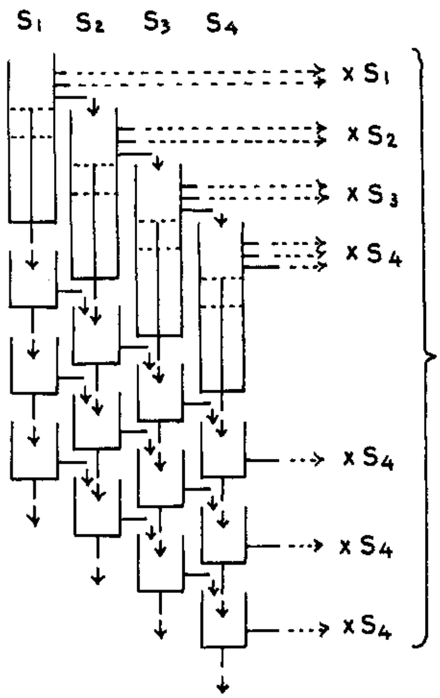

Fig. 5

2.2.5 When the dry season comes, free water of the highest zone decreases faster than that of other zones by water transfer to lower zones. After vanishment of free water, soil moisture begins to decrease because there is no water supply from lower free water. In this way, the highest zone becomes dry earliest, and then the second zone, the third zone, etc. become dry, while the dry season goes on.

In the opposite way, when the wet season comes, the lowest zone becomes wet at first, and then the second zone, and the third zone, etc. become wet, successively.

The change of wet area can be represented automatically in this way.

2.2.6 The areal ratio of zones $S_1 : S_2 : \cdots : S_m$ is an important parameters in this model. If we have enough information about hydrological, topographical and geological characters of the basin, we may be able to determine the ratio by using the given information. If we have little or no information, however, we must determine them by trials and errors, where we may usually assume, for convenience, that $S_1 : S_2 : \cdots : S_m$ is a geometrical progression, for example, as follows:

$$S_1 : S_2 : S_3 : S_4 = 3^3 : 3^2 : 3 : 1 = 67.5 : 22.5 : 7.5 : 2.5,$$

$$S_1 : S_2 : S_3 : S_4 = 2^3 : 2^2 : 2 : 1 = 53.3 : 26.7 : 13.3 : 6.7.$$

2.2.7 The top tank of the model has two types of outlet in the side wall:

a) Output through the outlet of type A directly goes to the river channel.

b) Output through the outlet of type B goes to the top tank of the next zone, except in the lowest zone where the output goes to the river channel.

Though the model in Fig. 5 has outlets of both types, there are in our results the outlets of type A only in the case of the Mae Nam Nan at Tha Pla, the Mae Nam Yom at Kaeng Luang and the Mae Nam Ping at Wang Kra Chao, and on the contrary, in the case of the Mae Nam Chao Phraya at Nakhon Sawan there are outlets of type B only.

2.3 Structure for soil moisture

2.3.1 We divide the soil moisture into two parts, primary and secondary. Rainwater goes into primary soil moisture and when primary soil moisture is filled up, the excess rain water becomes free water in the top tank, which partly infiltrates into the second tank and partly discharges into the river channel or goes to the top tank of next zone, according to the rule of the tank model.

2.3.2 Water in primary soil moisture goes gradually to secondary soil moisture. We assume that the transfer velocity T_d is given as a linear function of the storage amount of secondary soil moisture X_s.

$$T_d = c_o + c\ (1 - X_s / C_s),$$

where c_o and c are constants, and C_s the saturation capacity of secondary soil moisture. It means that when secondary soil moisture is empty, the transfer amount per day is $c + c_o$, and it tends to c_o when secondary soil moisture tends to its saturation value.

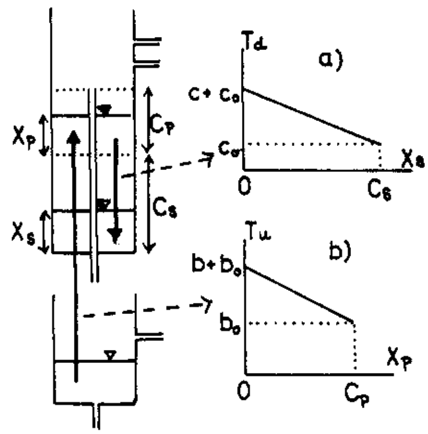

Fig. 6

In the present report, the following values are used in most cases:

C_s = 150 — 250 (mm),

c_o = 0.5 (mm/day),

c = 1 (mm/day).

2.3.3 When primary soil moisture is not saturated and there is free water in lower tanks, water goes up by capillary action so as to fulfill the primary soil moisture. The transfer velocity T_u is assumed to be given as a linear function of the storage amount X_p of primary soil moisture as follows:

$$T_u = b_o + b(1 - X_p / C_p),$$

where b_o and b are constants, and C_p the saturation capacity of primary soil moisture.

In the present report, b_o = b = 3 (mm/day), and C_p is about 50 mm.

2.4 Evapotranspiration

2.4.1 To calculate the effect of evapotranspiration we subtract evaporation from the top tank as follows, where E is the amount of daily evaporation measured with a pan evaporimeter.

1) If there is enough of free water in the top tank, 0.8E is subtracted from free water in the top tank.

2) If there is no free water in the top tank, 0.6E is subtracted from confined water.

3) If there is not enough of free water X_f to subtract 0.8E from it, X_f is subtracted from free water and 75% of deficit, namely, $0.75(0.8E - X_f)$ is subtracted from confined water.

2.4.2 If there is no free water in the top tank and there is free water in lower tanks, the deficit of primary soil moisture caused by evapotranspiration is filled up by the water supply from the lower tanks. So it seems as if evapotranspiration is subtracted from lower free water. In fact, soil moisture begins to decrease by evapotranspiration, after all free water in lower tanks has vanished.

2.4.3 When the dry season goes on, some zones become dry from the mountain side. As no evapotranspiration can occur from the dry zones, mean evapotranspiration from the total basin becomes far smaller than 0.6E. In this way, this model can represent the decrease of evapotranspiration from ground water storage, automatically.

2.5 Deformation in river channel

2.5.1 The output from the tank model goes into the river channel, where its hydrograph is deformed by the storage effect of the channel. To give this effect, we use the storage type model shown in Fig. 7.

2.5.2 Usually, time lag is given to the calculated discharge to get good fit with the observed discharge.

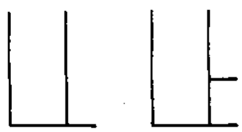

Fig. 7

3. Mean areal precipitation for basin

3.1 Estimation of areal precipitation is the most important and difficult problem in runoff analysis.

3.2 Difficulties mainly come from the following conditions:

1) All rainfall stations are installed along the rivers. There is no rainfall stations in mountainous part. The disposition of the stations is biased from the beginning.

2) The type of seasonal pattern of monthly rainfall changes from place to place.

3) There is a large areal fluctuation of rainfall distribution in the basin.

4) Moreover, there is little correlation between rainfall stations. In some cases, there is no correlation, even when two stations are not far from each other.

5) Under the conditions of large areal fluctuation and small correlation, the number of rainfall stations must be large enough to get a good estimation of areal mean. However, except in the case of Nakhon Sawan where there are twenty rainfall stations in or near the basin, the number of rainfall stations are not large enough.

We will explain these one by one.

3.3 Biased disposition of rainfall stations

Usually it rains heavy on mountain slopes, especially when rain has its cause in seasonal wind. In Japan, though rainfall stations are mostly in plains or along the rivers, there are some unmanned rain gauges on summits or ridges which give important information especially in case of storms. Strictly speaking, such a network, or the combination of stations set along rivers and on ridges, is also biased, because the heaviest rainfall might occur on mountain slopes somewhat lower than ridges. Unfortunately in the basin of the Mae Nam Chao Phraya, there are no rainfall stations in mountainous area, so we have no objective rainfall data to estimate the areal mean.

We have to find the correction factor for areal rainfall, by the comparison of calculated discharge with the observed one. Namely, we must calibrate the correction factor.

3.4 Variety of seasonal pattern of rainfall

The seasonal change patterns of monthly rainfall of twenty stations are shown in Fig. 8. In most stations a small peak is seen in May or June and a large peak in August or September. But there are some stations that have only one peak in August. In some stations, the peak in August or September is much higher than that in May, but in some stations not so much. The difference in seasonal patterns suggests us that the correction factor for areal mean rainfall must have seasonal changes.

3.5 Large areal fluctuation of rainfall distribution

To show the areal fluctuation of rainfall clearly, we calculate the mean and the standard deviation of monthly rainfall amounts of twenty stations (sometimes less than twenty when the data of some stations are lacking) for each month. The result is shown in Fig. 9, in which three curves show m and $m \pm \sigma$, where m is the mean, and σ the standard deviation. In most cases the coefficient of variation σ/m is about 50%, but in few cases it is about 100% or more. As the sample size is twenty, the value of standard deviation is fairly reliable. So we assume, for a while, that the coefficient of variation is equal to 50%.

If we assume that the set of rainfall amounts measured at twenty rainfall stations is a group of random samples, then the sample mean $(x_1 + x_2 + \cdots + x_{20})/20$ is the random variable whose distribution function is nearly normal with the standard deviation $\sigma/\sqrt{20} \fallingdotseq \sigma/4.5$. From this result and the above assumption that the coefficient of variation is 50%, the reliability of the sample mean $(x_1 + x_2 + \cdots + x_{20})/20$ will be judged by its coefficient of variation $50\% \div \sqrt{20} \fallingdotseq 11\%$. This is the reason why the result of Nakhon Sawan is fairly good.

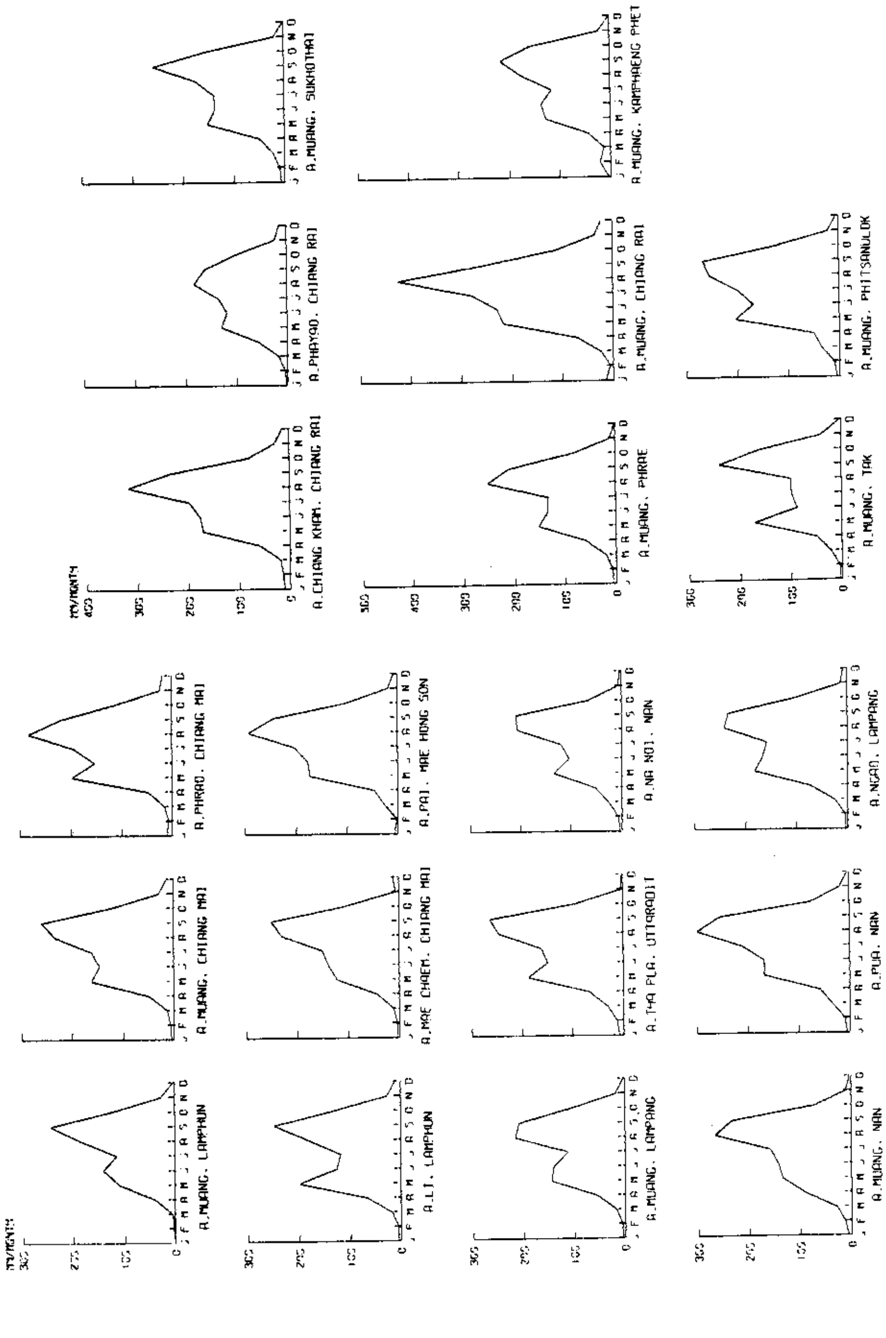

Fig. 8 Mean monthly precipitations

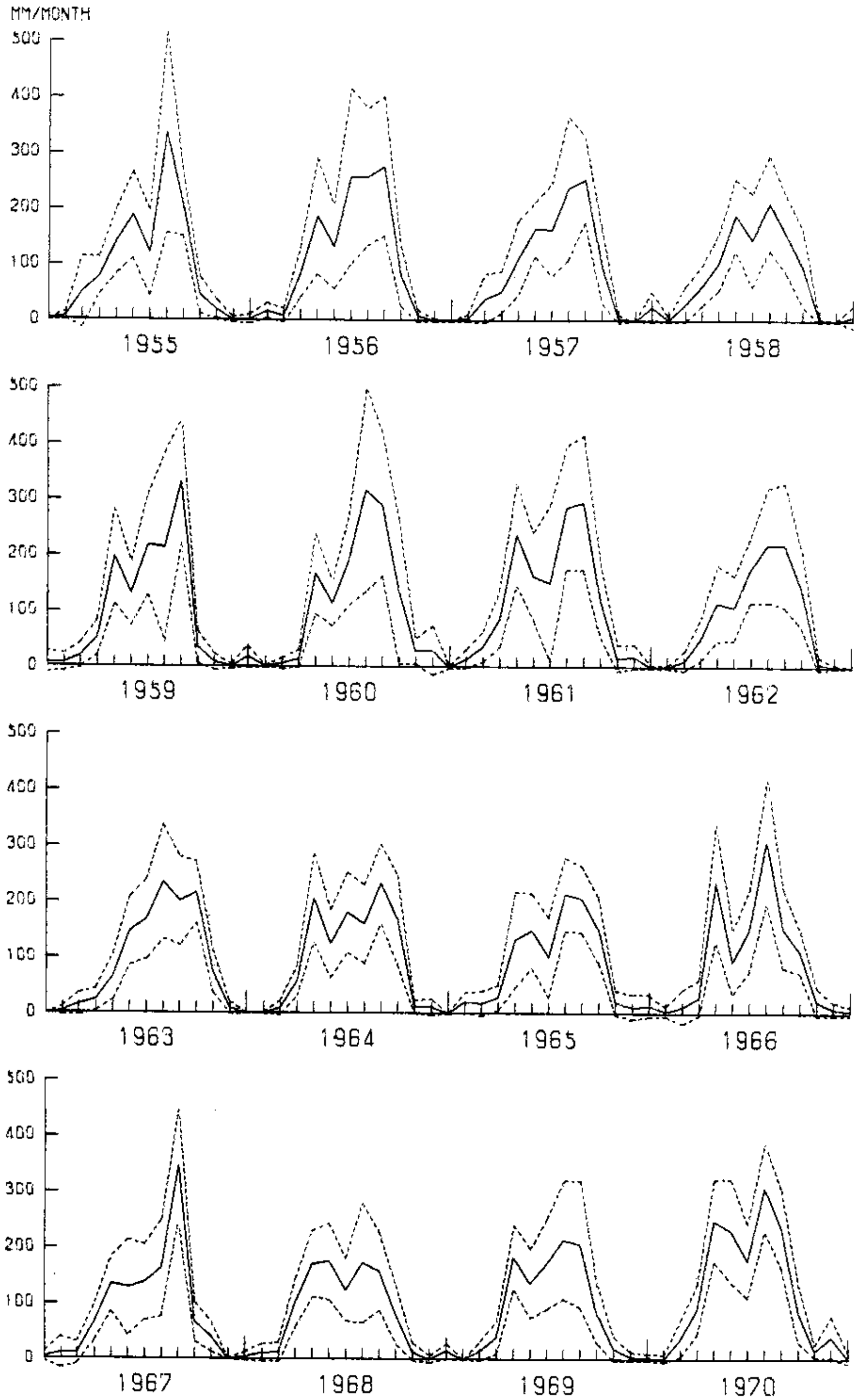

Fig. 9 The curves showing the areal fluctuation of monthly precipitations ——— m, ------- m ± σ

3.6 Correlation between rainfall stations

Though we assumed above that the set of rainfall amounts measured at twenty stations are the random samples from some population, it is not correct, because there is a correlation between the rainfall stations. If we calculate the correlation coefficient between monthly rainfalls, a fairly large correlation must be obtained because of the similar seasonal pattern. One way to avoid the effect of seasonal pattern is to calculate the correlation coefficient using the monthly precipitation of each definite month, Jan., Feb., ··· and Dec., separately. Then the result becomes not reliable because the sample size is small. So, we calculate the correlation coefficient using the following data, the deviation of monthly rainfall from the mean monthly rainfall being given by

$$\tilde{x}_{ij} = x_{ij} - \bar{x}_{\cdot j} ,$$

where i is the index for year, j that for month, x_{ij} the monthly rainfall of j-th month of i-th year, $\bar{x}_{\cdot j}$ the mean monthly rainfall of j-th month and $\tilde{x}_{ij}$ the deviation from the mean of j-th month. Table 1 shows the calculated correlation coefficients between monthly rainfall amounts at ten stations picked up from twenty stations, where the upper line is obtained from the data of May — October (sample size is about 70 — 110), the middle line is obtained from the data of August and September (sample size is about 30 — 40) and the lower line is the distance. Figures of the upper and middle lines are approximately similar and they are almost less than 0.5 and about 70% of them are less than 0.3. Therefore, generally speaking, they are nearly independent.

For the runoff analyses of the Mae Nam Nan, the Mae Nam Yom and the Mae Nam Ping, we use only several rainfall stations each. Tables 2 — 4 show the correlation between monthly rainfalls of several stations in or near each of the basins. In the basin of the Mae Nam Nan the correlation is fairly good, but in both the basins of the Mae Nam Yom and the

Table 1

Correlation coefficients between monthly rainfalls at several stations in or near the basin of Nakhon Sawan

upper: May — Oct. middle: Aug. & Sep. lower: distance

	Muang Lamphun	Phrao Chiang Mai	Mae Chaem Chiang Mai	Pai Mae Hong Son	Tha Pla Uttaradit	Pua Nan	Muang Phrae	Muang Chiang Rai	Muang Kamphaeng Phet	Muang Phitsanulok
Muang Lamphun	1.00	0.25	0.47	0.37	0.21	0.26	0.21	0.14	0.16	0.16
	1.00	0.25	0.71	0.53	0.32	0.24	0.05	0.12	-0.03	-0.02
		90km	70km	100km	190km	210km	130km	170km	230km	230km
Phrao Chiang Mai		1.00	0.16	0.35	0.28	0.29	0.30	0.42	-0.01	0.33
		1.00	0.49	0.43	0.39	0.50	0.21	0.45	-0.19	0.28
			130km	80km	230km	180km	160km	90km	310km	290km
Mae Chaem Chiang Mai			1.00	0.28	0.07	0.15	0.12	0.05	-0.09	-0.02
			1.00	0.33	0.28	0.31	0.15	0.17	-0.13	0.10
				90km	240km	280km	190km	220km	250km	260km
Pai Mae Hong Son				1.00	0.20	0.37	0.32	0.30	-0.13	0.04
				1.00	0.27	0.42	0.19	0.34	-0.26	-0.06
					280km	260km	220km	160km	330km	330km
Tha Pla Uttaradit					1.00	0.53	0.34	0.26	0.05	0.28
					1.00	0.65	0.26	0.15	-0.21	0.18
						170km	60km	250km	180km	100km
Pua Nan						1.00	0.29	0.22	-0.11	0.17
						1.00	0.25	0.19	-0.34	0.14
							140km	140km	330km	270km
Muang Phrae							1.00	0.16	0.26	0.28
							1.00	-0.02	0.12	0.11
								190km	190km	140km
Muang Chiang Rai								1.00	0.02	0.10
								1.00	-0.09	0.05
									380km	340km
Muang Kamphaeng Phet									1.00	0.48
									1.00	0.38
										80km
Muang Phitsanulok										1.00
										1.00

Table 2

Correlation coefficients between monthly rainfalls at several stations in or near the basin of Tha Pla

upper: May — Oct. lower: Aug. & Sep.

		A	B	C	D	E	F	G
A	Tha Pla Uttaradit	1.000 1.000	0.450 0.491	0.406 0.475	0.527 0.652	0.444 0.518	0.309 0.516	0.307 0.138
B	Na Noi Nan		1.000 1.000	0.468 0.500	0.491 0.565	0.346 0.495	0.240 0.416	0.305 0.154
C	Muang Nan			1.000 1.000	0.564 0.687	0.550 0.551	0.444 0.492	0.444 0.391
D	Pua Nan				1.000 1.000	0.477 0.592	0.386 0.467	0.287 0.244
E	Ngao Lampang					1.000 1.000	0.415 0.414	0.486 0.480
F	Chiang Kham Chiang Rai						1.000 1.000	0.345 0.490
G	Phayao Chiang Rai							1.000 1.000

Table 3

Correlation coefficients between monthly rainfalls at several stations in or near the basin of Kaeng Luang

upper: May — Oct. lower: Aug. & Sep.

		A	B	C	D	E	F
A	Ngao Lampang	1.000 1.000	0.415 0.414	0.486 0.480	0.188 0.046	0.440 0.223	0.485 0.248
B	Chiang Kham Chiang Rai		1.000 1.000	0.345 0.490	0.040 -0.052	0.205 0.134	0.259 0.273
C	Phayao Chiang Rai			1.000 1.000	0.175 -0.139	0.422 0.185	0.515 0.254
D	Muang Sukhothai				1.000 1.000	0.294 0.316	0.394 0.396
E	Muang Phrae					1.000 1.000	0.459 0.404
F	Muang Lampang						1.000 1.000

Table 4

Correlation coefficients between monthly rainfalls at several stations in or near the basin of Wang Kra Chao
upper: May — Oct. lower: Aug. & Sep.

		A	B	C	D	E	F	G
A	Muang Lamphun	1.000 1.000	0.527 0.589	0.247 0.246	0.618 0.667	0.473 0.705	0.370 0.527	0.418 0.356
B	Muang Chiang Mai		1.000 1.000	0.368 0.360	0.457 0.344	0.165 0.328	0.321 0.259	0.381 0.245
C	Phrao Chiang Mai			1.000 1.000	0.238 0.103	0.165 0.490	0.346 0.425	0.372 0.345
D	Li Lamphun				1.000 1.000	0.254 0.283	0.115 0.084	0.459 0.368
E	Mae Chaem Chiang Mai					1.000 1.000	0.275 0.332	0.220 0.422
F	Pai Mae Hong Son						1.000 1.000	0.220 0.203
G	Muang Lampang							1.000 1.000

Table 5

Correlation coefficients between monthly rainfalls at several stations in Japan not far from Tokyo
upper: correlation coefficient lower: distance

		A	B	C	D	E	F	G
A	Tokyo	1.000	0.790 100km	0.684 100km	0.581 220km	0.548 170km	0.444 170km	0.067 260km
B	Mito		1.000	0.628 130km	0.492 300km	0.525 250km	0.451 200km	0.153 210km
C	Maebashi			1.000	0.499 230km	0.444 150km	0.494 90km	0.133 170km
D	Hamamatsu				1.000	0.684 90km	0.423 220km	0.093 380km
E	Iida					1.000	0.603 130km	0.239 290km
F	Nagano						1.000	0.385 160km
G	Niigata							1.000

Mae Nam Ping some pairs of stations are nearly independent of each other. We can understand these facts from the topographical conditions that the basin of the Mae Nam Nan is rather simple while the two other basins are complicated and mountainous.

3.7 Comparison with Japanese case

From our experiences obtained from runoff analyses of Japanese rivers, the necessary number of rainfall stations is about five, irrespective of the area of basin. Even if the basin is small, several stations are necessary, and several stations are good enough also for large basins.

Table 5 shows the correlation coefficients of monthly precipitations of several stations in Japan not far from Tokyo, where the data show the deviation from the monthly mean, the same as the above tables. Distance between stations is also shown in the table. Among seven stations, only Niigata is situated on the Sea of Japan side and belongs to a different climate zone from others, and Iida and Nagano are situated in mountainous regions belonging to somewhat different climate zones from others.

Comparing Table 1 with Table 5, we can see that the rainfall in Japan has more spatial homogeneity than in Thailand. However, we have an experience in analysing the flood of the river Kuma in Kyushu, the southern part of Japan, that eight rainfall stations are not enough for good flood forecasting because of the locality of rainfall. In Thailand, rainfall shows a larger fluctuation locally than in southern part of Japan, so the rainfalls at two stations not so far from each other are nearly independent of each other, and therefore many stations are necessary for the river forecasting. From the example of Nakhon Sawan, we suppose that about twenty stations are necessary for good river forecasting, unless the topographical character of the basin is simple.

3.8 Weights for rainfall stations to obtain the areal mean

3.8.1 Thiesen method is not reasonable

The areal mean precipitation is usually given by the weighted arithmetic mean

$$\overline{P} = \sum_i w_i P_i \,/\, \sum_i w_i ,$$

where weight w_i is usually given by Thiesen method or equal weight. We think, however, Thiesen method is unreasonable from the following consideration. Consider the basin in which there are two rainfall stations A and B, near the exit of the basin as shown in Fig. 10 a). By Thiesen method, weight of A is small and that of B is large. However, if we settle A to A' as shown in Fig. 10 b), then by Thiesen method, weight of A' becomes large and that of B becomes small. It cannot be reasonable that a slight transposition of rainfall station causes the large change of weight. If Thiesen method is reasonable, such absurdity cannot occur.

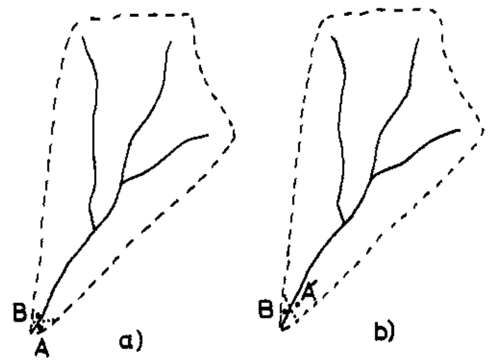

Fig. 10

The reliability of the rainfall station must depend on the maintenance of the rain gauge, the reliability of the observer, the surrounding conditions of the rain gauge, the micrometeorological conditions surrounding the station, etc. By Thiesen method, however, weights are determined only from geometrical condition, independent of the above physical conditions and others. This must be the reason why Thiesen method is unreasonable.

3.8.2 Isohyet is not so reliable also

There must be another method, the use of isohyet, but we cannot agree with it also. Because the isohyet is less reliable than the isobar or the isothermal line, because of the large spatial fluctuation of precipitation. It is not seldom that two very near stations show very different daily rainfalls. So it may be possible that the rainfall amount observed at some station is not representative of the local mean of the neighbourhood of the station.

We have some experiences that the areal precipitation obtained by using the given isohyets does not show a good fit with river discharge.

In our case of the Mae Nam Chao Phraya, all rainfall stations are along the river and we have no information about the rainfall in mountainous region, and moreover, the areal fluctuation of rainfall is very large. Therefore, it must be very difficult to draw a reliable isohyet.

3.8.3 The method we are now using

The method we are now using is as follows:

1) For the weights, only four values 1, 1/2, 1/4 and 0 are used.

2) At the beginning, we put all weights at 1, namely we use the simple arithmetic mean. Calibration of model parameters goes on for a while by using the simple arithmetic mean as input.

3) The calibration of the weights of rainfall stations begins, after we have obtained fairly good results by the calibration of model parameters.

If there is significant difference between the calculated and observed hydrographs at some time point, then we examine the rainfall data to find out the stations that cause significant errors. The stations that cause significant errors many times must be less representative. Then we switch the weights of these stations smaller than before, that is, from 1 to 1/2, from 1/2 to 1/4 or from 1/4 to 0, where the weight 0 means to neglect the station. If the correction is over, we reset some part of the weights as before.

4) After we have determined good weights by trials and errors, we may continue the calibration of model parameters if necessary.

We do not consider this method to be the best, but it is not so bad. There must be some statistical methods for determining the weights, but it is not reliable, we suppose. As there are correlations between rainfall data of stations, the discriminant value of the correlation matrix becomes small, and so the weights obtained by solving the normal equation are not so reliable and will show sometimes unreasonable values, a negative weight, for example.

We have some experiences that some rainfall station must be neglected for obtaining good discharge forecasting, even if its position, its circumstances, the maintenance of the gauge and its observer are all well. We cannot but think, it is not representative for the basin from the micrometeorological condition. On the contrary, in some cases, the station outside of the basin or on the boundary of the basin will largely contribute to the discharge forecasting.

3.9 Correction factor for the areal mean precipitation

3.9.1 Necessity of the correction

In most cases where the distribution of rainfall stations is biased, correction is necessary for estimation of the areal mean precipitation. This correction is made by multiplying some correction factor to the weighted mean of the observed precipitation amount at each of the stations. In our cases, all stations are along the river, there are no stations in mountainous regions, and it rains usually heavier in mountainous regions than in plains, so the correction must be necessary for obtaining the areal mean precipitation.

3.9.2 Seasonal change of the correction factor

In analysing the runoff structure of snowy mountainous basins in Japan, we cannot but assume that the snowfall in mountainous parts is much heavier than in plains. Without this assumption we cannot derive the large discharge from snow melt in spring. In summer, however, the runoff analysis shows that the rain in mountain regions is nearly the same as in plains. In most cases, of course, it rains somewhat heavier in mountains than in plains, but the difference is not so much as compared with winter. We wondered at the beginning, but all basins on the Sea of Japan side analysed by us show the same situation. Recently we knew, by the discussion held at IAHS Symposium on "Mathematical Models in Hydrology" in Bratislava in September 1975, that a similar situation had been found in Canada.

The heavy snowfall in winter on the Sea of Japan side is caused by the seasonal north-west wind which is made humid by the Tsushima Current that flows through the Sea of Japan. Such orographic snowfall must be far heavier in mountain regions than in plains. In summer, most rainfalls are of convective nature and less dependent on elevation. Therefore, the significant seasonal change of correction factor must be reasonable.

As the basin of the Mae Nam Chao Phraya lies in the monsoon zone, and as the main direction of wind changes according to seasons, so it must be reasonable that the correction factor for the mean areal rainfall will show significant seasonal changes.

Different seasonal patterns of mean monthly precipitation shown in Fig. 8 also suggest the seasonal change of the correction factor.

3.9.3 Calibration of the correction factor

The calibration of the correction factor for the areal mean is very effective and important. It begins usually somewhat later, namely, after we have obtained fairly good results by the calibration of model parameters.

4. Obtained results

4.1 The obtained models for each of the four basins and the obtained weights for rainfall stations are given in Figs. 11 — 14. In the case of Nakhon Sawan, the infiltration amount per day from the top

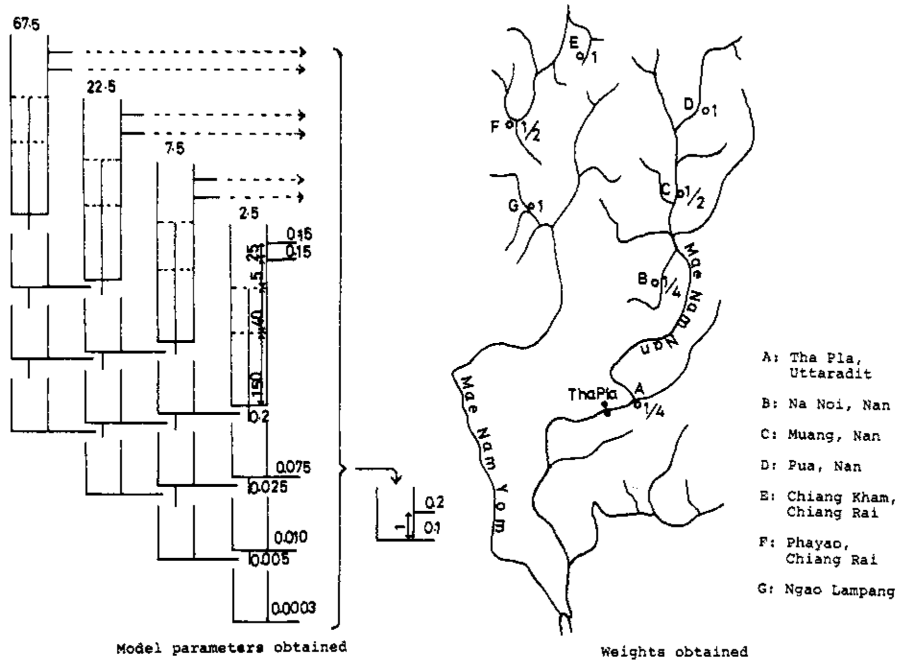

Fig. 11 Mae Nam Nan at Tha Pla (13,086 km^2) (Sirikit Dam)

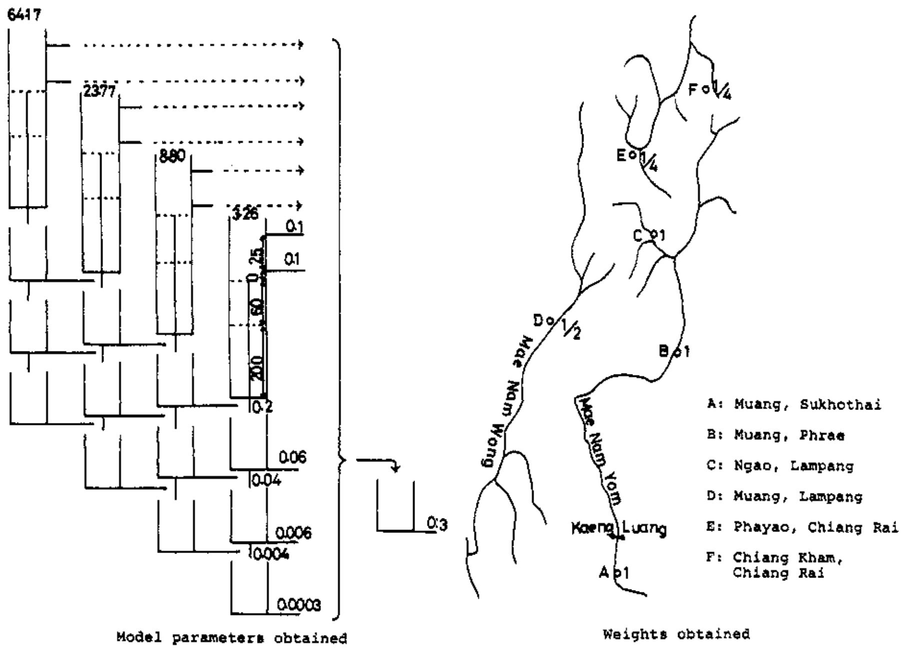

Fig. 12 Mae Nam Yom at Kaeng Luang (12,658 km^2)

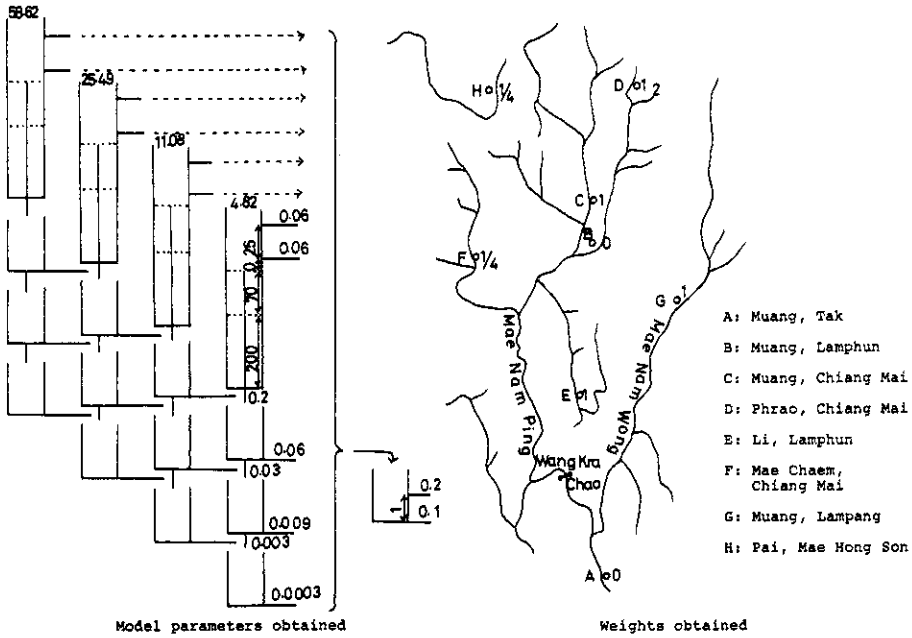

Fig. 13 Mae Nam Ping at Wang Kra Chao (26,396 km^2) (Bhumipol Dam)

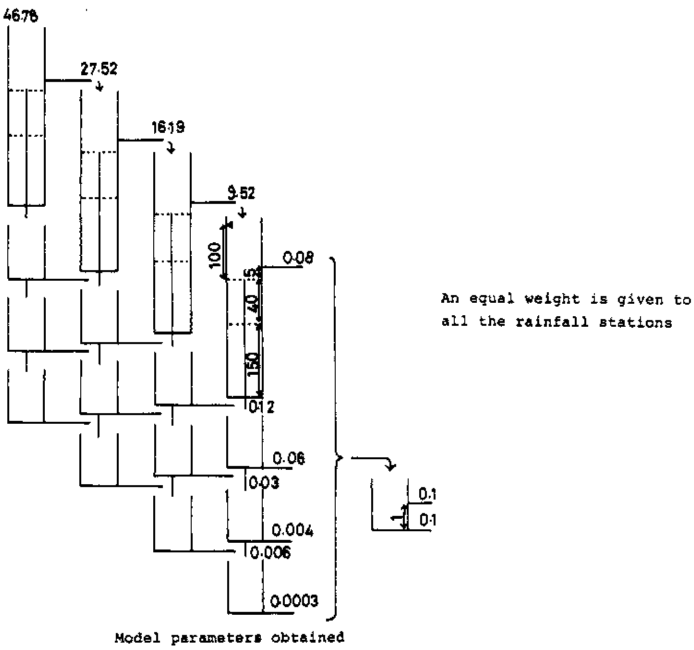

Fig. 14 Mae Nam Chao Phraya at Nakhon Sawan (110,569 km^2)

tank is limited to some saturation value I_s = 20 (mm/day) as shown in Fig. 15, where H_s = 100 (mm) is the corresponding saturation depth.

4.2 Other parameters are shown in Tables 6 — 8. Table 6 shows the correction factor that derives the estimated mean areal precipitation of the basin from the weighted mean.

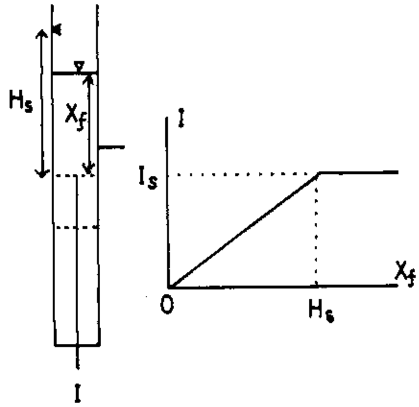

Fig. 15

Table 6 Correction factor for mean areal precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mae Nam Nan at Tha Pla	← 1.0 →						← 1.3 →			← 1.0 →		
Mae Nam Yom at Kaeng Luang	← 1.0 →											
Mae Nam Ping at Wang Kra Chao	← 1.0 →						← 1.1 →			← 1.0 →		
Mae Nam Chao Phraya at Nakhon Sawan	← 1.0 →								1.1	1.3	1.1	1.0

Table 7 shows the amount of daily evapotranspiration which is used for all the four basins. These values are obtained as the monthly mean values of the daily observed data of evaporimeter at Roiet in the period of 1961 — 1967.

Table 7 Daily evapotranspiration (mm/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5.0	5.6	6.2	6.3	5.4	5.2	4.9	4.2	3.9	4.8	4.8	4.8

Table 8 shows the time lag which is given to the output of the tank model.

Table 8 Time lag

Tha Pla	2 days
Kaeng Luang	2 days
Wang Kra Chao	3 days
Nakhon Sawan	4 days

4.3 Initial values of the tank model are given as follows. We have precipitation data from April 1952 to March 1971, with which we make a loop by binding the end of data to the top. We begin the calculation with arbitrary reasonable values from April 1952. When the calculation comes back to the top data again, initial condition will become stational state and the result is obtained in the second round.

4.4 The river discharge at Nakhon Sawan is influenced by the regulated discharge from Bhumipol Dam that began its work on 26 Nov. 1962. Thereafter, the discharge at Nakhon Sawan is derived as the sum of the observed discharge from Bhumipol Dam and the calculated discharge from the remaining basin. The latter is calculated also by means of the model of Fig. 14 where the input is the simple mean of fourteen rainfall stations after eliminating six rainfall stations in or near the catchment area of Bhumipol Dam.

4.5 The calculated and observed monthly discharges are shown in Figs. 16 — 19 and the calculated and observed daily hydrographs are shown in Figs. 20 — 23.

5. Some remarks

5.1 After having finished the calculation, we knew that there are more rainfall stations in the basin. So we can expect that it will be able to get better results if we can use more rainfall data.

5.2 As the evaporation data are not given for the present, we use the evaporation data of the basin of Nam Mune. If we can use the evaporation data of the object basins, the calculation must become more reasonable. Practically, however, there may be no large difference.

5.3 There are so many uncertainties about soil moisture. It is very difficult and rather impossible to determine the structure of soil moisture from our data, where the number of rainfall stations is not large enough in view of the locality of rainfall distribution. The most important problem in this region is to gather the data from as many stations as possible. The problems about evaporation and soil moisture are rather not so important as compared with the rainfall data.

5.4 In the present paper, we use the areal mean precipitation as input. By this method, however, we cannot simulate the fine structure of daily hydrograph. If there is a local heavy rainfall in the basin, there will occur local surface runoffs that make a peak of hydrograph which will not appear in the calculated hydrograph derived from areal mean rainfall. But it is not so difficult to modify the model for this problem, and so we will make the modification if we can get enough rainfall data.

(Manuscript received 18 May 1976)

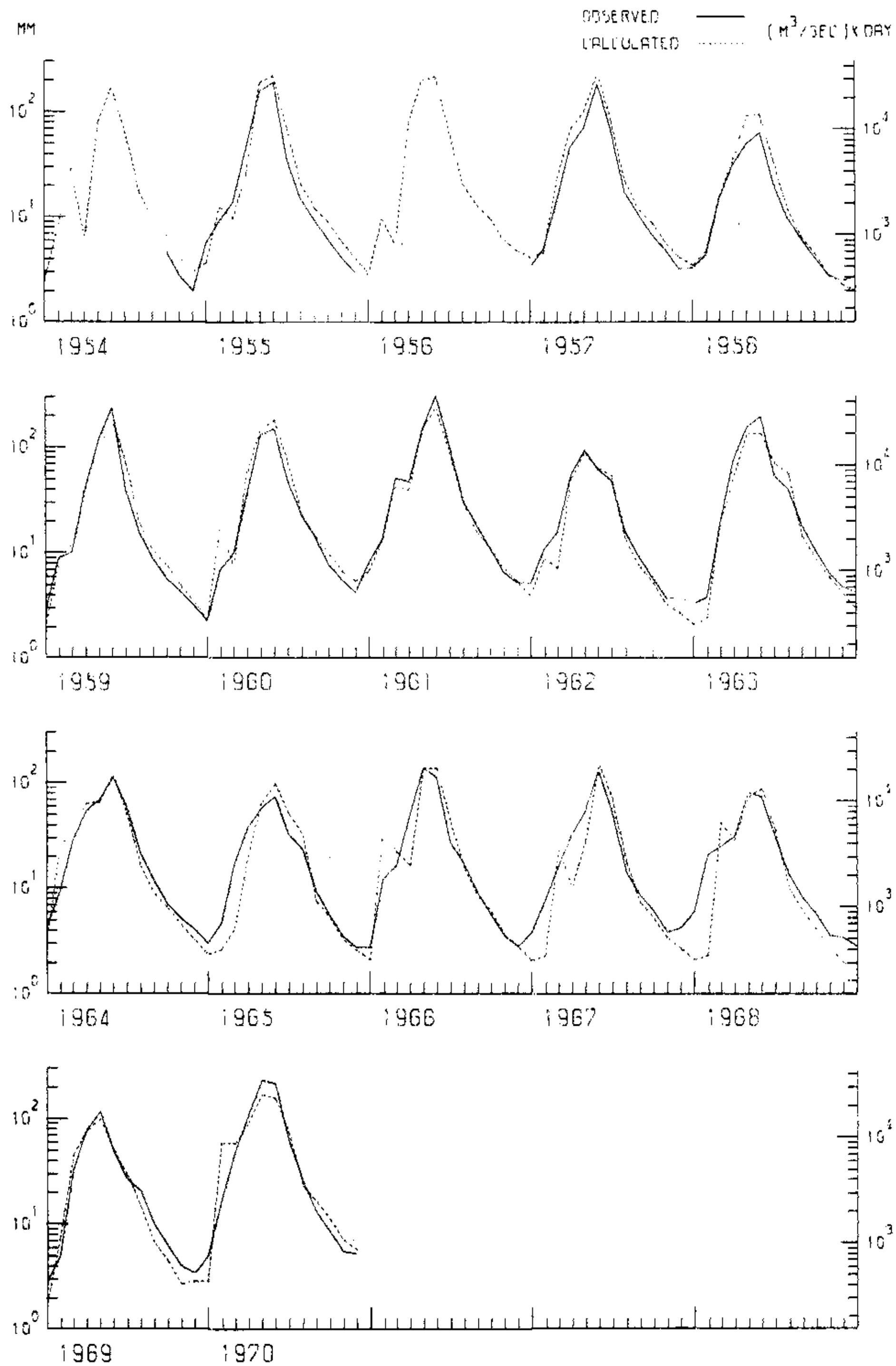

Fig. 16 Monthly discharges of the Mae Nam Nan at Tha Pla

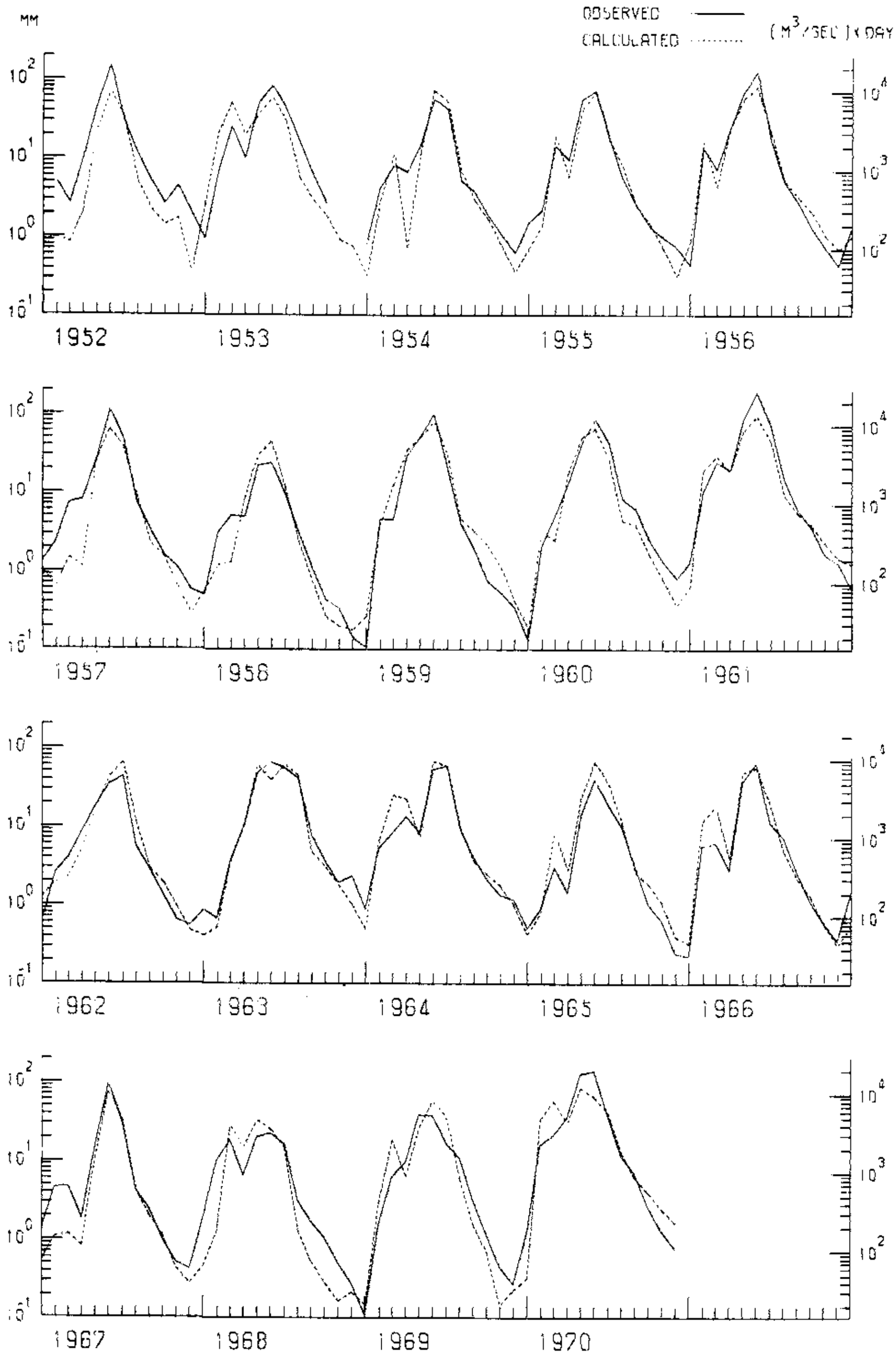

Fig. 17 Monthly discharges of the Mae Nam Yom at Kaeng Luang

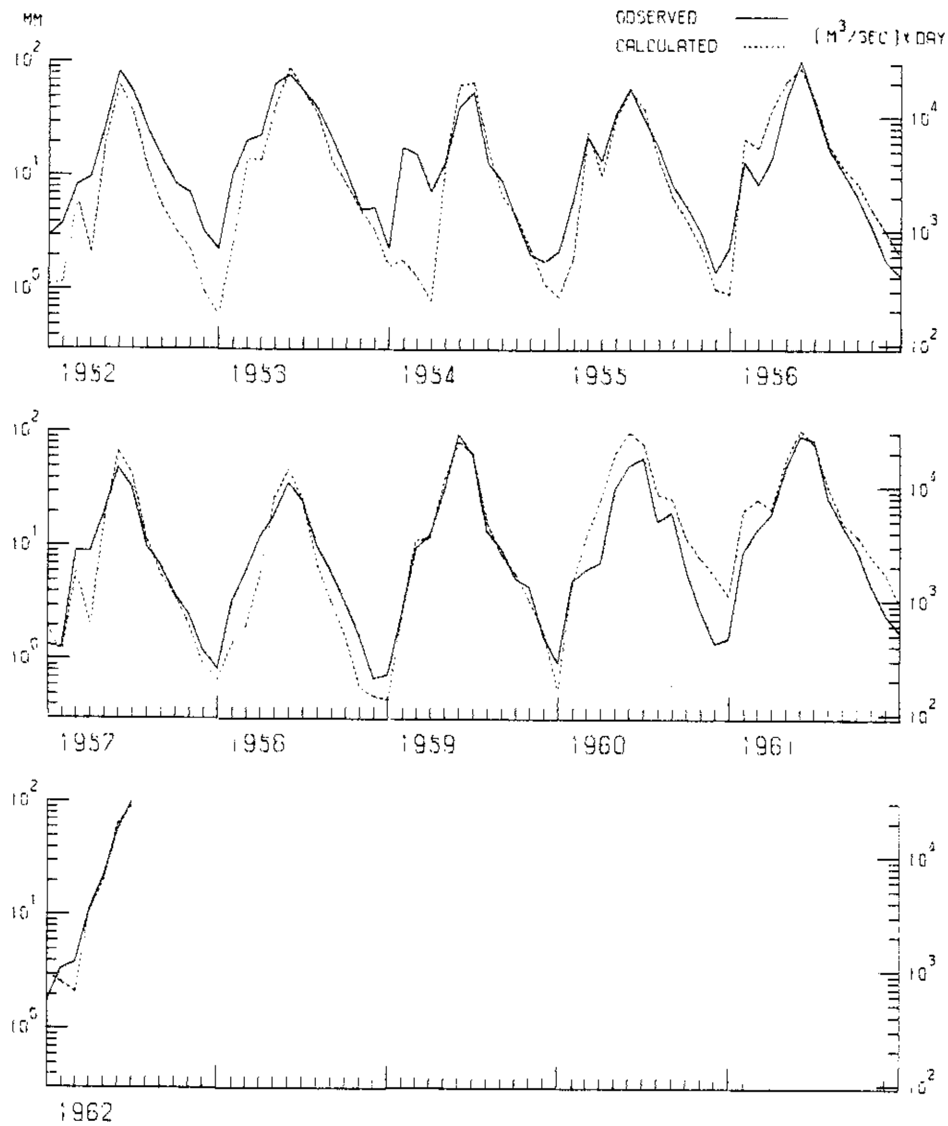

Fig. 18 Monthly discharges of the Mae Nam Ping at Wang Kra Chao

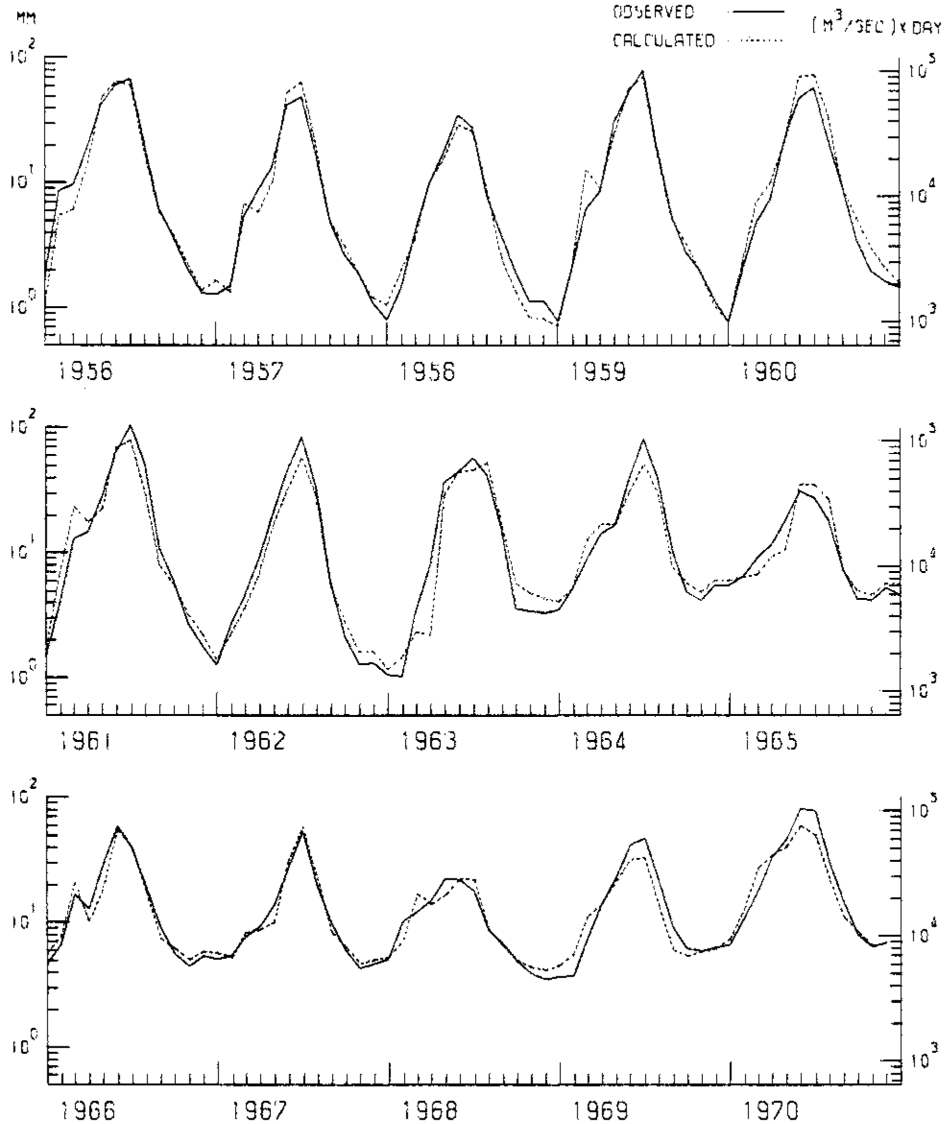

Fig. 19 Monthly discharges of the Mae Nam Chao Phraya at Nakhon Sawan

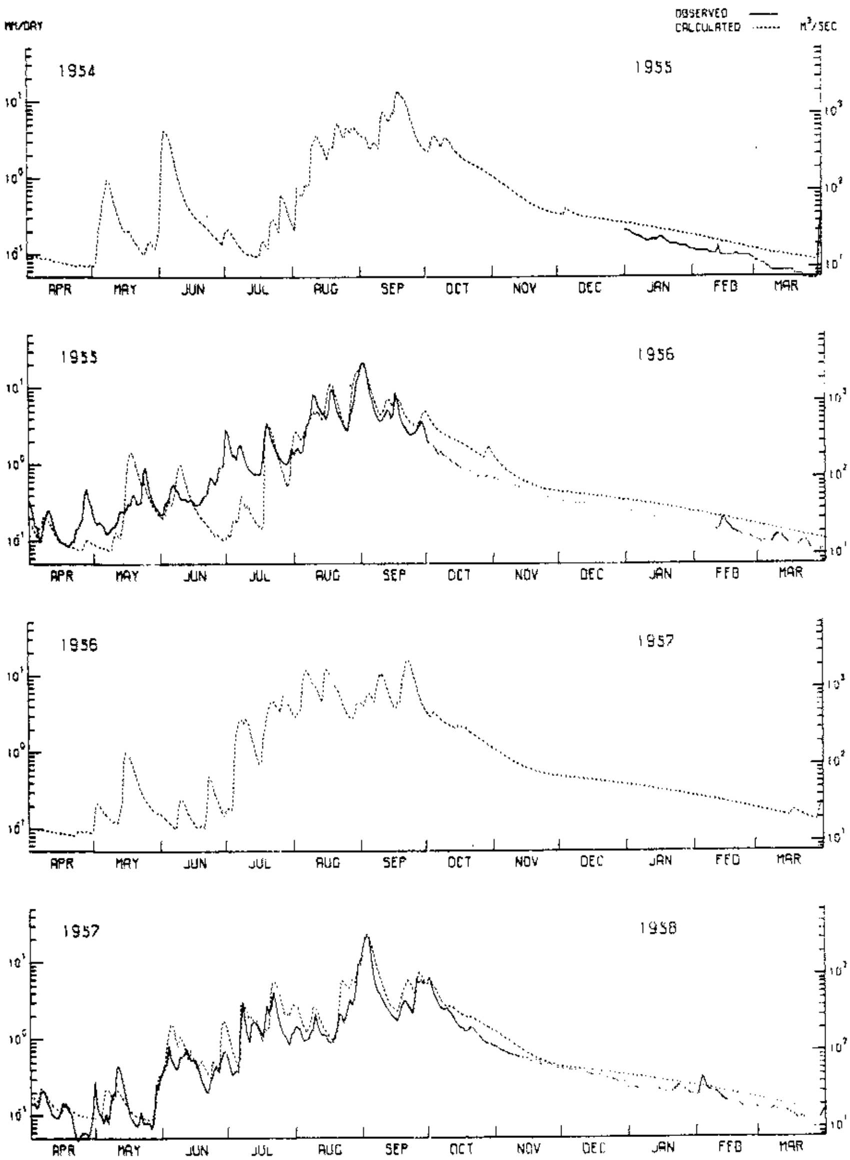

Fig. 20-1 Daily discharges of the Mae Nam Nan at Tha Pla

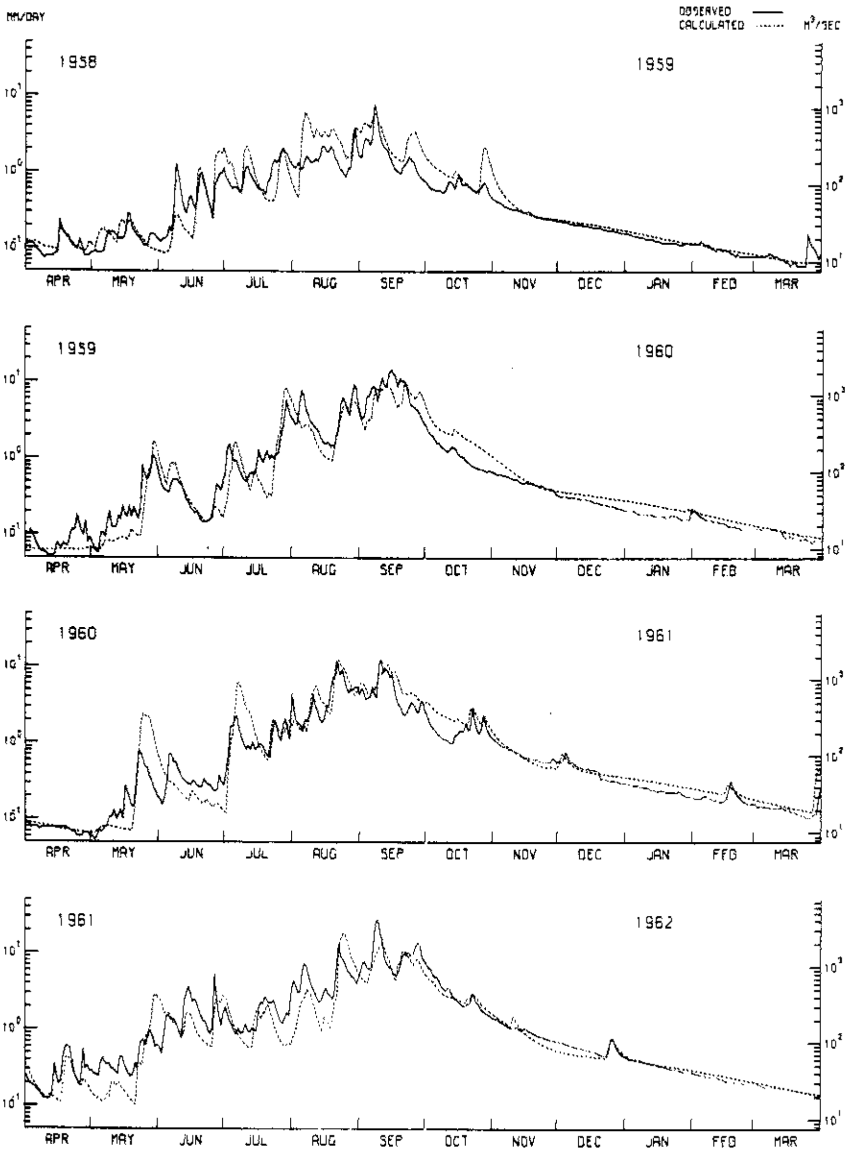

Fig. 20-2 Daily discharges of the Mae Nam Nan at Tha Pla

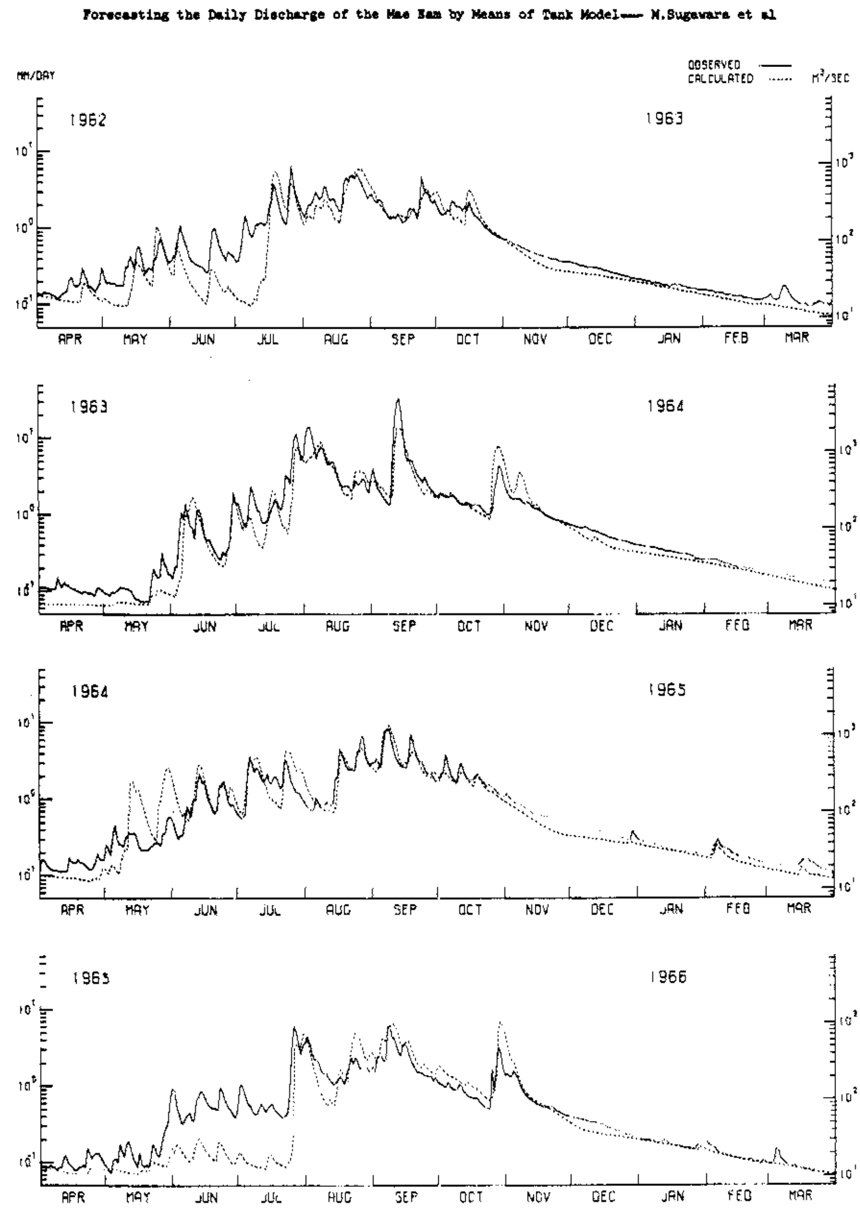

Fig. 20-3 Daily discharges of the Mae Nam Nan at Tha Pla

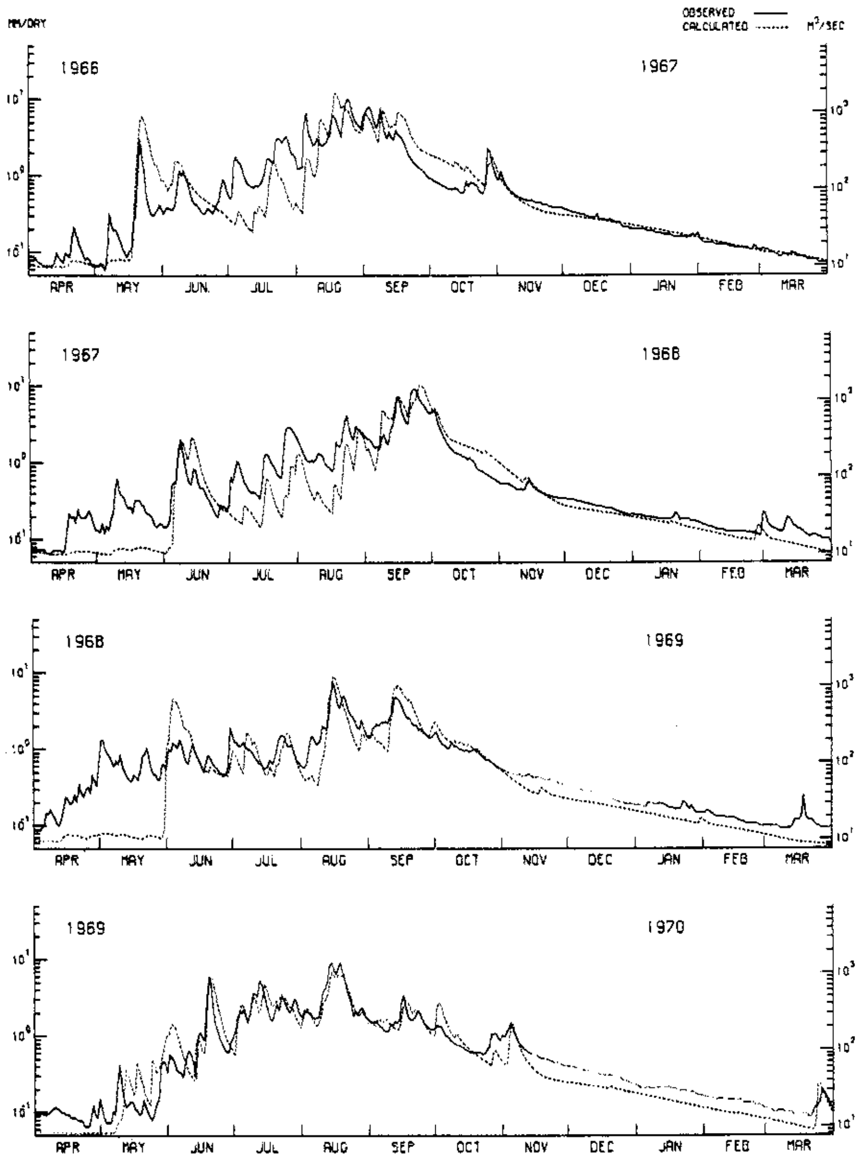

Fig. 20-4 Daily discharges of the Mae Nam Nan at Tha Pla

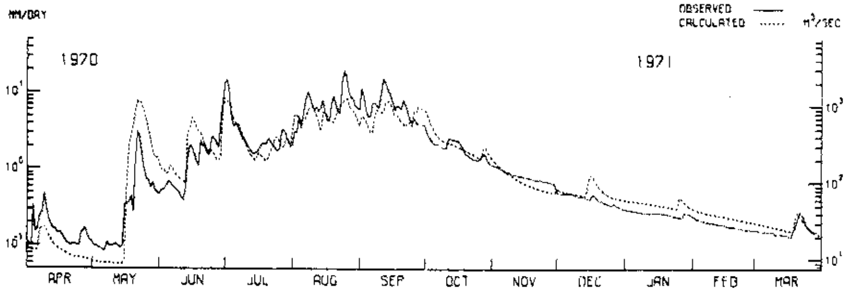

Fig. 20-5 Daily discharges of the Mae Nam Nan at Tha Pla

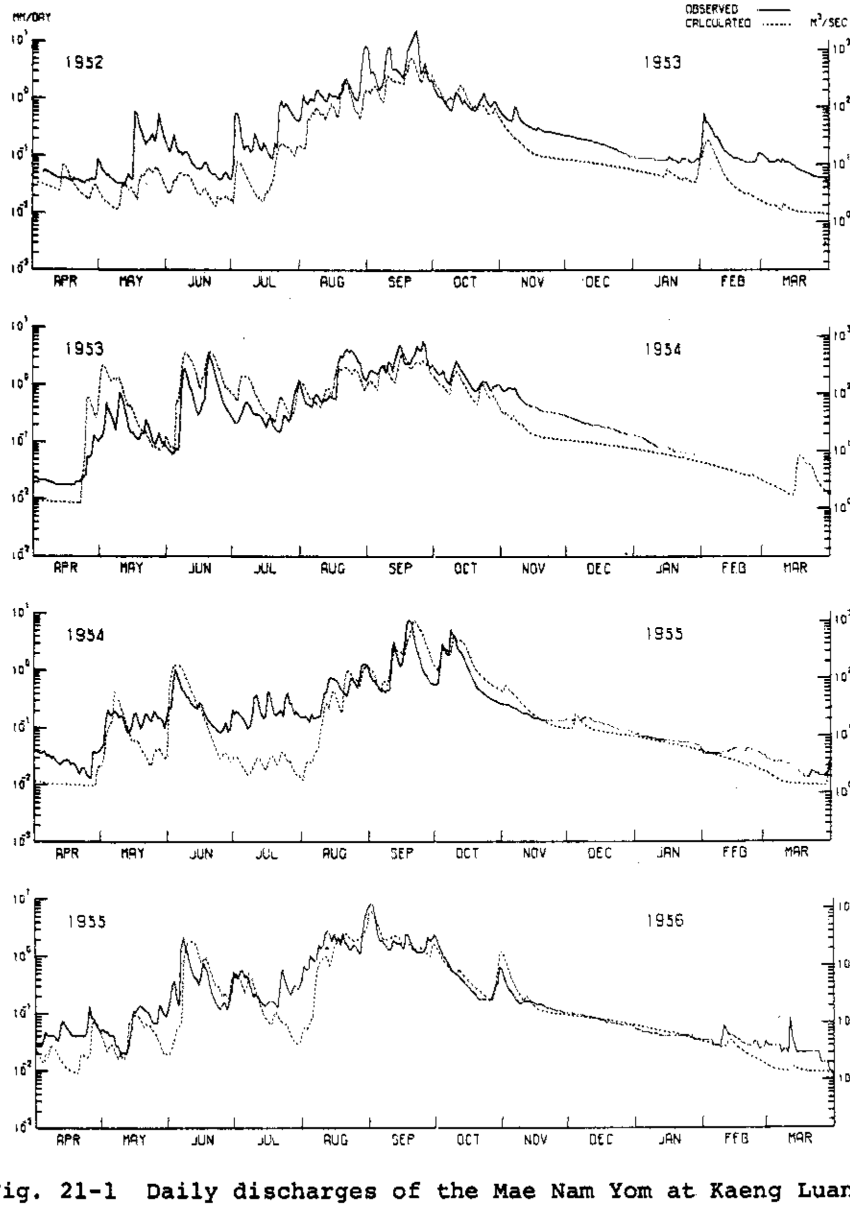

Fig. 21-1 Daily discharges of the Mae Nam Yom at Kaeng Luang

Forecasting the Daily Discharge of the Mae Nam by Means of Tank Model——M. Sugawara et al

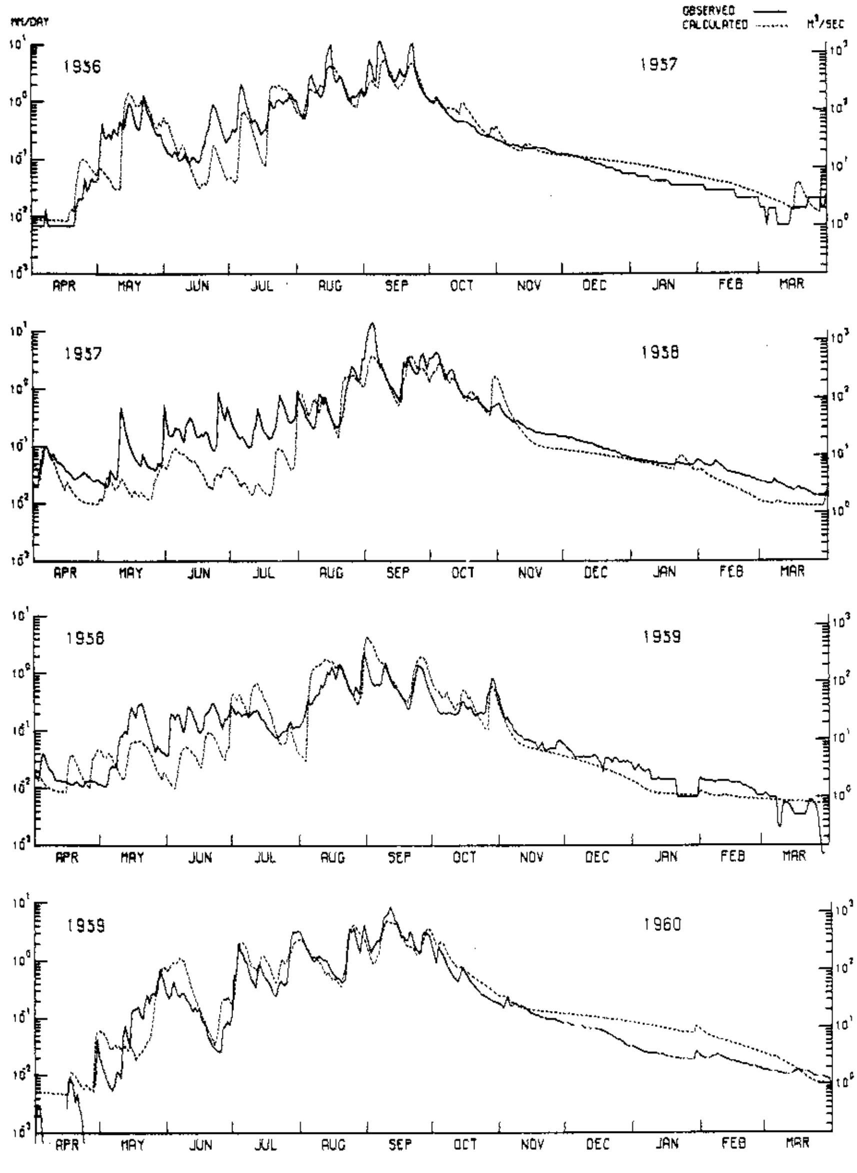

Fig. 21-2 Daily discharges of the Mae Nam Yom at Kaeng Luang

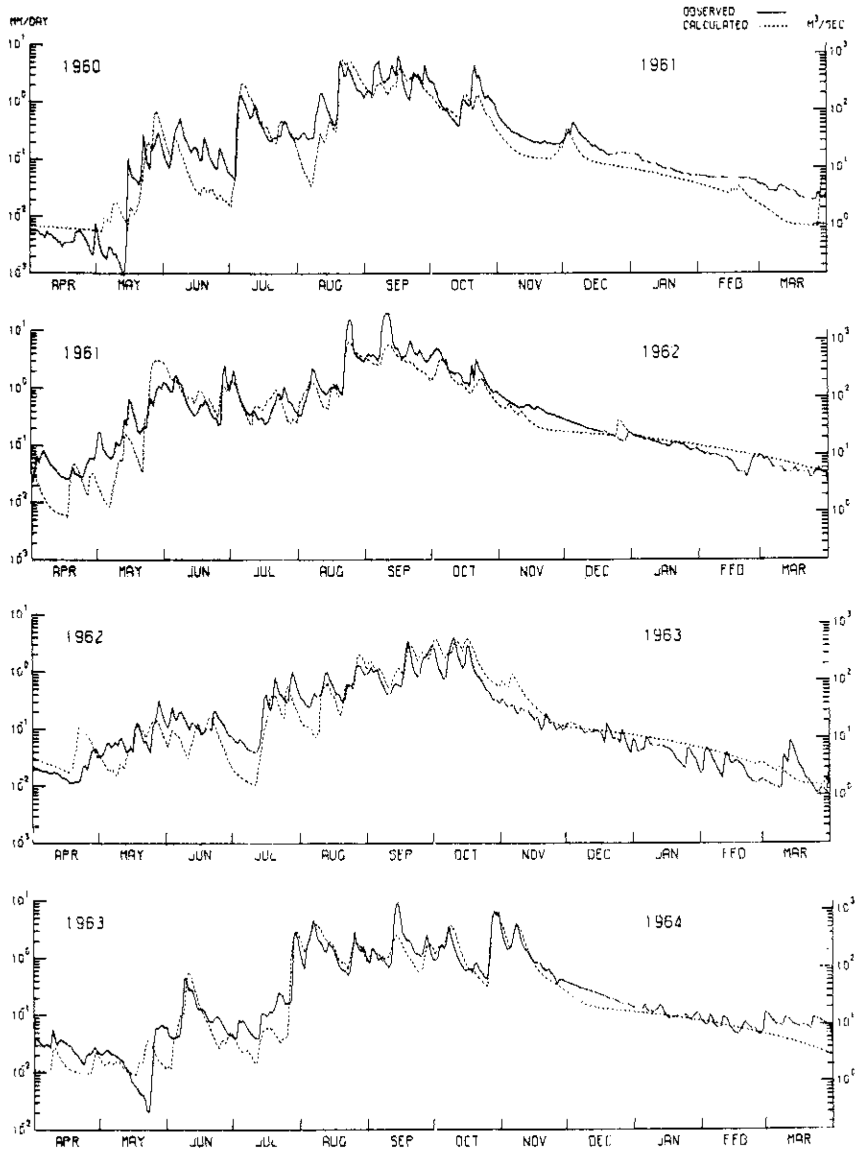

Fig. 21-3 Daily discharges of the Mae Nam Yom at Kaeng Luang

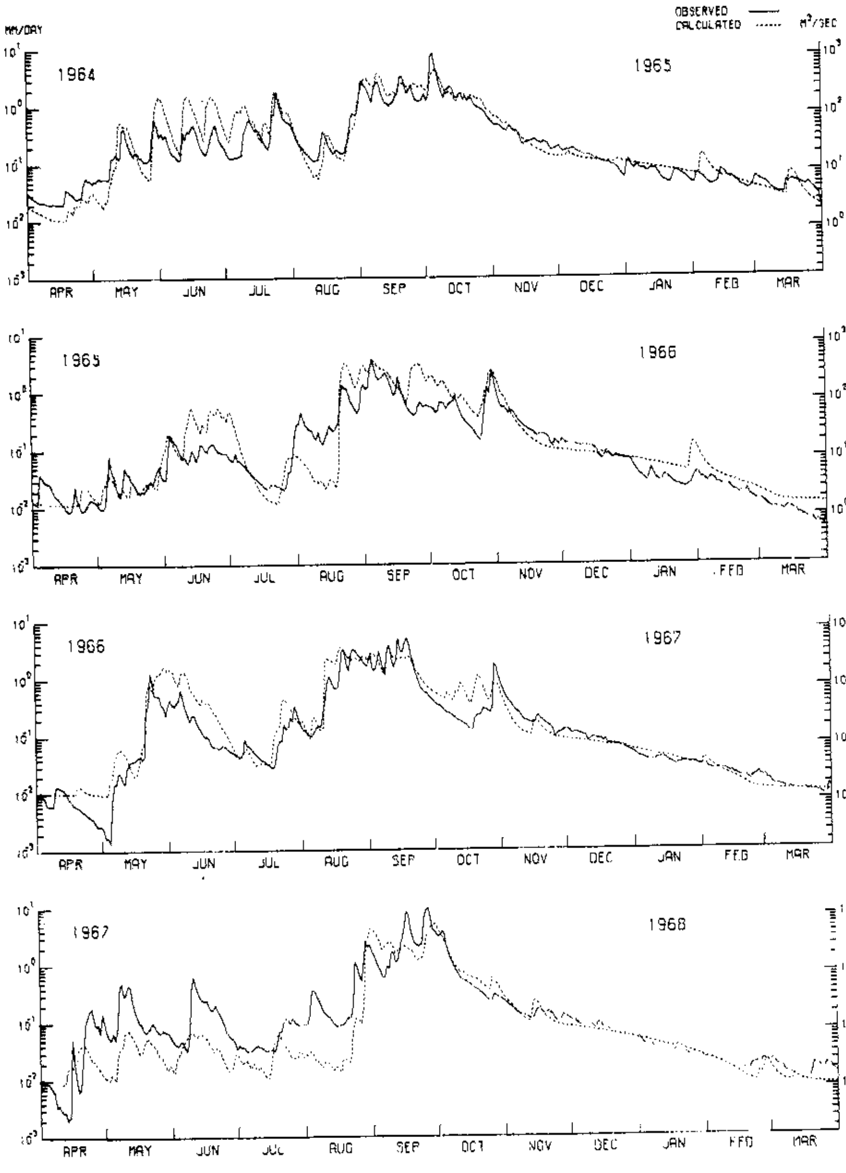

Fig. 21-4 Daily discharges of the Mae Nam Yom at Kaeng Luang

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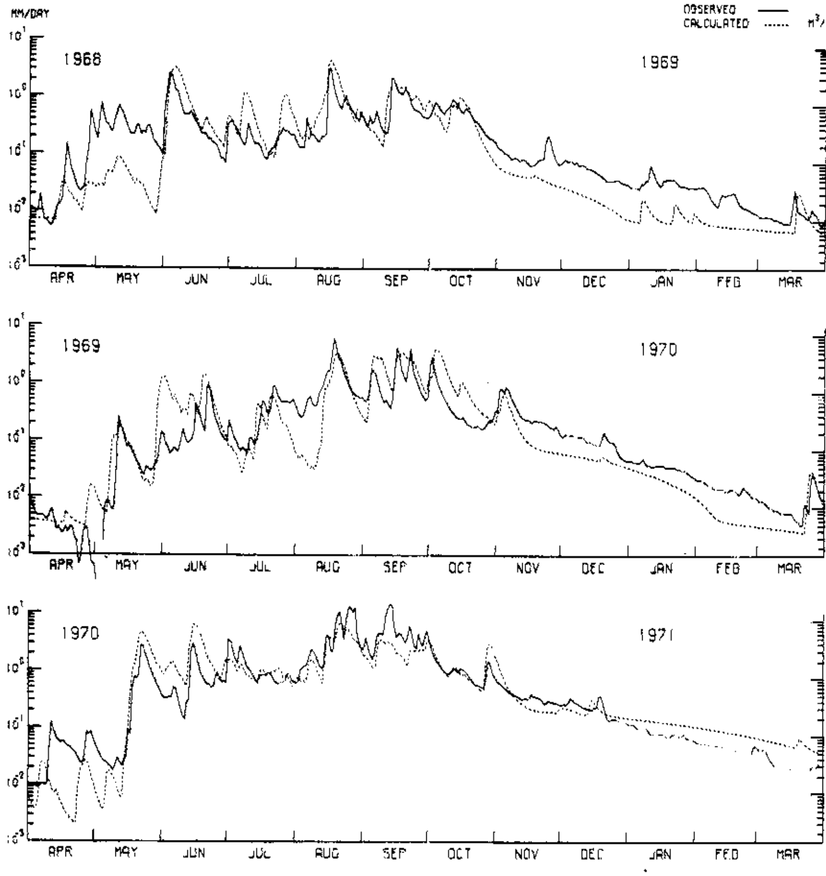

Fig. 21-5 Daily discharges of the Mae Nam Yom at Kaeng Luang

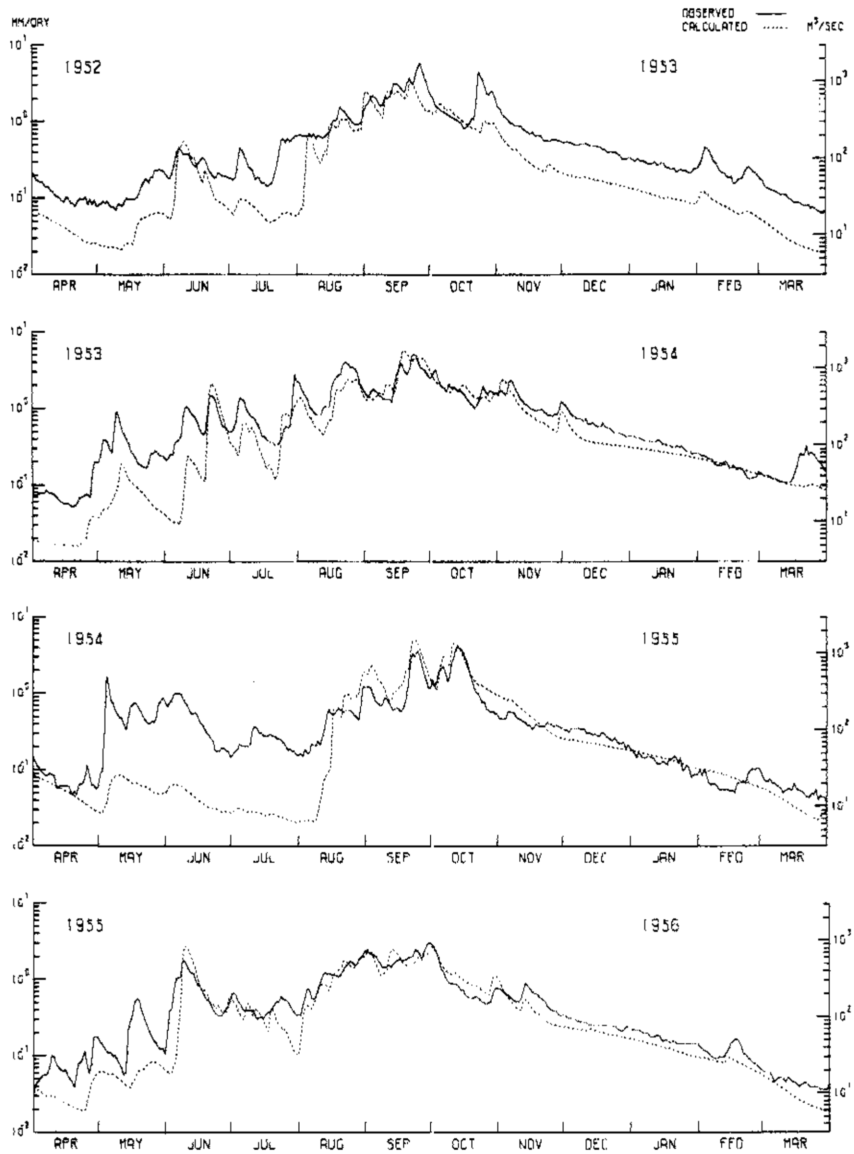

Fig. 22-1 Daily discharges of the Mae Nam Ping at Wang Kra Chao

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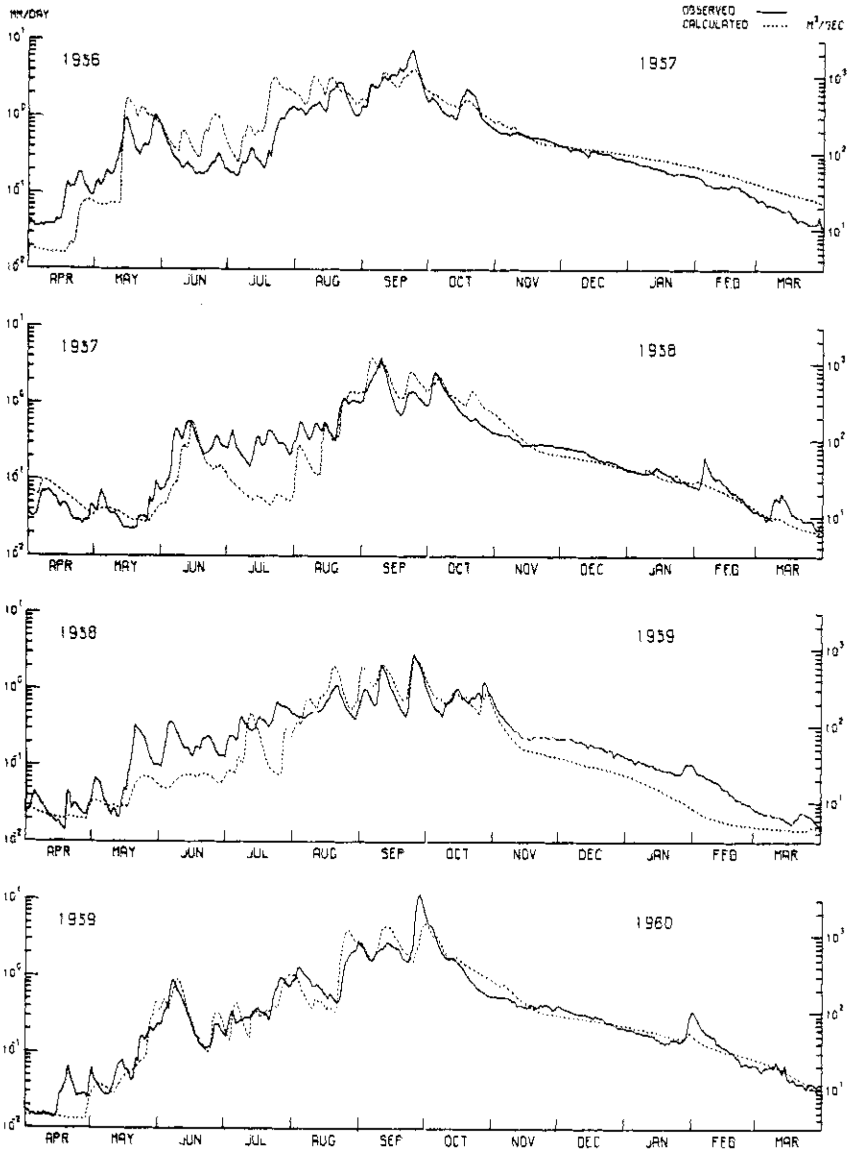

Fig. 22-2 Daily discharges of the Mae Nam Ping at Wang Kra Chao

Forecasting the Daily Discharge of the Mae Nam by Means of Tank Model—— M.Sugawara et al

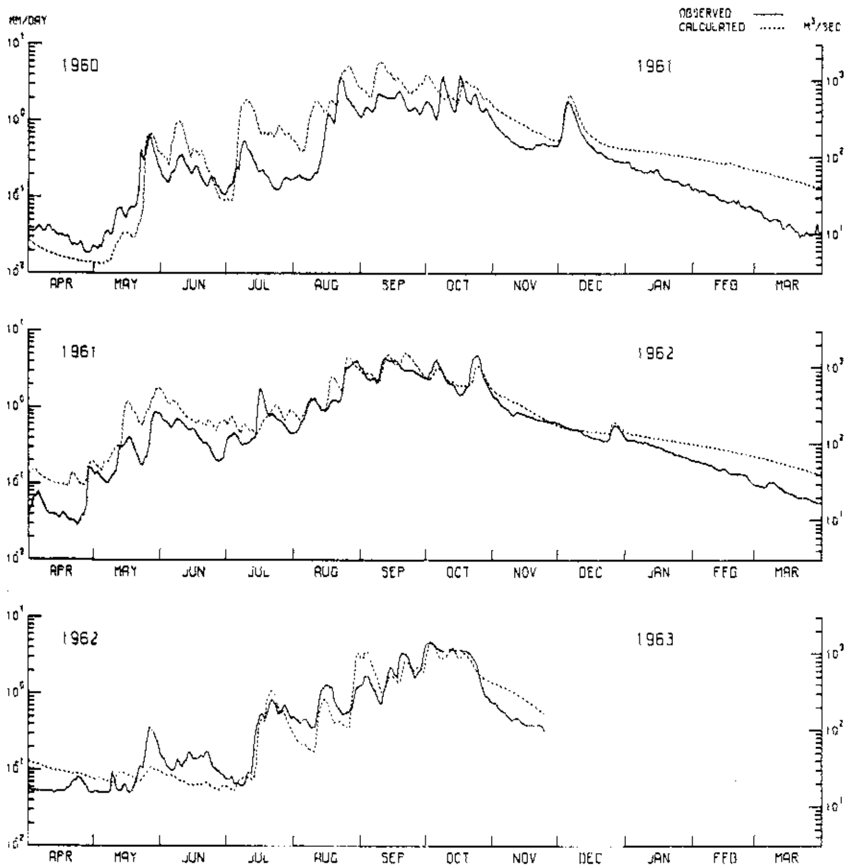

Fig. 22-3 Daily discharges of the Mae Nam Ping at Wang Kra Chao

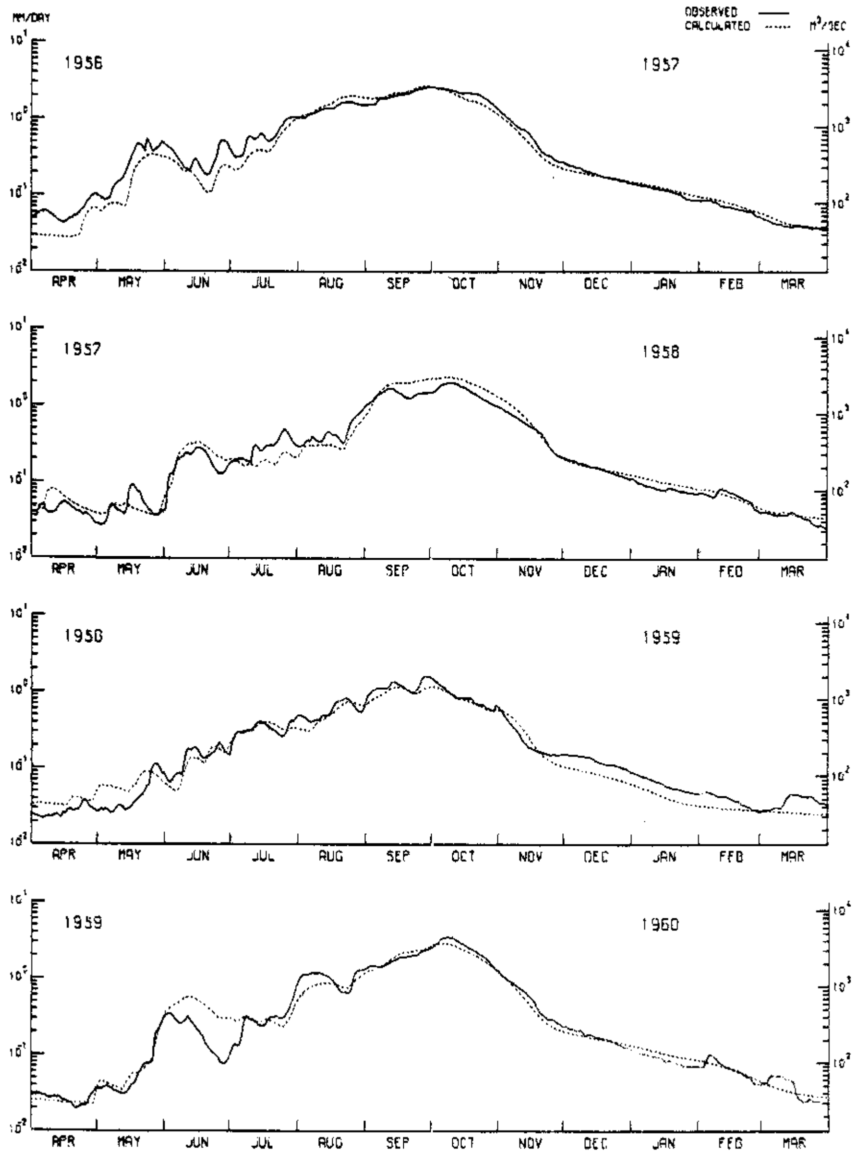

Fig. 23-1 Daily discharges of the Mae Nam Chao Phraya at Nakhon Sawan

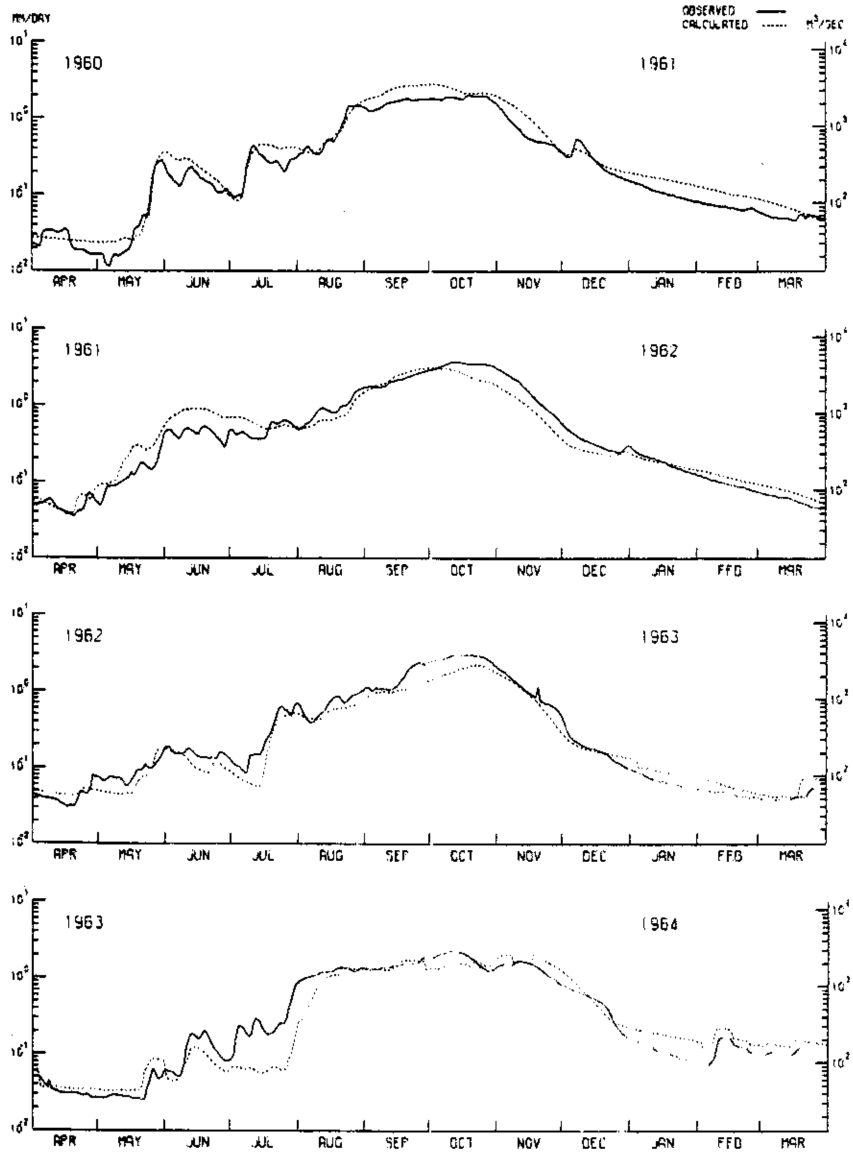

Fig. 23-2 Daily discharges of the Mae Nam Chao Phraya at Nakhon Sawan

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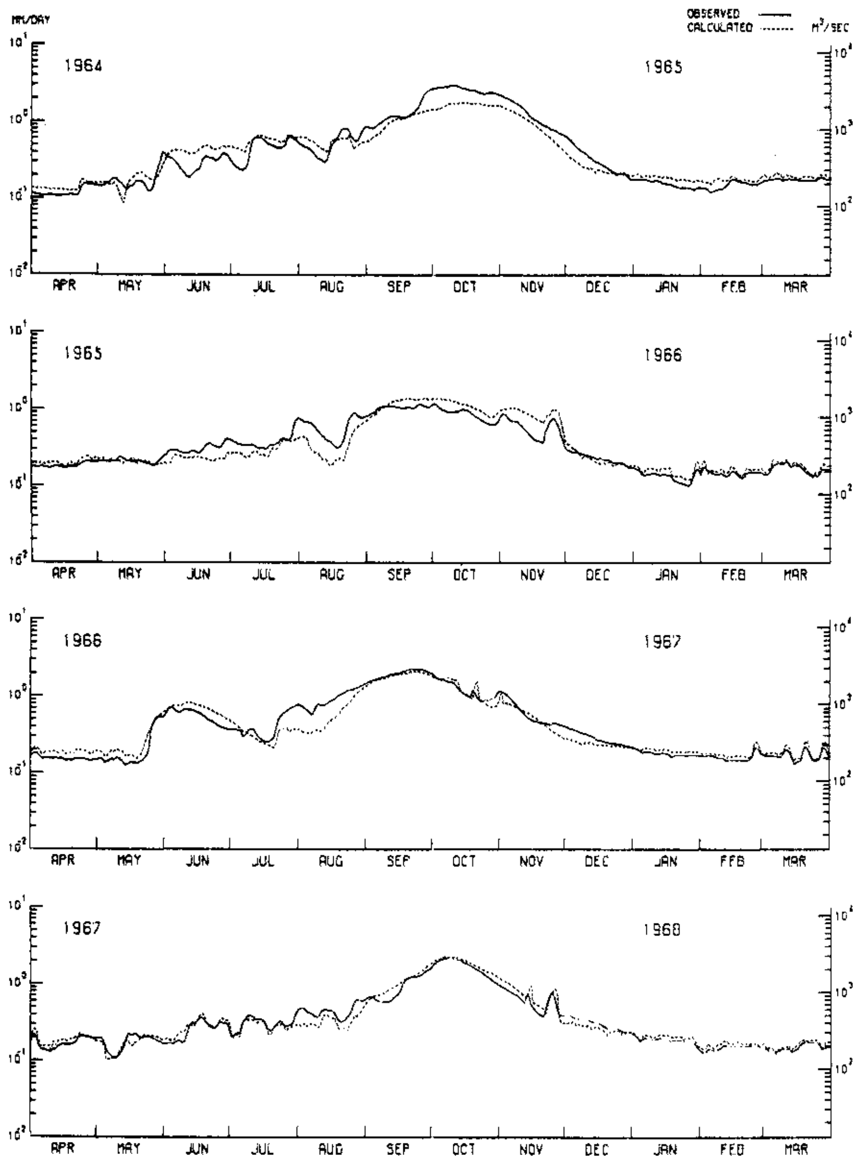

Fig. 23-3 Daily discharges of the Mae Nam Chao Phraya at Nakhon Sawan

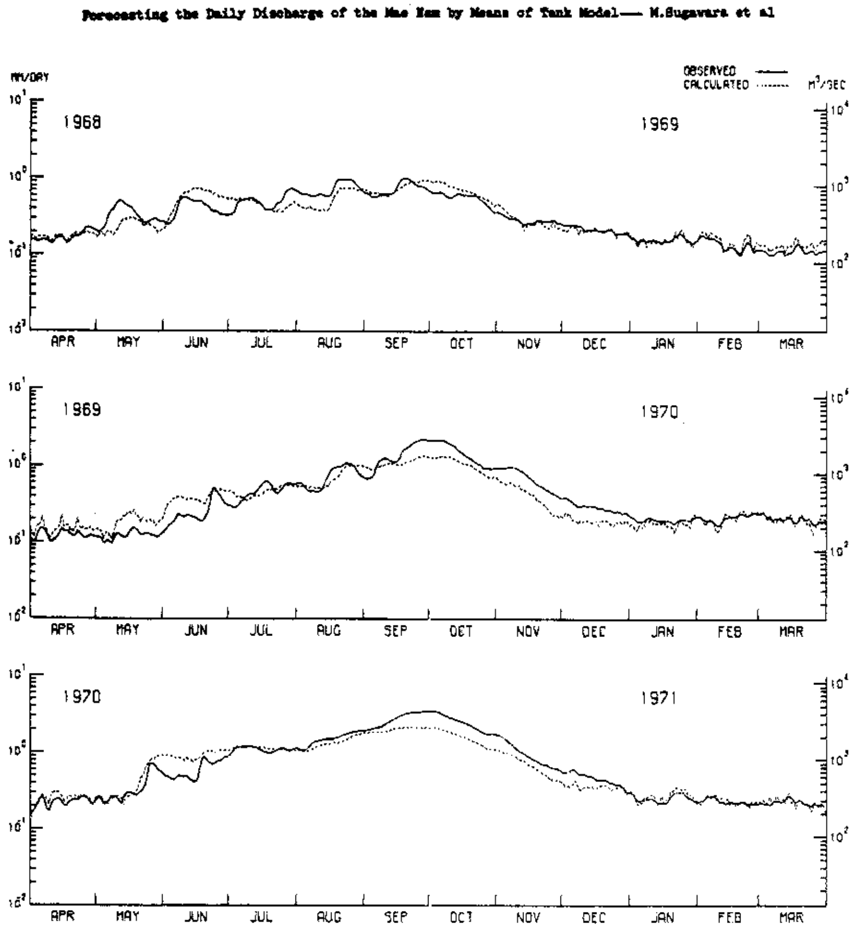

Fig. 23-4 Daily discharges of the Mae Nam Chao Phraya at Nakhon Sawan

国立防災科学技術センター研究速報　第２４号　１９７６年７月

チャオ・ピヤ河およびその支流上の諸地点における日流量をタンク・モデルにより算出する方法について（英文）

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タイ国チャオ・ピヤ河およびその支流上の４地点における日流量を，流域内および近傍の地点雨量から，非湿潤地帯用の４×４型タンク・モデルにより算出する．

東南アジア地域の熱帯性スコールの局地性により，得られた結果は必ずしも良好ではないが，２０地点の雨を用いて算出された本流のナコン・サワン（流域面積約１１万km^2）と，雨量分布がいくらか一様であるらしいナム河のタ・プラ（流域面積約１万３千km^2）の結果はかなり良好である．日流量の推定は，降雨の局地性によりあまりよくないが，月流量については，ほぼ満足してよい．

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