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Snowmelt Runoff Models for Operational Forecasts

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Remote sensing is changing the approach in snowmelt runoff modelling. Instead of a simulated snow cover, the areal extent of the real snow cover can be periodically evaluated. Adaptation of depletion curves of the snow coverage for real time forecasts is outlined.

Introduction

The importance of snow for runoff forecasts has been widely recognized more than 40 years ago (Linsley 1943). Relations between snow accumulation and seasonal runoff as well as procedures for short-term forecasts developed at that time would nowadays be called models. This expression was originally reserved for small scale models of hydraulic structures and river reaches. Later, it was also used for physical hydrological models, in other words, laboratory models representing existing or fictitious basins in a strongly reduced scale. Today, hydrologic models mainly mean mathematical formulations for simulating and forecasting runoff. This contribution concentrates on the transition from the simulation mode to operational runoff forecasts in real time. To this effect, depletion curves of the snow coverage are adapted for extrapolating their future course by forecasted temperatures. The method is applicable by all snowmelt models which contain the areal extent of snow cover. The evaluation is possible in partial zones of a basin in order to meet the usual modelling requirements in high mountain conditions.

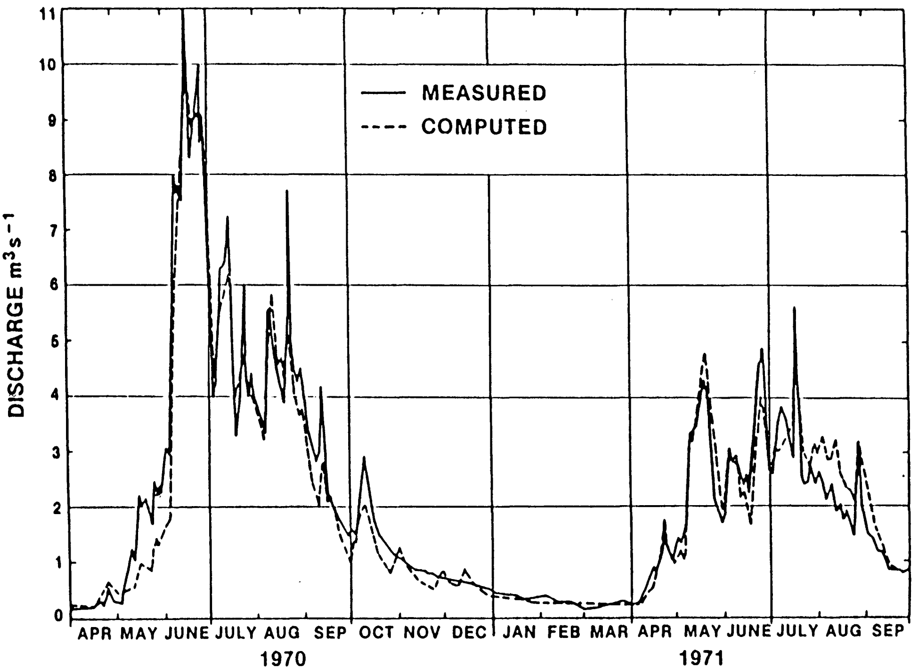

Fig. 1. Continuous streamflow simulations in the alpine basin Dischma in Switzerland.

Snowmelt Runoff Modelling

Fig. 1 shows an example of runoff simulations in the basin Dischma (43.3 km^2, 1,668-3,146 m a.s.l) which is situated in the Swiss Alps. The simulation period is extended to two years without up-dating, to demonstrate the effect of a big accumulation of snow in 1970 followed by a small accumulation of snow in 1971. The runoff was computed from snow covered areas monitored by aircraft and from measured temperatures by a relatively simple model (Martinec et al. 1983).

Before the advent of remote sensing, this deterministic approach was possible only in small basins. In the absence of snow data, many existing snowmelt-runoff models simulate the snow cover from precipitation data. A critical temperature is used to determine whether each daily precipitation was rain or snow. A seasonal snow cover is built up from the daily increments and subsequently melted in order to calculate the runoff. The simulated snow cover does not necessarily correspond to the real one. Even so, good results can be achieved if long-term historical data are available in the given basin to calibrate the model parameters, including the critical temperature. At present, most models use this approach. The quickly improving availability of snow cover data is likely to change this situation (Peck et al.,

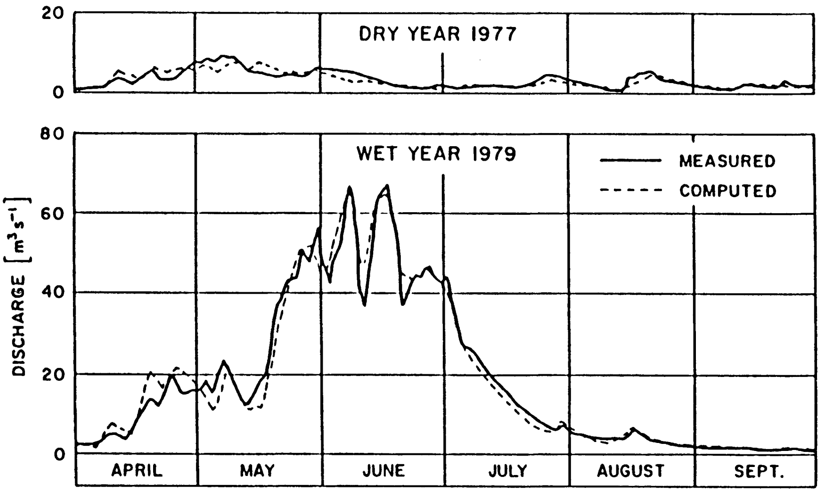

Fig. 2. Snowmelt-runoff simulations in the basin of the South Fork of the Rio Grande in the Rocky Mountains after Shafer (1980).

in press). Another possibility of an indirect evaluation of the snow covered area for runoff modelling has been reported by Ferguson (1984).

Snowmelt-runoff simulations in the basin of the South Fork of the Rio Grande River (559 km^2, 2,506-3,914 m a.s.l) shown in Fig. 2 are based on Landsat data (Shafer 1980). Depletion curves of snow covered areas are drawn from consecutive Landsat overflights and the required daily values of snow coverage are read off these curves.

Large scale satellite imagery is already used for operational forecasts of the seasonal runoff volume (Rango et al. 1977). Fig. 3 illustrates a relation between the average areal extent of the snow cover in April in the Kabul River basin (88,600 km^2, 305-7620 m a.s.l) as viewed by the NOAA-satellite and the runoff volume in April through July. However, it is usually not possible to relate snow covered area to the water volume stored in the snow cover (Martinec 1980).

Adaptation of Snow Cover Depletion Curves for Forecasts

Depletion curves indicating diminishing snow covered areas during the snowmelt season can be readily used to simulate snowmelt runoff in the past years. Recalling Fig. 2, different seasonal runoff volumes can be computed even without the knowledge of the initial accumulation of snow. In real time forecasts, the future course of these curves must be estimated from temperature forecasts in order to compute the snowmelt inputs in the coming days and weeks. To this effect, normal depletion

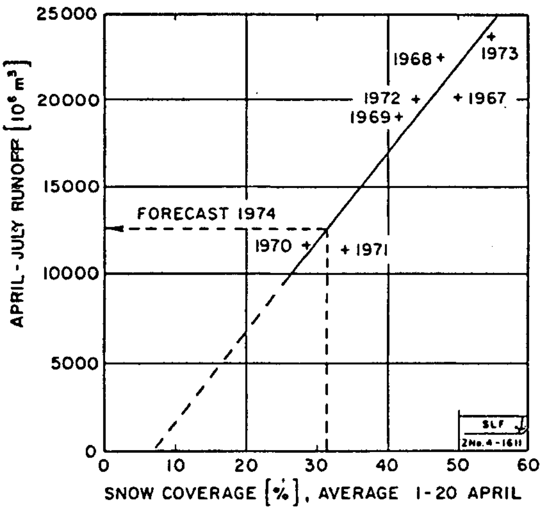

Fig. 3. Relation between the snow-covered area in April and the runoff volume in April through July, after Rango et al. (1977).

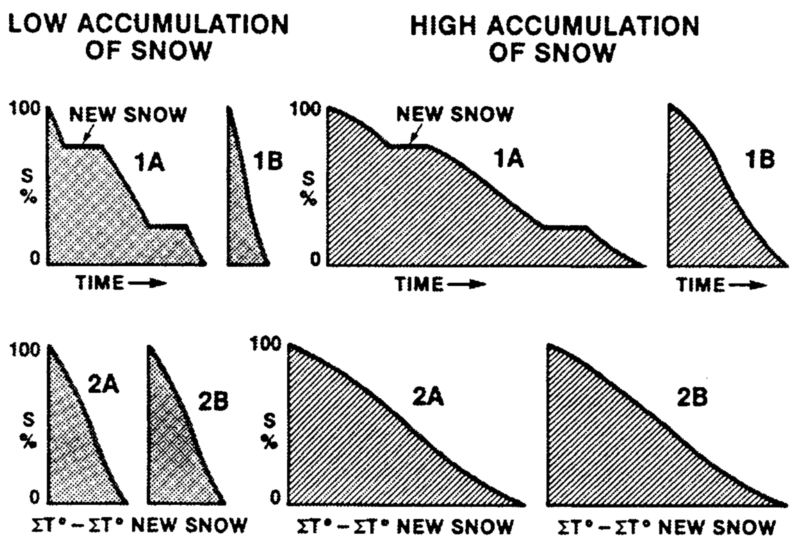

Fig. 4. Depletiton curves of snow covered areas for low and high initial snow reserves, influenced by: a) temperatures below normal, frequent snowfalls, b) temperatures above normal, no snowfalls during the snowmelt season.
Type 1: normal time scale. Type 2: time scale replaced by accumulated degree-days excluding degree-days necessary to melt new snow.

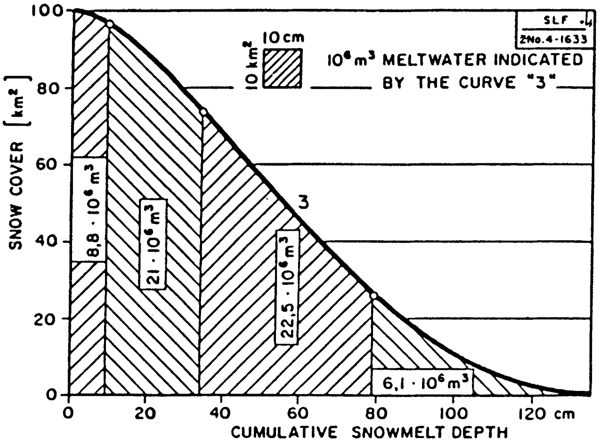

Fig. 5. Depletion curve type 3 with accumulated degree-days replaced by accumulated snowmelt depths. Curve indicates monthly meltwater volumes for assumed monthly snowmelt dephts of 9 cm, 24.8 cm, 45 cm and 55.8 cm

curves relating the snow coverage to the elapsed time are modified as illustrated in Fig. 4.

In a given basin, normal curves type 1 are influenced by:

1) Initial accumulation of snow
2) Temperature (representing the energy input)
3) Frequency of snowfalls during the snowmelt season

The steepest decline of the snow coverage occurs in a snowmelt season with a low initial accumulation of snow, temperatures above normal and in the absence of intermittent snowfalls. The slowest decline results from a high initial accumulation of snow, temperatures below normal and frequent snowfalls during the snowmelt season. As seen in Fig. 4, a very deep snow cover can under circumstances disappear faster (1B "high") than a shallow one (1A "low"). The course of these curves is unpredictable.

In the curves type 2, the time scale is replaced by accumulated degree-days. In order to eliminate also the distorting effect of summer snowfalls, degree-days necessary to melt the new snow are subtracted from the totals. Thus, the course of these curves reflects the accumulation of snow at the start of the snowmelt season and makes possible, in real time, an extrapolation by predicted degree-days.

Depletion curves type 2 are still slightly distorted by the variable degree-day ratios. In the curves type 3, accumulated degree-days are replaced by corresponding snowmelt depths so that in Fig. 5, the shaded areas below the curve are directly proportional to the melted water volumes. In the given hypothetical example, the partial areas indicate the meltwater volumes in four consecutive months.

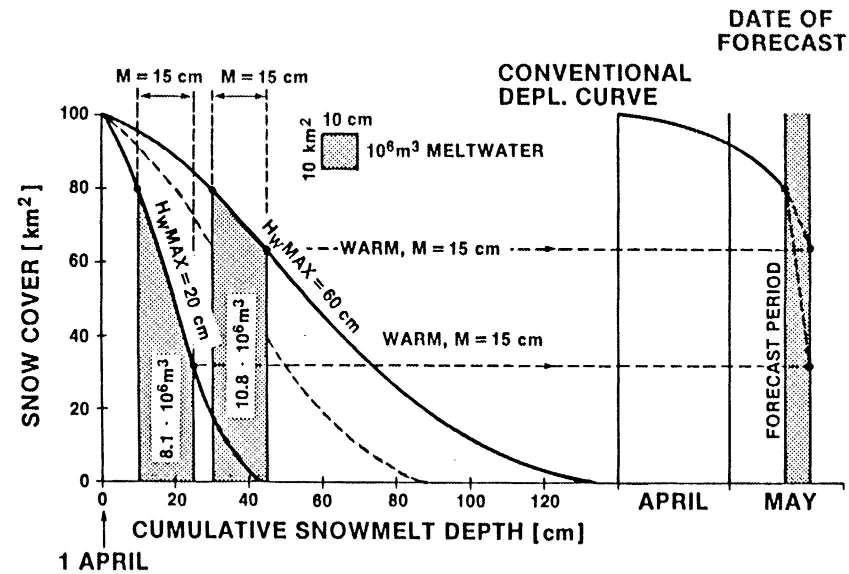

Fig. 6. Extrapolation of snow cover depletion curves in real time from curves type 3 with the use of temperature forecasts. $H_w \equiv$ water equivalent of snow cover at the beginning of the snowmelt season.

Procedure for Weekly Runoff Forecasts

Assumption – A family of depletion curves type 3 has been derived from the past snow cover monitoring and temperature measurements in the given basin. Two of these curves representing the initial water equivalents $H_w \equiv 20$ cm and $H_w \equiv 60$ cm are plotted in Fig. 6.

Example 1 – Snow accumulation in the basin unknown, snow coverage measured by Landsat on 15 May, $S = 80$ percent, cumulative snowmelt depth (from degree-days and degree-day ratios) to date: 30 cm. Temperature forecast: 30 degree-days for the next week, convered to meltwater depth $M = 15$ cm by a degree-day ratio $a = 0.5$ cm °C^{-1} d^{-1}. $S = 80$ percent and $\Sigma M = 30$ cm indicate that the curve type 3 for $H_w = 60$ cm is applicable. The snow coverage will drop to 64 percent in 7 days. Extrapolated conventional depletion curve indicates values for day-to-day discharge computations.

Example 2 – As above, but the cumulative snowmelt depth to date is only 10 cm. Consequently, the curve for $H_w = 20$ cm is applicable and the snow coverage will drop to 33 percent in 7 days, which leads to a different extrapolation of the conventional depletion curve and to a different weekly total of forecasted daily runoff

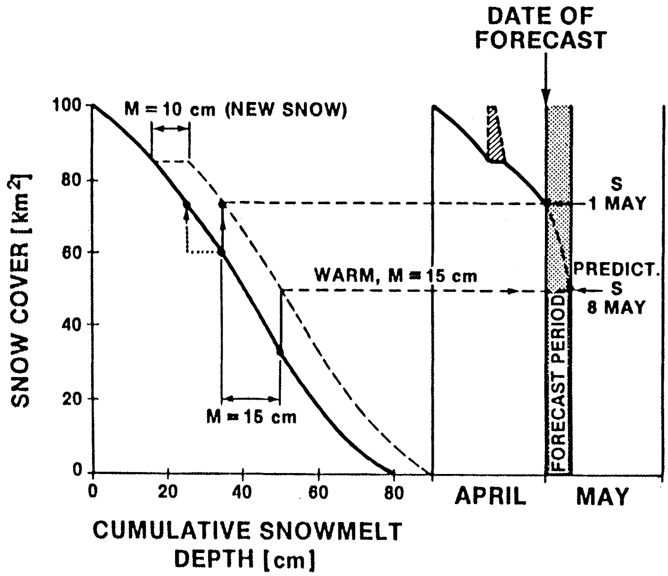

Fig. 7. Elimination of the effect of antecedent snowfall on the extrapolation of snow cover depletion curves. New snow fallen on snow-free areas is accounted for separately as precipitation. Satellite images showing the temporary snow cover at $S \equiv 100$ percent are disregarded.

volumes. If the initial water equivalent is known, for example from SNOTEL (a system of data transmission using meteor paths for reflecting the signals, operated in the U.S.A.), the appropriate curve type 3 can be selected already at the start of the snowmelt season. Otherwise, the average curve (dashed line in Fig. 6) is used until the correct curve can be identified by satellite data.

Snowmelt runoff models usually require a division of mountain basins into several elevation zones. The described procedure must then be carried out for each zone separately.

Fig. 7 illustrates the effect of new snow prior to the date of forecast. In this example, S (1 May) = 74 percent and ΣM = 35 cm seem to indicate that the maximum curve type 3 (H_w = 60 cm, Fig. 6) should be used. The subtraction of the melt depth of the new snow reveals however that the seasonal snow cover is only average, corresponding to the dashed curve in Fig. 6. By this curve, if the forecasted snowmelt depth M = 15 cm is added to ΣM = 35 cm, S drops from 60 percent to 33 percent. These auxiliary values are then transferred to the equidistant dashed curve in Fig. 7 and the real snow covered areas are obtained: 74 percent on the date of forecast and 50 percent after one week. These values, together with the interpolated data for the intermediate days, are used for runoff computations. Fig. 7 shows just one snowfall but a computer program takes into account each new snowfall during the snowmelt period. The computed meltwater volume on each day is multiplied by a runoff coefficient or processed by other factors, according to the structure of the respective snowmelt runoff model. The dashed curve in Fig. 7 is equidistant with the full line only under the simplifying assumption that the new snow is uniformly distributed and melted over the seasonal snow cover.

Conclusion

Snowmelt runoff models can be used for operational forecasts if the snow cover depletion curves obtained from satellite data can be extrapolated by temperature forecasts. To this effect, a set of auxiliary curves relating the snow coverage to accumulated snowmelt depths can be derived for a given basin. The selection of the appropriate curve in the given year is facilitated if the water equivalent of the snow cover at the beginning of the snowmelt season is measured and transmitted to the forecaster.

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