

BASIN STREAMFLOW ESTIMATION USING THE LANDSAT DATA AND ITS APPLICATION TO OPTIMUM CONTROL OF DAM WATER LEVEL

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ABSTRACT

Snowmelt runoff in the watersheds is one of our important natural energy resources. Accurate and rapid forecasts of the runoff volume by snowmelt are necessary for hydroelectric reservoir operations. We studied the daily streamflow in the Sai River basin in Japan from 1979 to 1981, using the snow cover-extent data monitored by the Landsat. We found that the computer simulation of streamflow for the Sai River basin based on the Martinec's Snowmelt Runoff Model (SRM) has an accuracy of more than 90%, compared with the measured streamflow data. Furthermore, we found that the snow cover depletion curve may be estimated from the value of maximum snow depth in the basin. This finding is very useful for the year when the Landsat data is not available due to bad weather in a snowmelt period. Finally, we show by the simulation that we can maintain the optimum water level of the Sai River Dam with the use of streamflow data computed by the SRM.

1. INTRODUCTION

Winter snow accumulation in the mountainous regions has an important value as the primary water resource in a spring-summer period. We use runoff in many ways, such as irrigation, hydroelectric power, municipal and industrial supplies. The main purposes of this study are to estimate the basin streamflow accurately and find a way for enhancing hydroelectric reservoir operations.

Firstly, we estimated the daily streamflow in the Sai River basin for three years between 1979 and 1981, using the Martinec's Snowmelt Runoff Model (hereinafter, abbreviated by SRM) [Ref.1]. Then, we showed by computer simulation that the optimum control of the dam water level may be possible if we use the daily streamflow data forecasted by the SRM.

2. USE OF LANDSAT DATA

The Sai River basin selected for the testing of the Martinec's SRM is located near the Kanazawa city in Hokuriku district of Japan. The basin size is about 57 km² and the range of the basin altitude is from 300m to 1600m. The SRM requires daily air-temperature and precipitation data and the periodically monitored snow cover extent data in a given basin. We used the landsat MSS data sets in 1981 to compile the snow

cover depletion curve. Three Landsat data sets were available during the snowmelt season in 1981. They were taken on March 19, April 25, and June 17. We computed the temporal variations in the snow covered area from the Landsat imageries for 1981 as follows:

1) Since the Landsat imagery includes various geometric distortions due to the orbital inclination, the effect of the Earth's rotation, and other effects, we need to correct them. We used the Ground Control Points (GCP) method in the geometric correction and the nearest neighbor method in the resampling process. By using these methods, we obtained the registration accuracy of the imagery within one pixel (corresponding to the ground resolution of 57m), when compared with the 1:25000 scale topographic map covering the study site.

2) We classified the geometrically corrected Landsat data in a multi-spectral band space with the use of the supervised classification method.

3) We divided the Sai River basin into three elevation zones, namely, zone A (altitude > 1000m), zone B (1000m > altitude > 500m), and zone C (altitude < 500m). The boundaries of these zones were overlaid with the classified Landsat imagery by computer. The ratios of the snow covered area to the zone area for these three zones can be found by this overlaying.

These three steps were applied for each of three Landsat data sets and The classified Landsat images in March, April and June are shown in Fig.1, Fig.2, and Fig.3, respectively. The boundary of the Sai River basin is also given in the central portion of the imagery. The snow cover depletion curves for three zones interpolated from these Landsat images in step 3) are shown in Fig.4.

3. SNOWMELT RUNOFF MODEL

In this study, we shall adopt the SRM by Martinec. It has been reported recently that the SRM by Martinec is a very effective model when applied to basins in both the United States and Switzerland. The SRM simulates the average daily streamflow over the study period and requires the actual sequence of air-temperatures, precipitation P, and the ratio of the snow cover area to the zone area S. For three elevation zones, A, B, and C, the daily discharge Q_n from the basin is given by Eq. (1).

$$Q_{n+1} = \left[c_{An} [a_{An} (T_n + \Delta T_{An}) S_{An} + P_{An}] \frac{A_A \cdot 0.01}{86400} + c_{Bn} [a_{Bn} (T_n + \Delta T_{Bn}) S_{Bn} + P_{Bn}] \frac{A_B \cdot 0.01}{86400} + c_{Cn} [a_{Cn} (T_n + \Delta T_{Cn}) S_{Cn} + P_{Cn}] \frac{A_C \cdot 0.01}{86400} \right] \times (1 - k_{n+1}) + Q_n k_{n+1} \quad (1),$$

where $0.01/86400$ is a conversion factor from the unit of $\text{cm} \cdot \text{m}^2 / \text{day}$ to that of m^3 / s , T and ΔT are the number of degree-days, and its temperature adjustment by lapse rate, respectively. A,



Fig. 1. Landsat imagery on March 19, 1981. The boundary of the Sai River basin is shown in the center of image.

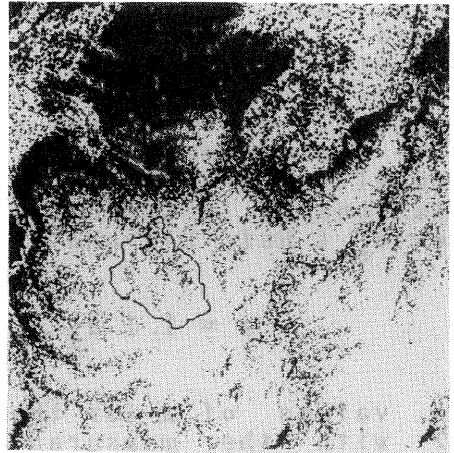


Fig. 2. The same as in Fig. 1, except that on April 25, 1981.

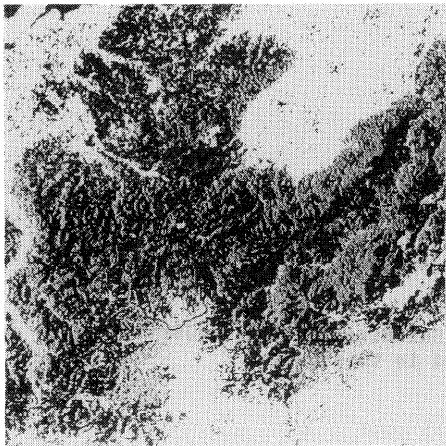


Fig. 3. The same as in Fig. 1, except that on June 17, 1981.

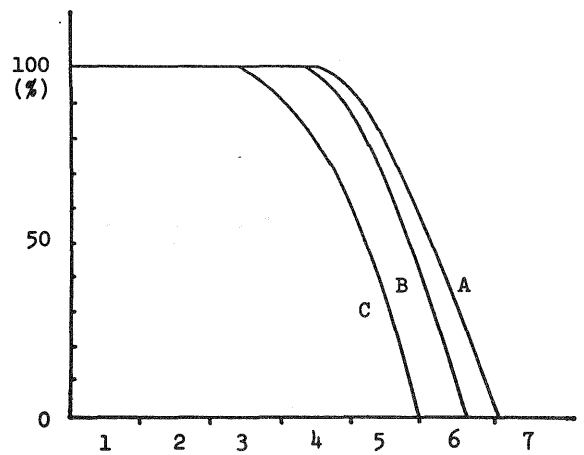


Fig. 4. The snow-cover depletion curves for 1981. The horizontal axis represents month and vertical axis represents ratio of snow-cover area to the total zone area. The indices A,B, and C refer to the appropriate elevation zone.

a, c, and k are the area of the basin, degree-day factor, runoff coefficient, and the recession coefficient, respectively. The indices in Eq. (1), A, B, and C refer to the appropriate elevation zone. The subscript n in Eq. (1) represents the sequence of days in the study period.

The degree-day factor, a, is used to convert degree-days to snowmelt expressed in depth of water. There is an empirical relationship between the degree-day factor and the density of snow d_s [Ref. 2] and it is given in Eq. (2).

$$a = 1.1 d_s \quad (2)$$

The values of a for the study period were estimated from Eq. (2) with the measured snow density data for the Sai River basin. The recession coefficient k is defined as a ratio of discharge of one day to that of the next day in a period without rainfall. We can estimate the values of k by plotting measured streamflow Q_n on a given day against measured Q_{n+1} on the following day. The runoff coefficient c is left as an unknown parameter in the SRM and the values of c are so determined that we can obtain the closest match between the measured and simulated discharge values.

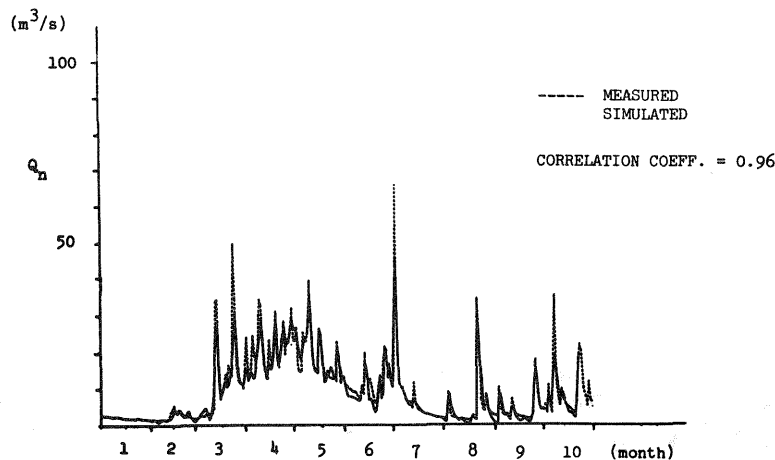


Fig. 5. Simulated and measured streamflow in the Sai River basin for January - October 1981. A good agreement is obtained in this case.

In Fig. 5 the simulated streamflow record by the SRM (solid line) is shown, together with the measured one (broken line) for 1981. The overall correlation between them is very good with the correlation coefficient of 0.96. We should pointed out here that the streamflow simulated by the SRM is less accurate when we have significant amounts of rainfall. This comes from the fact that we had to use less accurate precipitation data in

the simulation. The precipitation data are collected at a single point (the Sai River Dam Control Station) located at the lowest elevation in the study basin. To increase an accuracy of runoff simulation in the case of heavy rainfall, we need more precipitation data collection points in the Sai basin. The values of c were found to be close to 1.0 in the snow accumulation and rainy periods, whereas those of c were between 0.3 to 0.7 in the snowmelt and dry periods. We should note that P in the right-hand side of Eq. (1) had to be replaced by P_{n+1} in order to get a good agreement between the measured and simulated values.

4. CONTROL OF DAM WATER LEVEL

The predicted increment of water level of the Sai dam can be computed by Eq. (3).

$$\Delta h_n = -0.0003hs_{n-1} + 0.00838(Q_n - r_n) + 0.09942 \quad (3),$$

where r_n and hs_{n-1} are the amounts of released water for hydroelectric use on n -th day and the dam water level on $(n-1)$ -th day, respectively. Let h_c be the critical water level corresponding to an upper limit of dam water level. Note that Q_n in this section is not the streamflow, but the predicted inflow. The optimum control of dam water level can be done by using the predicted inflow and Eq. (3). Let $n-1$ and n be a certain day and the following day, respectively. Then the predicted water level h_p on the n -th day is $h_p = hs_{n-1} + \Delta h_n$. When $h_c > h_p$, water should be released for avoiding flood until water level = h_c . When $h_p < h_c$, we do not need to do that. We assume that the water release for hydroelectric power is made whenever it is requested. The simulated water level hs_n on the n -th day can be computed by Eq. (4).

$$hs_n = \begin{cases} hs_{n-1} + \Delta ha_n, & h_p < h_c \\ hs_{n-1} + \Delta ha_n - \Delta h_n, & h_p > h_c \end{cases} \quad (4),$$

where Δha_n is the actual increment of water level based on the actual inflow Qa_n and it is found by substituting Qa_n in the place of Q_n in Eq. (3). We can compute the simulated water level hs_n iteratively, using Eqs. (3) and (4). The results of the simulated water level for January 1 - July 31, 1981 are presented in Fig. 6. In the simulation we assume $h_c = 349m$ and the simulated streamflow values for 1981 by the SRM were adopted as the predicted inflow data. It was shown that we can store much water in the Sai River Dam than the operators at the dam control station by 1.6 million tons of water, or in terms of water level, by the increment quantity of 3.7m by the end of

July. This is due to the fact that in the simulation we have a priori knowledge of the next day's inflow, but the dam operators do not have such knowledge.

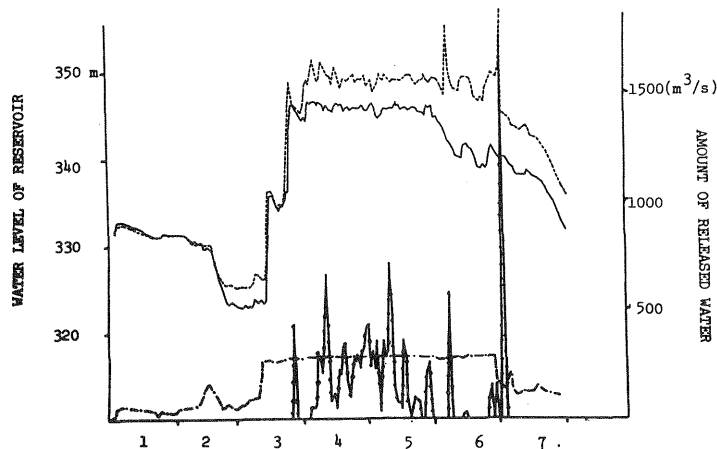


Fig. 6. Control of reservoir water level with the use of predicted streamflow by the SRM.

- Controlled water level with the use of predicted streamflow
- Actual reservoir water level manually controlled by the Sai River dam station without a priori information on streamflow
- · - · - Amount of released water for hydroelectric power
- × — Amount of released water for avoiding flood

5. WITHOUT LANDSAT DATA

The Landsat data sets were not available in 1979 and 1980 due to bad weather. We extrapolated the snow cover depletion curves for these years under the following assumptions:

- 1) The shape of the depletion curve remains the same as for 1981. The starting and ending dates of a snowmelt season vary every year.
- 2) The values of parameters in the SRM remain constant every year.

Based on the above assumptions, we found that the snowmelt season for 1979 starts and ends earlier than for 1981 by $x = 60$ days. Similarly, the snowmelt season for 1980 was found to start and end by $x = 30$ days earlier than for 1981. The value of the shifting factor x is determined so that we can have a maximum correlation coefficient between the measured and simulated streamflow. We obtained the values of the maximum coefficient, 0.72 for 1979 ($x = 60$ days) and 0.84 for 1980 ($x = 30$ days). After finding the shifting factor x , we may discard the assumption 2) and allow variations in parameters. Our preliminary study shows that we could increase an accuracy of runoff simulation up to 90% by changing the values of parameters for 1979 and 1980.

As is shown in Fig.7, we found that the ending dates of the

snowmelt season for 1979 - 1981 depend linearly on the value of the maximum snow depth in the basin. If we know the value of maximum snow depth in the basin, that occurs usually in the middle of February, we can obtain the ending date of the basin's snowmelt period with the aid of Fig.7. Then, it is possible that we may forecast the basin streamflow with an accuracy of at least 70 - 85 % under the assumptions 1) and 2).

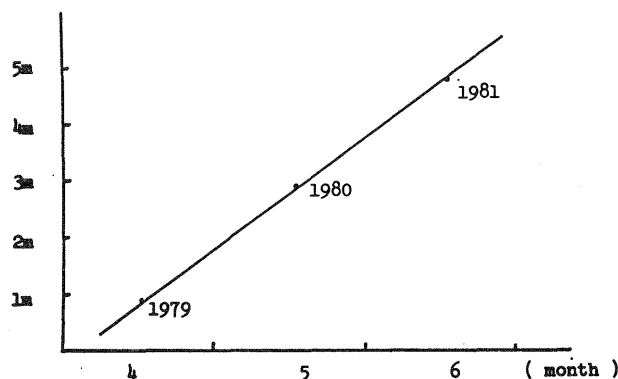


Fig. 7. Correlation between the maximum snow depth and the completion date of snowmelt for the Sai River basin. The vertical and horizontal axes correspond to the maximum snow depth and completion date of snowmelt.

6. CONCLUSIONS

Our conclusions based on this study are as follows:

- 1) We studied the daily streamflow in the Sai River basin for 1979 - 1981. The simulation of streamflow based on the Martinec's SRM was successfully done with an accuracy of more than 90 %, compared with the measured streamflow data. This proved the applicability of the Martinec's SRM to Japanese basins.
- 2) It was found that the ending date of a snowmelt period in the Sai River basin depends linearly on the maximum snow depth. Based on this finding, together with certain assumptions, it is possible to predict the streamflow with an accuracy of about 80 %.
- 3) We showed by computer simulation that we can maintain high water level throughout the snowmelt season from March to July with an aid of predicted inflow data computed by the SRM.

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REFERENCES

1. J. Martinec, A. Rango, and E. Major, 1983, The Snowmelt Runoff Model, NASA Ref. Publ. 1100.
2. J. Martinec, 1980, Remote Sensing Application in Agriculture and Hydrology, Rotterdam, p.447.