HYDROLOGICAL FORECASTING AND REAL TIME MONITORING IN FINLAND: THE WATERSHED SIMULATION AND FORECASTING SYSTEM (WSFS)

Bertel Vehviläinen and Markus Huttunen
Finnish Environment Institute, P.O.Box 140, FIN-00251 Helsinki, Finland,
e-mail: Bertel.Vehvilainen@Vyh.Fi, Markus.Huttunen@Vyh.Fi
June 14, 2001

Abstract: A real-time monitoring and forecasting system based on hydrological watershed models is widely used in Finland for forecasting and real-time monitoring. The main operating part of the watershed simulation and forecasting system (WSFS) consists of 22 different watersheds. The models simulate the hydrological cycle using standard meteorological data. The operation of a watershed model includes collecting meteorological and hydrological data and data assimilation run, which corrects the simulation according to the latest observation and simulation of the system with 36 different meteorological data series so that the uncertainity in the forecast can be estimated. These steps are made fully automatic and the system produces forecasts for 300 water level and discharge observation points daily or several times a day. The system covers 286 000 km^2 or 86 % of the area of Finland. The latest version of the watershed model utilizes an elevation model for approximation of areal temperature and precipitation and for snow cover simulation. The simulation in that model version is made in 1 km grid size. User interface to the system is based on www. The system can be used over internet. The user need to have a browser and an internet connection. In the user interfase one can look at the meteorological and hydrological observations and the weather forecast, save missing observation, look at the simulated variables, snow, soil moisture, ground water, runoff, etc., look at the water level and discharge forecasts and simulate different possible ways to regulate lakes. The simulated variables and forecasts are presented as graphs and maps. The graphs and maps are also printed automatically to users in several locations in Finland every time a new forecast is made. A map-based user interface with access to simulated data is included in WSFS. Connections to different water quality models are tested: INCA (nitrogen), different phosphorus, VEPS-system for diffuse load simulations.

Keywords: conceptual hydrological model, HBV model, real time forecasting, data assimilation, www-interface, hydrological forecast maps

1 GENERAL DESCRIPTION OF THE SYSTEM

The main operating part of the watershed simulation and forecasting system (WSFS) consists of 22 watershed models which simulate the hydrological cycle using standard meteorological data. The watershed models are fully automatic.

The other independent systems to which the WSFS is connected are the hydrological data register (HYTREK), operative watershed management system (KTJ), automatic real-time reporting water level and discharge observation station net (PROCOL), synoptic weather stations reporting through the Finnish Meteorological Institute (FMI), automatic delivery of weather forecasts from European Centre of Medium-Range Weather Forecasts (ECMWF) via the FMI. Connection to diffuse load simulation system (VEPS) have also been built up.

The WSFS automatically reads watershed data from the registers, runs forecasts and distributes results to the Regional Environment Centers. The different stages in watershed forecasting are:

1. Weather data transfer in real-time from the FMI and additional precipitation data from HYTREK.
2. Automatic collection of watershed data from registers: HYTREK, KTJ, and PROCOL.
3. Automatic watershed model updating according to information obtained in real-time.
4. Forecast runs by watershed models.
5. Distribution of forecasts through the data net of the Finnish environment administration to the Regional Environment Centers, into KTJ and into www-pages (http://www.vyh.fi/tila/vesi/ennuste/index.html) and map based user interface.

The inflow forecasts for a number of regulated large lakes are transferred to the KTJ to make further simulations of the lake regulations.

The developed map-based user-interface makes it possible to examine on a map hydrological variables simulated by watershed models in altogether 3500 different sub-basins or 50% of Finland. At the user-interface it is possible to choose the watershed in interest. Within this watershed, one can move between first, second and third level of watershed sub-divisions. In each level all the simulated daily data are available. The map-based user interface contains information from snow, soil moisture, discharge, runoff, temporary, subsurface and groundwater storages, lake levels and inflows into lakes. The map-based user-interface is mostly used to monitor and collect areal hydrological information. This interface provides large amount of otherwise hardly available data in real time.

2 WATERSHED MODEL

2.1 Hydrological and hydraulic model components

The basic component of a watershed model is a conceptual hydrological model which simulates runoff using precipitation, potential evaporation, and temperature as input (Fig. 1). The main parts of the hydrological model are precipitation, snow, soil moisture, subsurface, and ground water models. A watershed is divided into 10 - 500 sub-basins to distribute the watershed model and to increase the accuracy in the sub-basin simulation. Precipitation and snow are calculated on grid with elevation model. The basic hydrological model is then calibrated more or less specifically for all the sub-basins in the watershed depending on the available data. The runoff from different sub-basins is then connected with river routing and lake models. The combination of hydrological runoff models, river routing models, and lake models forms the watershed model.

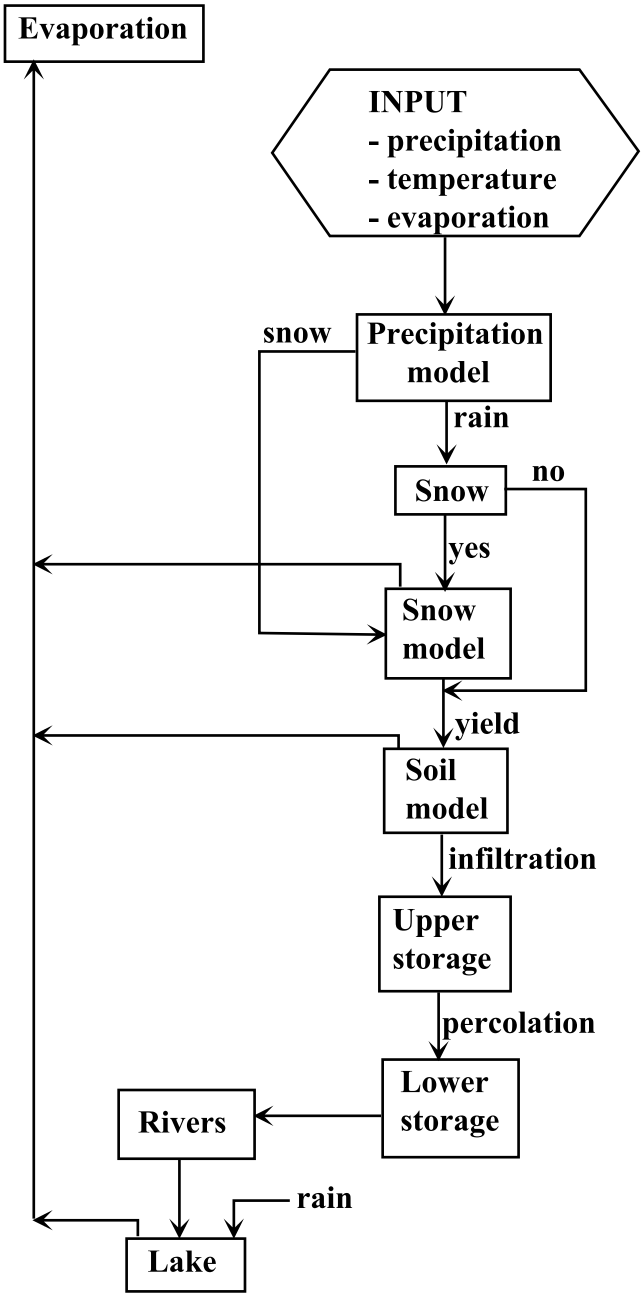


Figure 1: General structure of the basic snowmelt-runoff component of a watershed model.

2.1.1 Precipitation model

Precipitation model simulates the quantity of areal sub-basin precipitation according to Thiessen method and the form of precipitation. In newer version a grid based simulation with elevation model is used. Precipitation is corrected by a constant which is different for solid and liquid precipitation. This correction constant is also specific for sub-basins in the model and takes into account gauge error mainly due to wind, elevation, and other terrain effects resulting from location of the rain gauge in the basin. If the rain gauge is situated in the higher part of the basin it usually measures more precipitation than is obtained on the average in the sub-basin. When the rain gauge is located below or at mean altitude of a basin the measured precipitation is usually less than the average over the basin. Thus the correction coefficients may go also under 1.0 both for liquid and solid precipitation, but are typically 1.03 - 1.06 for liquid precipitation and 1.2 - 1.3 for snow (Vehviläinen 1992). Since the correction constants are specific for a sub-basin the combination of precipitation stations used should be constant, or if stations are changed the omitted station values are first approximated from existing stations.

Precipitation changes from snow to water within a temperature range approximately from -2.5 to 2.5 $^{\circ}C$ (Vehviläinen 1992) ; included in these threshold values are elevation, coastal and other effects influencing the form of precipitation. The temperature range is specific for a sub-basin with a certain combination of temperature stations. If the combination is changed the omitted station values must be calculated from the values of operative stations.

2.1.2 Snow model

Snow model simulates snow accumulation and snowmelt; the input is areal precipitation from precipitation model and areal daily temperature. Snowmelt is simulated by degree-day model with increasing degree-day value during the melt period. Open and forest snowmelts are simulated separately, which is essential for correct simulation of long melt periods with cold and warm spells and to create appropriate distribution of areal snow cover. The parameters in snowmelt model are more or less specific for a sub-basin and stations used. Other important processes in snow model simulation are liquid water retention in snowpack, refreezing of melted water, and simulation of snow-covered area and temporary surface storage during snow cover. Temporary storage causes delay in water outflow from the sub-basin due to snowdrifts and snowpack restricting water-flow through the terrain.

2.1.3 Soil moisture simulation

Soil moisture is simulated with a storage model in which input is rainfall and snowmelt, output terms are potential evaporation and actual soil evaporation, which is simulated according to the degree of saturation of soil. When the soil becomes saturated, the actual evaporation approaches potential evaporation; outflow from soil moisture storage into the subsurface storage is an exponential function of the degree of saturation of soil. Soil moisture storage is active and changing during summer, when risk for flood and long drought can be forecasted based on the state of soil moisture storage and precipitation forecast. When soil moisture storage is full abundant rainfall causes flooding, when empty, the soil surface is dry, rainfall creates little runoff and inflow into lakes and rivers remains low.

2.1.4 Subsurface and groundwater storage

Water from soil moisture storage recharges the subsurface storage: the outflow from the subsurface storage creates mainly the runoff peaks during high flow. From the subsurface storage water goes into the groundwater storage whose outflow is the baseflow. The model structure is based on the old hydrological concept of runoff formation, where runoff is divided into subsurface and groundwater flows. New knowledge based on isotope studies in which runoff formation is due more to the functioning of recharge/nonrecharge areas is not taken into account directly. The use of many sub-basins leads generally to a similar simulation of recharge/nonrecharge areas: the sub-basins near river or lake usually have small soil, subsurface and groundwater storages and respond more quickly to rainfall and melt. The upper sub-basins have larger storages and longer response times, and the outflow remains higher for longer periods; thus quantitatively, the old hydrological concept of runoff formation works well in watershed forecasting.

2.1.5 River models

Most river models are simple routing models which simulate the delay and damping of peak flow in a river stretch. These routing models, usually Muskingum models (e.g. Linsley et al. 1975), are sufficient in discharge simulation. Models which can simulate the level, area and volume of flooded area as well as routing and damping are used when more detailed information is needed from floods in rivers (Quick and Pipes 1975). Fully physical hydraulic models have been used, when water levels are needed along the river. These river models are based on Saint Venant equations (see e.g. Forsius 1984).

2.1.6 Lake models

Lake models are simple water balance models whose input terms are inflow from river, runoff from the surrounding land, and direct precipitation and output terms are lake outflow and lake evaporation. During winter the diminishing storage due to ice layer remaining on the lake bottom is taken into account in heavily regulated lakes and reservoirs. The calibration of discharge rating curve for lake outflow is possible in the watershed model when water level observations from an unregulated lake are available. It is a quick and inexpensive way to construct a rating curve for a lake. If the daily inflow is large compared with lake volume the simulation time step could be shortened to one hour or even less to maintain the simulation stable.

For regulated lakes it is possible to give the regulation rules and change them automatically or manually as needed in forecasting. The testing of different regulation procedures in a difficult flood situation is often needed to minimize the damage caused by flooding.

2.2 Watershed model implementation

A watershed model is built with the sub-models presented above. This hydrological model including precipitation, snow, soil moisture, subsurface, and ground water models is very similar to the HBV model presented by Bergström (1976). Watershed model implementation begins by dividing the watershed into sub-basins according to the classification of Finnish river basins presented by Ekholm (1993). The aim is to divide the watershed into small homogeneous sub-basins according to elevation, land use, snow distribution, and lakes and avoiding the combination of hydrologically different areas into one sub-basin model; for example the connection of two areas with different snowmelt speeds and times leads to the simulation of mean snow values with no possibility of updating and verifying the model properly against the observed snow data. The number of sub-basins within a watershed model is typically 30 - 50; for each the hydrological runoff model (HBV) is calibrated. The area of a sub-basin ranges from 50 km^2 to 500 km^2. Regulated, large unregulated, observed, and otherwise important lakes are described by lake model in the watershed model. This allows the correct simulation of water levels and outflow in a lake and improves the simulation of areal runoff. The effects on runoff due to a lake not described in the model are taken into account mainly in the subsurface, ground water and flood routing models. This leads, however to biased parameter values in them. Still, the accuracy of discharge simulation remains good, because lakes damp the variation of runoff from the basin and damped catchments are easy to model. Finally the basic hydrological runoff and lake models are connected together with river models to form the watershed model.

2.3 Model calibration

The optimization criteria in the calibration are the sum of the square of the difference between the observed and simulated water equivalents of snow, discharge, and water level. All available observations are used in the calibration and thus up to 100 different calibration criteria can be available in watershed model calibration.

The procedure used is the optimization algorithm presented by Rosenbrock (1960), which has been developed in to a fully automatic procedure using quite much computer time but little interactive manual work time. There are 5 - 10 important basin-specific parameters in each sub-model which must be calibrated for each sub-basin and 5 - 10 ’constant’ parameters which are slightly tuned for each sub-basin, thus the total number of calibrated and tuned parameters within a 30 - 50 -sub-basin watershed is large. To manage the calibration properly it is started by the same parameter set for all sub-basins. This stage is divided into two steps: first the parameters of precipitation and snow models are calibrated against observed areal snow values after which other parameters are calibrated against the total water balance (discharge or water level and outflow) of the watershed. The 30 - 50 sub-basins are then divided into 2 - 4 homogeneous groups for which the same procedure is repeated: the snow and precipitation models are calibrated against the observed snow measurements and the runoff parameters against the total water balance to obtain 2 - 4 different sets of parameters for each group of sub-basins. Finally all the parameters of each sub-basin are calibrated against the nearest water balance observation. In this final stage the snow simulation is not allowed to fall below a certain limit of optimization criteria for snow. The final result of this calibration procedure is a realistically distributed watershed model in which the calibration has been done against snow and water balance (discharge,water level) observations.

The key points in the automatic calibration are the restriction of previously reached calibration results for snow at a certain level with the optimization criteria, upper and lower limits for allowed parameter values, and beginning of the calibration with the same parameter set for sub-basin groups. Further details are provided in Vehviläinen (1992).

2.4 Areal coverage of watershed models

The watershed forecasting and simulation system (WSFS) in the Finnish environment institute (FEI) now consist of 22 watershed models ranging from 600 km^2 to 60 000 km^2 and covering 86% of Finland. Each watershed model consists of 1 - 500 independent sub-basins with simulations of areal precipitation, temperature, water equivalent of snow, soil moisture, changes in subsurface and groundwater storage and formation of runoff (Figure 1). The number of forecasted discharge and observation points is 300 and simulated sub-basins is 1000.

3 OPERATIONAL USE

The operational use of a watershed model consist of weather and watershed data collection, basic simulation run, updating of model according to observations, runs with different regulation rules for regulated lakes, the forecasting run with weather forecast and different weather statistics and the delivery of forecast to the regional environment centers. Owing to the large number of forecasts done, the entire operating system has been developed into a fully automatic system. In new model version access to system is via www-interface.

3.1 Registers and data collection

3.1.1 Weather data

The precipitation and temperature data come daily from the Finnish Meteorological Institute. In the forecasting system every watershed model has its own host program which collects the daily weather data for a watershed for further processing, in the case of missing data the values are approximated from those of the nearest operative station.

The collection of Class-A pan evaporation data, which are used as potential evaporation estimates, is done weekly for each watershed model. These data are usually available with a 1-month delay from HYTREK (the hydrological register of the finnish environment administration), before that the monthly mean values were used as first approximation.

Additional precipitation data are also available from HYTREK with 1-month delay and are helpful in winter for snow cover simulation. Denser precipitation data will improve the accuracy of snow cover simulation. In summer, when watershed reacts on rainfall within days, the updating of watershed model according to discharge and water level observations reduces the importance of additional delayed precipitation data.

3.1.2 Water level and discharge data

The real-time discharge and water level data are collected mainly from the automatic water level and discharge measurement system - PROCOL, additional data are also available from the KTJ and 1-month delayed data are collected from HYTREK. Every watershed model has its own host program which collects the data from PROCOL and the KTJ. The data from HYTREK are collected weekly and collection of the snow data which is also two to four weeks delayed is done weekly. Collected data are gathered into files specific for each watershed model. Manual storage of data is also possible.

3.2 Updating of watershed models

One important part of the WSFS is the automatic model updating system developed in the FEI. This updating system guarantees that the watershed models are in the best possible state before forecast evaluated according to observations and makes the updating possible: a task impossible to do manually due to the large amount of simulated observation points (250) and sub-basins (500). Model updating is done against the water level and discharge data gathered from different registers. When new watershed data become available the updating procedure corrects the model simulation by changing the areal values of temperature, precipitation and potential evaporation so that the observed and simulated discharges, water levels and water equivalent of snow are equal.

Daily corrections for precipitation, temperature and potential evaporation over long periods for sub-basins lead to large number of parameters to be optimized. To reduce the dimensionality in the updating, one ’correction-term’ for each day with values of -1 ... +1 was introduced; the precipitation, temperature and potential evaporation corrections are calculated from this term. With a positive correction term precipitation and temperature are increased and potential evaporation is decreased within prescribed limits and vice versa. Furthermore, the correction is the same for 30- day groups. If the result of optimization is not satisfactory, groups of 15, 8 ,4 days and even 1 day may be used to improve the accuracy. The same correction terms are also used for all sub-basins above an observed water-level or a discharge point. Typically the updating is done for the last 100 days with 4-day groups. This correction procedure is also denoted data assimilation, as for example in Chui and Chen (1991).

The optimized error function consists of 12 different error terms. The error terms are:

- difference in simulated and observed discharge
- difference in simulated and observed volume
- difference in simulated and observed snow water equivalent
- Total amount of correction in precipitation, temperature and evaporation. Smaller corrections are preferrable.
- Areal variability of the correction terms. On the basins that are close to each other the correction terms should not be much different.

- Effect of the correction terms on water balance of the basin on the first day of the forecast. The correction procedure should not make unnecessary changes to the water balance.

An example of the time series of the error terms is in Fig. 2.

The direct search Hooke-Jeeves optimization algorithm (Hooke and Jeeves 1960, Kuha 1993) is used in the updating. It was found to be more reliable and numerically stable than gradient-based Quasi-Newton and Levenberg-Marquardt algorithms; this is perhaps due to the fact that the function (watershed model) to be optimized is not differentiable and is high-dimensional. Another good feature of the Hooke-Jeeves algorithm is that it is not a 'line-minimizer' type of algorithm, i.e. the optimization routine does not try to correct the entire error in the simulation with corrections for the first few days.

Wintertime precipitation correction is not permitted before total snowmelt because the effects of snow and snow correction are not realized before all snow is melted. Winter is very troublesome in updating because ice in river causes unreliable discharge observations based on water levels and discharge curve. The only reliable discharge data are direct measurements made once or twice during winter. The accuracy of snow simulation is supported by use of all available precipitation measurements even with 1 - 2-month delays. During snow-free periods the precipitation affects with 1-2-day delay on the water balance, i.e. water levels and discharges. Thus updating can be done almost up to the last observed values of water level and discharge.

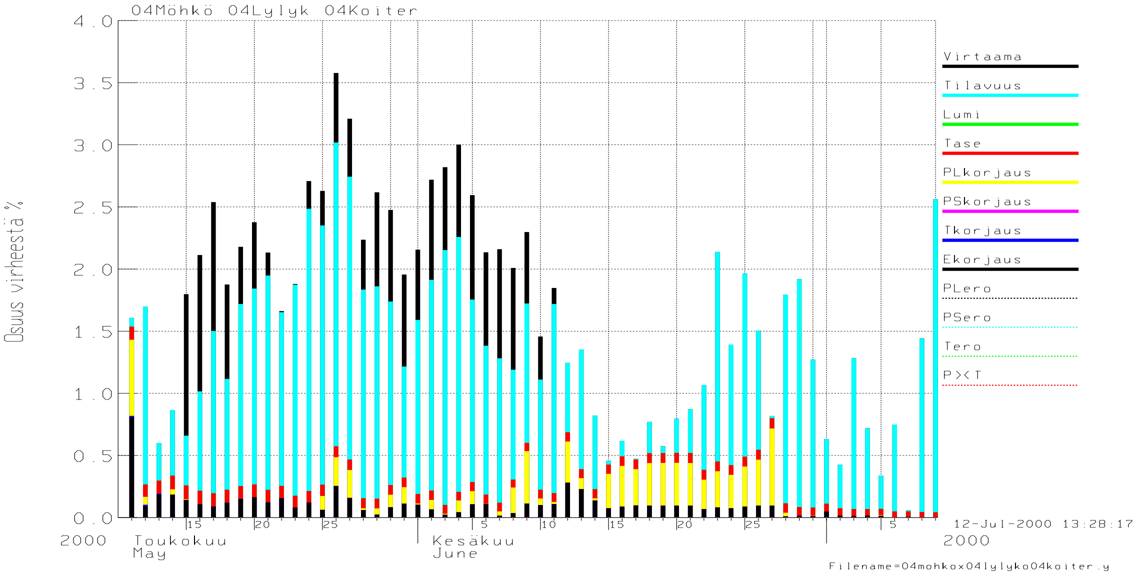


Figure 2: In the updating procedure total of 12 different error terms are minimized. These error terms include errors in simulated discharge and volume, amount of modifications in the input precipitation and temperature and the areal variability of the correction terms. This figure presents the time series of the different error terms. Y-axis shows the percentage of the total error.

3.3 Forecasting

3.3.1 Short-term forecasts

Weather forecasts come originally from the ECMWF in Reading UK via the FMI and consist of 10-day daily mean temperatures and precipitation quantities. Weather forecasts are updated daily. Precipitation forecasts are based on direct climate model results. Temperature forecasts are corrected in the FMI by 4-parameter Kalman filter which corrects the forecasts according to the errors made in previous days. The main problems with weather forecasts occur with near-zero temperatures, when snowmelt and precipitation models are very sensitive to temperature. Precipitation quantities are difficult to forecast accurately for longer than 1 - 2 days in advance. Weather forecasts are presented as point forecasts to all 30 synoptic weather stations used in the watershed models and are prepared for each watershed model by choosing only relevant stations for the watershed. The mean monthly values of Class-A pan evaporation values are used as first estimates of potential evaporation.

Short-term forecasts are the relevant forecasts for watersheds with short response times and low lake percentages, where the time between snowmelt or rainfall event and flood is only a few days. These watersheds with short response time need also real-time data from discharges and water levels and continuous updating to maintain the quality of simulations and forecasts. Forecasts must be made daily in flood periods.

3.3.2 Long-term forecasts

In long-term forecasting the system is simulated using 36 different meteorological time series on the forecast period. These time series are observed precipitation and temperature time series on the years 1961-96. This method makes possible to approximate the reliability of the forecast. From the simulation results variation of different variables (discharge, water level, etc) can be estimated and presented in the forecast graphs (Figs 10-13).

Long-term forecasts are the main forecasts for large watersheds with large lake percentages. For the largest watersheds only long-term forecasts are needed; practically no changes occur within the 10-day forecast.

3.3.3 The frequency and timing of forecasts

Usually forecasts are made once or twice a week, even for the largest watersheds with long response times. This is done partly to test the entire system from the data collection to the delivery of results for possible problems to correct them in time before the forecasts are mostly needed. For watersheds with short response times twice a week is too seldom a forecasting frequency during floods; thus forecasting runs are started whenever rainfall, discharge or water level exceeds a given limit. In early warning system where some of the models are implemented, forecast frequency is short, 1-3 hours.

3.3.4 The use of forecasts

Watershed forecasts are used for the supervision of water levels, discharges, snow, soil moisture and runoff formation. In flood situations watershed models are used to plan the regulation of lakes and reservoirs so that the flood damages are as small as possible. The forecast of possible overtopping of river embankments helps the regional environment centers to take necessary precautions in advance. The ability of watershed models to simulate water equivalents of snow is valuable when estimating flood potentials during snowmelt periods in real-time. The damages that can be and were prevented with correct regulation may be many millions of Finnish marks e.g. in spring 1993 at the River Kemijoki in northern Finland the damages could have been FIM 5 million more for the city of Rovaniemi without decisions based also on forecasts with the Kemijoki watershed model.

In more slowly responding watersheds with abundant lakes the forecasts are used for long-term planning of regulation. It takes 1 - 2 months from a flood peak to route through Vuoksi watershed via long lake courses. The precipitation between forecast day and future flood peak strongly affects the final results. Statistical precipitation, temperature and potential evaporation series must be used to provide the needed information.

One of the aims of the Tornionjoki watershed model is to forecast the ice break-up time; this forecast is based on temperature sums. The ice break-up model has been developed by Forsius and Granholm (1988); with this model it is possible to forecast ice break-up time 1-2 weeks in advance usually with a 1-3-day error.

3.3.5 Delivery of results

The computer network in the FEI and internet gives excellent possibilities for automatic delivery of watershed forecasts to all its offices and to the regional environment centers. The regional environment centers could then inform and supervise all local authorities and organisations needing the information in their work. In the case of flood danger the regional environment centers and FEI inform the press, radio and television.

3.3.6 The quantity of forecasts

The number of forecasted discharge and water level points is 300 every day. The watershed models also simulate areal precipitation, actual soil and lake evaporation, snow cover, soil moisture and more or less groundwater changes in real-time for the 500 sub-basins included in the 20 watershed models. The amount of available information is so large that most of it is not normally used. A map-based user-interface system with windows for easy handling of the information on a sub-basin level is developed to ease the use of simulated watershed data for example in diffuse load calculations in other systems (VEPS).

3.3.7 Connections to other systems

The main use of inflow forecasts to large regulated lakes is in planning the regulation of these lakes in the water resources management system KTJ, where the effects of different regulation schemes can be evaluated. This system is used operatively by the FEI and the regional environment centers. The net inflow forecast for the KTJ is at present delivered to Lakes Saimaa, Kallavesi and Pielinen in the Vuoksi watershed; Lakes Saimaa and Pielinen are regulated only in exceptional situations. Lakes Vuohijärvi and Puulavesi in the Mäntyharju watercourse, Lake Keitele in the upper Kymijoki watershed, Lake Inari in the Paatsjoki watershed and Lake Lappajärvi in the Ähtävänjoki watershed also obtain net inflow forecast for further use in KTJ.

Net inflow forecasts have been earlier made for many of these lakes with regression models at biweekly intervals. The advantage of operating with conceptual watershed models is the possibility for daily updating and forecasting with new real-time information; further more these models themselves simulate the water equivalent of snow in real-time and thus there is no need to wait two weeks for field observations of snow measurements. In a flood situation two weeks wait can be too long time to wait with the old regulation decisions in use.

The automatization of ice correction evaluations for discharges is a development project in which watershed models are tested to help in database quality control; the corrected data are stored in HYTREK. This work has been preliminary presented by Leppäjärvi (1992).

In the case of observation break-ups in water levels and discharges the simulated data from watershed models can be used to fill the gaps. Further more, the comparison between model simulations and observation data quickly reveals most of the observation and recording errors; thus watershed model simulations can be used as primary quality controls for observations in registers.

4 USE IN GENERAL WATERSHED PLANNING AND IN RESEARCH

Watershed models could also be very effective tools in general water resources planning; however they are seldom used for it at present. Planning concerning short-time regulation in flood protection is an activity which is always in use in normal forecasting. But the problems arising with low-flow periods, e.g. water supply during droughts have also been solved by watershed models in a few cases.

The watershed models in the River Perhonjoki and Valkeala watercourse have been used to evaluate the possibilities of maintaining a certain minimum discharge in the lower part of the main river during droughts by using the water stored in reservoirs. At Lake Kallavesi the watershed model was used in autumn 1993 to evaluate the risk of exceeding the regulation limits during dam preparation work when the outflow capacity was limited. A close connection with normal forecasting was also obtained with a regulation optimization model in which the effects of regulation were evaluated based on damages or benefits to fisheries, agriculture, summer cottages, piers and other built-up areas along lake strands and water power production. This optimization model uses the inflow forecast for Lake Pielinen for choosing the best possible regulation rule during floods (Mutanen 1991), similar regulation planning is also done in the KTJ.

Contrary to what was previously believed, pollution due to agriculture and forestry has proved to be much more important than point-source pollution (Rekolainen 1993). The evaluation of rural pollution from agriculture and forestry needs runoff and discharge data from relatively small areas. Watershed models which simulate discharges for small sub-basins (50

- 500 km^2) will prove to be very valuable information sources in this context. It may even be possible to simulate agricultural phosphorus loads with phosphorus models connected directly to watershed models (Kallio 1992). INCA-model application in FInland uses WSFS simulated distributed runoff data for nitrogen load calculations.

Large watershed models have been used lately in Finland and Norway to evaluate the effects of climate change on water resources, especially on snow cover, discharge and water level changes. Results of these studies have been presented by Vehviläinen et al. (1991) in Finland and Saelthun et al. (1990) in Norway. The work continues within the Finnish Research Programme on Climate Change (SILMU) in which the Vuoksi watershed is a research area. Preliminary results reveal that the effects on water level changes are different in the upper and lower parts of the watershed due to long routing times through lake courses; work is also continuing to connect watershed models with water quality models and data.

5 USE OF GIS DATA

In Finland we have available an elevation model, land use data and soil type data. These are grid based data covering whole land area in Finland. Grid size of the elevation model and land use data is 25 m and in soil type data it is 85 m. Accuracy of the altitude data in the elevation model is a few meters, which is enough for example in estimation of areal precipitation and temperature, but it is not accurate enough for drawing maps of flooded areas. In the land use data the land use is classified into about 50 different classes. In the soil type data the number of different classes is 10.

In the latest version of the watershed model simulation is carried out in 1 km grid size. Therefore we calculate from the GIS data for each 1 km cell the mean altitude and distributions of different land use and soil type classes. The simulation is carried out by first estimating daily precipitation and temperature for each grid cell and then the runoff model (Fig. 1) is simulated in each cell separately. The result of the simulation is the runoff of each grid cell, which are then collected as runoff of each sub-basin. The runoff of the sub-basins are routed forward using river models, as described in chapter 2.1.5.

The elevation model is used in estimation of areal precipitation and temperature. First the daily precipitation and temperature of each grid cell is interpolated from the observations of nearest observation stations and after this the estimated values are corrected by altitude difference between the stations and the grid cell. In finnish conditions the correction for precipitation is +10 % / 100 m and for temperature -1^oC / 100 m increase in altitude.

We are also developing an interpolation method for precipitation that could take account of wind speed and direction together with slopeness of the landscape and distance from coast line. In finnish conditions these have effect especially on winter time precipitation.

The land use data is used in the watershed model by dividing each grid cell into forest and open area. Snowmelt in forest and open areas are simulated separately (chapter 2.1.2). The soil type data is not currently used in the watershed model but we are currently developing a calibration procedure that could find similar parameter values for the runoff model on the basins with same soil type.

6 MAP-BASED USER INTERFACE

A map-based user-interface developed for WSFS makes it possible to examine on a map the hydrological variables simulated by watershed models in different sub-basins 3500 altogether covering 50% of Finland. At the start-window of map-based user interface the watershed of interest is chosen. From the chosen watershed with the first level sub-basin division one can go to second (Fig 3) and even to third level sub-division. In each level all the data, are available: snow water equivalent, soil moisture, discharges, storages, lake level, inflow and groundwater storage.

From an ’output’-icon it is possible to store any simulated daily data into a file for further use. This possibility is intended especially for users who need discharge and runoff data for areas and rivers with no observations. The map-based user interface is a source of simulated discharge values for 3500 sub-basins over 160 000 km^2 of Finland for use with water quality observations, planning, etc., when it is impossible or too expensive to make direct observations. The time range for the simulated data is 2 months backwards from the day of model run. Longer series are also available by request. The simulated data are used also for real time watershed monitoring and water resources management. The quality of simulated data is maintained by continuous updating of the watershed models against the observed water level and discharge values.

The map-based user interface is mostly used for monitoring simulated areal hydrological information from watersheds. For hydrological monitoring the interface provide large amount of otherwise hardly available data in real time, for example soil and lake evaporation, daily snow melt, soil moisture. For water quality monitoring watershed models and this user interface provides a huge amount of simulated discharge and runoff data, which is otherwise impossible to obtain.

7 WWW BASED USER INTERFACE

User interface to the system is based on www. The system can be used over internet, the user only need to have a browser and an internet connection. In the user interfase one can look at the meteorological and hydrological observations and the weather forecast, save missing observation, look at the simulated variables, snow, soil moisture, ground water, runoff, etc., look at the water level and discharge forecasts and simulate different possible ways to regulate lakes. The simulated variables and forecasts are presented as graphs and maps.

The main view of the interface is in figure 4. On the top of the view there is a bar, which shows the state of the system, for example it shows if the system is currently running the simulation. On the left side there is the list of functions and on the right there are forecast graphs for the most important points. On the second view (Fig. 5) there is the form for viewing and editing the 10 day precipitation forecast. On the third view (Fig. 6) there is the form for viewing and editing the water level observations.

For each observation point there is a serie of forecast graphs. These graphs show all the main variables of the watershed model, which are: precipitation, temperature, evaporation, snow water equivalent, depression storage, soil moisture, upper ground water storage, ground water storage, runoff, discharge, water level, cumulative precipitation and cumulative discharge.

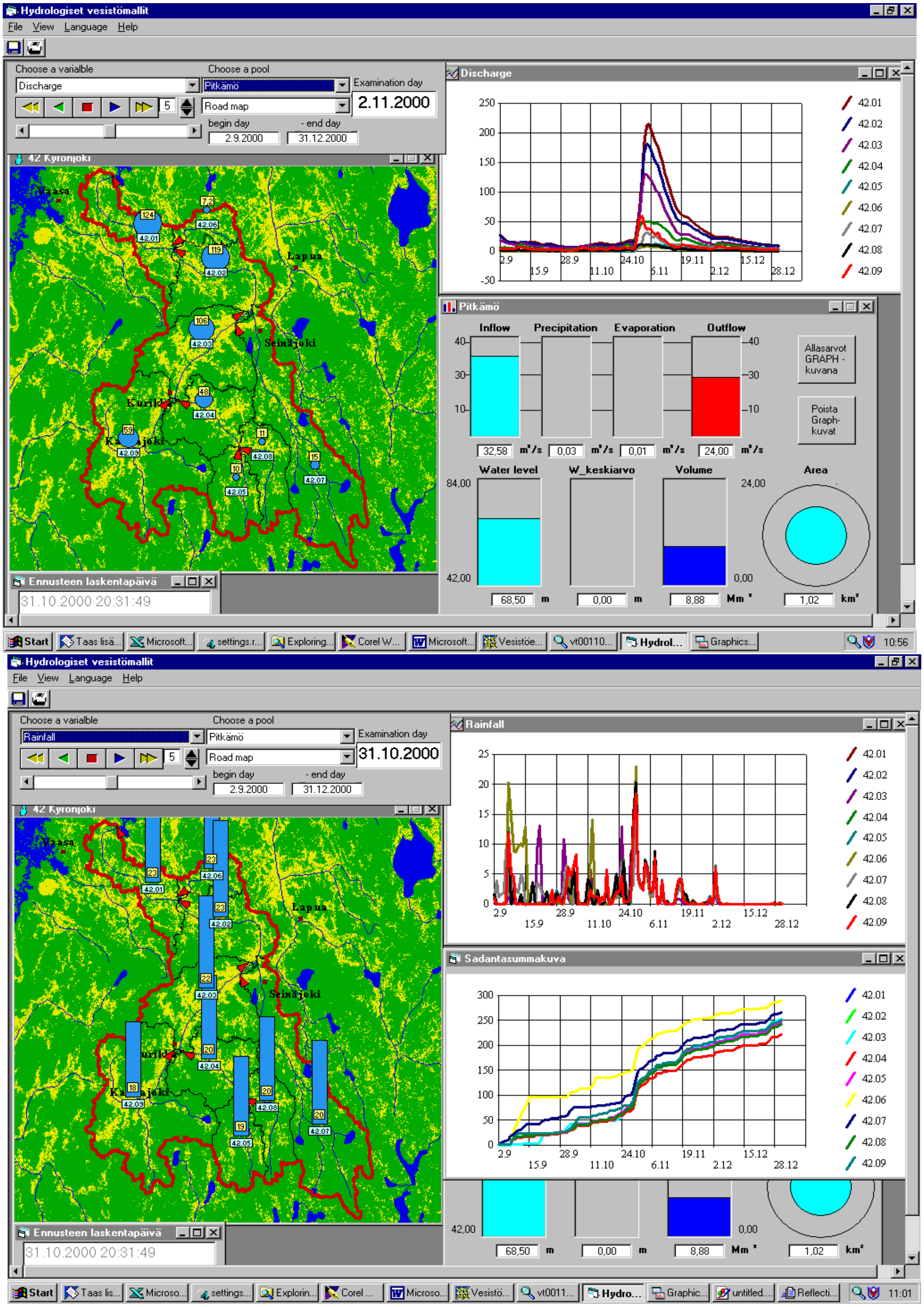
An example of the forecast graphs for one point is in figures 10-13.

7.1 WWW-pages for public

The www-interface is aimed for a restricted set of professional users. Most forecasts are however available for public via a public www-server. The main page of the public www-pages is in (Figure 7). On public www-pages there are discharge and water level forecasts for each forecast points, these can be accessed via the map on the main page. There are available also map based presentations of overall hydrological state in Finland, maps of the main hydrological parameters (precipitation, evaporation, runoff, etc.) are presented as in (Figure 8).

7.2 Map based presentations of forecasts

The simulated variables are also presented as map based presentations in the user interface. These presentations give better view of the areal distribution of the variables. An example of the maps are in (Fig. 9), whish presents the runoff forecast for Kemijoki river basin.


Hydrologiset vesistömallit

Choose a variable: Discharge

Choose a pool: Pitkämö

Road map

Examination day: 2.11.2000

begin day: 2.9.2000 - end day: 31.12.2000

Ennusteen laskentapäivä: 31.10.2000 20:31:49

Pitkämö

Inflow: 32,58 m³/s

Precipitation: 0,03 m³/s

Evaporation: 0,01 m³/s

Outflow: 24,00 m³/s

Water level: 68,50 m

W_keskiarvo: 0,00 m

Volume: 8,88 Mm³

Area: 1,02 km²

Hydrologiset vesistömallit

Choose a variable: Rainfall

Choose a pool: Pitkämö

Road map

Examination day: 31.10.2000

begin day: 2.9.2000 - end day: 31.12.2000

Ennusteen laskentapäivä: 31.10.2000 20:31:49

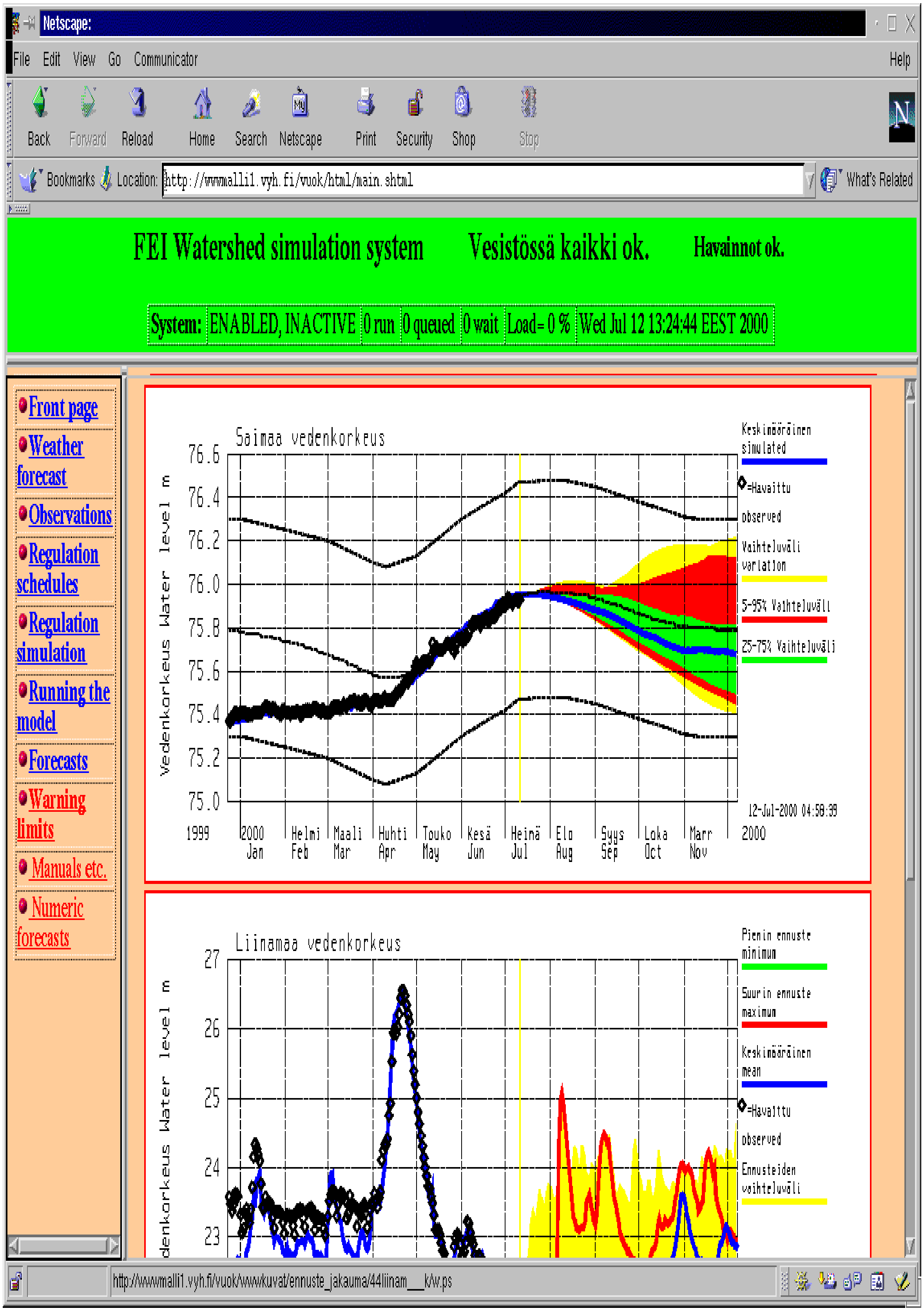
Water level: 68,50 m

W_keskiarvo: 0,00 m

Volume: 8,88 Mm³

Area: 1,02 km²

Figure 3: Discharge and rainfall data windows of map-based user interface from the basin of Kyrönjoki.



http://wwwmalli1.vyh.fi/vuok/html/main.shtml

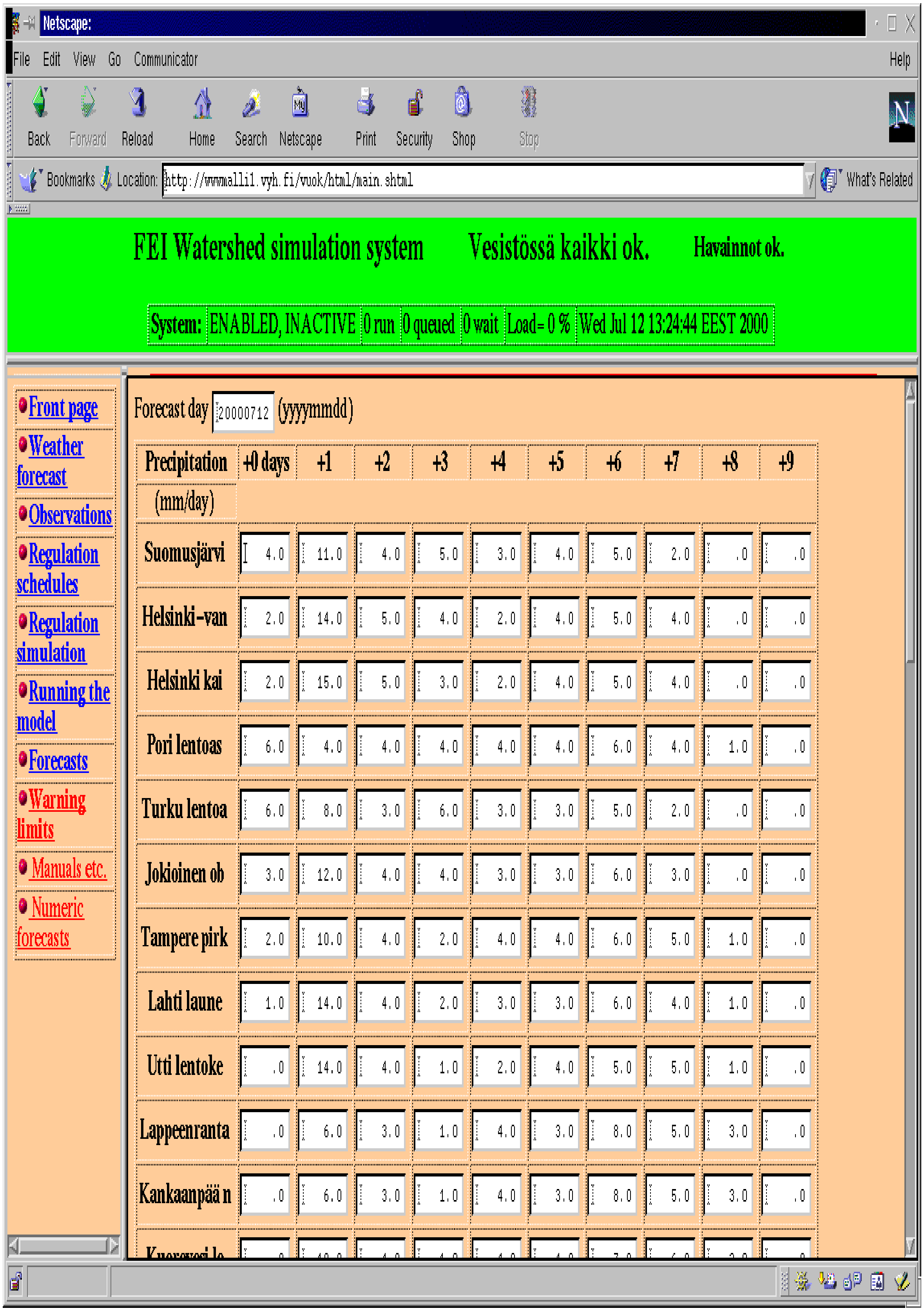
FEI Watershed simulation system Vesistössä kaikki ok. **Havainnot ok.**

System:	ENABLED, INACTIVE	0 run	0 queued	0 wait	Load= 0 %	Wed Jul 12 13:24:44 EEST 2000

- Front page
- Weather forecast
- Observations
- Regulation schedules
- Regulation simulation
- Running the model
- Forecasts
- Warning limits
- Manuals etc.
- Numeric forecasts

http://wwwmalli1.vyh.fi/vuok/wwwkuvat/ennuste_jakauma/44liinam__k/w.ps

Figure 4: Front page of the www interface.



Location: http://wwwmalli1.vyh.fi/vuok/html/main.shtml

FEI Watershed simulation system Vesistössä kaikki ok. Havainnot ok.

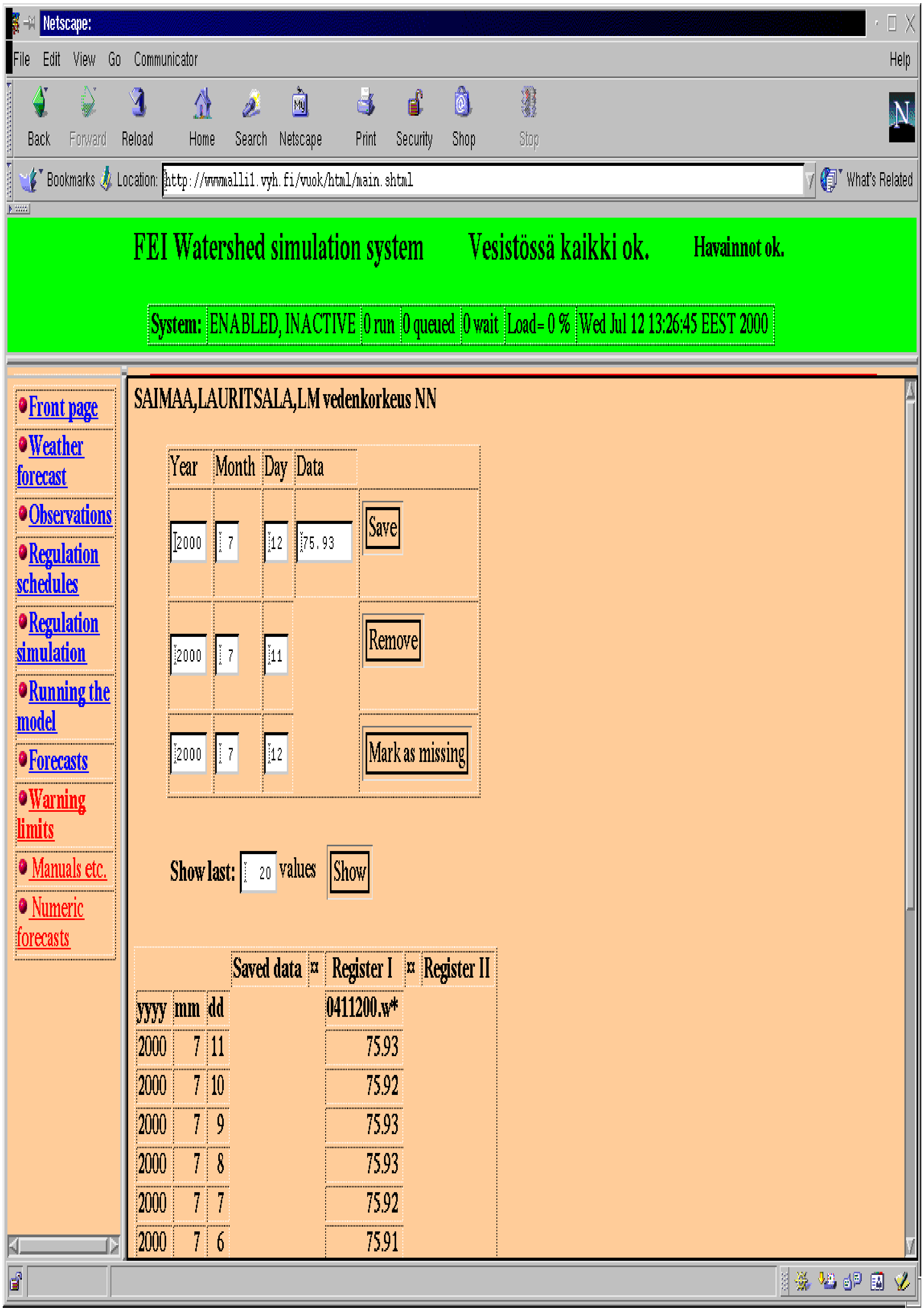
System:	ENABLED, INACTIVE	0 run	0 queued	0 wait	Load= 0 %	Wed Jul 12 13:24:44 EEST 2000

- Front page
- Weather forecast
- Observations
- Regulation schedules
- Regulation simulation
- Running the model
- Forecasts
- Warning limits
- Manuals etc.
- Numeric forecasts

Forecast day 20000712 (yyyymmdd)

Precipitation (mm/day)	+0 days	+1	+2	+3	+4	+5	+6	+7	+8	+9
Suomusjärvi	4.0	11.0	4.0	5.0	3.0	4.0	5.0	2.0	.0	.0
Helsinki-van	2.0	14.0	5.0	4.0	2.0	4.0	5.0	4.0	.0	.0
Helsinki kai	2.0	15.0	5.0	3.0	2.0	4.0	5.0	4.0	.0	.0
Pori lentoas	6.0	4.0	4.0	4.0	4.0	4.0	6.0	4.0	1.0	.0
Turku lentoa	6.0	8.0	3.0	6.0	3.0	3.0	5.0	2.0	.0	.0
Jokioinen ob	3.0	12.0	4.0	4.0	3.0	3.0	6.0	3.0	.0	.0
Tampere pirk	2.0	10.0	4.0	2.0	4.0	4.0	6.0	5.0	1.0	.0
Lahti laune	1.0	14.0	4.0	2.0	3.0	3.0	6.0	4.0	1.0	.0
Utti lentoke	.0	14.0	4.0	1.0	2.0	4.0	5.0	5.0	1.0	.0
Lappeenranta	.0	6.0	3.0	1.0	4.0	3.0	8.0	5.0	3.0	.0
Kankaanpää n	.0	6.0	3.0	1.0	4.0	3.0	8.0	5.0	3.0	.0

Figure 5: Precipitation and temperature forecast can be viewed and modified in the interface.



Location: http://wwwmalli1.vyh.fi/vuok/html/main.shtml

FEI Watershed simulation system Vesistössä kaikki ok. Havainnot ok.

System:	ENABLED, INACTIVE	0 run	0 queued	0 wait	Load= 0 %	Wed Jul 12 13:26:45 EEST 2000

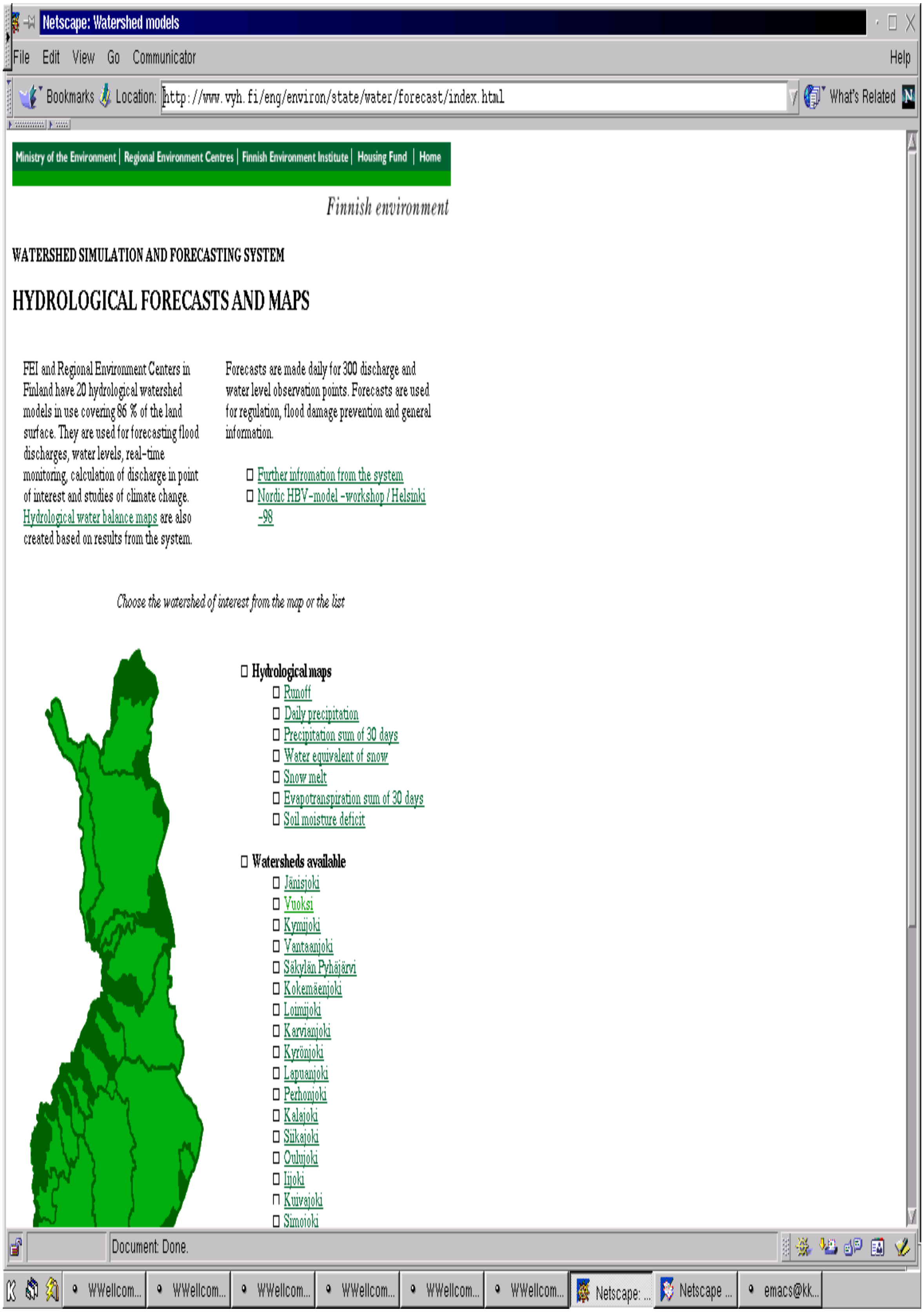
SAIMAA,LAURITSALA,LM vedenkorkeus NN

Year	Month	Day	Data	
2000	7	12	75.93	Save
2000	7	11		Remove
2000	7	12		Mark as missing

Show last: 20 values Show

			Saved data ¤	Register I ¤	Register II
yyyy	mm	dd		0411200.w*	
2000	7	11		75.93	
2000	7	10		75.92	
2000	7	9		75.93	
2000	7	8		75.93	
2000	7	7		75.92	
2000	7	6		75.91	

Figure 6: Observation data from the automatic stations can be viewed and errors can be corrected in the interface.



Location: http://www.vyh.fi/eng/environ/state/water/forecast/index.html

WATERSHED SIMULATION AND FORECASTING SYSTEM

HYDROLOGICAL FORECASTS AND MAPS

FEI and Regional Environment Centers in Finland have 20 hydrological watershed models in use covering 86 % of the land surface. They are used for forecasting flood discharges, water levels, real-time monitoring, calculation of discharge in point of interest and studies of climate change. Hydrological water balance maps are also created based on results from the system.

Forecasts are made daily for 300 discharge and water level observation points. Forecasts are used for regulation, flood damage prevention and general information.

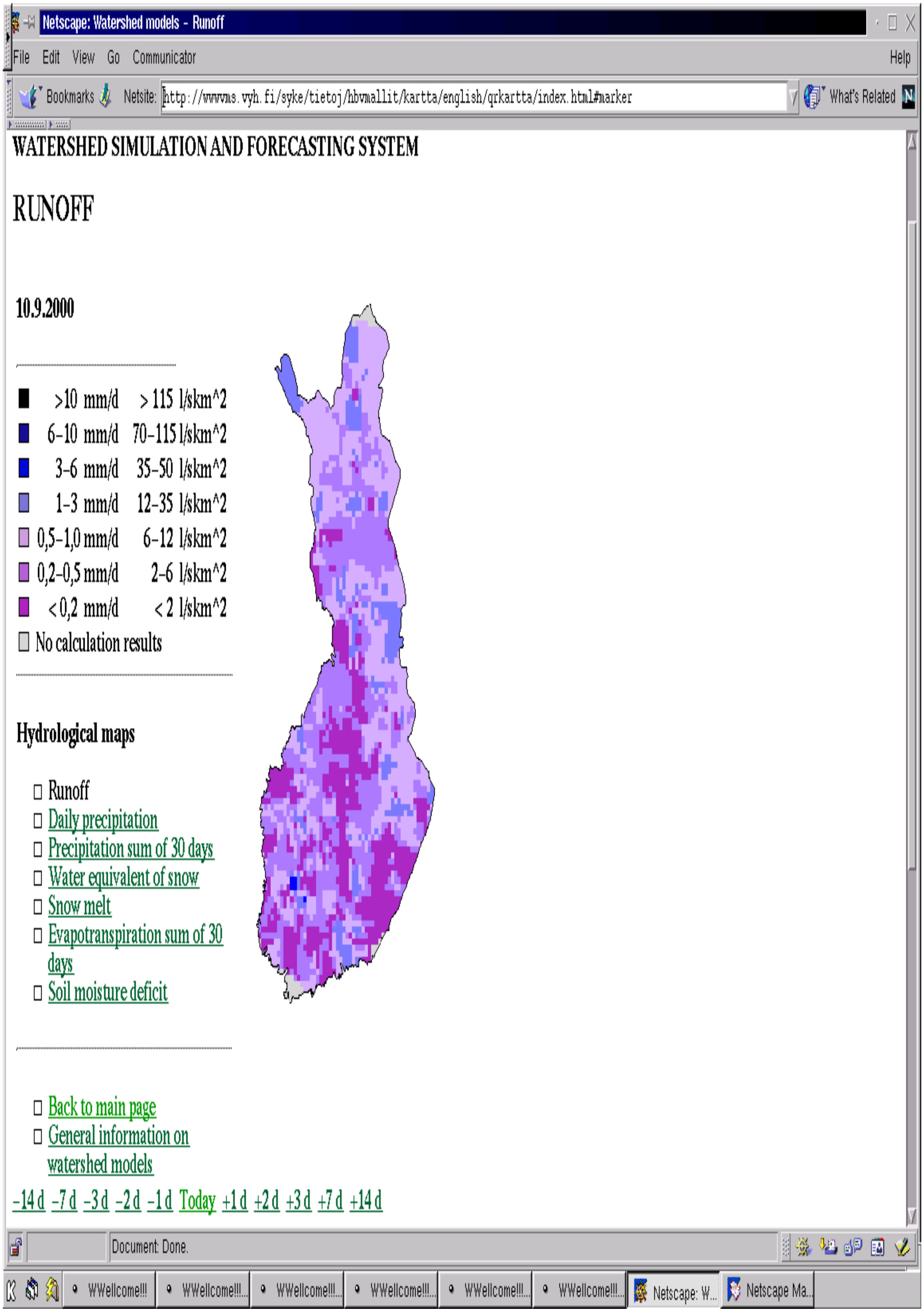
- Further infromation from the system
- Nordic HBV-model -workshop / Helsinki -98

Choose the watershed of interest from the map or the list

- **Hydrological maps**
  - Runoff
  - Daily precipitation
  - Precipitation sum of 30 days
  - Water equivalent of snow
  - Snow melt
  - Evapotranspiration sum of 30 days
  - Soil moisture deficit
- **Watersheds available**
  - Jänisjoki
  - Vuoksi
  - Kymijoki
  - Vantaanjoki
  - Säkylän Pyhäjärvi
  - Kokemäenjoki
  - Loimijoki
  - Karvianjoki
  - Kyrönjoki
  - Lapuanjoki
  - Perhonjoki
  - Kalajoki
  - Siikajoki
  - Oulujoki
  - Iijoki
  - Kuivajoki
  - Simojoki

Document: Done.

Figure 7: The main page of the public forecast pages.



WATERSHED SIMULATION AND FORECASTING SYSTEM

RUNOFF

10.9.2000

■	>10 mm/d	> 115 l/skm^2
🟦	6-10 mm/d	70-115 l/skm^2
🟦	3-6 mm/d	35-50 l/skm^2
🟦	1-3 mm/d	12-35 l/skm^2
🟪	0,5-1,0 mm/d	6-12 l/skm^2
🟪	0,2-0,5 mm/d	2-6 l/skm^2
🟪	< 0,2 mm/d	< 2 l/skm^2
☐	No calculation results	

Hydrological maps

- Runoff
- Daily precipitation
- Precipitation sum of 30 days
- Water equivalent of snow
- Snow melt
- Evapotranspiration sum of 30 days
- Soil moisture deficit

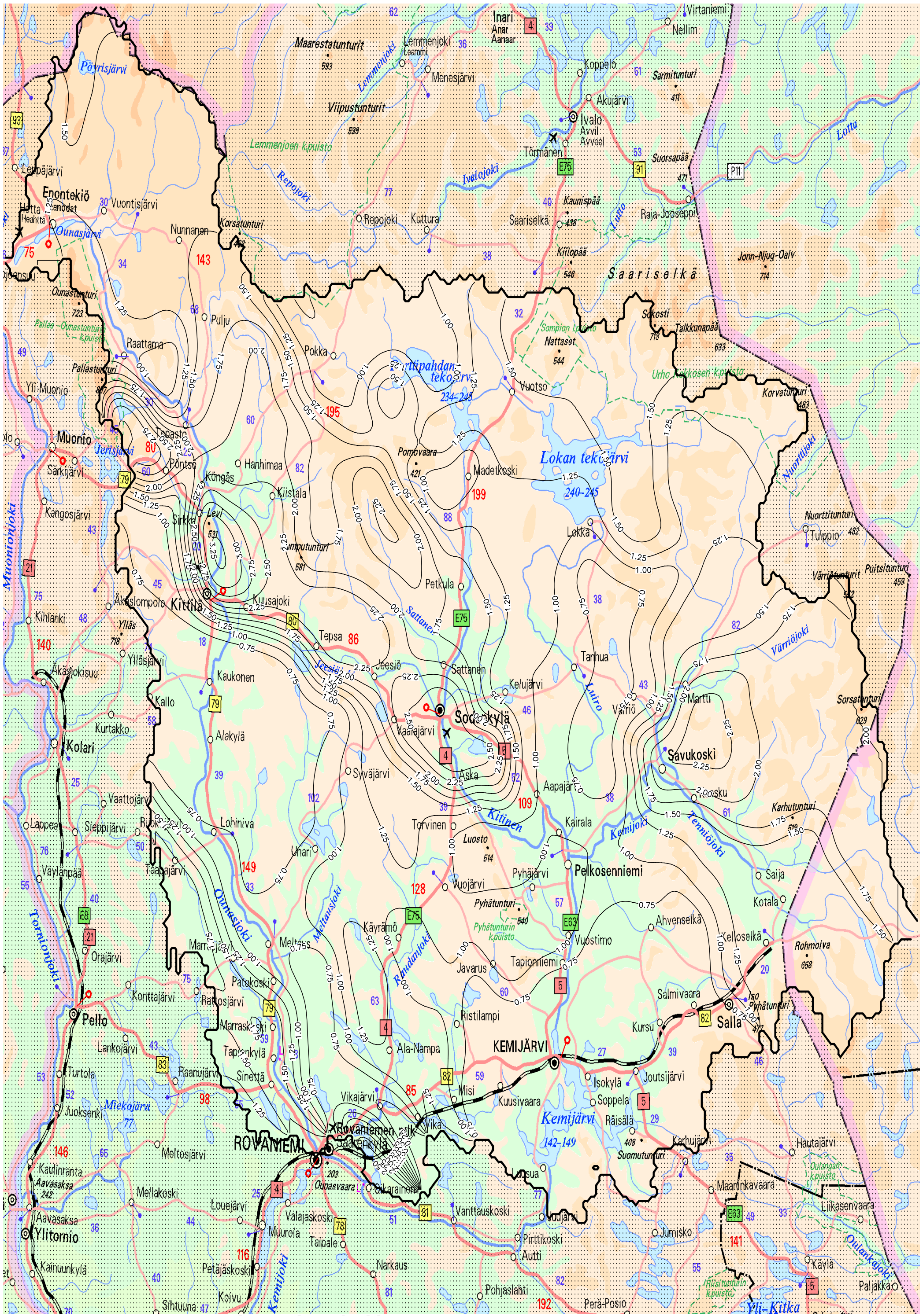
- Back to main page
- General information on watershed models

-14 d -7 d -3 d -2 d -1 d Today +1 d +2 d +3 d +7 d +14 d

Document: Done.

Figure 8: The daily overall hydrological state in Finland is presented as maps.

Vesistömallit - FEI Watershed models



Valuma (mm/vrk) 10. 7.2000

Forecast day 10. 7.

Runoff (mm/day) 10. 7.2000

Figure 9: Map based presentation of the WSFS runoff forecast. These maps are made daily.

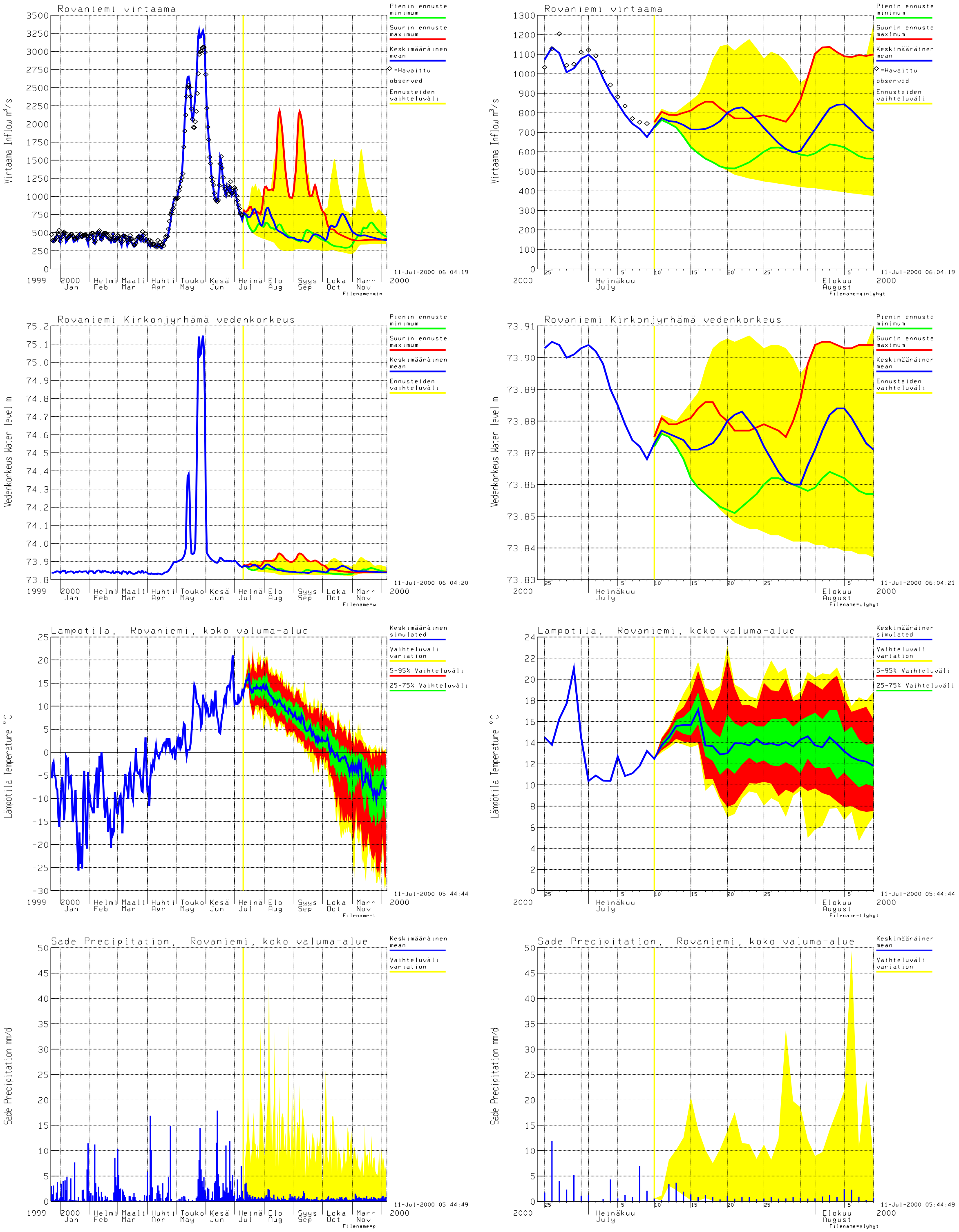


Figure 10: Discharge, water level, temperature and precipitation forecast for the basin of Kemijoki at Rovaniemi.

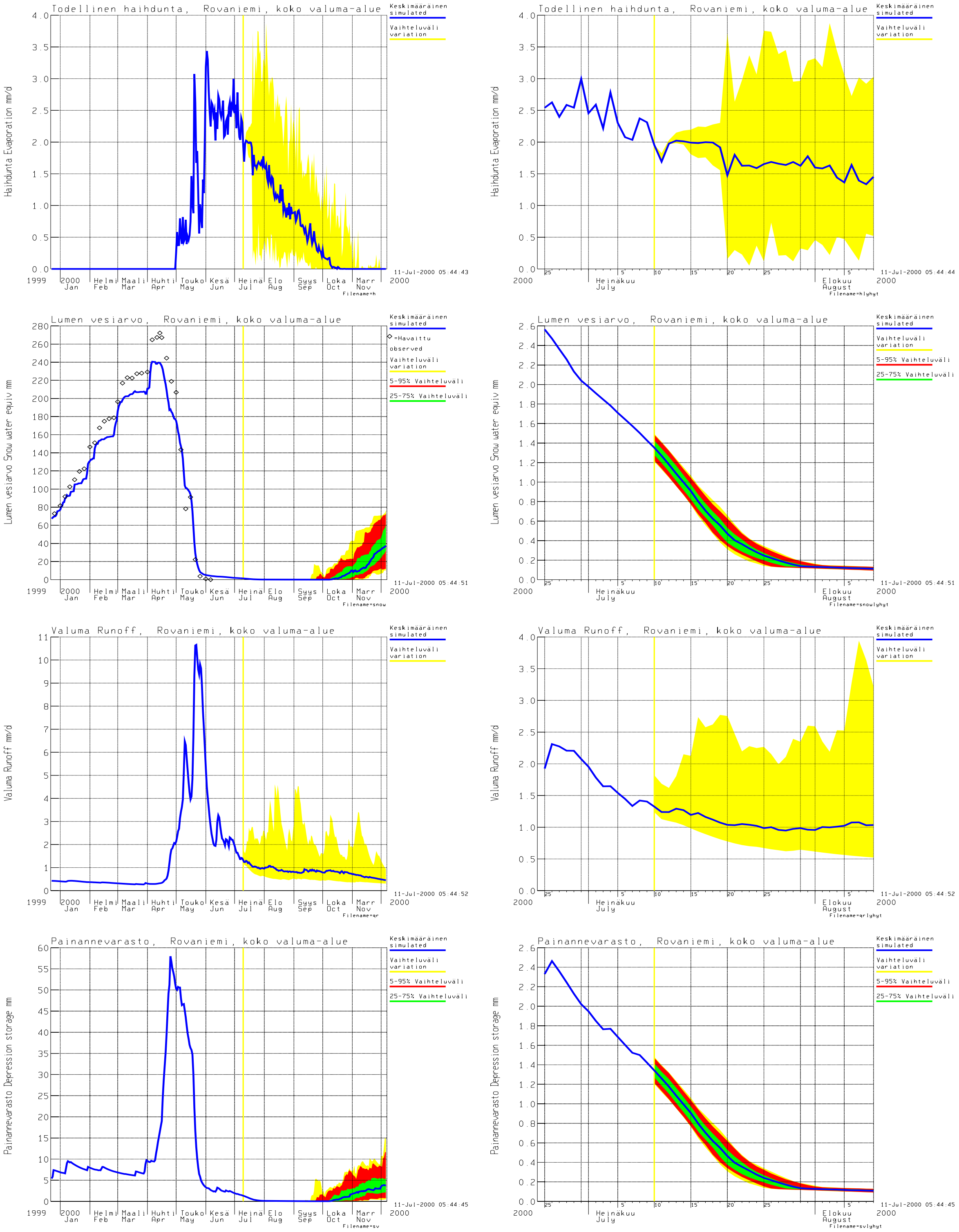


Figure 11: Evaporation, snow water equivalent, runoff and depression storage forecasts for the basin of Kemijoki at Rovaniemi.

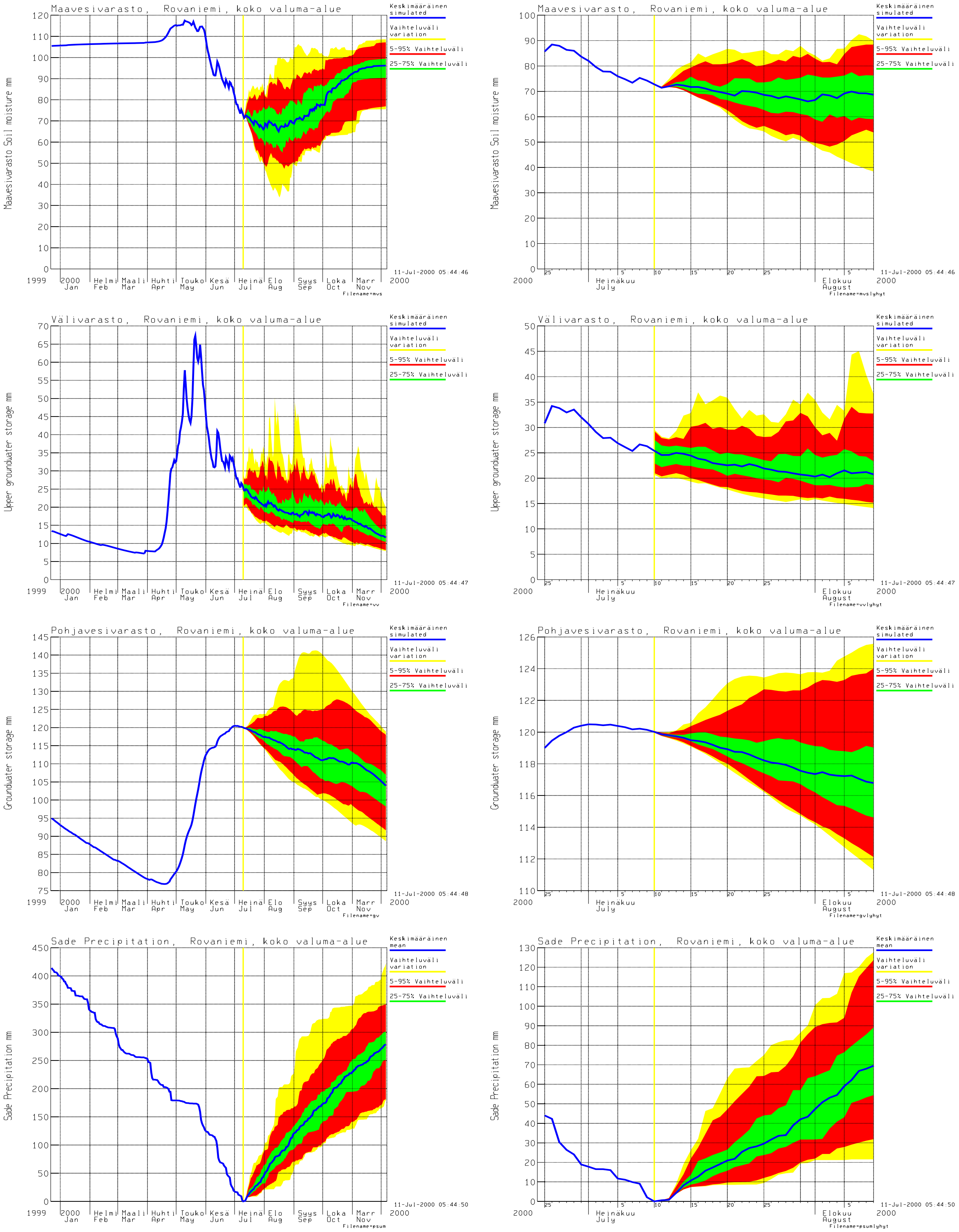


Figure 12: Soil moisture, upper ground water storage, ground water storage and cumulative precipitation forecasts for the basin of Kemijoki at Rovaniemi.

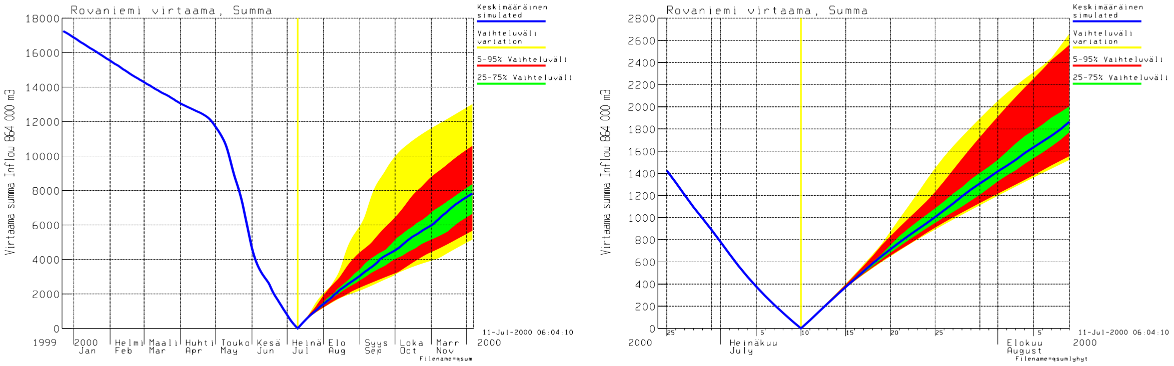


Figure 13: Cumulative discharge forecast for the basin of Kemijoki at Rovaniemi.

REFERENCES

Bergström, S. 1976. Development and application of a conceptual runoff model for Scandinavian catchments. SMHI. Nr RH7. Norrköping.

Chui, D. K., and Chen, G., 1991. Kalman filter with real-time applications, *Springer Series in Information Sciences, Vol. 17,* Springer-Verlag.

Ekholm, M. 1993. Suomen vesistöalueet. Vesi- ja ympäristöhallinnon julkaisuja - sarja A 126. Helsinki. 166 p. In finnish.

Forsius, J. 1988. Predicting River Ice Breakup Using Hydrometric Station Records. 7th Northern Research Basins Symposium, Illulissat, Greenland, 25 May - 1 June 1988.

Forsius, J. 1984. Computing unsteady flow and tracer movement in a river. Publications of the Water Research Institute, National Board of Waters. Finland.

Forsius, J. and Granholm, G. 1988. Statistical Model for Predicting of Ice Breakup in River Torneälven. Proceedings of the Nordic Expert Meeting on River Ice, Espoo 2-4 November 1987, NHP-Report No 21, Helsinki.

Hooke, R. and Jeeves, T. 1961. Direct Search Solution of Numerical and Statistical Problems. Journal of the ACM, Vol. 8, No. 2. p. 212-229.

Kallio, K. 1992. Modelling of phosphorus transport from an agricultural basin. In M.L. Fossdal (ed.): Vann- og stoffbalanse i smånedbörfelt. Nordisk Hydrologisk Program, NHP, NHP-rapport 29. p.150-158.

Kuha, J. 1993. Funktion arvojen vertailuun perustuva epälineaarinen optimointi. Pro gradututkielma. Tietojenkäsittelyopin laitos. Helsingin yliopisto. 61+18p. In finnish.

Leiviskä, P. 1993. HBV-valuntamallin sovittaminen Ähtävänjoen vesistöalueelle. Diplomityö. Oulun Yliopiston rakentamistekniikan osasto.Oulu. 52 p. In finnish.

Leppäjärvi, R. 1992. Ice-reduction of winter discharges. NHK 1992. Alta, Norge, 4.-6. august 1992. p.536-567.

Linsley, R., Kohler, M. and Paulhus, J. 1975. Hydrology for engineers. McGraw-Hill. Second edition.

Mutanen, J. 1991. Stokastinen dynaaminen ohjelmointi Pielisen ja Koitereen juoksutuksien suunnittelussa. Teknillinen korkeakoulu, Espoo. Diplomityö. 78 p.

Puupponen, M. 1988. Real-time hydrological data collection at the Finnish National Board of Waters and the Environment. Nordisk hydrologisk konferens 1988, Rovaniemi, Finland. Vol 2, NHP-report 22.

Quick, M. and Pipes, A. 1975. Nonlinear channel routing by computer. Journal of the hydraulics division. Vol. 101. No HY6.

Rekolainen, S. 1993. Assessment and mitigation of agricultural water pollution. Publications of the Water and Environment Research Institute 12.Helsinki.

Rosenbrock, H.H. 1960. An automatic method for finding the greatest or least value of a function. Computer Journal 3.

Saelthun,N.R., Bogen, J., Flood, M.H., Laumann, T., Roald, L.A., Tvede, A.M. and Wold, B. 1990. Klimaendringar og vannressurser. Bidrag til Den interdepartementale klimautredningen (Climate change and water resources. Contribution to the Interministerial Climate Change Policy Study). Norwegian Water Resources and Energy Administration, publication V30, ISBN 82-410-0085-5. In Norwegian with English summary, 110 p.

Vehviläinen, B. 1992. Snow cover models in operational watershed forecasting. Publications of Water and Environment Research Institute 11. Helsinki. 112 p.

Vehviläinen, B. and Lohvansuu, J. 1991. The effects of climate change on discharges and snow cover in Finland. Hydrological Sciences Journal - des Sciences Hydrologiques, 36, 2, 4/1991. p. 109-121.