Watershed simulation and forecasting system with a GIS-oriented user interface

BERTEL VEHVILÄINEN & JARI LOHVANSUU
Finnish Environment Agency, PL 140, SF-00251 Helsinki, Finland

Abstract The watershed simulation and forecasting system used in the Finnish Environment Agency consists of 26 watershed models, data registers, real-time observation systems, automatic model updating and automatic forecast distribution. The watershed models cover 221,000 km$^2$ or 65% of the area of Finland. Total number of forecasted lakes is 100 and forecasted water level and discharge points is 250 in rivers and lakes. The number of annual water level and discharge forecasts is over 10,000. Forecasts are normally made weekly and during flood periods daily. A map-based user interface has been developed for the system which makes it possible visualize on a map the changes of variables simulated by watershed models in three levels of sub-basin division. The simulated variables are: areal precipitation, temperature, evapotranspiration, snow, runoff, soil moisture, groundwater storages, lake levels. It is further possible to store daily data from pictures in a file for further use. This possibility is intended especially to users who need discharge and runoff data from areas without observed data. The Watershed Simulation and Forecasting System (WSFS) is a source of simulated discharge values for over 3000 sub-basins for use with water quality observations, planning, etc., when it is impossible or too expensive to make direct observations. The updating procedure of watershed models corrects the simulations at the observation points and also improves the quality of unobserved discharge simulations.

GENERAL DESCRIPTION OF THE SYSTEM

The main operating part of the watershed simulation and forecasting system WSFS (Vehviläinen, 1994) consists of 26 watershed models (Fig. 1) which simulate the hydrological cycle using standard meteorological data. 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.

The WSFS automatically reads watershed data from the registers, runs forecasts and distributes results to the Regional Environment Centres. The different stages in watershed forecasting are:
- weather data transfer in real-time from the FMI and FEA;
Fig. 1 Start-window for the map based user interface of WSFS. The watershed is chosen from the map or from the list.

- automatic collection of watershed data from registers;
- automatic watershed model updating according to information obtained in real-time;
- forecast runs by watershed models;
- distribution of forecasts through the data net to the Regional Environment Centres.

The operational watershed models have a subroutine, which gathers the areal information and stores it to be used in map-based user interface. Thus the available data in the user interface are more or less in real-time, especially in flooding periods at spring and autumn. In summer and winter, during low-flow periods the data may be some days old, the watershed models are run one or two times per week. With the map-based user interface almost all information produced by watershed models are available at the scale of a whole watershed (1000 to 10 000 km$^2$) down to 30 km$^2$ areas. The main menu of the user interface is the window presented in Fig. 1. From this main menu, one can choose first the watershed and after that the subarea of interest. In all levels of watershed division, the following information data windows are available: discharge and runoff, snow, soil moisture, storages (surface, sub-surface and ground water), lakes (level, volume, inflow, outflow), pictures (graphs of water level, discharge, water balance, soil and lake evaporation etc.) and optional (graphs of 25 hydrological variables from 3000 sub-basins). Thus far five operational watershed models are connected to the map-based user interface covering 115 740 km$^2$ or 34% of the area of Finland.
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The main parts of the hydrological model are precipitation, snow, soil moisture, subsurface, and groundwater models. Watershed model implementation begins by dividing the watershed into sub-basins. The aim is to divide the watershed into small homogeneous sub-basins according to elevation, land use, snow distribution and lakes avoiding the combination of hydrologically different areas into one sub-basin model. The number of sub-basins within a watershed model is typically 30-50; for each the hydrological runoff model (HBV-type) is calibrated. Each sub-basin model simulates areal precipitation, temperature, water equivalent of snow, soil moisture, changes in subsurface and groundwater storage and formation of runoff. The area of a sub-basin ranges from 50 to 500 km$^2$. Regulated, large unregulated, observed, and otherwise important lakes are described by lake model. Hydrological runoff models and lake models are connected together with river models to form the watershed model. The watershed forecasting and simulation system (WSFS) in the FEA now consist of 26 watershed models ranging from 600 to 60 000 km$^2$ and covering 65% of Finland. The number of forecasted discharge and observation points is 250.
WATERSHED FORECAST

Before forecast run the watershed models are updated. The updating system of WSFS 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 subbasins (3000). Model updating is done against the water level and discharge data gathered from different registers. 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.

The weather forecasts to WSFS come originally from the ECMWF in Reading UK via the FMI and consist of 10-day daily mean temperatures and precipitation quantities. The mean monthly values of Class-A pan evaporation values are used as first estimates of potential evaporation.

Short-term forecasts based on the weather forecasts are the main 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 need real-time data from discharges and water levels and continuous updating to maintain the quality of simulations and forecasts.
In long-term forecasting, use is made of statistical precipitation, temperature and potential evaporation data after the 10-day weather forecast. The long-term forecasts are based on mean (50%), 5 or 10% and 90 or 95% precipitation sums for 1, 2, 3, and 6 months. Especially at the beginning of winter, long-term forecasts are sensitive to temperature; thus the 25, 50 and 75% probability values for temperature are used for the first month. Long-term forecasts are the main forecasts for large watersheds with large lake percentages.

The number of forecasted discharge points is 140 and water level points 110; thus the total number of discharge and water level forecasts is over 250 per week or over 13 000 per year. 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 3000 sub-basins included in the 26 watershed models. The amount of available information is so large that most of it is not normally used. A map-based user-interface system is developed to ease the use of simulated watershed data.

**MAP-BASED USER INTERFACE**

A map-based user-interface makes it possible to examine on a map the changes of variables simulated by watershed models in different sub-basins 3000 altogether. The map-based user interface is taken in use through WINDOWS user interface by choosing
Fig. 5 The discharge data window of Ylä-Kemijoki for the 8 November 1995. Presented are daily rainfall and snowfall; water equivalent of snow, snowmelt; runoff; discharge and temperature and discharge for each sub-basin.

Fig. 6 Snow window from Ylä-Kemijoki at 3 November 1995. Presented are water equivalent of snow, snow covered area/snow free area, daily snowmelt and snow in
Fig. 7 Soil moisture window from Ylä-Kemijoki. Presented are daily snowmelt and precipitation sum, daily soil evaporation, soil moisture, soil moisture deficit and runoff. In the left upper corner of window are presented graphs of soil moisture and evaporation sums from different sub-basins.

Fig. 8 Lake window for Kemijärvi Lake on 13 July 1995. Presented are water level, inflow, outflow, lake area and volume, precipitation to the lake and evaporation from.
the watershed models icon. At the start-window (Fig. 1) of map-based user interface it is possible to choose in use the watershed by mouse. The available map types to be chosen as background are road map, land use map, soil type map or a map showing the watershed boundaries. Next, one gets on the screen the chosen watershed with the first level sub-basin division (Fig. 2), from which one can go to second (Fig. 3) and even to third level (Fig. 4) subdivisions. In each division level all the data windows, which are chosen from the bottom bar of the map, are available. The data windows are: SNOW (Fig. 6), SOIL MOISTURE (Fig. 7), DISCHARGES (Fig. 5), STORAGE, LAKES (Fig. 8), PICTURES and OPTIONAL. From the PICTURES bar are available the graphs from lake levels and discharge observations in rivers, snow water equivalents, lake and soil evaporation, precipitation, temperature. From OPTIONAL bar is available graphs from 25 simulated variables from each subarea presented on the map. The time span of the data series to be examined is chosen by mouse from the left bar of the data window.

Each data window includes an "output" icon by which it is possible to store daily data in a file for further use. This possibility is intended especially for users who need discharge and runoff data from subareas and rivers without observations. The map-based user interface is a source of simulated discharge values for 3000 sub-basins over 100 000 km² of Finland for use in with water quality observations, planning, etc., when it is impossible or too expensive to make direct observations. The time range for data is 3 months backwards and 3 months ahead from the day of model run. Hydrological monitoring and water resources management use also the simulated data of water levels, discharges, areal snow water equivalents, areal soil and lake evaporation and soil moisture changes. The quality of simulated data is maintained by continuous updating to observed water level and discharge values.

CONCLUSIONS

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

REFERENCE