イラワジ河上流部Sagagingの流量のタンク・モデルによる予報方式(英文)

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River Forecasting of the Upper Irrawaddy River at Sagaing, Burma, Using the Tank Model

By

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Abstract

The daily discharge of the Upper Irrawaddy River at Sagaing (117,900 km^2) is derived from daily rainfall at four points, Putao, Myitkyina, Mogaung and Bhamo using the Tank Model. In March and April, considerable discharges are observed but only low rainfall is recorded at the four stations. Therefore, it was expected that this must be the effect of snowmelt. However, a trial with the snow model showed that the effect of snow is rather negligible. Thus, the discharge in March and April must be evidence of heavy rainfall in mountain areas. Consequently, a correction factor for precipitation data measured at the stations along the river becomes necessary.

After some trials, the snow model was abandoned for simplicity's sake and an automatic calibration method was introduced to determine the multiplication factor for precipitation. Values obtained by the automatic calibration program showed a very large seasonal change, i. e. they are very high in transition periods between dry and rainy seasons but very near one from June to August. In March and April; October and November, the multiplication factor is about two or three. That is to say, mean rainfall in the basin is around two or three times the amount of the rainfall measured along the river and, accordingly, the rainfall in the highest mountain areas must be several times that measured in the riverside areas. Such a conclusion seems somewhat unbelievable but it is the most important aspect of this runoff analysis.

1. Purpose

This paper describes studies to calculate the daily discharge of the Upper Irrawaddy River at Sagaing (117,900 km^2), Burma, from the daily precipitation data at four points, Putao, Myitkyina, Mogaung and Bhamo (see Fig. 1). The effect of snow was

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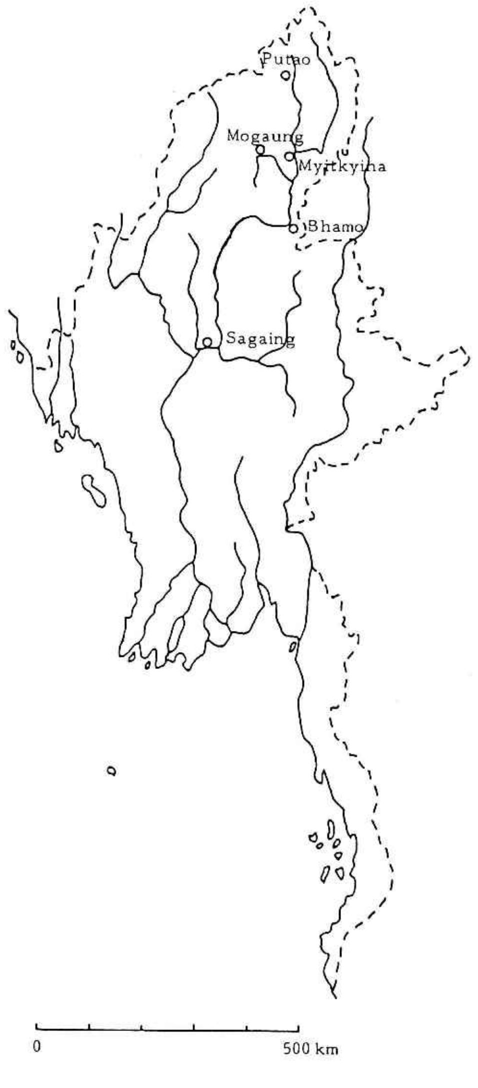

Fig. 1 Map of Burma

also considered, using the daily temperature at Putao, although this proved to be negligible.

2. Available data

Available data are as follows (Refer also Tin, 1984) :

1) Discharge: daily discharge data at Sagaing for four years 1980-1983.
2) Precipitation: daily precipitation data at Putao, Myitkyina, Mogaung and Bhamo for four years 1980-1983.
3) Temperature: daily temperature data at 9:30, daily maximum and daily minimum temperature at Putao and Myitkyina for four years 1980-1983.
4) Evaporation data were not available and the values given in Table 1 were assumed.

Table 1 Assumed daily evaporation (mm/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.0	4.5	6.5	8.0	8.0	5.0	5.0	4.5	4.0	4.0	3.0	3.0

3. The derived model and the results obtained

Daily precipitation data at four stations were put into the tank model shown in Fig. 2 separately after multiplication by the factor CP (M) shown in Table 2. Daily evaporation as given in Table 1 was subtracted from the tank model after multiplication by CE=0.6 (Sugawara et al., 1984).

Table 2 Multiplication factor for precipitation: CP(M)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2.65	2.62	2.60	3.30	2.75	1.03	1.03	1.03	1.22	2.03	2.70	2.68

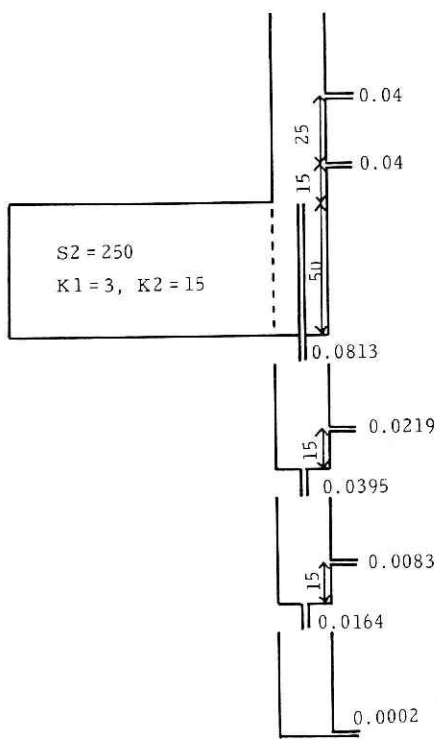

Fig. 2 Derived tank model

The four output series from the tank model corresponding to the four rainfall stations were combined with equal weights and with the time lags shown in Table 3.

Table 3 Weights and time lags for the combination of the outputs from the tank model corresponding to each rainfall station

	Putao	Myitkyina	Mogaung	Bhamo
weight	0.25	0.25	0.25	0.25
time lag (day)	6	5	4	3

The results obtained are shown in Fig. 3 and Fig. 4. As can be seen in Fig. 3, the observed and calculated daily hydrographs do not fit well although the monthly hydrographs shown in Fig. 4 fit very well.

Usually, the areal distribution of precipitation in tropical regions is very local and, accordingly, it is very difficult to estimate areal rainfall from few rainfall stations. A bad fit between the calculated and observed daily hydrographs is almost inevitable given the condition that there are only four rainfall stations in the basin. In spite of the bad fit between the two daily hydrographs, both duration curves of the daily discharge show a very good fit judging by the values of criteria shown in Table 4 (Sugawara, et al., 1984, pp. 23-24).

Table 4 Values of criteria for the calculated discharge

MSEQ	MSELQ	CRHY	MSEDC	MSELDC	CRDC	CR
0.2450	0.1726	0.2088	0.0846	0.0735	0.0791	0.2879

It is curious that in the derived model the values of CP(M), the multiplication factors for precipitation (Table 2) are very large in some months. In June, July and August, the main part of the rainy season, the values of CP(M) are nearly 1; however, at the beginning and at the end of the rainy season they are extremely large, especially in April, May, October and November. In such transition seasons, the climate will be particularly unstable in mountainous areas. In the Upper Irrawaddy basin all the rainfall stations are along the river, i. e. there are no stations in the mountains. The large values of CP(M) shown in Table 2 show that it rains very heavily on the mountain area in such transition seasons. In winter, from December to February, there is very little rainfall and the values of CP(M) are nearly meaningless. These values were determined by linear interpolation of the values in November and in March.

These CP(M) values were determined by subjective iudgement at the beginning and later by an automatic calibration method (Sugawara, et al., 1984, pp. 258-266). The results obtained by different methods are rather similar which probably shows that the CP(M) values are reliable and that it rains very heavily on mountain areas in the

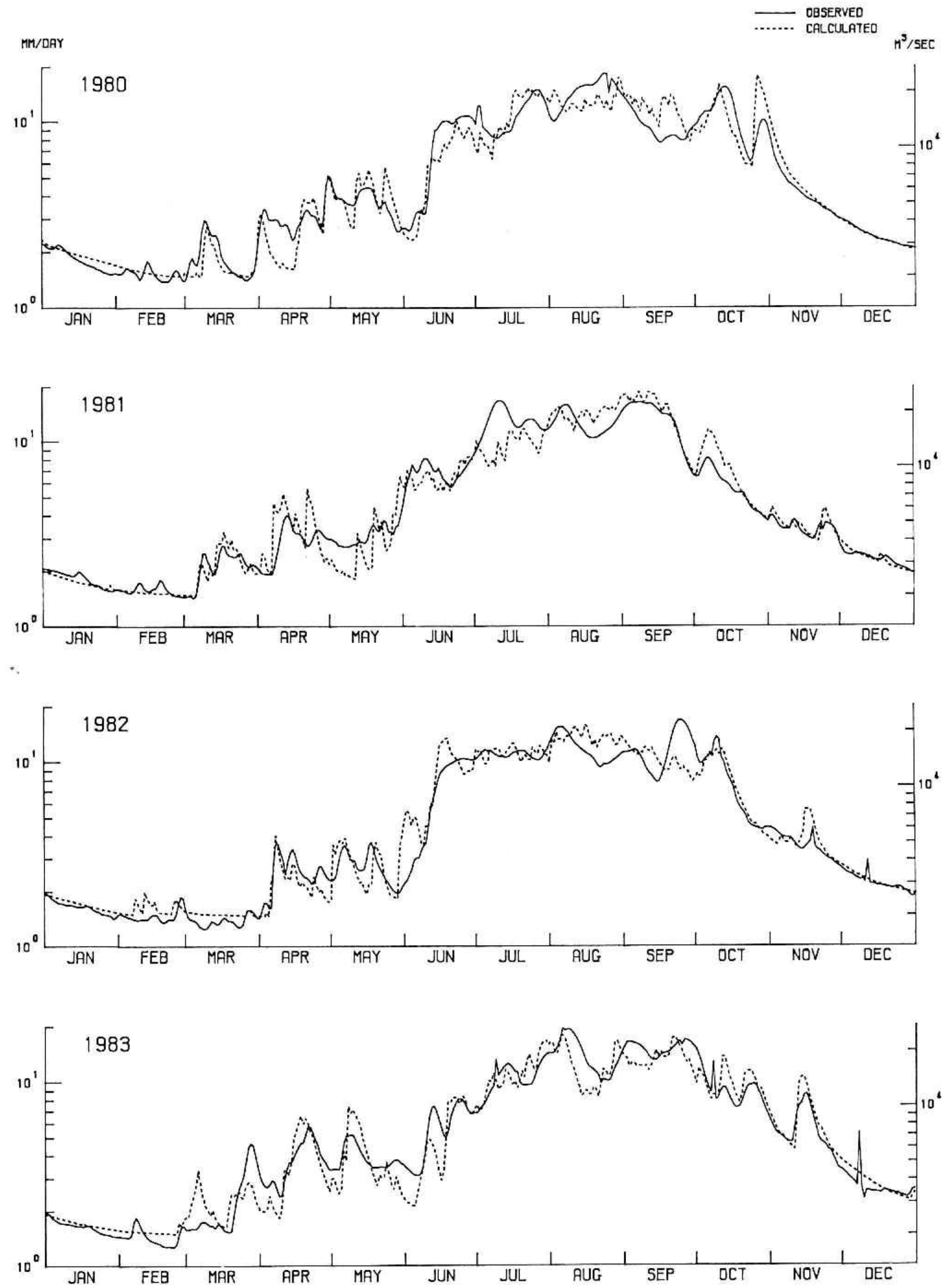

Fig. 3 Daily discharge of the Upper Irrawaddy River at Sagaing (117,900 km²)

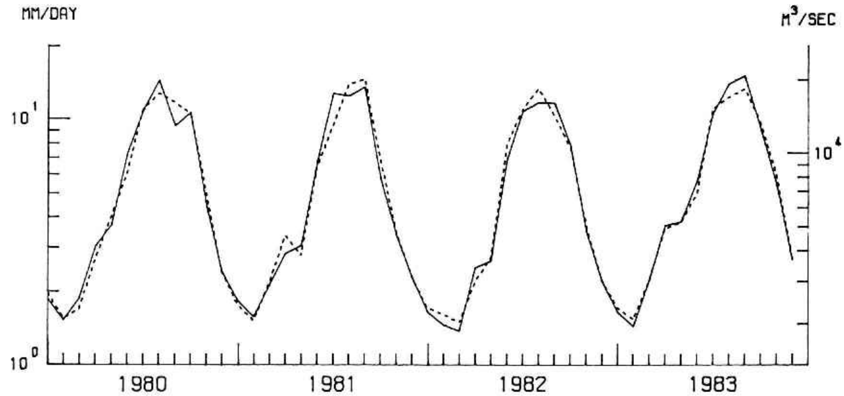

Fig. 4 Monthly discharge of the Upper Irrawaddy River at Sagaing (117,900 km²)

beginning and in the end of rainy season.

In the model, described here, the effect of snow was neglected.

4. Calibration procedure

4.1 Preliminary analysis without snow model

Preliminary trials No. 1—No. 5 were made without a snow model. In these trials, CE (multiplication factor for evaporation) was set to 0.7 and CP(M) was set to 1.4 for trials No. 1—No. 4 and then to 1.25 for trial No. 5. At this stage there was no seasonal change of CP (M). The calculated hydrograph was much smaller than the observed one in March and April and it was thought that this weak point could be solved by introducing the effect of snow. However, temperature data were not available at that time.

4.2 Trial with snow model

Trial No. 6 was made, after the arrival of temperature data, under the following assumptions (Sugawara et al., 1984, pp. 5-12):

a) The basin was divided into four subbasins of equal areas corresponding to four rainfall stations.

b) The snow model was applied only to the highest subbasin corresponding to Putao in the following way:

(1) The elevation range of the subbasin was assumed to be 300—5,300 m. This range was divided into five zones with an elevation interval of 1,000m. The area of each zone was assumed to be

16%, 26%, 28%, 20%, 10%

from the lowest zone to the highest zone.

(2) As daily maximum temperature seemed to be unstable, the weighted mean

$$T = 0.3T\max + 0.7T\min$$

was used as input temperature.

(3) The temperature correction term, T0, the decrease in temperature per zone, TD, and the snowmelt constant, SMELT, (the degree-day factor) were assumed to be:

$$T0 = 1, \quad TD = 6, \quad SMELT = 6.$$

(4) Precipitation increase constants PD(I) for the zones were assumed as: 0.00, 0.14, 0.28, 0.42, 0.56. These values were used so that the total precipitation on the whole subbasin is about 1.25 times of the rainfall at Putao, equal to the value used in trial No. 5.

(5) In the highest zone, temperature is nearly always below 0℃ and snow deposits would continue to increase if we did not include effects of avalanches or glaciers. Therefore, the assumption was made that 0.1% of the snow storage in the fifth zone transfers to the fourth zone everyday. Transfer of the snow storage from the fourth zone to the third zone was not considered because the snow storage in the fourth zone melts easily due to the higher temperature.

c) To simplify the program, the same snow model was applied for the other subbasins, with the conditions T0=0 and TD=0. This implies that, in these subbasins, because of the temperature there is no effect of snow in reality.

The result obtained was not good. Contrary to expectations, the effect of including snow was very small in this basin and could justifiably be ignored.

4.3 Introduction of the parameter CP (M), the multiplication factor for precipitation

The only way to increase the calculated discharge in March and April is to increase the input precipitation by multiplying by some factor CP(M). In trials No. 1—No. 5, such a factor was introduced but without a seasonal change, by putting CP(M) to 1.40 or 1.25. Considering the results of these trials, it seemed to be necessary to introduce a seasonal change in CP(M), i. e. CP(M) must be large in March and April but need not be large in June and July.

Trials No. 7—No. 13 were made changing CP(M) and PD(I) as shown in Table 5.

Trial No. 13 gave very good results.

4.4 Introduction of the parameter C(M), the seasonal correction factor for PD(I), instead of the parameter CP(M)

In spite of the good result obtained in trial No. 13, there was an anomaly in the model structure, in which the precipitation in the I-th zone in the M-th month was given as

$$CP(M) \times (1 + PD(I)) \times P,$$

where P is the measured precipitation.

In March and April, CP(M) is very large and the above formula shows that the precipitation in the first zone, in which PD(I)=0, is CP(M)×P. As the rainfall station is located in the first zone, it is not reasonable that the mean precipitation in the first zone in March and April is about twice or three times the measured value at the station.

Table 5 Values of CP(M) and PD(I) used in trials No. 7—No. 13

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. 7	CP (M)	1.0	1.0	1.5	1.5	1.5	1.0	1.0	1.0	1.3	1.3	1.3	1.0
	PD (I)		0.00		0.14		0.28		0.42		0.56		
No. 8	CP (M)	1.0	1.0	1.5	2.0	2.0	1.0	0.9	0.9	1.1	1.5	1.5	1.0
	PD (I)		0.00		0.10		0.20		0.30		0.40		
No. 9	CP (M)	1.0	1.0	2.0	4.0	3.0	1.0	0.95	0.95	1.1	2.0	2.0	1.0
	PD (I)		0.00		0.12		0.24		0.36		0.48		
No. 10	CP (M)	1.0	1.0	2.0	3.0	2.0	1.0	0.9	0.9	1.1	1.7	1.7	1.0
	PD (I)		0.00		0.10		0.20		0.30		0.40		
No. 11	CP (M)	1.0	1.0	2.5	3.5	2.5	0.9	0.9	0.9	1.1	1.7	1.7	1.0
	PD (I)		0.00		0.08		0.16		0.24		0.32		
No. 12	CP (M)	1.0	1.0	2.8	3.5	2.0	0.9	0.9	0.9	1.1	1.7	1.7	1.0
	PD (I)		0.00		0.07		0.14		0.21		0.28		
No. 13	CP (M)	1.0	1.0	2.8	3.5	2.0	0.9	0.9	0.9	1.2	1.8	1.8	1.0
	PD (I)		0.00		0.075		0.15		0.225		0.30		

To eliminate such an unreasonable point, the parameter C(M) was introduced instead of CP(M) so that the mean precipitation in the I-th zone in the M-th month is given by

$$(1+C(M)\times PD(I))\times P.$$

Values of C(M) can be easily determined by putting the sum $\sum_{I} ZA(I)\,(1+C(M)\times PD(I))$ equal to the sum $\sum_{I} ZA(I)\,CP(M)\,(1+PD(I))$, where the values of CP(M) are the ones used in trial No. 13 and ZA(I) is the area of the I-th zone.

Trials No. 14—No. 17 were made in such a way. In trials No. 7—No. 13, the same set of values of PD(I) were assumed for all four subbasins. The highest subbasin, corresponding to Putao, shows a large elevation range but in other subbasins it is much smaller; consequently, it is better to assume different set of values of PD (I) for each subbasin. Trials No. 14—No. 17 were made changing the values of C(M) and PD(I).

Trial No. 17 was made using the values of C (M) and PD (I) shown in Table 6 and

Table 6 Values of C (M) and PD (I) used in trial No. 17

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C(M)	12	14	16	22	10	0.2	0.2	0.2	2	8	10	11

	PD (1)	PD (2)	PD (3)	PD (4)	PD (5)
Putao	0.00	0.09	0.18	0.27	0.36
Myitkyina	0.00	0.07	0.14	0.21	0.28
Mogaung	0.00	0.05	0.10	0.15	0.20
Bhamo	0.00	0.04	0.08	0.12	0.16

the result was good, but not as good as No. 13, judging from the value of criterion CR.

Assuming that the criterion CR is some sort of random variable and consequently includes some noise component a small difference of CR is probably meaningless and the result of trial No. 17 can be considered comparable to the result of trial No. 13. As model No. 13 includes an unreasonable structure, model No. 17 can be considered to be better than model No. 13.

4.5 Trials excluding the snow model but including the parameter CP(M) with seasonal change

Trials No. 6—No. 17 were made applying by the snow model to the highest Putao subbasin. In reality, the effect of snow is not large and the model including the snow model is rather complicated. Therefore, the snow model was neglected in future trials to simplify the model. Neglecting the snow model means that the automatic calibration program to determine CP (M) can be applied. This program was developed in 1978 for basins in the Upper Nile region. Since that time, there have been some change in the tank model and the automatic calibration program for CP(M) was rewritten for the present tank model.

Trial No. 18 was made using this program to determine CP (M). Trial No. 19 was made with the values of CP (M) obtained and the result was very good. This is the final model.

Inspecting the result obtained, we expected that by increasing the weight for Putao the result would become better because Putao seemed to be more representative than other stations. Trial No. 20 was made to determine CP(M) with the following weights:

Putao	Mytkyina	Mogaung	Bhamo
0.4	0.2	0.2	0.2

Trial No. 21 was made using the CP(M) obtained by trial No. 20. The result was, however, worse than before.

4.6 Some trials with the snow model

As the result of No. 19 was very good, an idea occured that by adding the snow model to model No. 19 the result would become better. However, there was some difficulty. As described previously, the parameter CP(M) does not fit for the snow model in most cases. Moreover, the automatic calibration program for CP (M) cannot be applied to the model with a snow component. Therefore, the values of CP(M) used in model No. 19 were transformed into equivalent values of C(M) and they were applied to the snow model. Trials No. 22—No. 24 were made with some modifications but the results obtained were not good and the trials were ended.

5. Some considerations and problems for the future

There are many further possible trials, e. g. by changing weights for rainfall stations, by changing CP(M) for each rainfall stations respectively, etc. However, observing the bad fit between calculated and observed daily hydrographs, such modifications cannot be considered as meaningful and effective. In the previous trials, there was some progress in the value of the criterion CR. However, in observing the daily hydrographs, there was not much change in the shape of calculated daily hydrograph. In those periods where the daily hydrographs showed a bad fit, the calculated hydrograph continued to show a bad fit with the observed one throughout many trials. This originates from the important fact that the rainfall data at only four stations cannot represent areal precipitation in tropical regions. The large values of CP(M) in transitional seasons show that rainfall data measured at stations along the river are not so reliable.

Rainfall at Putao is much larger compared with the other stations as shown in Table 7.

Table 7 Annual rainfall at four stations

	Putao	Myitkyina	Mogaung	Bhamo
1980	4069	2228	1785	1645
1981	3589	2013	1968	1961
1982	4063	1769	1752	1850
1983	3701	2136	2272	1977
mean	3856	2036	1944	1858

As a result of this fact, a large part of the discharge at Sagaing must be composed of the outflow from the upper part of the basin represented by Putao. If the discharge could be measured at some place near Putao, such discharge data would be very important and useful for the river forecasting at Sagaing.

To measure the discharge of the Upper Irrawaddy River at Putao or Myitkyina, or both, would be very effective for river forecasting at Sagaing. Probably, accurate river forecasting at Sagaing would be possible with a three day lead time.

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イラワジ河上流部 Sagaing の流量のタンク・モデルによる予報方式

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要　旨

タンク・モデルにより，ビルマのイラワジ河の上流部 Sagaing (117,900 km²) の日流量を，流域内4地点 Putao，Myitkyina，Mogaung，Bhamo の日雨量から，タンク・モデルを用いて算出した．

予備的試算により，3月，4月に雨量地点であまり雨が降っていないのに，河川にかなり増水が見られるのは，雪どけの影響であると考えられた．しかし，雪の影響は，試算してみると，無視し得るほど小さい。したがって，3月，4月に河川にかなりの流量があるのは，流域内のどこかで雨が降っていることを示す．河沿いの4地点にあまり降雨がないのだから，山地で降っているに違いない．雨季の6月，7月，8月には，観測雨量を少し割り増しすれば，観測流量に合うのであるから，雨季の始めと終りに気象が不安定で，山地に大雨が降るらしい．つまり，雨に掛ける補正係数に大きな季節変化が必要である．雪の影響を無視し，雨に掛ける補正係数を求める自動化プログラムを用いて補正係数を求め，それにより推定流量が算出された．

流量を雨から算出することよりも，春と秋に，山地で大雨が降っているに違いないという結論に意義があろう．

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