BIWI-TR-115 MAY 1990

RUNOFF FORECASTS IN AN ALPINE CATCHMENT BY SATELLITE SNOW COVER MONITORING

R. Baumann, U. Burkart, K. Seidel

Research sponsored by the

Swiss National Science Foundation

Electric Company of Northeast Switzerland Ltd. (NOK)

TeleColumbus Ltd.

Swiss Federal Institute for Snow and Avalanche Research

RUNOFF FORECASTS IN AN ALPINE CATCHMENT BY SATELLITE SNOW COVER MONITORING

R. Baumann, U. Burkart, K. Seidel
Institut für Kommunikationstechnik ETHZ
Bildwissenschaft ETZ F86, ETH-Zentrum
8092 Zürich, Switzerland

ABSTRACT

The paper describes a study to use remotely sensed satellite data, together with conventional ground-based meteorological and hydrological data for an operational discharge forecast in an alpine catchment area. The runoff forecast is part of a project for operational discharge evaluations in a hydroelectric scheme.

The Snowmelt Runoff Modell (SRM) is used to generate weekly and seasonal forecasts. Snowmelt runoff simulations have been carried out in a large basin and in several subbasins for different years. To demonstrate a runoff forecast procedure, we focussed our interest on the snowmelt runoff period from April to September 1985 in two subbasins of the alpine catchment area of Rhein-Felsberg, Graubünden, Switzerland. All snow cover maps are based on multisensor satellite recordings such as Landsat-MSS and NOAA/AVHRR.

The objective of the study is to prove that a promotion from snowmelt runoff simulation to operational snowmelt runoff forecast is achievable. High quality forecast values are a prerequisite for a more efficient management of multistage hydropower generation. The economic benefits of this procedure are discussed in this paper.

KEY WORDS: snow melt runoff forecast, hydropower management, hydrologic model, snow cover monitoring, remote sensing, satellite imagery

INTRODUCTION

A dominant feature of alpine basins is the seasonal accumulation of snow and the subsequent snowmelt water runoff. The snow covered area gradually decreases during the snowmelt period which affects the discharge of the catchment area. The unaccessibility of remote parts of mountain basins and the size of the basin make it difficult to measure snow reserves directly. Therefore remote sensing methods are being applied to solve this problem. It is possible to evaluate the snow accumulation in an alpine catchment by monitoring the seasonal snow coverage with the aid of satellite imagery. This method enables the direct evaluation of the snow reserves.

60 % of the Swiss electricity is being produced by hydroelectric power stations. A large portion of this hydroelectric energy is produced by snowmelt runoff. To utilize this potential energy in form of snow, a better knowledge of the stored water volume is required. It is

becoming important to optimize the utilisation of the runoff for the production of hydroelectric energy of existing power stations. For an efficient water management of multistage power generation units it is necessary to have forecasts on a weekly or daily basis or for a whole season.

THE STUDY AREA AND DATA AVAILABLE

The study area includes two subbasins Sedrun (108 km², 1840 - 3210 m.a.s.l.) and

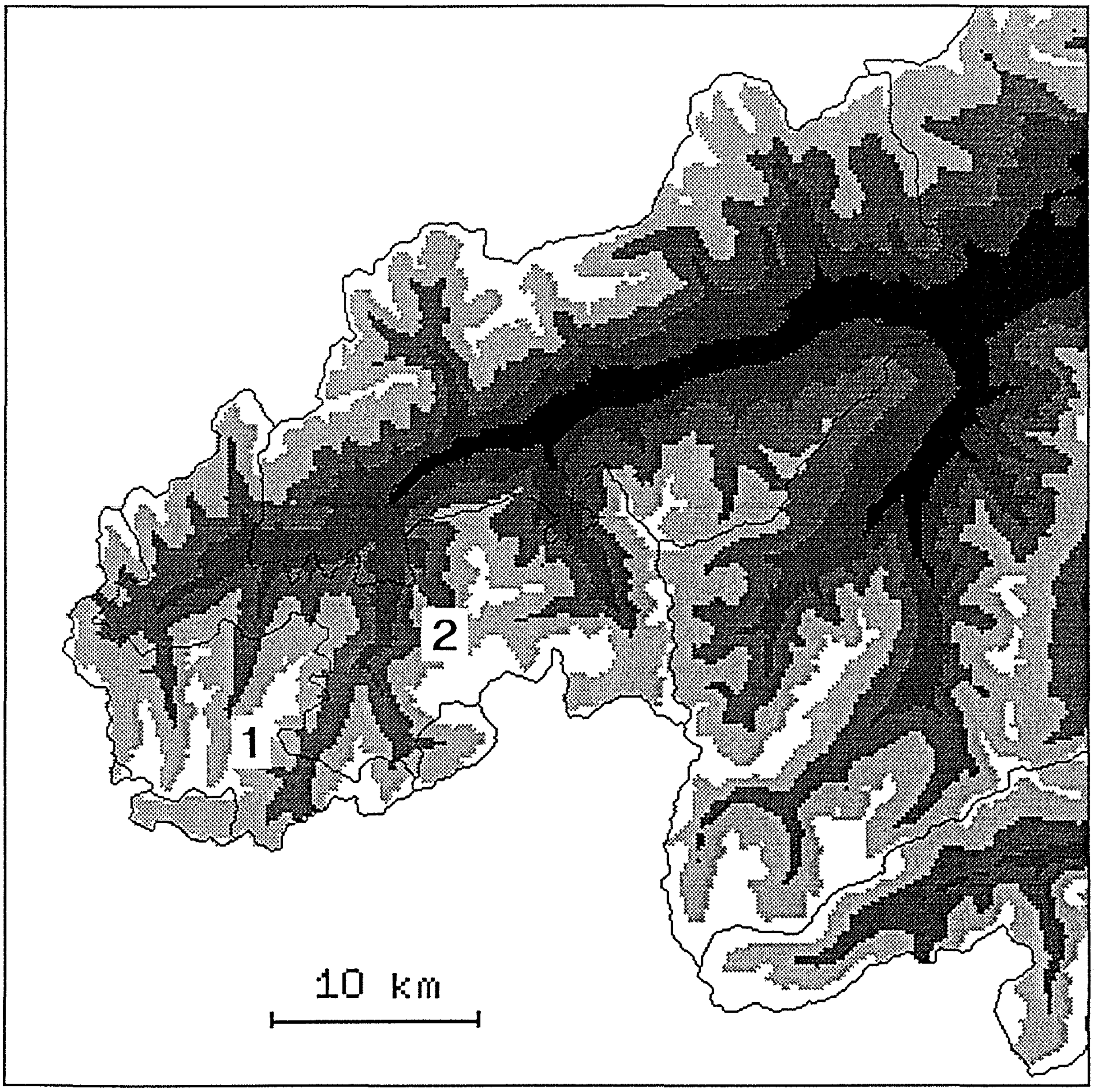

Fig. 1 The elevation zones A (black) to E (white) of the subbasins Sedrun (1) and subbasin Tavanasa (2). Elevation zones:
A: 560 - 1100 m.a.s.l. D: 2100 - 2600 m.a.s.l.
B: 1100 - 1600 m.a.s.l. E: 2600 - 3614 m.a.s.l
C: 1600 - 2100 m.a.s.l.

Tavanasa (215 km^2, 1277 - 3210 m.a.s.l.) which are located in the upper Rhine area of Rhein-Felsberg (3250 km^2, 560 - 3614 m.a.s.l.) in the Northeastern part of Switzerland. The area of the two subbasins is mountainous with small glaciers at the top. The basin Sedrun is subdivided in three elevation zones and the basin Tavanasa in four elevation zones (Fig. 1). Complexity is added by the fact that the watershed of the two catchment areas under the supervision of a hydroelectric company is not identical with the watershed of the natural basin.

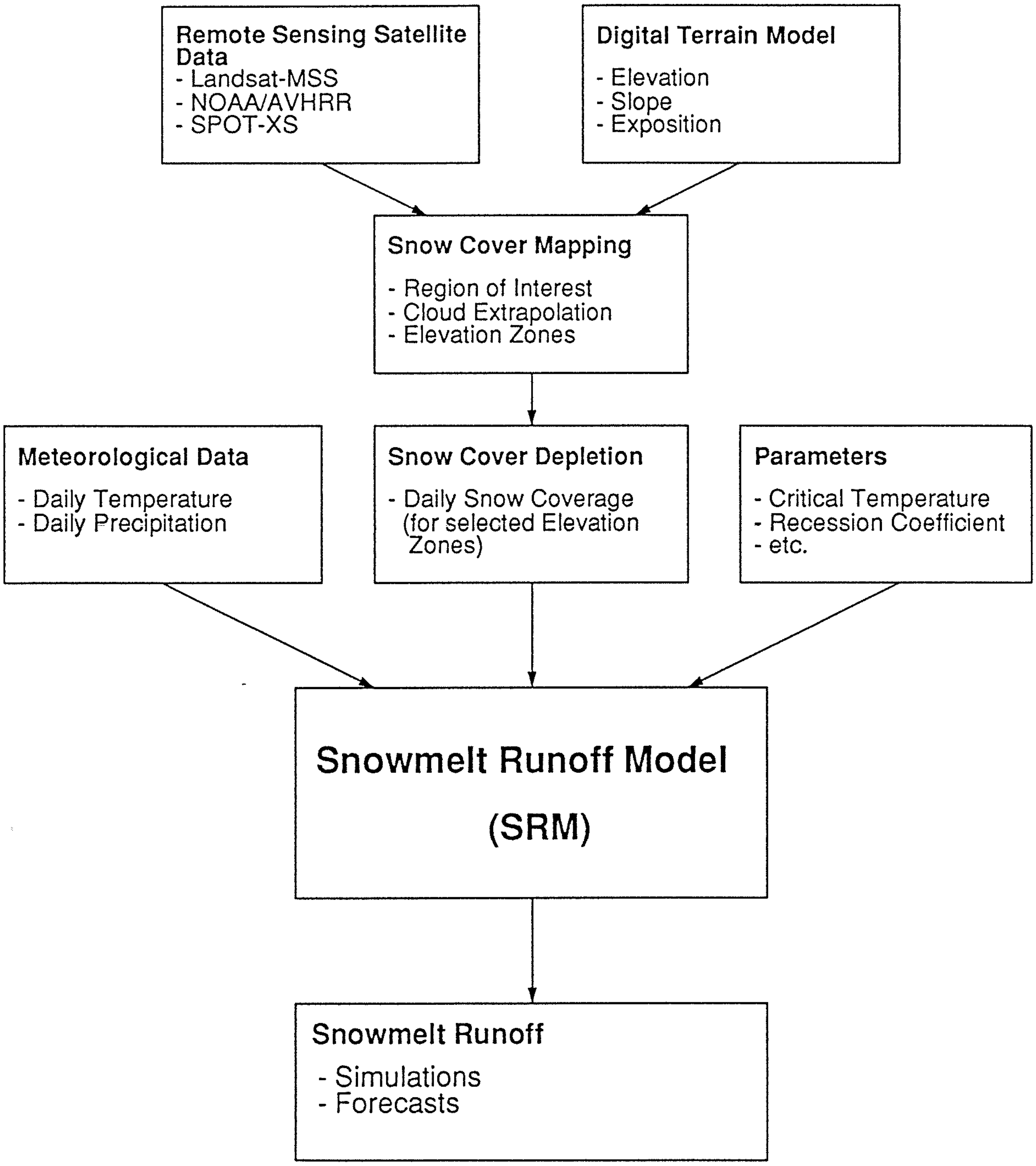

Fig. 2 Flowchart of the procedure of snowmelt runoff simulations based on remote sensing satellite data.

To avoid flow data affected by diversion, only subbasins that did not have water diversion were selected. The two multistage hydroelectric power stations, Sedrun (1400 m.a.s.l.) and Tavanasa (800 m.a.s.l), which are located outside of these two subbasins measure the flow. The meteorological data was obtained from the official meteorological station Disentis located on 1190 m.a.s.l. This station is located below the lowest point of our two subbasins. The study period is April to September 1985.

Following satellite datasets have been used to evaluate the runoff season in 1985:

29-MAR-85	Landsat-5/MSS	29-MAR-85	NOAA-9/AVHRR
16-MAY-85	Landsat-5/MSS	18-APR-85	NOAA-9/AVHRR
24-MAY-85	Landsat-4/MSS	15-MAY-85	NOAA-9/AVHRR
01-JUN-85	Landsat-5/MSS	03-JUN-85	NOAA-9/AVHRR
09-JUN-85	Landsat-4/MSS		
03-JUL-85	Landsat-5/MSS		

Not each recorded dataset is usable as our test area is partially or completely cloud covered during the first part of the examined period due to seasonal evaporation. This results in the difficulty to distinguish between clouds and snow depending on the multispectral resolution. Therefore recordings of different sensors are utilized in order to make use of as many informationen sources as possible.

For a real time forecast it is necessary to obtain the images in less then twentyfour hours to analize the snow coverage as immediate input for the model. For fast data delivery purposes we established a computer network link to the receiving station facilities enabling us to transfer a limited number of satellite datasets.

EVALUATION PROCEDURE AND HYDROLOGIC MODEL

For the evaluation procedure initial preprocessing steps have to be carried out for determining the output data for the model. The flowchart (Fig. 2) illustrates the procedure of snowmelt runoff simulations or forecasts based on remote sensing data.

For the snow mapping above mentioned satellite images are digitally enhanced and analized with the aid of an interactive image analysis system. In a series of preprocessing steps the images are geometrically and radiometrically corrected. These corrected images are integrated into a Geographic Information System (GIS) for interpretation, resulting in snow maps for each image representing the snow cover distribution for the specified date in our catchment area (Fig. 3). With the aid of a Digital Terrain Model (DTM) the snow cover analysis is computed for the different elevation zones. From the snow cover maps the snow cover depletion curves are generated.

The deterministic *Snowmelt Runoff Model* (SRM) is a degree-day based model designed on one hand to simulate and on the other hand to forecast the daily discharge in mountain basins, resulting mainly from snowmelt but also from precipitation. For each basin a set of parameters has to be determined once prior to any runoff simulation.

Finally in the simulation mode all input data (temperature, precipitation and snow cover) has to be entered and the output is the simulated daily streamflow. This flow is compared

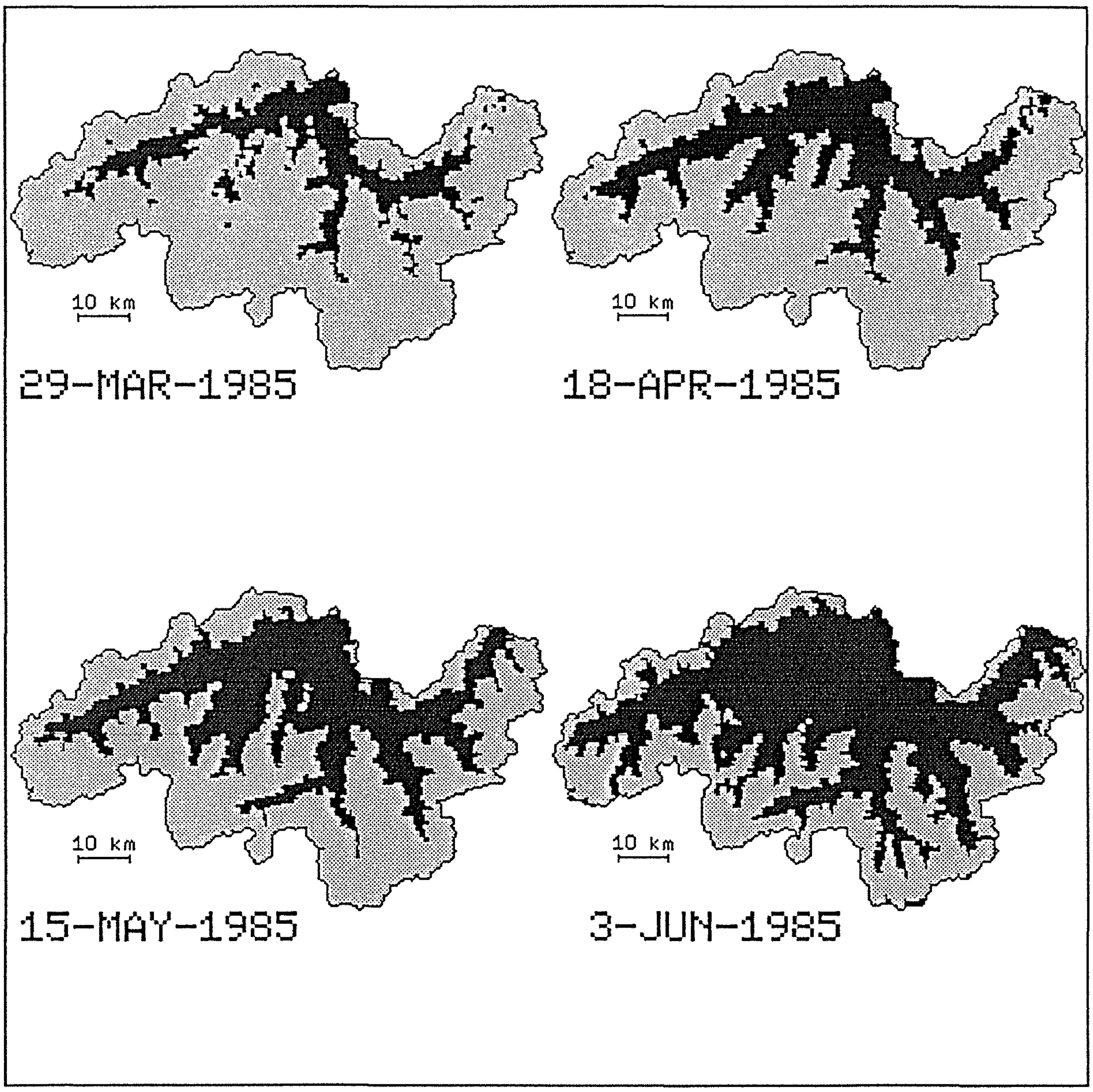

Fig. 3 Multitemporal snow cover maps (grey: snow, black: snowfree) classified from NOAA/AVHRR satellite images of the Rhein-Felsberg basin in Switzerland.

with the observed streamflow to evaluate the performance. The volume deviation is given by

$$D_V = \frac{V - V'}{V} \, 100$$

where

Dv = volume difference

V = measured runoff volume
V' = computed runoff volume

and the model performance can be quantified by the curve fitting value according to Nash-Sutcliffe

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Q_i - Q_i')^2}{\sum_{i=1}^{n} (Q_i - \overline{Q})^2}$$

where

R^2	= measure of model efficiency
Q_i	= measured discharge day i
Q_i'	= computed discharge day i
$\overline{Q}$	= mean of measured discharge
n	= number of daily discharge values

As an example we show the seasonal runoff simulation for 1985 in Fig. 4 and 5. The peaks especially in August occur when runoff from heavy rainfalls is superimposed on the snowmelt runoff. This shows that the runoff could be simulated using the snow cover mapping as well as temperature and precipitation data from just one meteorological station at 1190 m.a.s.l.

SNOWMELT RUNOFF FORECAST

In forecast mode the SRM allows to simulate the runoff for certain time periods (days, weeks, season) in advance. The actual snow coverage has to be evaluated whenever a satellite recording becomes available. Together with adequate temperature and precipitation forecasts the SRM enables a runoff forecast. The forecast accuracy is strongly dependant on the data availability. In realtime forecast these images are not always available for the specified area and time period under consideration or are useless due to the fact of cloud coverage at the moment. For runoff forecasts in an operational scheme it is evident to utilize satellite data from the different orbiting sensor types (multisensor processing) including fast data delivery services from the receiving stations to the processing facilities.

SHORT TERM FORECAST

In a short term forecast (weekly or daily) the user may be able to use forecasts of temperature and precipitation from meteorological services. In addition the realiability of the proposed method depends very much on the availability of actual snow cover extent measurements. The accuracy of the forecasted results is affected by the quality of the meteorological input together with the snow cover evaluations.

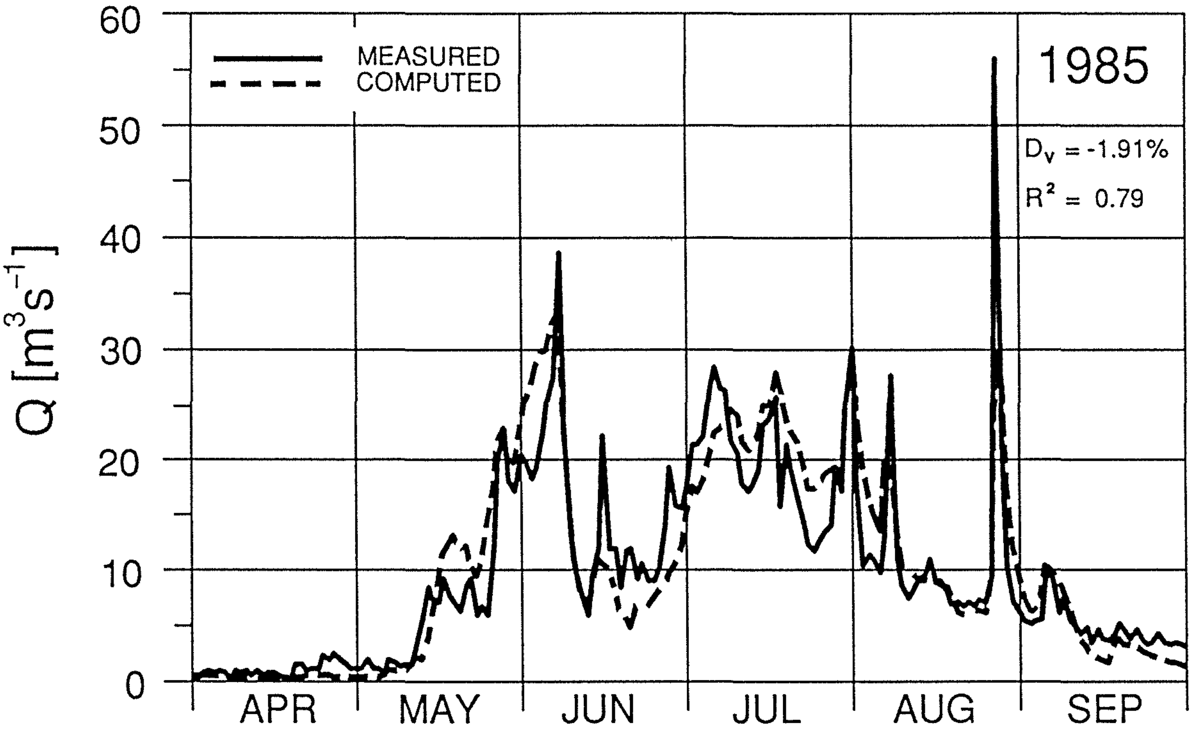

Fig. 4 Computed (- - -) and measured (——) discharge from the catchment area of the hydroloelectric station Sedrun.

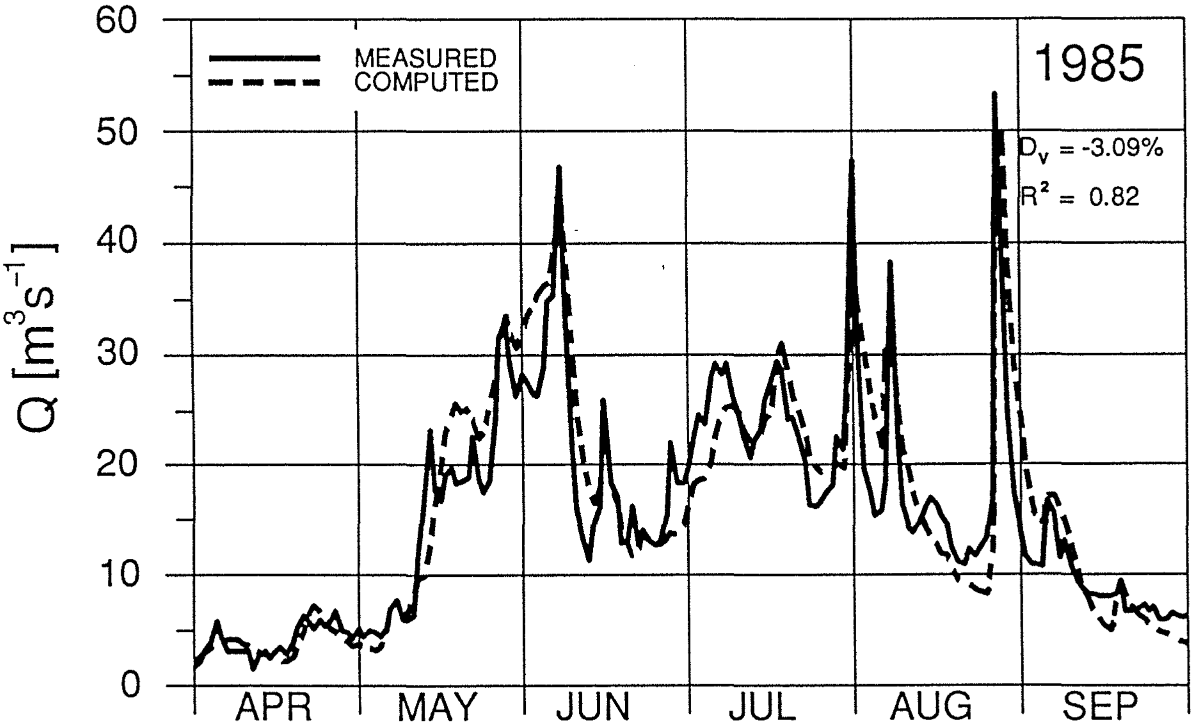

Fig. 5 Computed (- - -) and measured (——) discharge from the catchment area of the hydroloelectric station Tavanasa.

The project deals with daily and weekly runoff forecasts of multistage power stations with different catchment areas and different runoff characteristics (storage stage and running stage). The forecast period should be at least three to seven days. A forecast on the day i includes three to seven forecasted daily volumes $Q_{i,k}$ for every catchment area k:

$$Q_{i,k} = (Q_{i+1,k}; Q_{i+2,k}; .....; Q_{i+7,k})$$

A new forecast is produced for every day. Newly aquired information such as temperature, precipitation and measured runoff are integrated into the current forecasts. According to the runoff from the running stage additional runoff is added from the storage stage.

In order to illustrate the method interest has been focussed on daily and weekly forecasts for the catchment areas of Sedrun and Tavanasa. The distinction has been introduced as the catchments follow different runoff characteristics (storage and running stage). Fig. 6 shows a sequence of forecast curves for the two subbasins Sedrun and Tavanasa for a selected period within the runoff season 1985. Again the difference of the solid the dotted line indicate a measure for the forecast accuracy.

SEASONAL FORECAST

A major requirement for hydroelectric power management for the catchment areas of Sedrun and Tavanasa is the knowledge about the amount of water being at disposal. Seasonal snowmelt runoff forecasts will become available as soon as a reliable set of depletion curves of a number of different seasons have been derived. The intended procedure is to select (for a season under investigation) in an early stage preferably on April 1, a depletion curve together with a seasonal temperature and precipitation behaviour. This will become input to the SRM resulting in the requested seasonal forecast.

ECONOMIC BENEFITS OF RUNOFF FORECASTS

The majority of hydro power stations in the Alps are multistage production units whereby each production unit has its own catchment area. The objective of a runoff forecast (daily, weekly or seasonal) is to predict the runoff seperately for the catchment area of each production unit. Due to the fact that each catchment area varies in size and covers different elevation zones with characteristic temperature profiles, the streamflow of the each stage differs largely regarding quantity and lag time. According to the management of the different units in a multistage power station production scheme the energy produced can result from runoff of the storage stage (peak energy) or runoff from the running stage (band energy) or the combination of both.

With the aid of such a forecast the power station is able to forsee favorable (surplus runoff) or unfavorable (deficit runoff) situations for the production. This knowledge enables the power station to optimize the utilisation of the runoff resulting in a more efficient disposal of the available energy on the energy market.

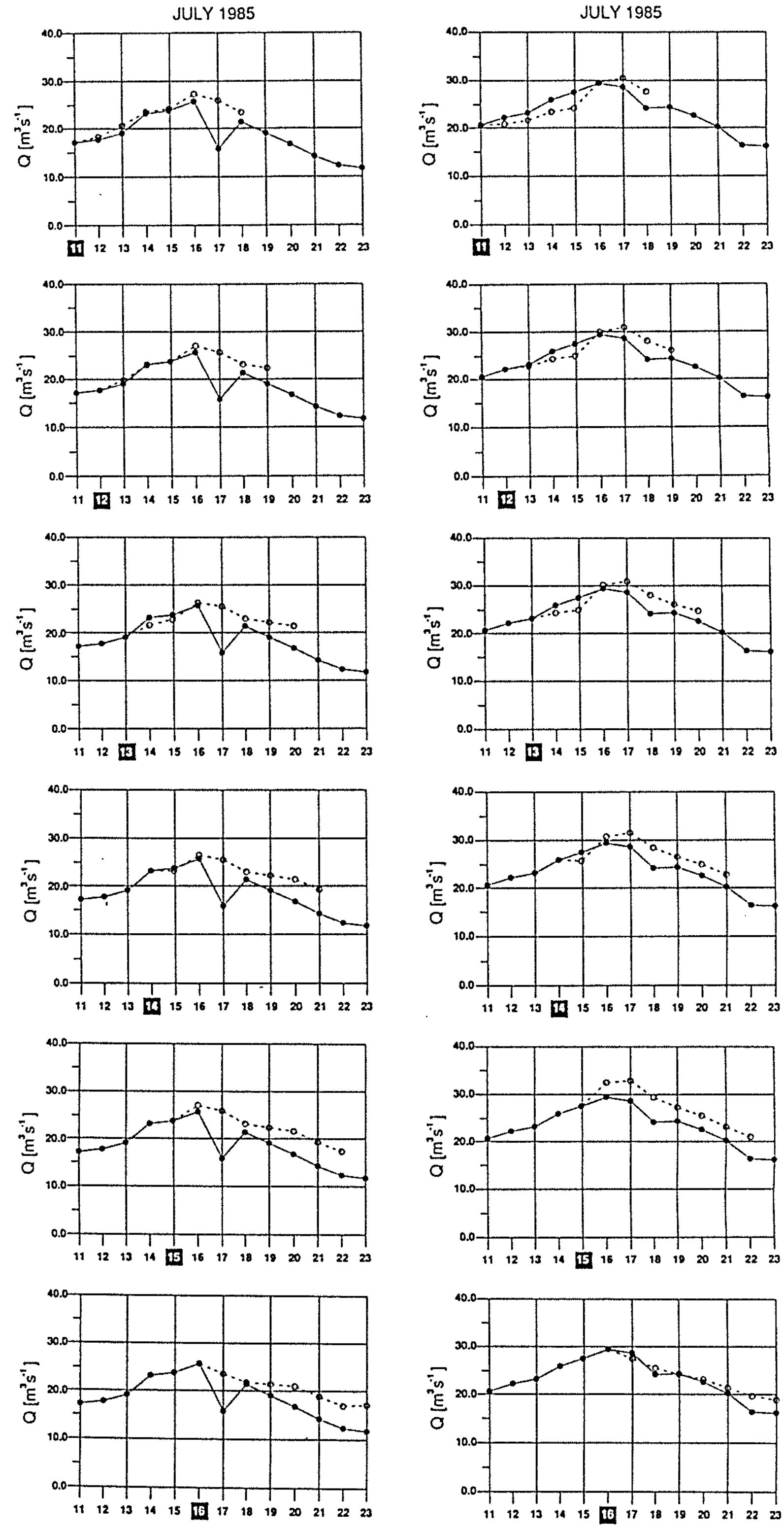

Fig. 6 Weekly forecasted (- - -) and measured (——) runoff for the power stations Sedrun (left) and Tavanasa (right). Starting day is marked reversed.

CONCLUSIONS

Remote sensing images enable us to monitor the snow cover as input to the Snowmelt Runoff Model (SRM) for achieving runoff forecasts in an operational hydroelectric sheme.

With the help of this technique it is possible to improve the runoff management of hydroelectric production and in particular of multistage hydroelectric power generation units.

It is necessary to evaluate satellite recordings from different orbiting sensor systems (multisensor processing). In addition, for an operational short term forecasting procedure a fast data delivery service is an essential prerequisite.

Seasonal runoff forecasts may lead to a more efficient disposal of the available hydroenergy on the energy market. This runoff will become more predictable as soon as reliable comparisons with corresponding depletion curves out of a historical database are possible.

ACKNOWLEDGEMENTS

This project is supported by the Swiss National Science Foundation, the Electric Company of Northeast Switzerland (NOK), TeleColumbus Ltd. and by the Swiss Federal Institute for Snow and Avalanche Research (EISLF) at Weissfluhjoch-Davos. Special thanks to Dr. J. Martinec (EISLF) and Dr. J. Wiedemeier (NOK) for their help and stimulations.

REFERENCES

Hall, D.K., and Martinec, J. (1985), Remote Sensing of Ice and Snow, Chapman & Hall, London - New York

Martinec, J., Rango, A., and Major, G. (1983), The Snowmelt-Runoff Model (SRM User's Manual, NASA Ref. Publ. 1100, Washington, D.C.

Rango, A. (1989), Evolution of a research-oriented snowmelt runoff simulation model into an operational forecasting tool, Proceedings of the 57th Annual Western Snow Conference, Vancouver, B.C., pp. 45 - 51

Seidel, K., Burkart, U., Baumann, R., and Martinec, J. (1989), Snow Cover Monitoring by Satellites and Real Time Runoff Forecasts, Proceeding of the IGARSS '89 Conference, Vancouver, B.C., pp. 558 - 561