SNOWMELT RUNOFF MODEL IN JAPAN

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INTRODUCTION

Preliminary results [1] of Japanese snowmelt runoff modelling were proposed at First Japan/US Snow and Evapotranspiration Workshop held in Tokyo on March, 1982. Aiming at the daily snowmelt runoff forecasting, the preliminary model was designed through multiple regression analyses based on the hydrological conception. However, it involved several operational defects as follows:

i) containing three input variables of mean air temperature, precipitation and snow cover area at the day of which the inflow ought to be forecast.
ii) insufficient concordance between the hydrological conception and the parameters which resulted from the multiple regression analyses.

In the present study the model was, then, so modified that all the input variables are of the antecedent days. The inflow of the previous day is also taken into account. The new model was developed in use of the 1980 data in the Okutadami River Basin, chosen again as the test basin, and was adapted to the other years for its operative efficiency.

The optimum contribution of the Satellite imagery to the snowmelt runoff forecasting is the extraction of the snow coverage. Japan is, unfortunately, covered with much cloud in snowmelt season. Only in a fortunate season, one can obtain only one or two useful imagery. Unlike US it is, therefore, impossible in Japan to draw the depletion curve of snow coverage based on the imageries. However, a few imageries obtained in the past were effectively utilized for the verification and modification of the depletion curve induced from the snow water equivalent distribution at maximum stage and the accumulated degree-days at one representative point selected in the basin. This point is equipped with data collection facilities and is expected to fully function as DCP.

Together with the depletion curve, the relationship between the basin-wide daily snowmelt amount and the air temperature at the point above were exhibited in form of nomograph for the convenience of the model user.

The Japanese model proposed in the present study is, thus, the practical model of the snow melt runoff forecasting.

TEST BASIN

The Okutadami River basin (area 414 km^2) chosen as the test basin for this analysis is situated in Central Japan shown in Figure 1. The highest and lowest altitudes of the basin are 2346 m and 782 m respectively. The altitude difference is, therefore, 1564 m. This basin is one of the heaviest snowfall area in Japan; the maximum snow depth recorded in recent 20 years was 598cm at Okutadami Meteorological Observing Station located at the dam site in the basin. The station runs the measurement of snow water equivalent and inflow into the reservoir as well as the general meteorological observation. Located slightly outside the basin is the Hinoemata meteorological observing station of air temperature and precipitation. Two stations above and the representative point (mentioned later), Maruyama, provide all the necessary input data of the model. Those locations are shown in Figure 2.

The snow depth measurements by helicopter at ten to twenty points scattered in the basin are carried out at the maximum stage of snow depth at about the end of every winter season by the Electric Power Development Company. The measurement points by helicopter are shown in Figure 3.

CONCEPT OF SNOWMELT RUNOFF MODEL

Two forms of multiple regression models were considered. First model is as follows;

$$R_n = c + a_1X_{n-1} + a_2X_{n-2} + a_3X_{n-3} + b_1Y_{n-1} + b_2Y_{n-2} + b_3Y_{n-3} \tag{1}$$

$$X_{n-i} = (M_{n-i} + P_{n-i})S'_{n-i} \tag{2}$$

$$Y_{n-i} = P_{n-i}S''_{n-i} \tag{3}$$

where

R_n : daily direct inflow (m^3/sec) into reservoir on the day, n

c : constant

$a_1, a_2, a_3, b_1, b_2, b_3$: partial regression coefficient

M_{n-i} : mean snowmelt amount on the day $n-i$ ($m^3 \cdot sec^{-1} \cdot km^{-2}$)

P_{n-i} : mean rainfall amount on the day $n-i$ ($m^3 \cdot sec^{-1} \cdot km^{-2}$)

S'_{n-i} : area where daily mean air temperature is above 0°C within snow cover area on the day $n-i$ (km^2)

S''_{n-i} : area where daily mean air temperature is above 0°C within non-snow cover area on the day $n-i$ (km^2)

The second model, in which the direct inflow of the previous day, R_{n-1}, is added to the variables of the first model, is as follows;

$$R_n = c + dR_{n-1} + a_1X_{n-1} + a_2X_{n-2} + a_3X_{n-3} + b_1Y_{n-1} + b_2Y_{n-2} + b_3Y_{n-3} \tag{4}$$

where

d : partial regression coefficient

DEPENDENT VARIABLE

Direct Inflow

The dependent variable of the model is the daily direct inflow, R_n, into the reservoir. The base flow which should be subtracted from the daily inflow to obtain the direct inflow, R_n, is expressed by

$$r_t = r_0 (1.0+0.00124t) \tag{5}$$

where

r_t : base flow after t days from the day when first discharge occurs due to snowmelting in the season (m³/sec)

r_0 : inflow before the snowmelt season starts (m³/sec)

The equation (5) was empirically determined by the inflow data recorded at the beginning and end of the several snowmelt seasons

INDEPENDENT VARIABLES

Snow Cover Area and Its Related Areas, S_{n-i}, S'_{n-i} and S''_{n-i}

The snow coverage information from Landsat MSS is scarcely obtainable in Japan. Then, the snow line during snowmelt season was considered to appear when snow water equivalent in a mesh (shown in Figure 2) became equal to the snowmelt amount which can be calculated by the degree-day method (mentioned later). In order to extract the snow line, the computation of the snow water equivalent in each mesh at the maximum stage is required. Then, the computation was made by following three methods; the topographic method [3] in use of the extensive snow survey data in 1980, the degree-day method [4] in effective use of two Landsat MSS data fortunately obtained in 1979 and the comparison method [5] in use of the regional snow depth data obtained for several years with helicopter. Next, the date when all the snow deposits disappear was calculated for each mesh, applying the degree-day method. The snow cover area and its related areas, s_{n-i}, s'_{n-i} and s''_{n-i} were then counted for every day during each snowmelt season.

Total Snowmelt Amount, $M_{n-i} \cdot S'_{n-i}$

The degree-day method was adopted for the snowmelt calculation, expressed by

$$M = K\Sigma T \tag{6}$$

where

M : snowmelt amount (g/cm^2)

ΣT : accumulated daily mean air temperature above 0°C (°C•day)

k : degree-day factor (0.45; average value in preceding studies)

The daily mean air temperature at the Okutadami Meteorological Observing Station was adopted as the standard for the estimation of the air temperature at all meshes assuming the lapse-rate as -0.6 °C/100 m.

Applying the equation (6), the calculation of the daily snowmelt amount was made for each mesh within the area, S'_{n-i}, during each snowmelt season. By summing up them, the total snowmelt amount in whole basin, $M_{n-i} \cdot S'_{n-i}$ was then obtained.

Total Rainfall Amount, $P_{n-i} \cdot S'_{n-i}$ and $P_{n-i} \cdot S''_{n-i}$

The Okutadami Station is the only one rainfall observation station within the basin running throughout snowmelt season. However, located at the lowest elevation and the northern edge of the basin, it does not give the mean rainfall of the basin. Then, the Hinoemata Station was adopted for this purpose, although it is located at slightly outside the basin. After careful meteorological inspection, it was assumed that the precipitation at Hinoemata is equal to the rainfall amount in each mesh where the daily mean air temperature is above 0°C both in snow cover and non-snow cover area. The total rainfall amount, $P_{n-i} \cdot S'_{n-i}$ and $P_{n-i} \cdot S''_{n-i}$ were then obtained.

CONSTRUCTION OF SNOWMELT RUNOFF MODEL

Now, all the input data were prepared for the determination of the constant and partial regression coefficients of the equations (4) and (5). The multiple regression analyses were, then, carried out in use of data in 1980. The resultant constructed two models are presented in Table 1.

The comparison between the observed and calculated inflow, exhibited in Figures 4 and 5, shows that the models would stand the practical use the snowmelt runoff forecasting.

NOMOGRAPHS FOR PRACTICAL USE OF MODELS

In course of the model construction, the input variable values were obtained through the complex calculation procedure relating to the mesh. Necessary for the convenience of the practical use of the models is an easy acquisition of the input variable data. Following nomographs were, then, devised.

Nomograph (I) for Basin-Wide Snow Amount at Maximum Stage

The Maruyama shown in Figure 2 was selected among several tens proposed sites in the basin as the best representative site, whose snow water equivalent has a linear correlation with the basin-wide snow amount throughout both snowfall and snowmelt seasons. Based on the six years data is

Figure 6 (nomograph (I)), which exhibits a relationship between the basin-wide snow amount and Maruyama's snow water equivalent at the maximum stage.

The Maruyama is situated at roughly mean altitude of the whole basin and is at present equipped with DCP.

Nomograph (II) for Snow Cover Area

The depletion curve of snow cover area with increasing degree-day at the Maruyama was obtained for four snowmelt seasons, and is exhibited in Figure 7. The curves seem to depend on the snow amount at the maximum stage. Then, the relation was investigated between the snow amount above and the Maruyama's degree-day accumulated up to the first day when the bare ground appears somewhere in the basin, namely, $S_{n-i}/A<1$. A is the basin area. A linear correlation was found as shown in Figure 8. Based on this correlation, the depletion curve was standardized. The resultant curve shown in Figure 9 is the nomograph (II).

Nomograph (III) for Basin-Wide Snowmelt Amount

A clear relation was found between the basin-wide daily snowmelt amount and the daily mean air temperature at the Maruyama through the medium of the ratio (S_{n-i}/A). This relation shown in Figure 10 is the nomograph (III) for $M_{n-i}-S'_{n-i}$.

Nomograph (IV, V) for Basin-Wide Rainfall

In the models, two kinds of basin-wide rainfall amount are taken into account; one in the snow cover area (S_{n-i}) and another in the non-snow cover area ($A-S_{n-i}$).

Regarding the snow cover area, the extraction of the area ($S'_{n-i}n-i$) where the daily mean air temperature is above 0 °C is necessary. For simplicity, the relation was obtained between the total rainfall amount ($P_{n-i}\bullet S'_{n-i}$) and the Hinoemata precipitation (P_{n-i}) through the medium of the product of the Okutadami daily mean air temperature and the ratio (S_{n-i}/A). The relation shown in Figure 11 is the nomograph (IV) for $P_{n-i}\bullet S'_{n-i}$.

As for the non-snow cover area, this area is usually above 0 °C during a snowmelt season, so that $S''_{n-i}n-i \div A - S_{n-i}$. Exhibited in Figure 12 is the nomograph (V) for $P_{n-i}\bullet S''_{n-i}$.

VERIFICATION OF SNOWMELT RUNOFF MODELS

In order to verify the models (Table 1 constructed for the 1980 data, the models were applied to the other two years, 1979 and 1982. All the input values were obtained in use of the nomographs (I)-(V). The results are shown in Figures 13-16. A good agreement can be seen except May 26-28, 1979. A large difference in this period may be caused by heavy rainfall unusually in a snowmelt season which occurred on May 26 and 27. In Japan the rainy season starts at the beginning of June, and often heavy rainfall occurs. The fact above shows that the models should not be applied in case the heavy rainfall happened near the end of snowmelt season when the snow cover area shrinks up to the top of the high mountains.

CONCLUSION

In the present study scarce Landsat MSS data obliged the limited but efficient utilization for the verification of the depletion curve of the snow cover area. In order to construct the models, the complex topographic mesh analyses were carried out. However, the data of final necessity become only the mean air temperature and precipitation for the daily use of the models.

The runoff forecasting procedure is summarized in Figure 17.

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3. Ishihara, K. (1956): Estimation of Snow Depth at Ungauged Point Using Regression Analysis of Topographic Effects. Journal of the Japanese Society of Snow and Ice, Vol. 33, No. 3, p. 134-138, (in Japanese).

4. Takeda, K. and Y,. Takahashi (1981): Estimation of Basin-wide Snow Water Equivalent Using Landsat-derived Snow Line and Degree-day Method. Proceedings of the Japan Society of Civil Engineers, No. 311, p. 81-92 (in Japanese).

5. Electric Power Development Company (1980): Data Report of Snow, Weather and Discharge in Okutadami Region (1957-1959). p. 1-424.

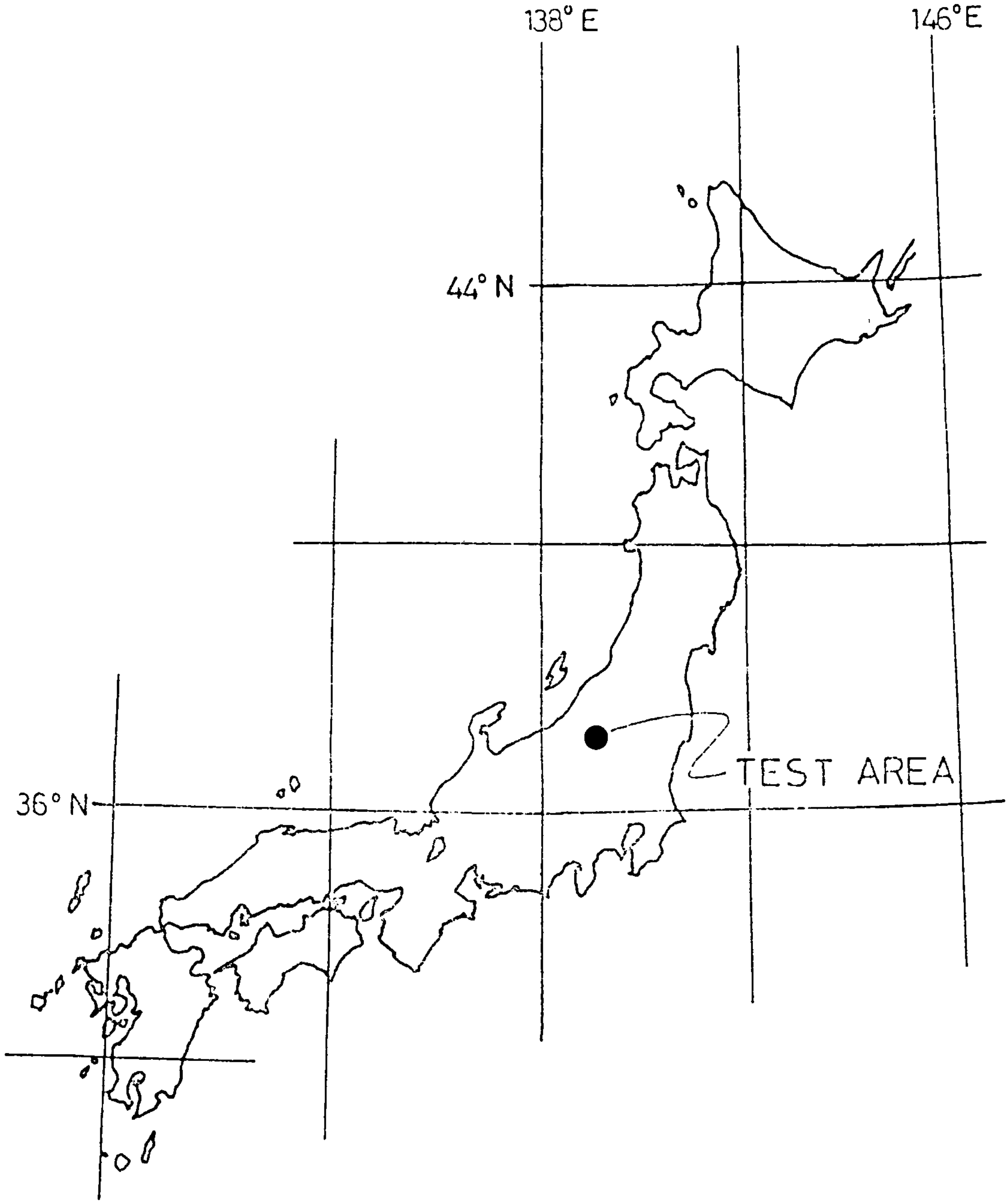

Figure 1. Location of The Test Basin

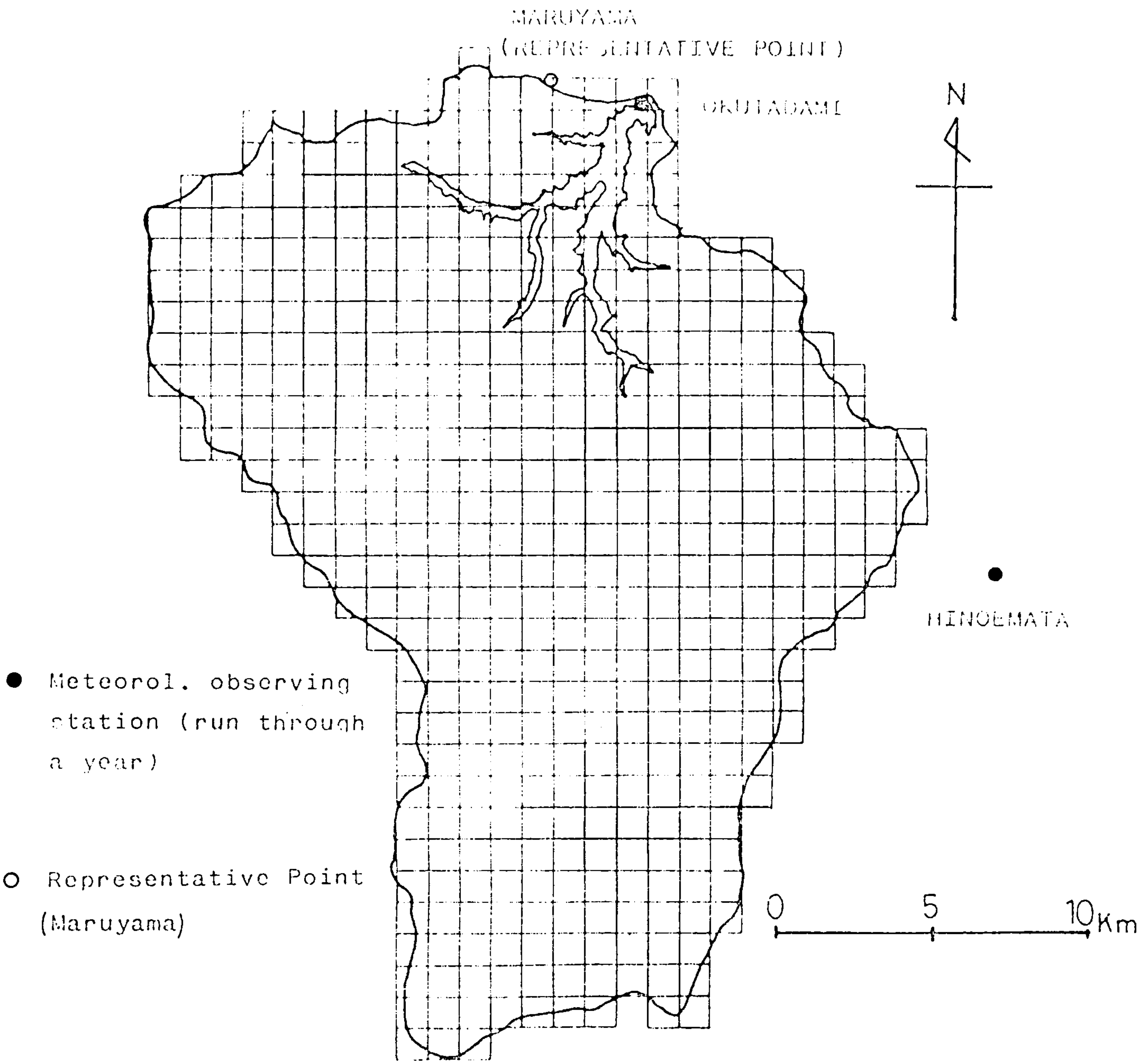

Figure 2. Location of Two Meteorological Observing Stations (Okutadami, Hinoemata) and Representative Point (Maruyama)

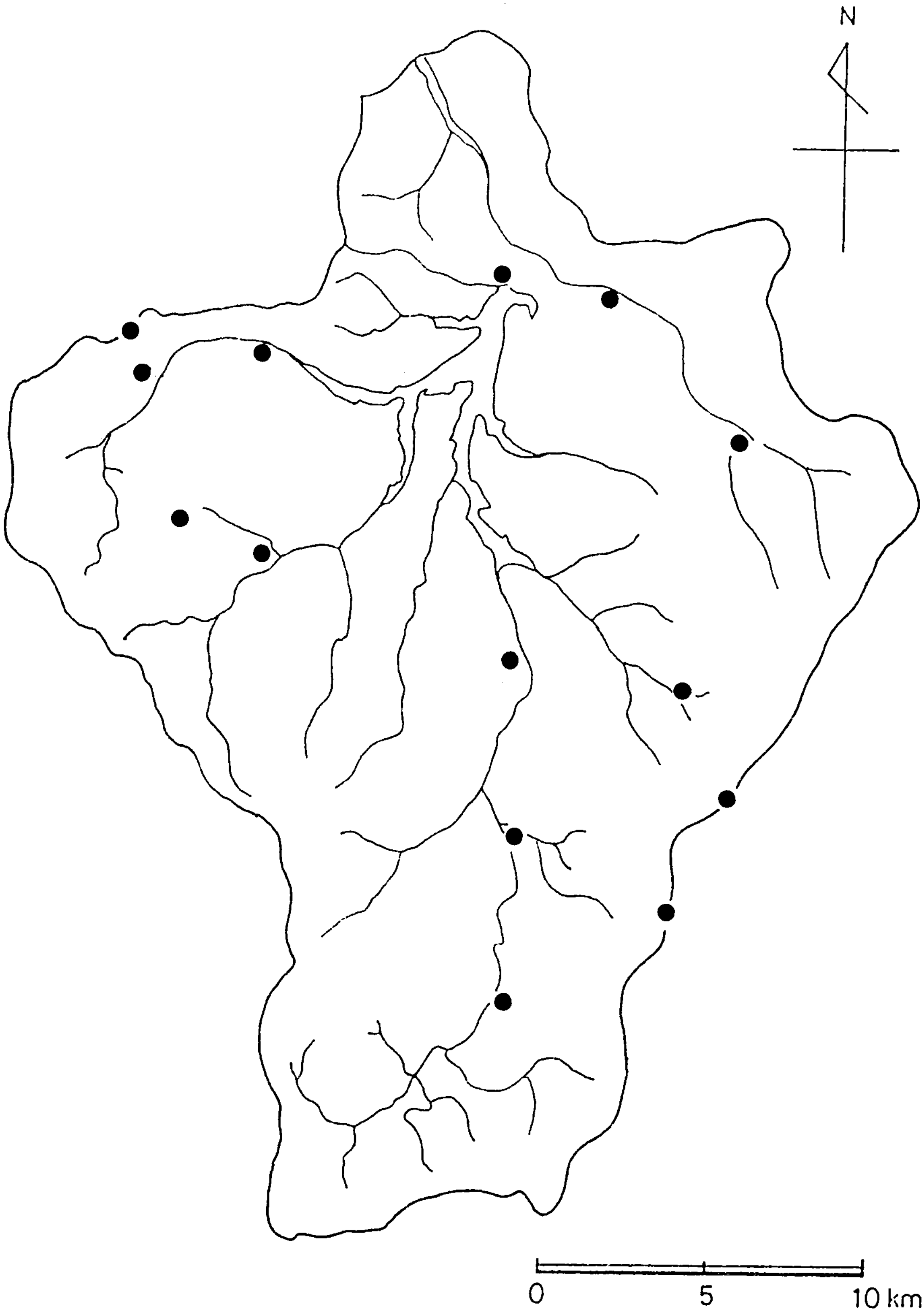

Figure 3. Locations of Points Where Snow Depth and Its Water Equivalent were Measured by Electric Power Development Co.

Table 1
Snowmelt Runoff Model

MODEL-I

$$R_n = 14.0 + 0.491\,X_{n-1} + 0.106\,X_{n-2} + 0.044\,X_{n-3} + 0.121\,Y_{n-1} + 0.120\,Y_{n-2}$$

m.c.c. : 0.921 s.d. : 17.2

MODEL-II

$$R_n = 7.33 + 0.549\,R_{n-1} + 0.392\,X_{n-1} - 0.110\,X_{n-2} - 0.057\,Y_{n-1}$$

m.c.c. : 0.943 s.d. : 14.7

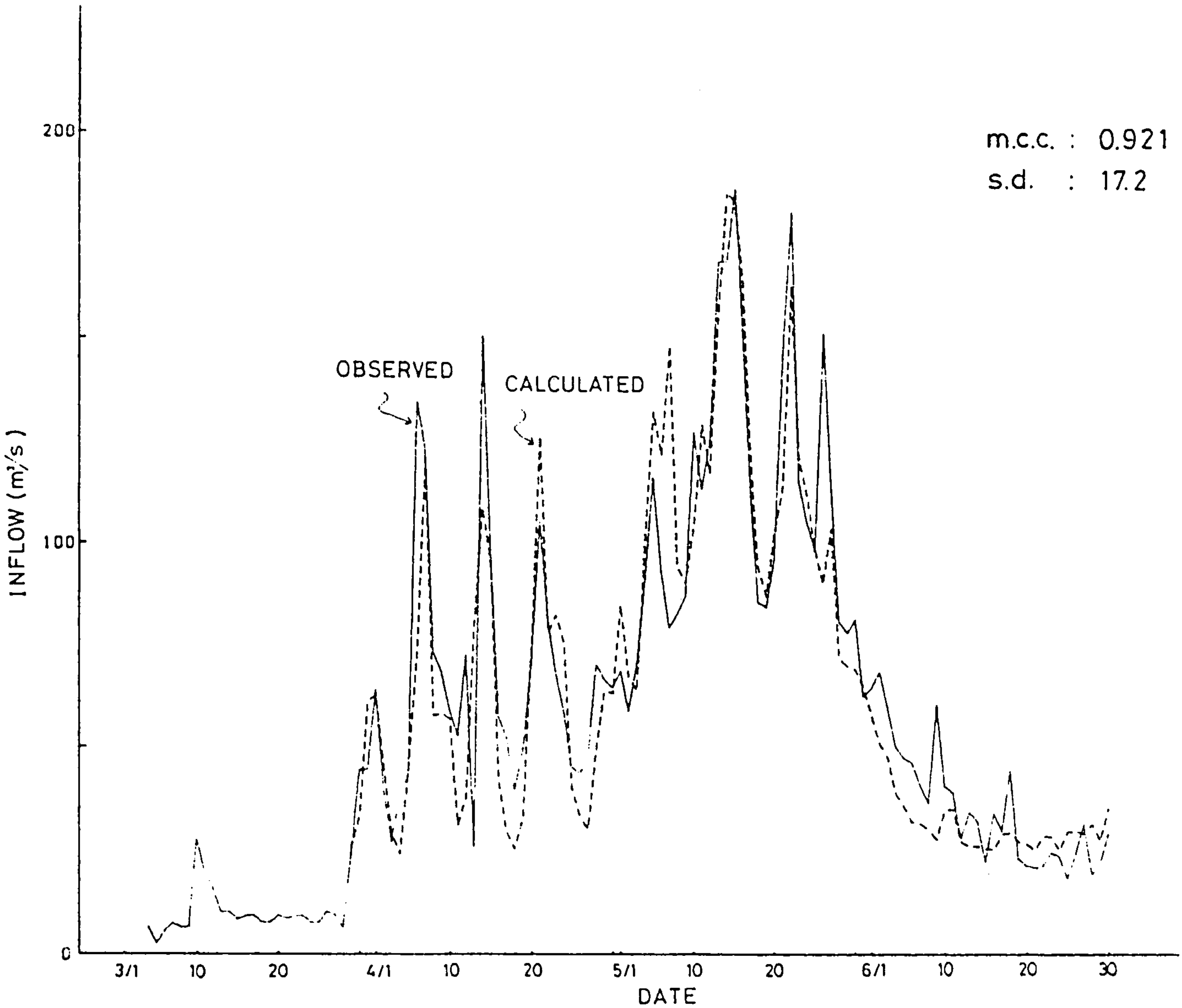

Figure 4. Comparison Between Observed (Solid Line) and Calculated (Broken Line) Inflow in Use of MODEL-I for 1980 Snowmelt Season

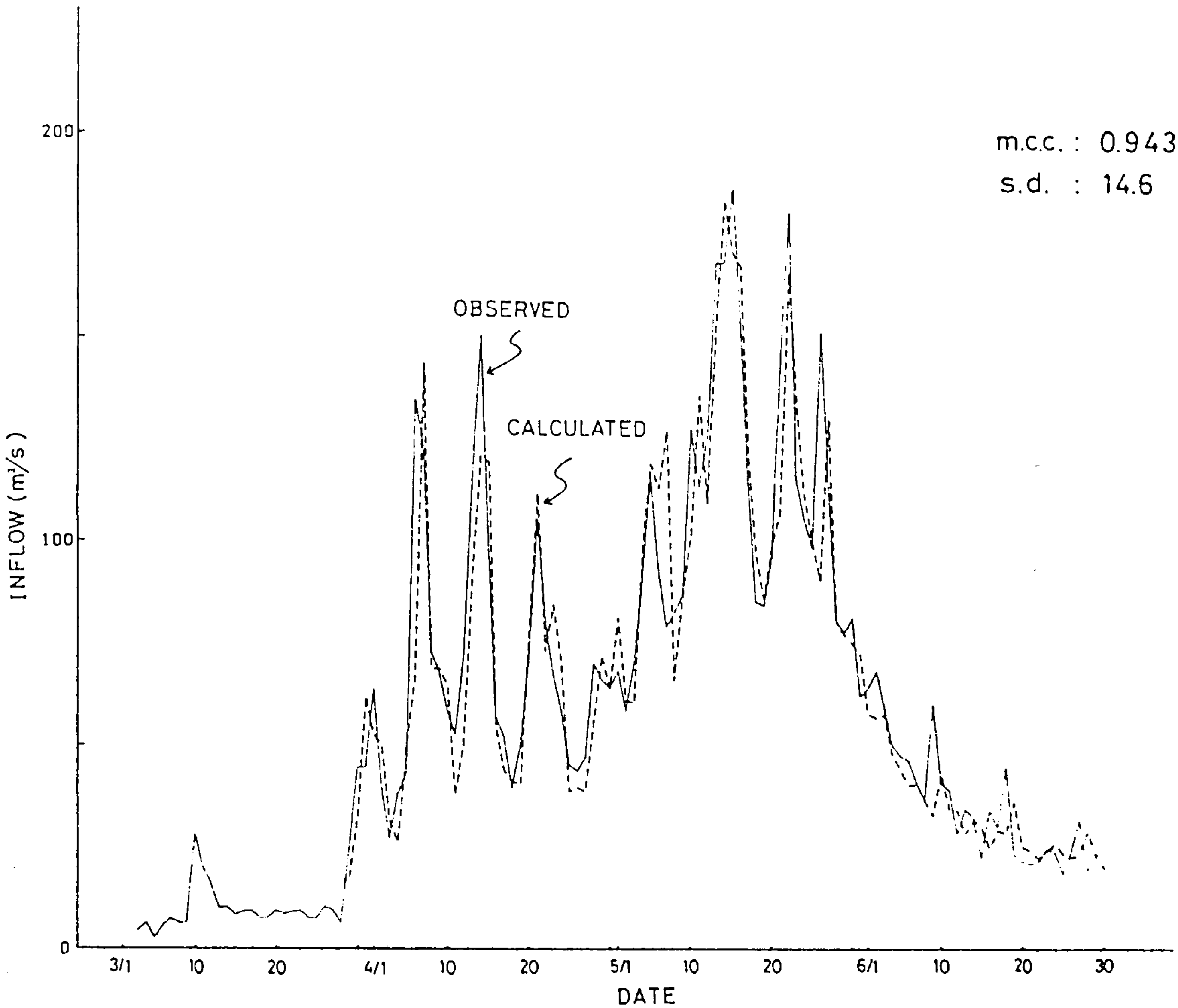

Figure 5. Comparison between observed (Solid Line) and Calculated (Broken Line) Inflow in Use of MODEL-II for 1980 Snowmelt Season

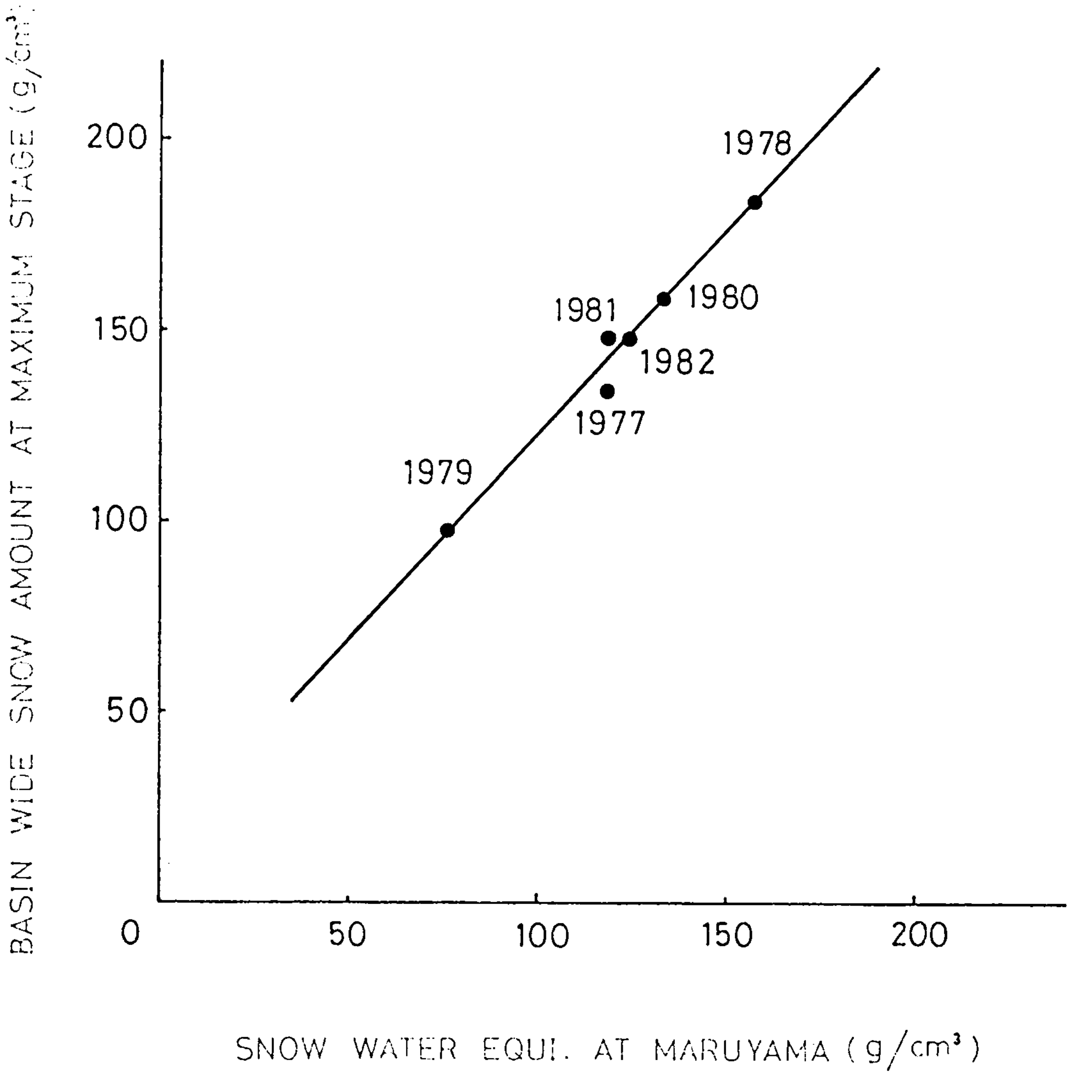

Figure 6. NOMOGRAPH(I) for Basin-Wide Snow Amount at Maximum Stage in Use of Snow Water Equivalent at Maruyama

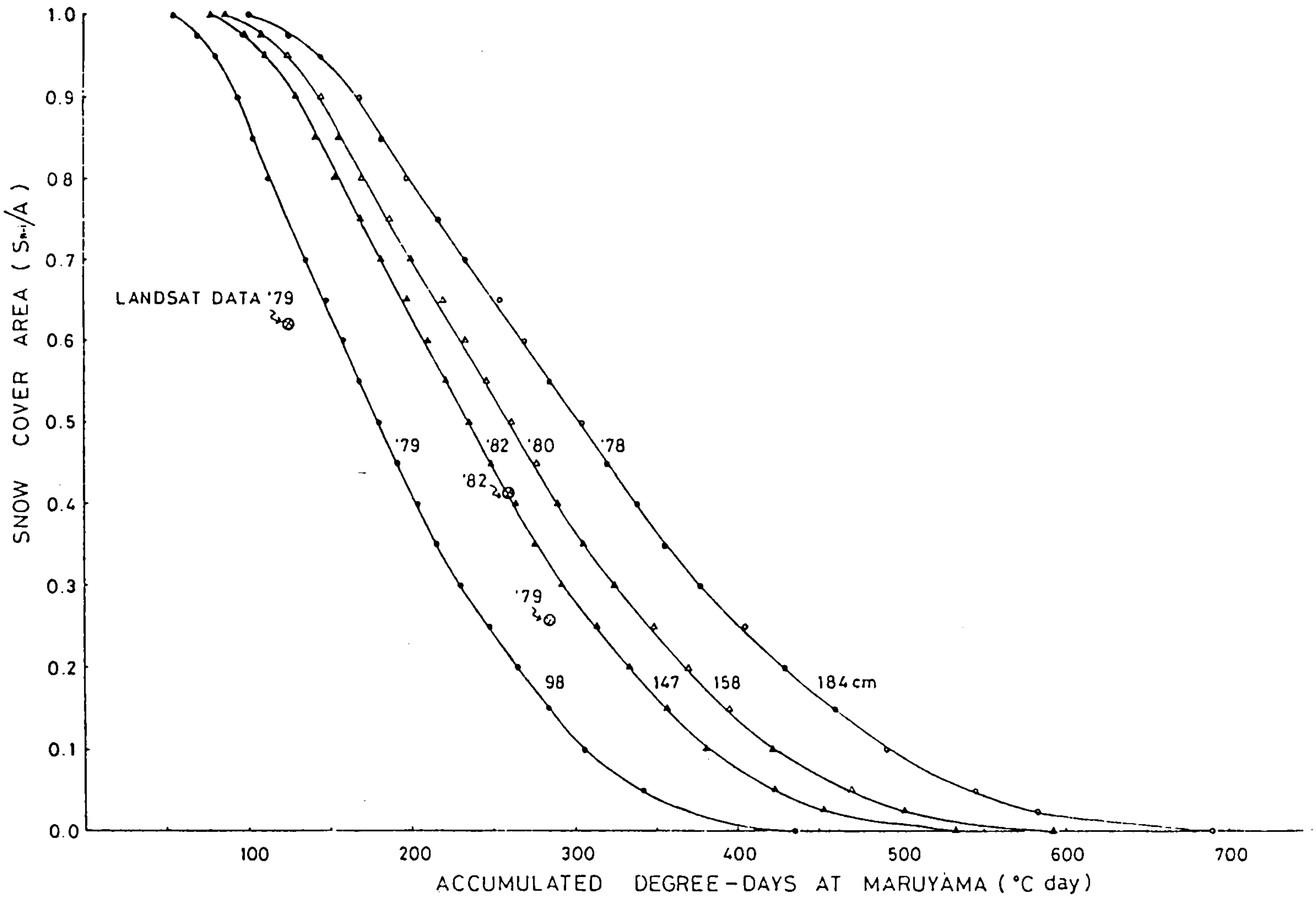

Figure 7. Relationship Between Depletion of Snow Cover Area and Accumulated Degree Days at Maruyama (Parameter: Basin-Wide Snow Amount at Maximum Stage)

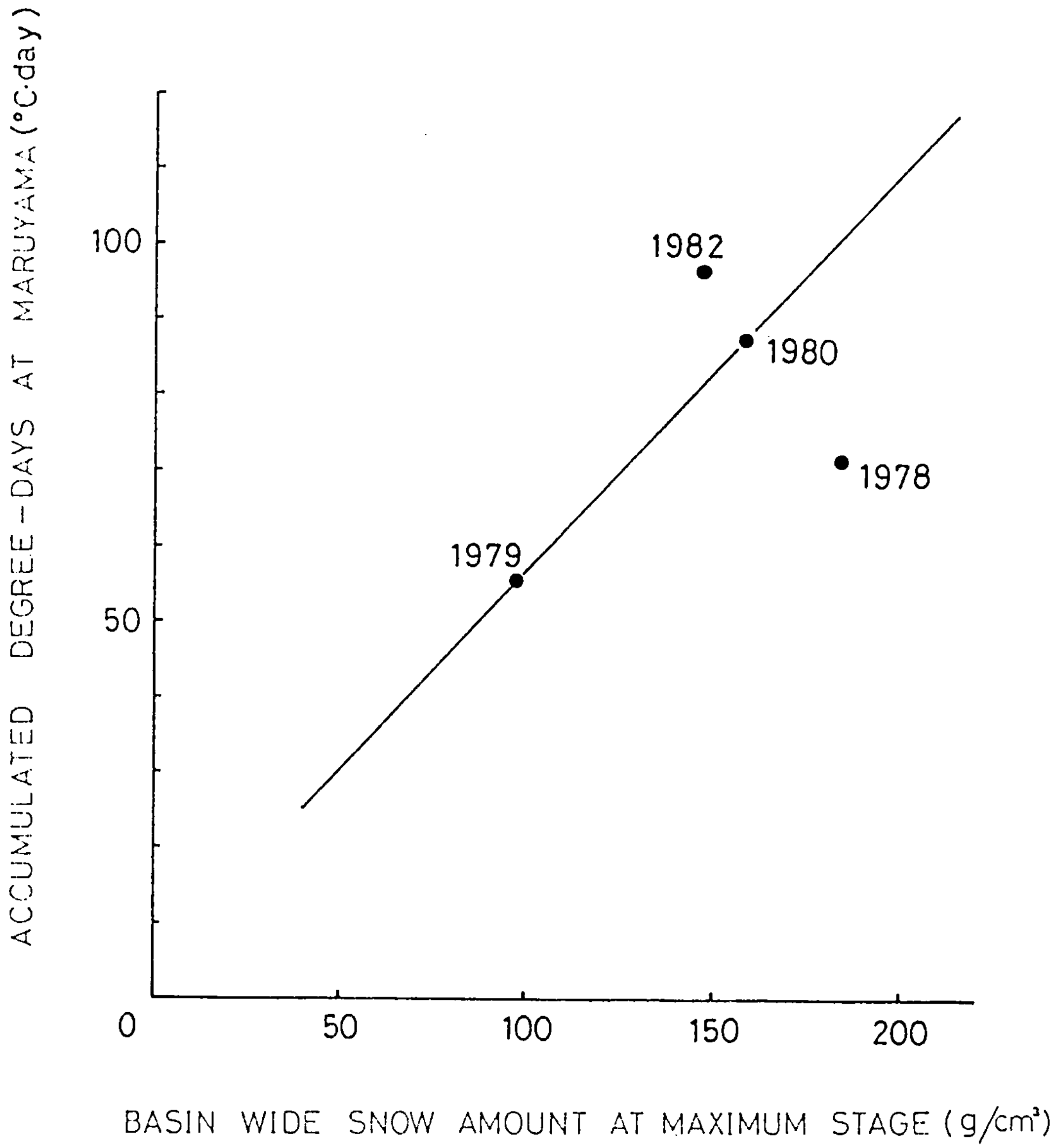

Figure 8. Relationship Between Basin-Wide Snow Amount and Accumulated Degree-Days at Maruyama Before Snow Cover Area Depletion Starts

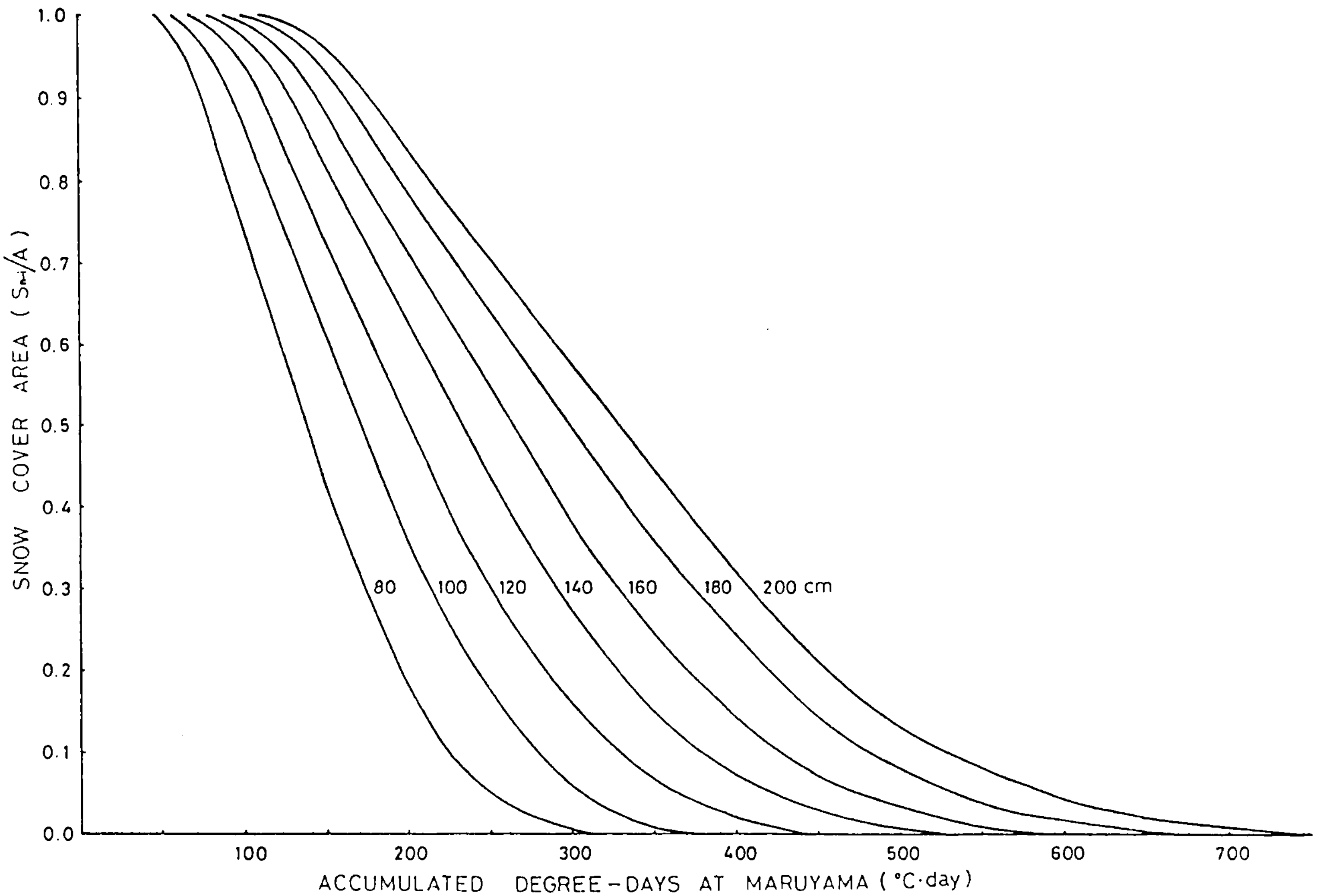

Figure 9. Nomograph(II) for Snow Cover Area. (Parameter: Basin-Wide Snow Amount at Maximum Stage.)

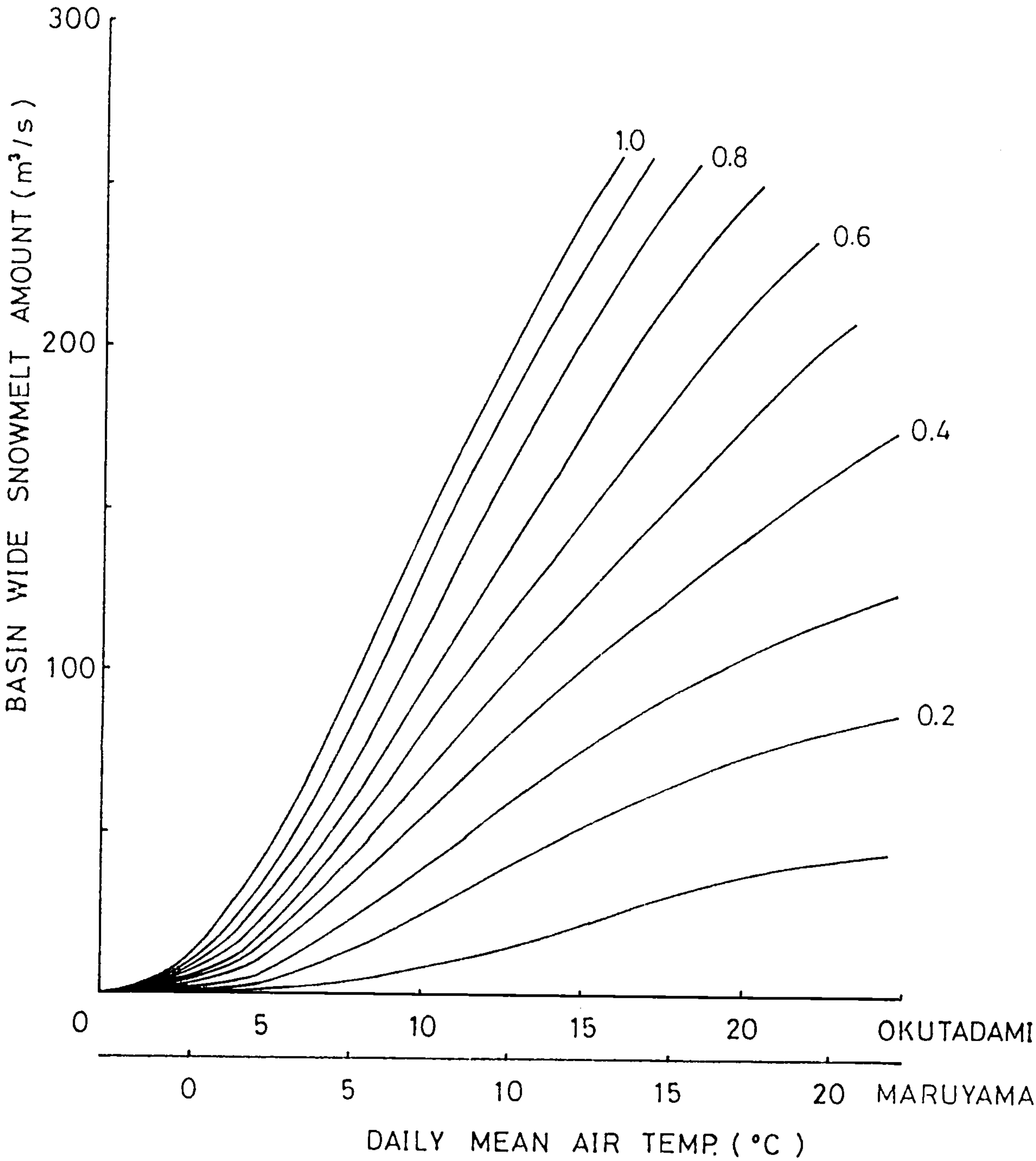

Figure 10. Nomograph(III) for Basin-Wide Snow-Melt in Use of Daily Mean Air Temperature at Maruyama. (Parameter: Relative Snow Cover Area, S_{n-i}/A)

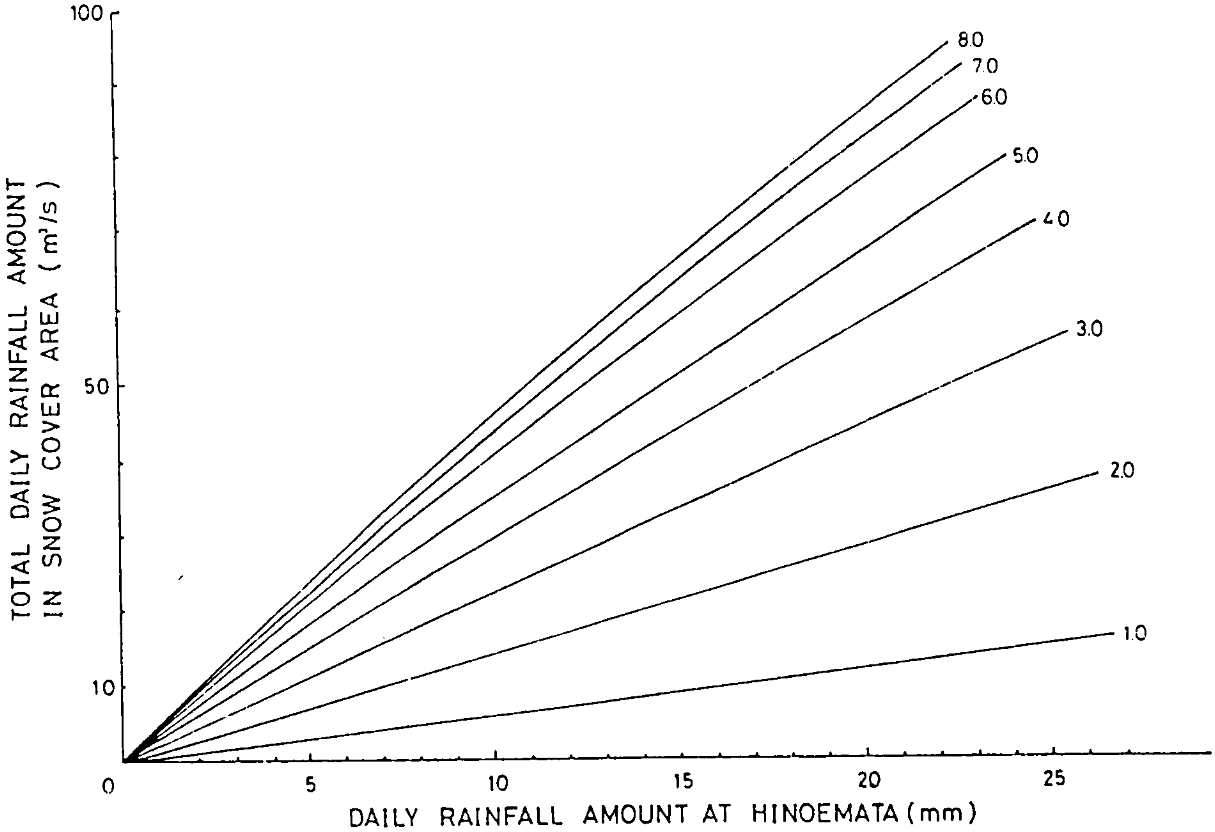

Figure 11. Nomograph(IV) for Total Daily Rainfall Amount in Snow Cover Area in Use of Daily Rainfall at Hinoemata (Parameter: Daily Mean Air Temperature × Relative Snow Cover Area)

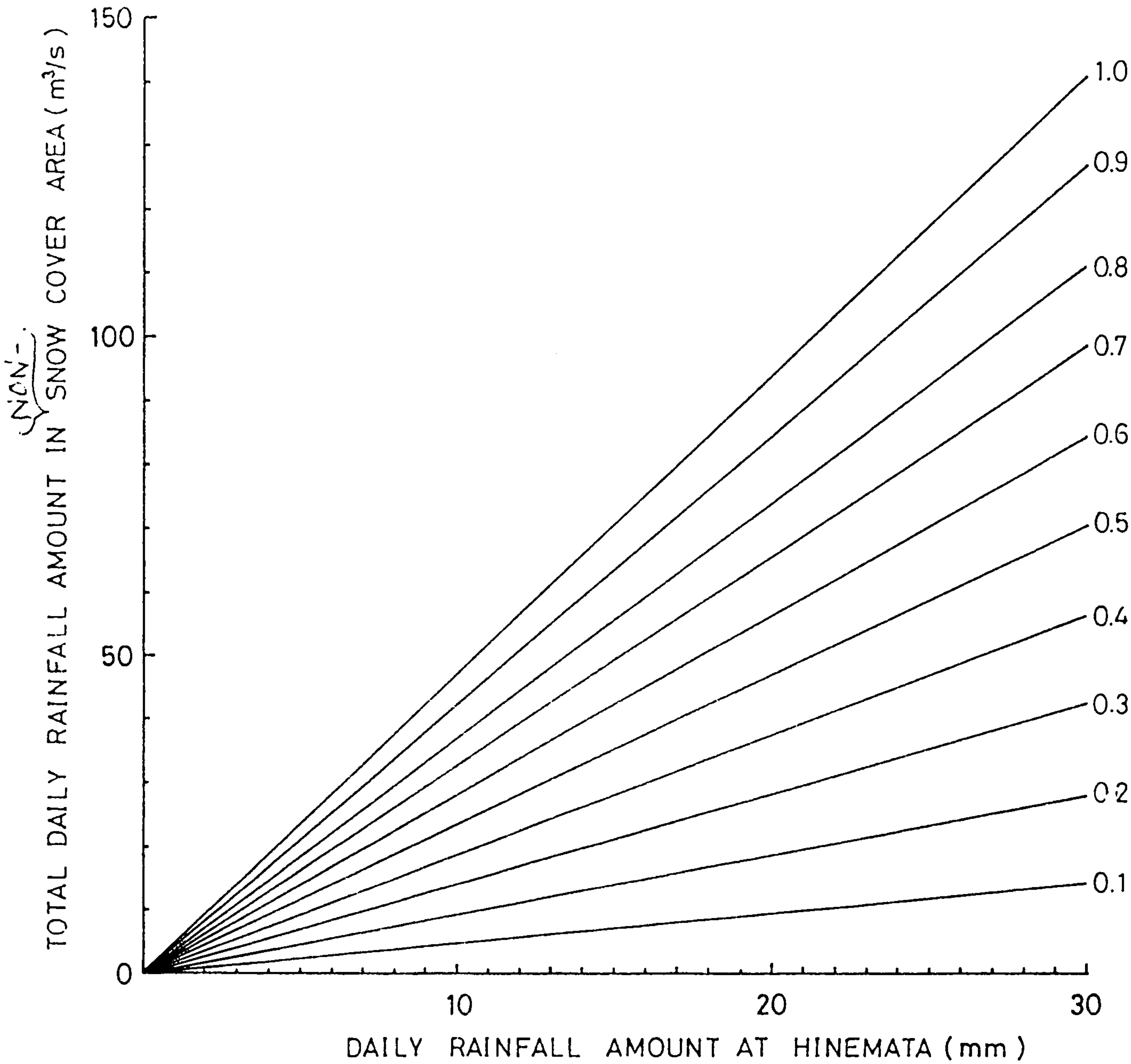

Figure 12. Nomograph(V) for Total Daily Rainfall Amount in Non-Snow Cover Area in Use of Daily Rainfall at Hinoemata Station. (Parameter: Relative Non-Snow Cover Area, $1\text{-}S_{n-i}/A$)

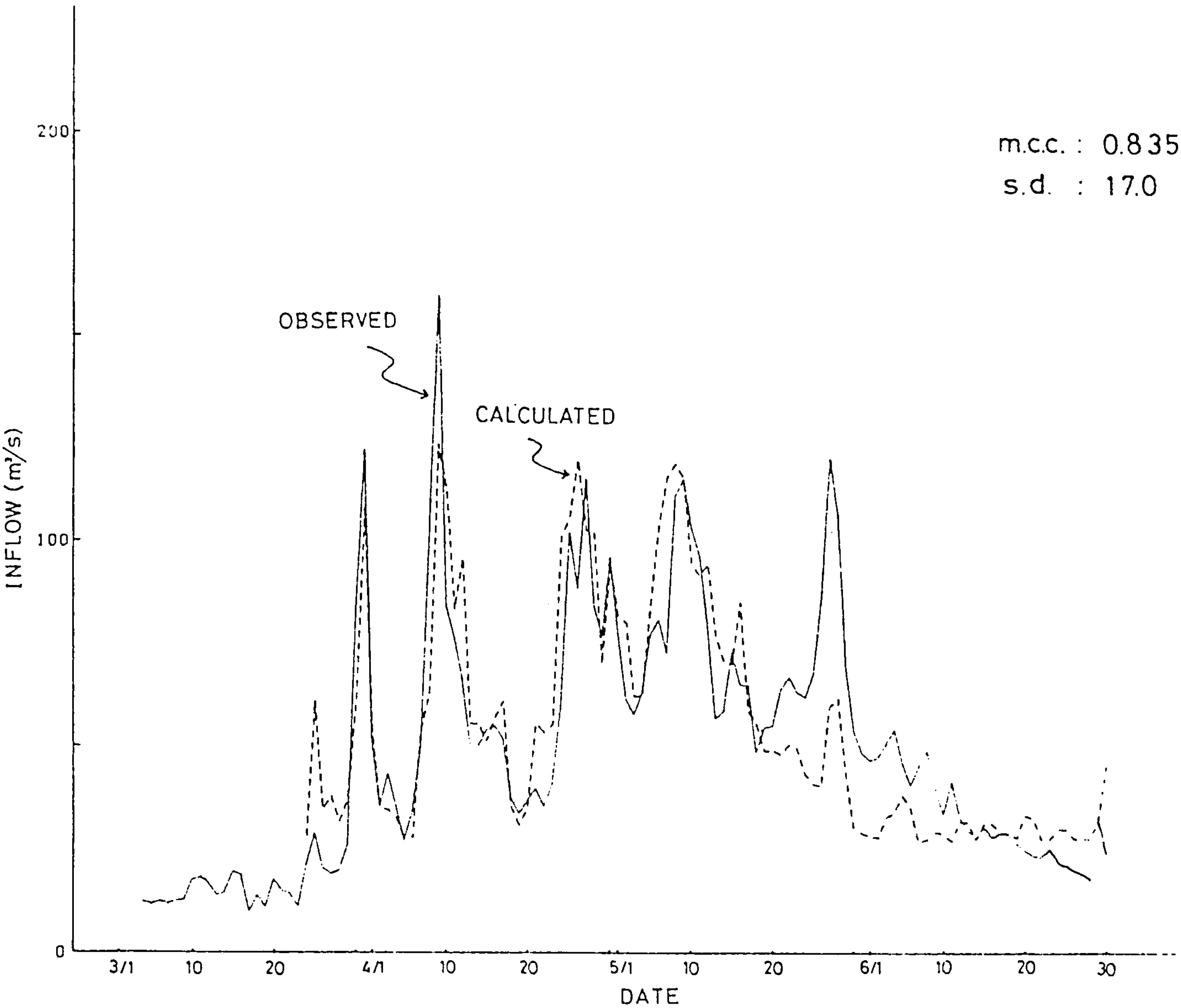

Figure 13. Comparison Between Observed (Solid Line) and Calculated (Broken Line) Inflow in Use of MODEL-I for 1979 Snowmelt Season

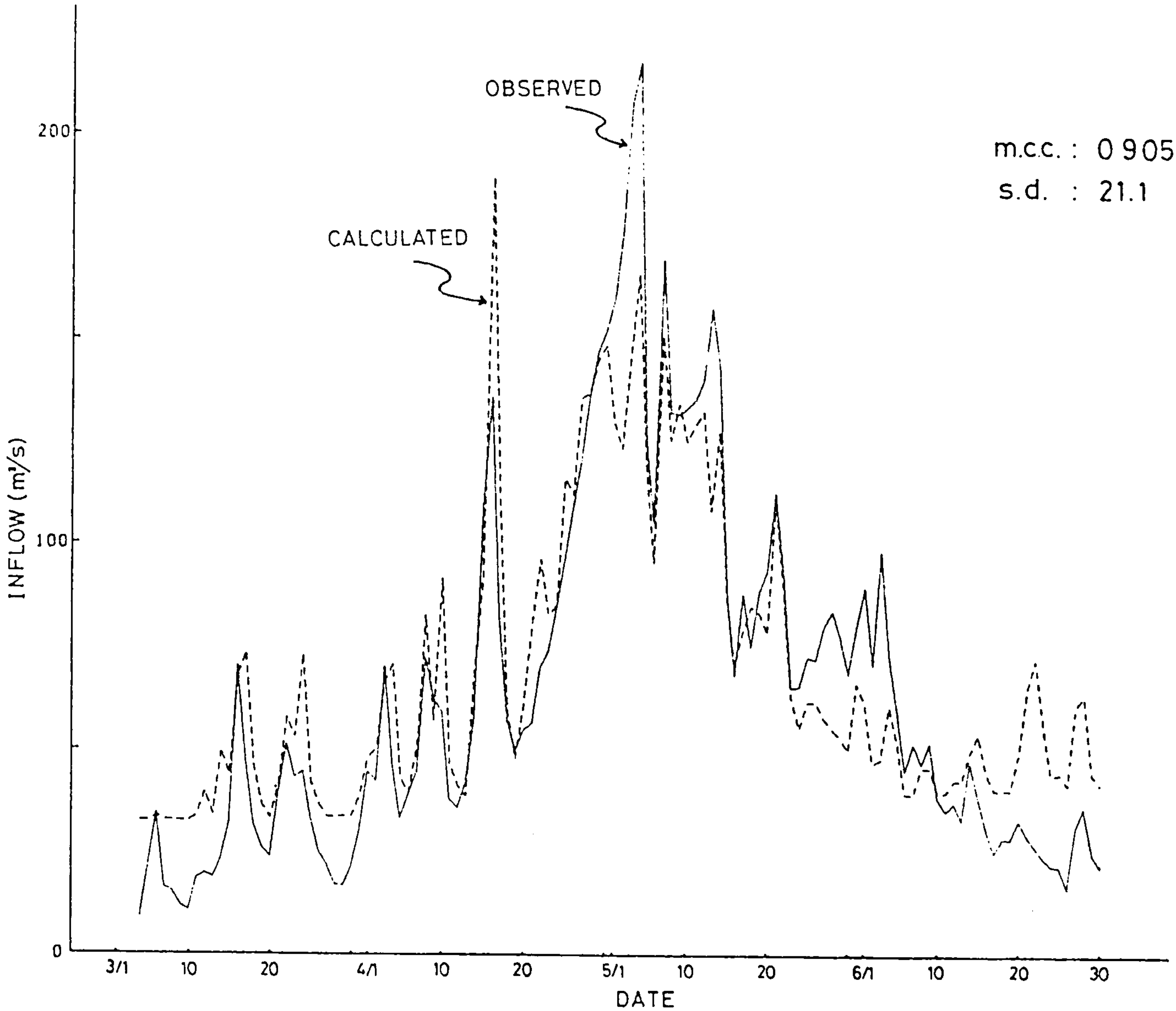

Figure 14. Comparison Between Observed (Solid Line) and Calculated (Broken Line) Inflow in Use of MODEL-I for 1982 Snowmelt Season

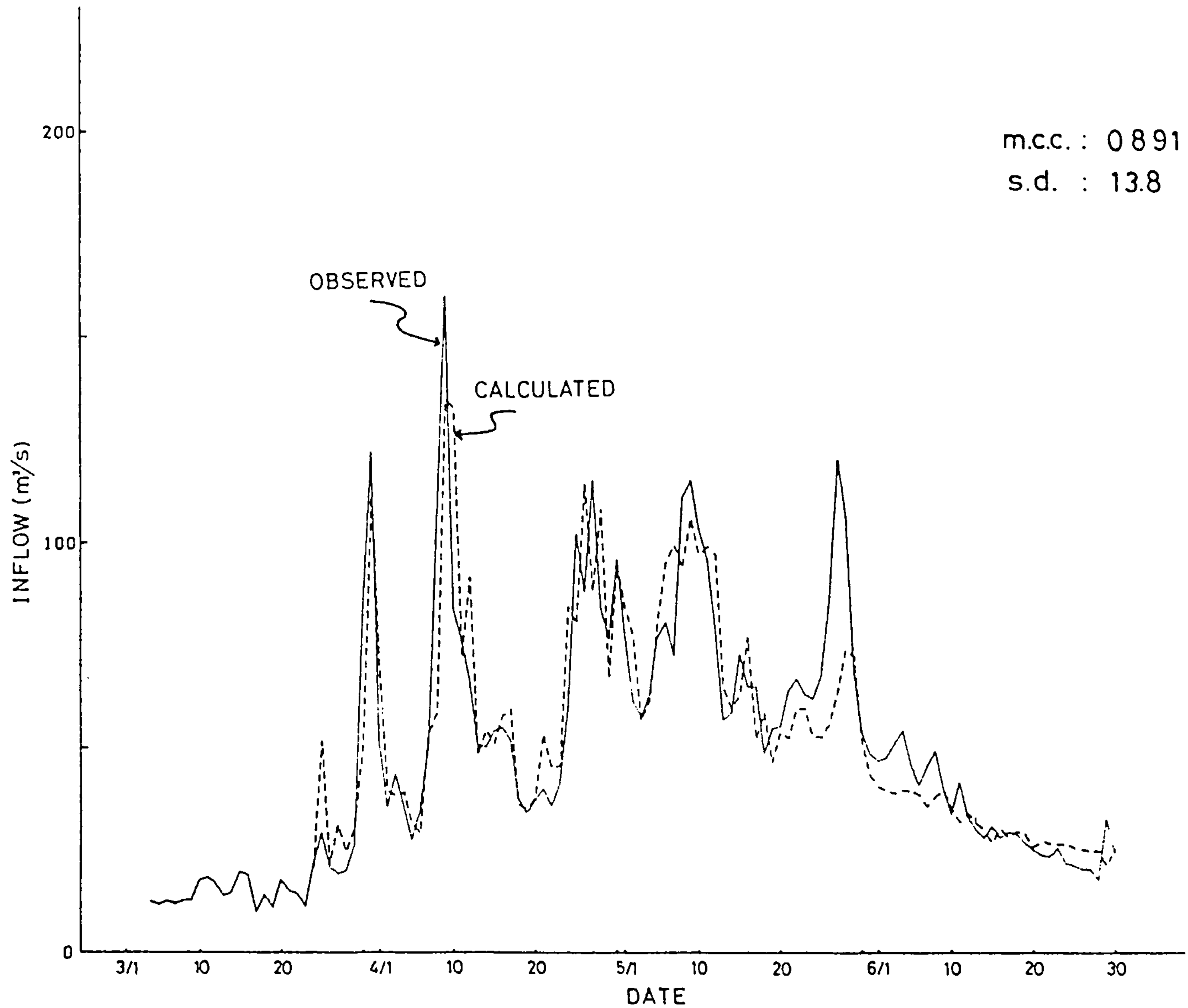

Figure 15. Comparison Between Observed (Solid Line) and Calculated (Broke Line) Inflow in Use of MODEL-II for 1979 Snowmelt Season

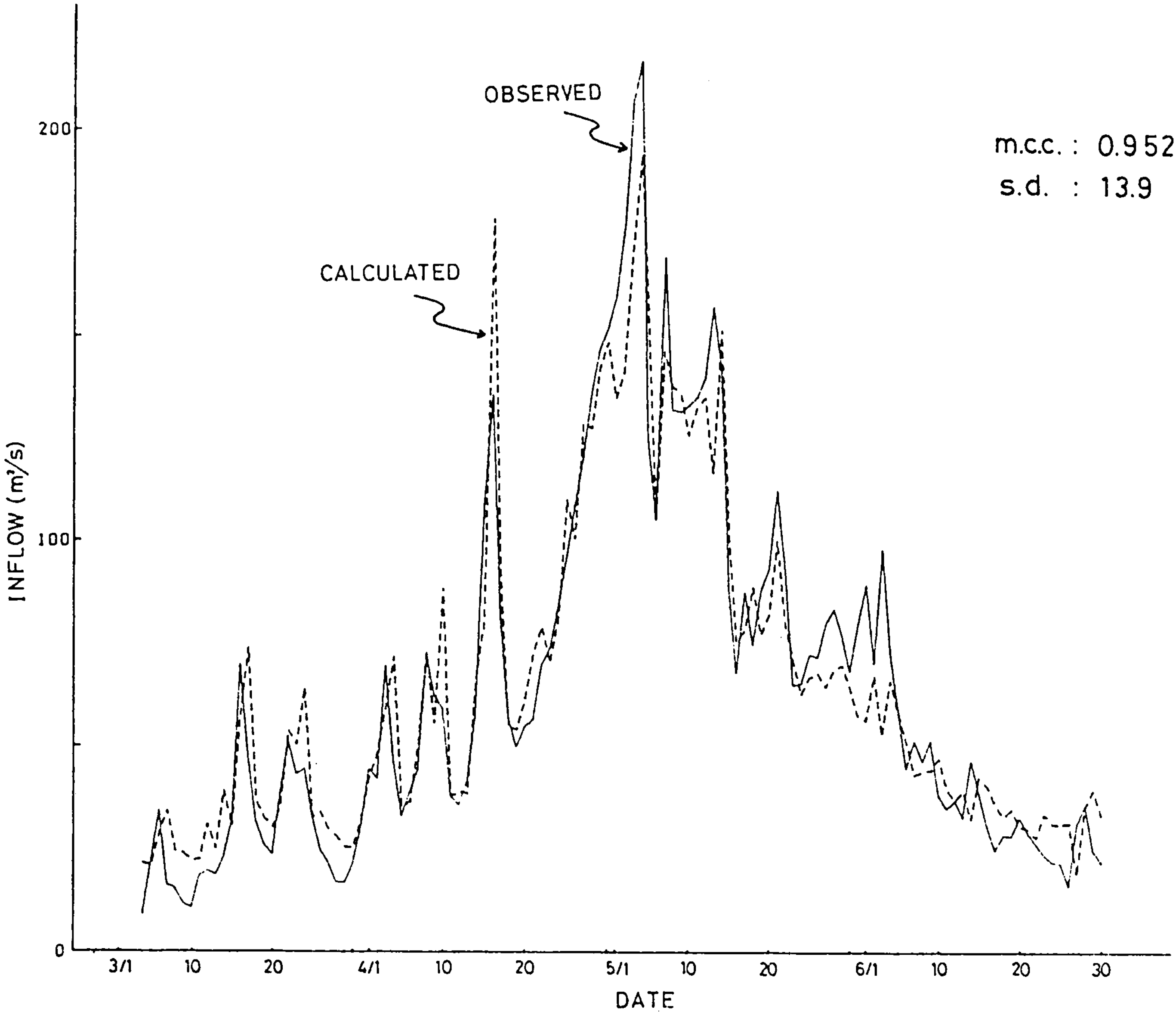

Figure 16. Comparison Between Observed (Solid Line) and Calculated (Broken Line) Inflow in Use of MODEL-II for 1982 Snowmelt Season

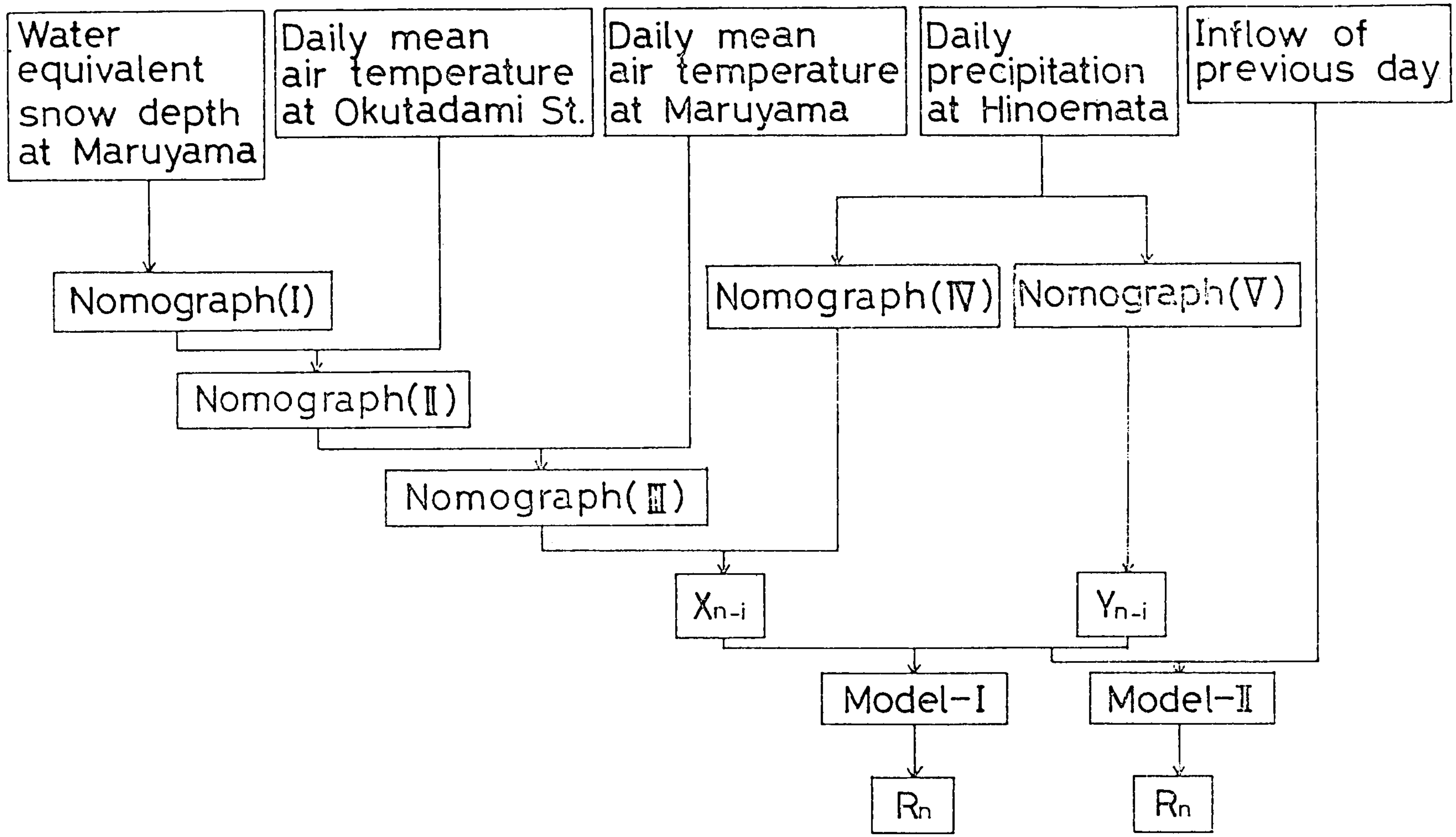

Figure 17. Procedure of the Snowmelt Runoff Forecasting