RESULTS OF THE SNOWMELT-RUNOFF MODEL IN AN INTERNATIONAL TEST

778-85

BY

A. Rango[1]

INTRODUCTION

The snowmelt-runoff model (SRM) is designed to simulate and forecast daily streamflow using remote sensing input of snow extent in mountain basins where snowmelt is the major runoff component. Description of the model and results of testing on large snowmelt river basins were reported by Rango (1983). To facilitate application of the model, a user manual has been published (Martinec et al. 1983).

In 1979, the World Meteorological Organization (WMO) initiated a project on the Intercomparison of Models of Snowmelt Runoff to potentially include all member countries likely to use snowmelt-runoff models. Eleven models (including SRM) from eight countries were included in the project, and six standard data sets from six countries were compiled (World Meteorological Organization, 1982). The technical results of the project were reviewed by participants at a meeting in Norrköping, Sweden in September, 1983. The final report will be published by WMO.

WMO INTERCOMPARISON PROJECT

The eleven snowmelt-runoff models participating in the WMO project are listed in Table 1 along with an indication of location and/or organization where the model was originally developed plus the year the model was first used for simulations. Nine of the eleven models calculated snowmelt using a form of the degree-day method. A simple degree-day index equation was used by UBC, ERM, TANK, HBV, SRM, and SSARR; a degree-day index equation modulated by a solar radiation factor was employed by CEQUEAU; the degree-day index approach modified by the difference between air temperature and snowpack temperature was utilized by NAM II; and NWSRFS used the degree-day equation during non-rain periods switching to a simplified energy balance equation during rain on snow situations. Both PRMS and SHE/IHDM models used an energy balance approach for calculating snowmelt.

Data sets were assembled and used for testing the models on the six basins shown in Table 2. Specifics on the basins are listed in Table 2 along with the number of models completing a simulation for at least one full snowmelt season or entire year. Examination of Table 2 and supplemental data reveals that three basins have a strong similarity to western U.S.A. snowmelt water supply basins, namely, Durance, Dischma, and Illecillewaet. The Kultsjon and Dunajec have fewer characteristics similar to major snowmelt runoff basins in the West. The Kultsjon runoff is dominated by the snowmelt component, but the basin itself has a limited elevation range and is influenced strongly by the climate of the polar region. The Dunajec has 20% of its area similar to a mountain snowmelt basin, but the rest of the area at low elevation dominates runoff processes in the basin. Finally the W-3 basin is considerably different from most important snowmelt-runoff basins in that it has a relatively small elevation range, the snowmelt component of runoff does not dominate, and significant precipitation can occur during the snowmelt season. Data quality was generally high in all the data sets with a few exceptions.

Table 3 presents a specific breakdown of the basins on which each of the models was tested for at least one full snowmelt season or total year's runoff. Because of model data requirements, SHE/IHDM could not be tested for any extended period of time. Table 4 presents the verification criteria used in the WMO project for evaluating the model output data. Each of the criteria will be provided in the WMO final report for each of the models to facilitate evaluation by readers.

Presented at the Western Snow Conference, 1985, Boulder, Colorado

1/ Chief, Hydrology Laboratory, USDA-Agricultural Research Service, Beltsville, MD 20705

Table 1. Listing of models participating in the WMO project, model development information, and year when first used for simulations.

Model Name	Location and/or Organization	Year
1. UBC Watershed Model (Canada) (University of British Columbia)	Vancouver, Canada	1974
2. CEQUEAU Model (Canada)	University of Quebec, Canada	1971
3. ERM (Empirical-Regressive Model)	Bratislava, Czechoslovakia	1978
4 NAM II (Nebdor-Afstromningsmodel, Version II)	Technical University of Denmark	1973
5. TANK Model	National Research Center for Disaster Prevention, Japan	1963
6. HBV Model	Swedish Meteorological and Hydrological Institute	1976
7. SRM (Snowmelt-Runoff Model)	Federal Institute for Snow and Avalanche Research, Switzerland	1973
8. SSARR Model (Streamflow Synthesis and Reservoir Regulation Model)	Corps of Engineers, Portland, Oregon, U.S.A.	1967
9. PRMS Model (Precipitation-Runoff Modelling System)	U.S. Geological Survey, U.S.A.	1973
10. NWSRFS Model (National Weather Service River Forecast System-Snow Accumulation and Ablation Model)	National Weather Service, U.S.A.	1973
11. SHE/IHDM Model (Système Hydrologique Européan/Institute of Hydrology Distributed Model)	U.K., Denmark, France	1979

SRM PERFORMANCE

Before the WMO project SRM was only used for runoff simulation during the snowmelt period. The WMO project, however, required that year-round runoff simulation be performed and evaluated in addition to snowmelt season simulation. To comply with WMO requirements, SRM was run for the first time after snowmelt was no longer a factor.

The WMO project was structured so that the data sets were divided into a calibration and a verification period as shown in Table 2. SRM has no formal calibration procedure, instead relying on physical-based estimates of model coefficients to provide an accurate simulation. Adjustments of coefficients within a physically realistic range are allowed. As a result the calibration and verification periods were treated the same in running SRM with the only difference being that WMO withheld the verification period discharge data for later evaluation.

SRM was applied to the Dischma, Durance, Dunajec, and W-3 basins, whereas the Illecillewaet and Kultsjon basins did not have sufficient snow cover data to permit SRM to be run. The quality and duration of snow cover data was a problem on five of the six basins. WMO supplied snow cover data were complete only on the Dischma basin. For Durance and Dunajec some snowline elevations were supplied which were not of much use, whereas no pertinent snow cover data were available for W-3, Illecillewaet or Kultsjon. As a result, snow cover extent data were obtained from Landsat for the Durance and Dunajec basins. The Landsat and the Illecillewaet period of records did not overlap enough to provide sufficient data for effective snow cover mapping. For Kultsjon not enough Landsat data were available because of a combination of limited foreign data acquisition and persistent cloud cover. Landsat could not be used on the W-3 basin because of its small area. Because of the small area and large number of snow courses on W-3, however, the movement of the snowline and change in snow cover could be inferred fairly easily. Hence, the following snow cover data were used in running SRM: Dischma - WMO supplied snow cover from aircraft orthophotos; Durance - Landsat; Dunajec - Landsat; and W-3 - snow cover inferred from snow course records. The complete 10 years of runoff were simulated for Dischma and W-3. For Durance, inadequate foreign Landsat data acquisition before 1975 limited the simulation period to 1975-1979. For Dunajec, delay in acquiring the foreign Landsat data permitted only one year of discharge simulation (1976).

Table 2. Description of the WMO project test basins and the data periods of interest.

Basin	Area (km^2)	Elevation Range (m)	Calibration Period	Verification Period	Snowmelt Season	Number of Models Used
Durance River (France)	2170	786-4105	10/1/69-9/30/75	10/1/75-9/30/79	Apr-Jun	10
W-3 Watershed (U.S.A.)	8.4	346-695	10/1/68-9/30/74	10/1/74-9/30/78	Mar-May	9
Dunajec River (Poland)	680	577-2301	10/1/70-9/30/76	10/1/76-9/30/80	Feb-May	10
Dischma Basin (Switzerland)	43.3	1668-3146	10/1/69-9/30/75	10/1/75-9/30/79	Apr-Jul	9
Illecillewaet River (Canada)	1155	1155-3107	10/1/66-9/30/72	10/1/72-9/30/76	Apr-Sep	6
Kultsjon (Sweden)	1110	540-1580	10/1/69-9/30/75	10/1/75-9/30/79	May-15 Jul	6

Table 3. WMO project participating models and basins on which they were tested.

Models	Basins
UBC	Durance, W-3, Dunajec, Dischma, Illecillewaet, Kultsjon.
CEQUEAU	Durance, W-3, Dunajec, Dischma, Illecillewaet, Kultsjon.
ERM	Durance, Dunajec, Dischma, Illecillewaet, Kultsjon.
NAM II	Durance, W-3, Dunajec, Dischma.
TANK	Durance, W-3, Dunajec, Dischma, Illecillewaet, Kultsjon.
HBV	Durance, W-3, Dunajec, Dischma, Illecillewaet, Kultsjon.
SRM	Durance, W-3, Dunajec, Dischma.
SSARR	Durance, W-3, Dunajec, Dischma, Illecillewaet, Kultsjon.
PRMS	Durance, W-3, Dunajec, Dischma.
NWSRFS	Durance, W-3, Dunajec.

Table 4. Verification criteria used in the WMO project.

Graphical	Numerical
1. Simulated vs. observed hydrographs of daily discharge.	1. CO: Ratio of standard deviations of computed to observed discharges.
2. Flow duration curves.	2. NTD: Coefficient of determination of daily discharges (R^2).
3. Scatter diagrams of simulated vs. observed peak flows.	3. NTM: Coefficient of determination of monthly discharges.
	4. S: Ratio of the standard deviation of the residuals to the mean observed discharge.
	5. NS: Coefficient of gain from daily means (peasant model).
	6. PD: Difference in observed and computed runoff volumes.
	7. R: Ratio of the mean error to mean observed discharge.
	8. A: Ratio of absolute error to mean observed discharge.

In evaluations of SRM performance during both the calibration and verification periods, three of the verification criteria in Table 4 were emphasized. First, the graphical plot of simulated versus observed daily discharge was examined to evaluate overall correspondence and to identify any major simulation errors. Second, the NTD (or R^2) value was examined to determine the relative accuracy of the daily discharge values. Finally, the PD (or D_v) value was examined to evaluate the seasonal volume simulation accuracy.

Figures 1-4 provide examples of the hydrograph plots of simulated versus observed discharge for each of the basins tested along with the corresponding NTD(R^2) and PD(D_v) values listed. Figures 1-4 are for the major period of interest of SRM, namely, the snowmelt runoff season. Figure 5, on the other hand, is a 365-day simulation for the Dischma basin. Because calibration and verification periods were basically treated the same by SRM, Table 5 provides average statistics for the entire period of record tested for each basin. Comparison of snowmelt season and total year results indicate that SRM performed about equally well in both periods. Table 6 provides a comparison of statistics for the calibration and verification periods. In the verification as opposed to the calibration period no physically-based adjustments of coefficients in SRM could be instituted to improve the simulation fit because no actual streamflow data were available during verification. The results are generally as expected, i.e., the statistics drop in moving from calibration to verification. For the snowmelt period the average calibration period NTD and PD values are 0.85 and 0.05, respectively, whereas the average verification period NTD and PD values are 0.80 and 0.07, respectively. The calibration period statistics are exactly in line with the SRM average values from all the other basins previously tested. The drop in the statistics during the verification period is not drastic which gives hope that SRM would perform well in a true forecasting situation or on an ungaged basin.

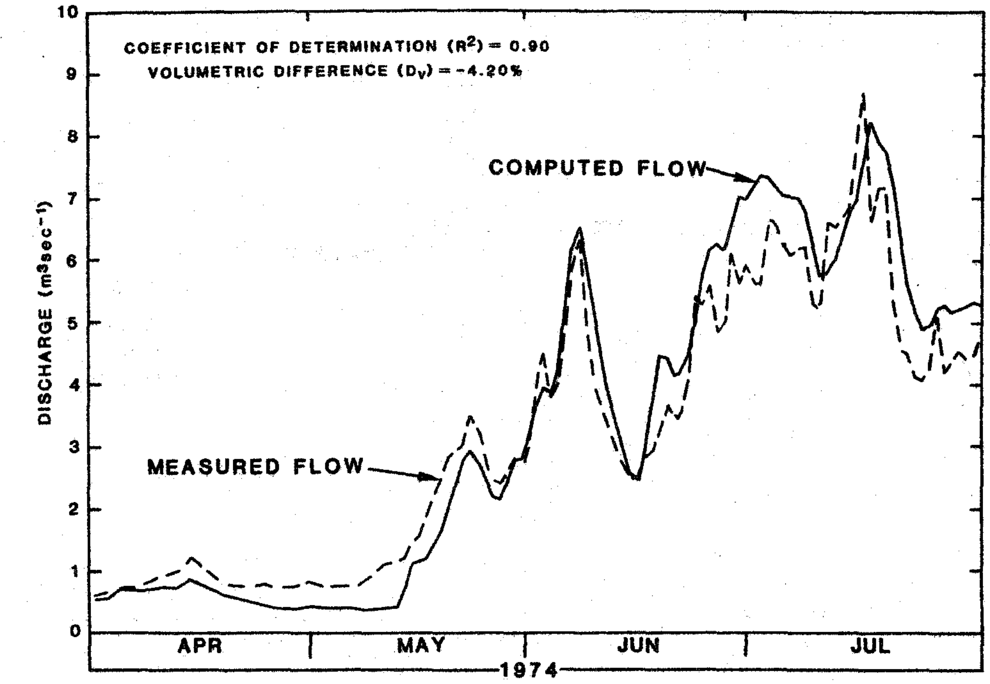

Figure 1. Discharge simulation for the Dischma basin (43.3 km^2), Switzerland using SRM.

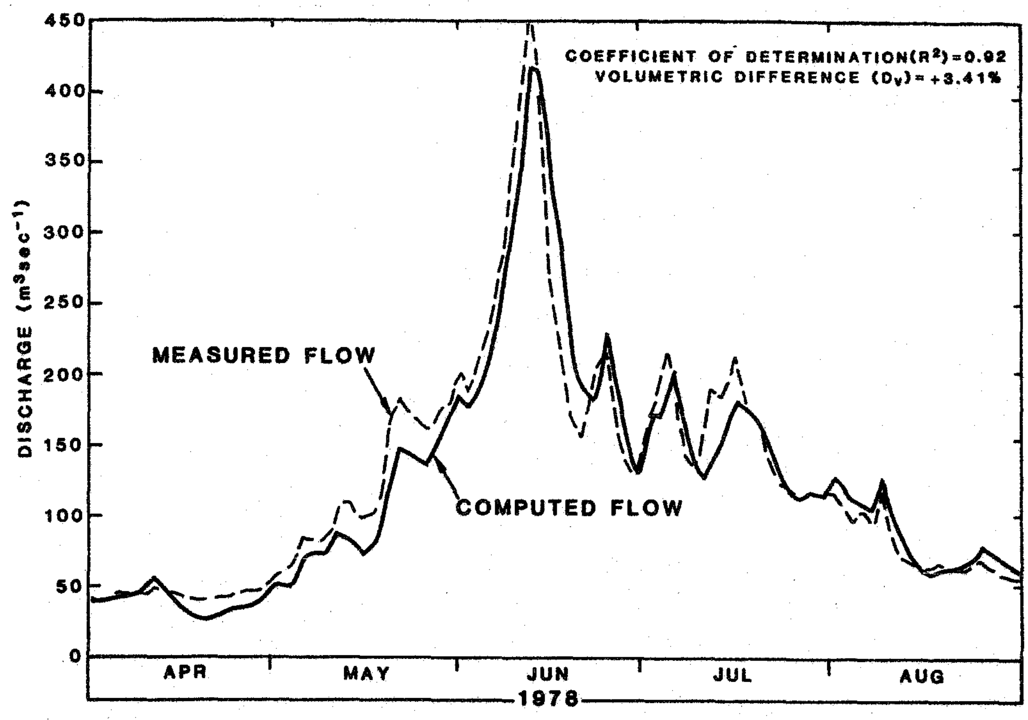

Figure 2. Discharge simulation for the Durance River basin (2170 km^2), France using SRM.

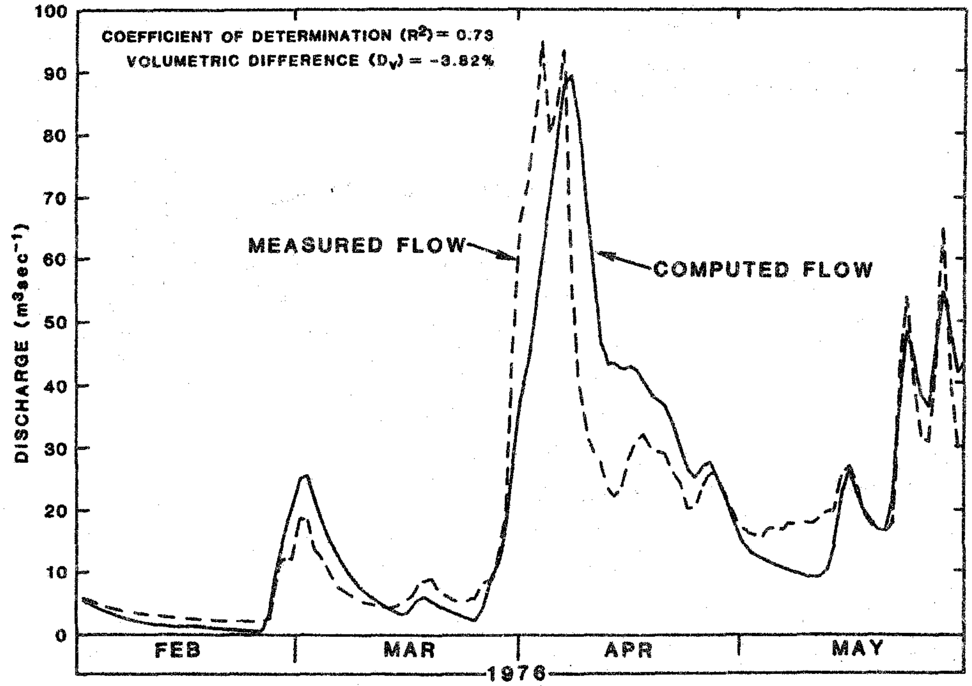

Figure 3. Discharge simulation for the Dunajec River basin (689 km^2), Poland using SRM.

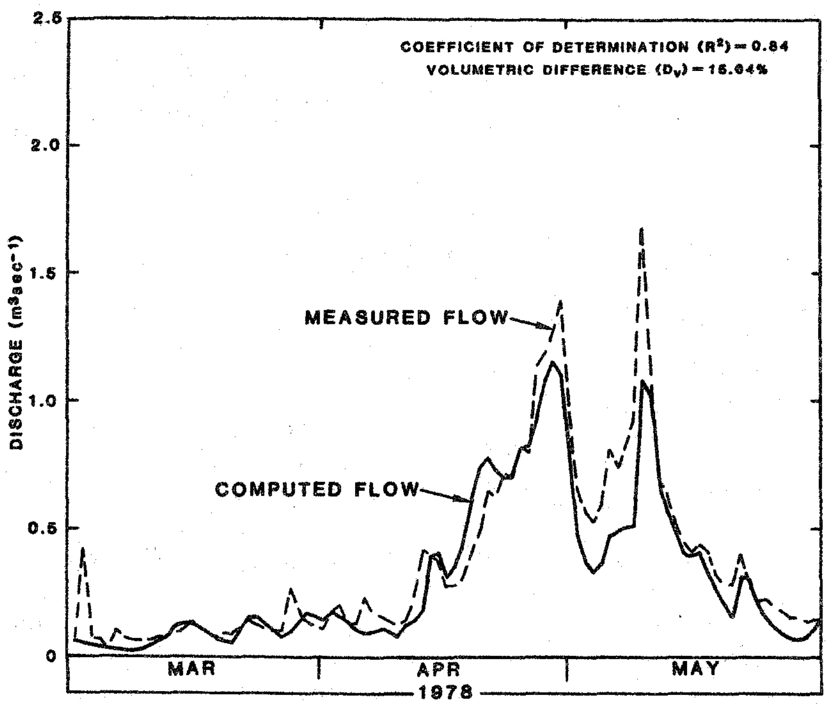

Figure 4. Discharge simulation for the W-3 basin (8.42 km^2), Vermont, U.S.A. using SRM.

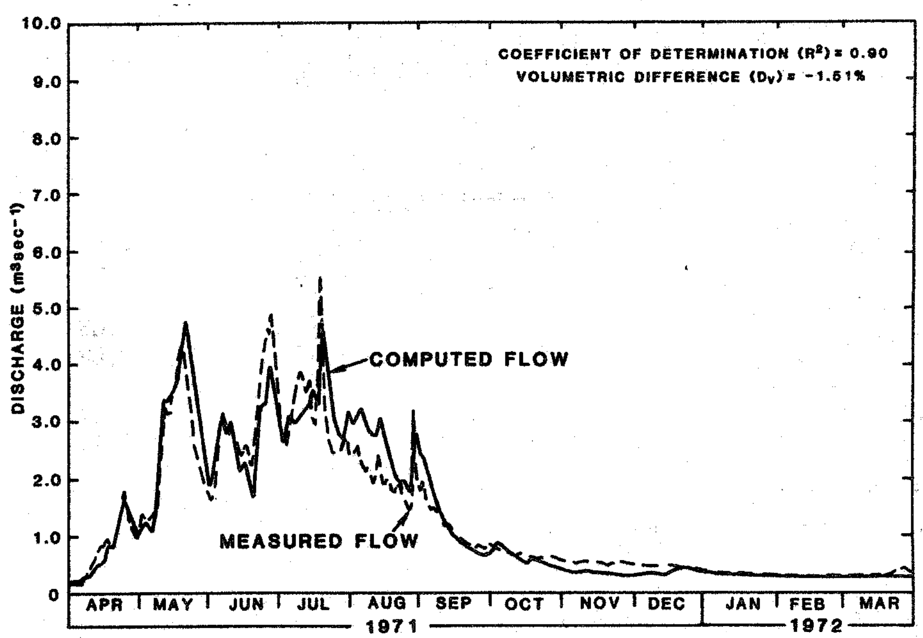

Figure 5. Discharge simulation for the Dischma basin (43.3 km^2), Switzerland using SRM (365 days).

Table 5. WMO project average statistics for SRM simulations.

Basin	n	Snowmelt Season	Total Year
Dischma	10	$\overline{NTD}$ = 0.84	$\overline{NTD}$ = 0.87
		$\overline{PD}$ = 0.03	$\overline{PD}$ = 0.06
Durance	5	$\overline{NTD}$ = 0.85	$\overline{NTD}$ = 0.86
		$\overline{PD}$ = 0.07	$\overline{PD}$ = 0.05
W-3	10	$\overline{NTD}$ = 0.80	$\overline{NTD}$ = 0.77
		$\overline{PD}$ = 0.08	$\overline{PD}$ = 0.13
Dunajec	1	$\overline{NTD}$ = 0.76	$\overline{NTD}$ = 0.75
		$\overline{PD}$ = 0.05	$\overline{PD}$ = 0.01

Table 6. Comparison of calibration (C) and verification (V) period average statistics for SRM snowmelt season simulations.

Basin	n	$\overline{NTD}$	$\overline{PD}$
Dischma	6 (C)	0.88	0.03
	4 (V)	0.78	0.02
Durance	1 (C)	0.91	0.03
	4 (V)	0.84	0.08
W-3	6 (C)	0.82	0.07
	4 (V)	0.78	0.11

CONCLUSIONS

The results obtained by SRM in the WMO project are very promising in that they are consistent with earlier tests of the model. Additionally, the statistics during the verification period are still high which indicates a good potential for forecasting. It was also discovered that SRM could operate effectively on basins other than the classical mountain snowmelt basin, and that it could provide adequate simulations for the entire year as well as for the snowmelt season. For year-round simulation, however, improvements in precipitation and evapotranspiration algorithms would be desirable.

It is apparent that despite the efforts of WMO, snow cover data is generally not routinely collected even when data set owners say they have it. Landsat can supply the necessary snow cover data when it is available. Even then, additional research is needed on topics like how to handle snow mapping in areas of discontiguous snow cover ablation.

The WMO project and the data sets associated with it are very valuable for model testing and evaluation as well as for model development. Additional organized tests on common data sets are encouraged so that potential users become more familiar with the capabilities of the various available models. It is recommended that the interested reader obtain a copy of the WMO report when it is published so that detailed cross comparisons of model performance can be made. It promises to be a valuable document.

ACKNOWLEDGEMENTS

The SRM results for the WMO project were obtained as a result of important contributions by Dr. J. Martinec, Mr. Eugene Major, and Mr. James Foster.

REFERENCES

Rango, A., 1983: Application of a Simple Snowmelt-Runoff Model to Large River Basins, Proceedings of the 51st Annual Western Snow Conference, Vancouver, WA, pp. 89-99.

Martinec, J., A. Rango, and E. Major., 1983: The Snowmelt-Runoff Model (SRM) User's Manual, NASA Reference Publication 1100, 118 pp.

World Meteorological Organization, 1982: WMO Project for the Intercomparison of Conceptual Models of Snowmelt Runoff, Hydrological Aspects of Alpine and High Mountain Areas (Proceedings of the Exeter Symposium, IAHS Publication No. 138, Exeter, U.K., pp. 193-202.