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Operational Spring Time Forecasting Difficulties and Improvements

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A modified version of HBV-3 model has been used since 1981 for operational spring-time forecasting in Finland. This model is ready now for eleven river basins ranging from 500 to 30,000 km^2. From the experience with these models in forecasting we have learned to know the common difficulties and errors in real-time forecasting and some methods to improve forecasting results.

The main difficulties with forecasting during spring time in Finnish conditions have been: unstable parameters in snowmelt models, heavy unforecasted rainfall, evaluation of areal water equivalent of snow and ice-dams in rivers.

The methods to overcome these difficulties are: the development of more physically based snowmelt models, new methods to determine initial value of areal water equivalent of snow, the use of statistical error models with hydrological model, the automatization of observation and transport of hydrological and meteorological data and the improvement of areal precipitation calculations.

Snowmelt Models

The snowmelt model used in forecasting models is the widely used temperature index model. Temperature index models are not very stable. The best value of degree-day constant varies from spring to spring and within spring (Vehviläinen and Kuusisto 1984). Spring time forecasting models are especially sensitive to errors in snowmelt model during the initial part of snowmelt period. Quite small errors in forecasted temperature values or in degree day factor can cause serious errors in discharge values. The updating of snow model is very essential at this stage to get satisfactory results. The errors in snowmelt simulation are corrected by changing observed temperature values so that observed and simulated discharges/ waterlevels are equal. An example of this is presented in Fig. 1. The changing of observed temperatures is preferred against the changing of parameter values, because it is not reasonable to calibrate parameters against a few days of unchecked data. During the latter part of snowmelt period the forecasts are not so sensitive to errors in snowmelt model, because snowmelt processes are steady going on and the ripening period of snow is over. However, one error in snowmodel can destroy everything even in the latter part of snowmelt period forecasting. It is the initial value of areal snow water equivalent. If it differs very much from the true value one can get quite good results during the initial period of snowmelt, but the error reveals itself just during the time of flood peak forecasting; forecasted and observed flood peaks differ considerably from each other in timing, volume and peak value of flood (Fig. 2).

In order to get more stable snowmelt models the basic degree-day model is developed into the following directions.

Modified Degree-Day Model

A degree-day model with increasing degree-day factor and decreasing liquid water retention capacity, both as a function of cumulative snowmelt, has been tested on two river basins 21 and 1,900 km^2 in area (Vehviläinen 1985). The basis for this is that due to the changing physical characteristics of snow, snowpack absorbes more shortwave radiation and retents less liquid water in the latter part of snow-melt period.

Energy Balance Snowmelt Model

By using energy balance snowmelt model one expects to get a model, which is stable from spring to spring and does not cause errors due to variable model parameters. In energy balance model the following terms have been taken into account: short and long wave radiation, sensible heat, latent heat, heat from liquid precipitation and cold content of snowpack. Further, the following snowpack characteristics have been also calculated, because they are needed in energy balance model: albedo, density and depth of snow (Vehviläinen 1985).

Combined Degree-Day and Energy Balance Methods

According to the results from energy balance model, short wave radiation dominates snowmelt especially during the first part of melt period (Vehviläinen 1986). So the inclusion of short wave radiation into degree-day model may give some improvement especially in cases when temperature is near or under zero and degree-day model is incapable to simulate snowmelt. Also sensible heat term and

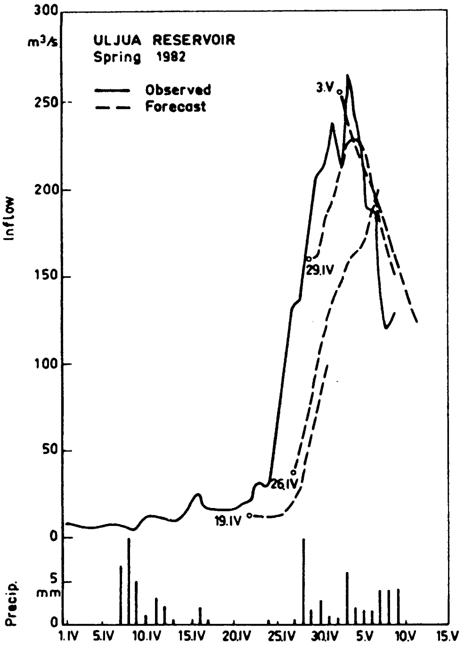

Fig. 1.
Example of the effect of updating forecasting model during the initial part of snowmelt. Updating is made before the forecast 29.IV.

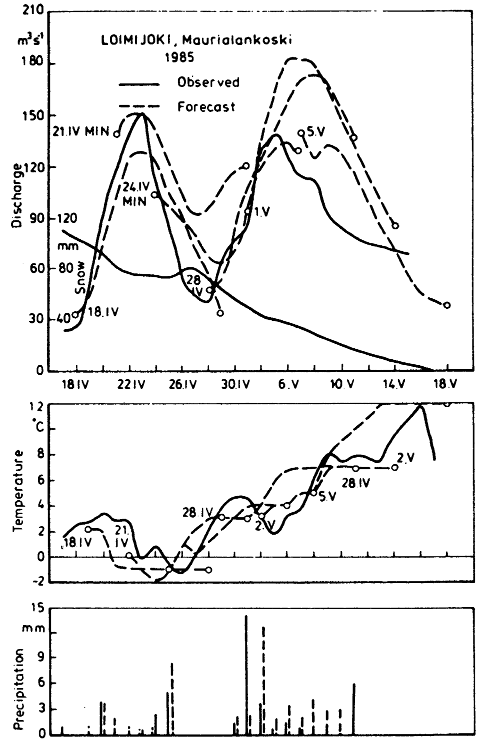

Fig. 2. Example of the effect of wrong initial value of areal snow water equivalent (about 30 mm too great initially). After large error forecast is corrected by AR-model (forecast 5.V).

latent heat term may give some improvement. With the best modified degree-day model the following extra terms have been tested: short wave radiation, sensible heat, latent heat and heat from precipitation.

Results

All these models have been tested on Tujuoja river basin (21 km^2) and some on Loimijoki basin (1,900 km^2). Both are forested, flat and lakeless areas. The criteria of model efficiency has been the sum of squares of residuals (F^2) or $R^2 = (F_0^2 - F^2) / F_0^2$, where F_0^2 is the variance of discharge data. The value one of R^2 means complete model. The results according to the R^2-value are given in Table 1.

In this comparison the best model according to the verification period has been the modified degree day model. The energy balance model did not give better

Table 1

	Tujuoja		Loimijoki	
	C	V	C	V
Basic degree day model	0.82	0.64	0.86	0.74
Modified degree day model	0.86	0.74	0.86	0.77
Energy balance model	0.84	0.65		
Combined degree day model				
with short wave term	0.85	0.73		
with sensible heat	0.84	0.74		
with latent heat	0.84	0.70		
with precipitation heat	0.84	0.72		

C = calibration (period 1976-1981)
V = verification (period 1970-1976)

results. The reason for this could be the fact that energy balance model needs five input values to run as compared to the two values in degree-day model (temperature, precipitation) and that every new input value imports its own error into the model. Besides although parameters in energy balance model are quite fixed, still the parameters vary a little and energy balance model includes three times more parameters than temperature index model. Thus it can be stated that physically based models are not better than simpler conceptual models. However, the energy balance model worked better in some difficult situations (temperature below zero, but energy balance positive) than degree-day model.

Heavy Rainfall during Melting Period

It is possible to make fairly accurate quantitative rainfall forecast only one or two days ahead. Thus a heavy rainfall during melting leads inevitably to poor discharge forecasts. We have very little possibility to reduce these errors. We can speed up the data transport of precipitation and discharge observations by using automatic observation stations and measure rainfall by weather radar in order to get correct information in real time for hydrological forecast models.

Areal Water Equivalent of Snow

Wrong initial value of areal water equivalent of snow causes error in timing, volume and peak value of the flood.

In Finland areal water equivalent of snow is normally evaluated on the basis of snow-line measurements. There are about 160 snow-lines in Finland. This is not

Table 2

Sub-bassin	area km^2	mean snow mm	R^2
Tujuoja	21	80	0.87
Venetjärvi	196	79	0.90
Isolamujärvi	188	98	0.91
Kortteinen	179	86	0.96
Lamujoki	620	79	0.94
Karesuvanto	5 670	117	0.86
Muonio	3 600	91	0.85
Raudanjoki	3 537	122	0.93

$R^2 = (F_o^2 - F^2) / F_o^2$ F^2 = sum of squares of residuals

F_{o2}^2 = variance of snow data

mean snow = mean of areal snow-water equivalent values from snow maps based on snow line measurements

enough. We may have sub-basins, from where we do not have a single snow-line. We have to make extra snow-line measurements in these small areas, if we want to get reliable information of areal snow water equivalent.

Another possibility is to use hydrological model to calculate areal snow-water equivalent. The usual procedure during calibration of forecasting model is to calibrate snow-model against snow-line measurements. The results from this have been so good, that there are good reasons to use forecasting model also for calculation of areal water equivalent of snow. The results of these model calibration with five years calibration period are given in Table 2 (snow measurements are made every second week).

The input data of the model is daily precipitation and mean temperature. The model calculates the form of precipitation and snow accumulation and melt.

Finnish Meteorological institute and National Board of Waters have a joint project going on where the aim is to improve areal precipitation calculations by precipitation corrections specific for every station and by taking into account the areal topographic effects on precipitation (Sherman and Salter 1975). The results of this project can also be used for the calculation of areal water equivalent of snow.

The third method used for measuring areal snow-water equivalent is the gamma-radiation measurement by aeroplane (Kuittinen and Perälä 1984). Natural gamma-radiation from ground is attenuated by water and snow over the ground. This method needs one calibration fligth before snow cover to define the radiation level without snow. The areal water-equivalent is calculated from the difference of radiation levels between calibration flight and flight during snow-cover.

The advantage of gamma-radiation method is speed, great areal coverage and information from the areal variation of snow-water equivalent. The disadvantages are expenses (flights and measuring equipments). For discharge forecasting purposes the most valuable gamma-radiation measurements are made during maximum snow cover. During snowmelt we cannot use results in models, because we do not know how much is snow and how much is liquid water in the measurement value.

Ice-Dams during Floods

Ice-dams have caused flooding problems and damage nearly every year in Finland during the last years. The prediction of time and quantitative effects of ice dams is a very difficult task and in Finland a project of river ice problems was started in 1985 (to which National Board of Waters is connected).

Ice dams prevent accurate observations of discharge and this prevents updating of forecasting models and the use of correction models. One way to get quite reliable information from runoff changes is to use water level and outflow observations from lakes and reservoirs to calculate runoff for updating of forecasting models.

The Use of Error Models with Hydrological Model in Forecasting

Statistical AR-models have proved to be quite effective in real-time forecasting, especially in those cases when it is impossible to locate the error source in model and correct it. AR-model corrects the forecast on the basis of error made during observation period (Lundberg 1982).

The parameters of error model are estimated from the time series of residuals during calibration period. For Loimijoki basin (1,900 km^2) an autoregressive AR (1)-model of the following form has been tested:

$z_i = \emptyset_1 z_{i-1} + a_i$

z_i = current value of error

$\emptyset_1$ = coefficient

a = current shock from a random process with zero mean and variance a^2.

With this model the following results with different lags have been obtained. In this test lag means how old in days is the error in use i.e. how many days ahead "forecast" is made in calibration period.

The error model improves results considerably for one to two days ahead, after which the effect diminishes very quickly (Fig. 2). The use of AR-model requires

Table 3

	Model efficiency, R^2
Basic hydrological model	0.864
With AR(1)-model, lag = 1	0.916
2	0.875
3	0.869
4	0.866
5	0.866

also accurate and fast transported data. Without daily observations of forecasted component (discharge, water level) AR-model is useless.

Development of Data Transport

Real-time forecasting needs real-time data from hydrological and meteorological observation stations. During 1985 National Board of Waters started a project to establish several automatic water-level measuring stations in river basins, where discharge variations are fast. These automatic stations are connected to the main computer for further processing of data and use for forecasting. In the same way meteorological data is going to come through the datanet of Finnish Meteorological Institute to the main computer of National Board of Waters for use of discharge forecasting models.

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