SYSTEM FOR OPERATIONAL FLOOD FORECASTING ON KOLUBARA RIVER

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Summary: *Frequent flooding on Kolubara river catchment imposed the necessity to create an automated system for the operational flood forecasting. The system relies on hydrological and meteorological data in real-time that are forwarded to the distributed hydrological model HBV via WISKI information system. Multi-day forecasted values of precipitation and temperature on the basin, provided by the model for weather forecasting, are used for the calculation of future discharge at twenty profile on Kolubara River. As an example of this joint work, the catastrophic flooding from May 2014 was used.*

Keywords: *forecast, flood, hidrologic model, HBV, Kolubara*

1. INTRODUCTION

Within two projects financed by Norwegian Government, Republic Hydrometeorological Service of Serbia (RHMSS), with assistance of the Norwegian Water Resources and Energy Directorate, has made important improvement in hydrometeorological data management and in creation of flood forecasting system for small and medium sized catchments in Serbia [1]. Contemporary hydrological information management system WISKI 7 from KISTERS AG for time series management for both real-time and non-real-time hydrological and meteorological data, has been installed on the RHMSS resources in 2010. In the same time, the IHMS-HBV [2] semi-distributed rainfall-runoff model for realtime flood warning and forecasting, was installed and models for twenty small and medium catchments in Serbia were developed [3]. Coupling of the daily IHMS-HBV model with weather forecast model WRF-NMM was also performed. The integration of all system components is providing smoothly operational data management and flood forecasting procedures in real-time [4]. Further improvement has been done within DRIHM FP7 project, where operational hydrometeorological chains composed of multiple weather forecast models and hydrological models were created. Within the project, RHMSS developed chain composed of distributed hydrological model wflow_hbv with hourly time step and WRF-NMM atmospheric model. Experiments performed within the

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project showed that WRF-NMM-wflow_hbv chain is valuable tool for flood forecasting in extreme hydrometeorological situations [5]. Implementation of this hydrometeorological chain into operational hydrologic practice was implemented through two phases. First phase included the development of the data interface between WISKI7 data management system and wflow_hbv hydrologic model. The interface provides export of the observed hydrometeorological data from database and import to wflow_hbv model. In the second phase data interface between hydrologic and weather forecast WRF-NMM model was created. The forecasted meteorological data for the next seventy-two hours become available for the import to hydrologic model for the simulations of the future discharges. In this paper, the joint work of two models is presented through the simulation of the catastrophic flooding episode in May 2014 on Kolubara river catchment.

2. KOLUBARA RIVER CATCHMENT

Experimental hydrometeorological chain is set-up for Kolubara river catchment. Recent major floods impose the necessity to create a flood forecasting chain on this river.
The Kolubara river catchment is located in western part of Serbia covering the area of 3658 km^2.

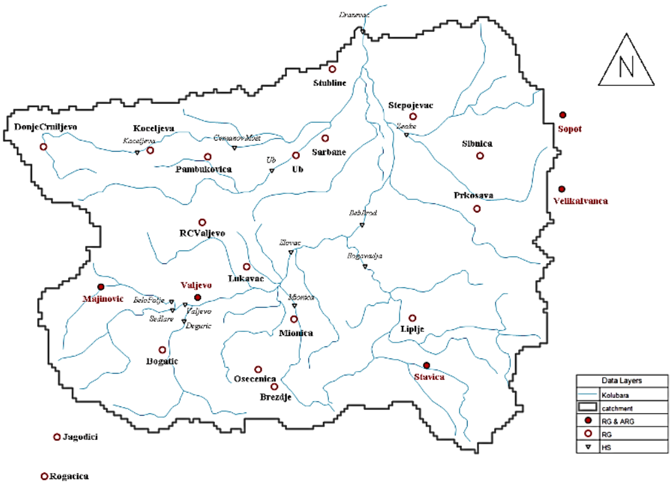

Figure 14: Location of the automatic rain gauges (red) and hydrologic stations (grey) on Kolubara river catchment

The Kolubara river displays distinct flow seasonality: flood flows mainly occur in March and April due to combined rainfall and snowmelt, while the lowest flows are observed from August to October [6]. In the Kolubara River catchment, floods also occur in the summer due to intensive convective rainfalls, which cause quick response of the (mainly torrential) headwater tributaries. Flood waves in the tributaries almost simultaneously reach the Kolubara river because of the specific geometry of the catchment [7].

Kolubara River is modelled for the discharge simulations on hydrological profile Draževac and all upstream profiles on main river and the tributaries. Precipitation for operational simulations with wflow_hbv model is available on three automatic rain gauges at Majinović, Štavica and GMS Valjevo installed on catchment area, and two stations Velika Ivanča and Sopot, in catchments vicinity. The temperature data are available on stations Majinović, Štavica and GMS Valjevo. The data on Majinović and Štavica are available from April 2014 and on Velika Ivanča and Sopot from April 2010 (Figure 14).
The potential evapotranspiration is calculated using Hamon's equation. The water level is measured at hydrological stations Valjevo, Slovac, Beli Brod, Bogovađa, Koceljeva, Ćemanov Most, Ub, Zeoke i Draževac.

3. COMPONENTS OF THE EXPERIMENTAL FLOOD FORECASTING CHAIN

Nowadays coupling meteorological and hydrological models is recognized by scientific community as a necessary way to forecast extreme hydrological phenomena, in order to activate useful mitigation measurements and alert systems in advance.
In our case, the elements of the experimental flood forecasting chain are 1) WISKI7 hydrometeorological data management system, 2) distributed hydrological model wflow_hbv and 3) weather forecasting WRF-NMM model. The operational mode the wflow_hbv model has two phases. First phase is the simulation of the system variables with the observed precipitation and temperature data, stored in WISKI7, for last twenty-four hours. The hourly wflow_hbv model uses the data from available meteorological sensors on catchment area to update the variables of the hydrological model before simulations with forecasted meteorological data. In the second phase, the model is forced with forecasted precipitation, temperature and potential evaporation data from WRF-NMM for three days (*Figure 15*). The future discharge values at the river profiles are post processed and prepared for the dissemination.

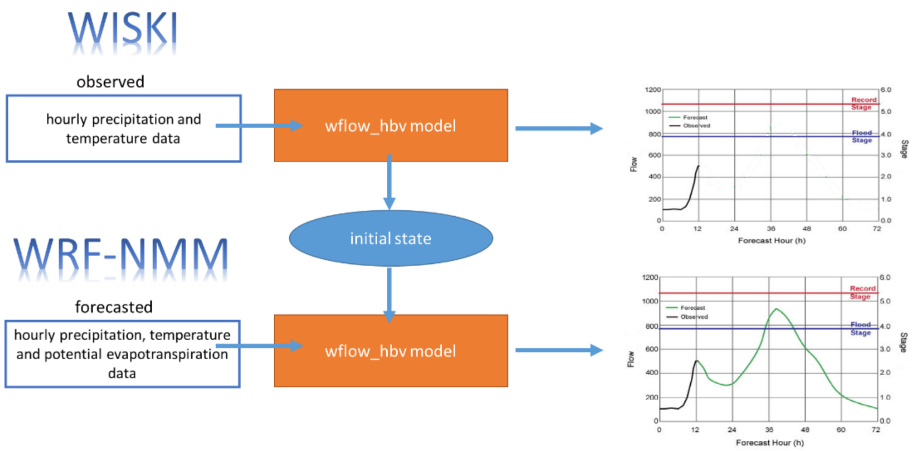

Figure 15: Workflow of the experimental hydrometeorological chain

3.1 WISKI

WISKI (Water Information System KISTERS) is hydrometeorological data management system designed as three-layered architecture. At the backend of the system there is ORACLE database. The mid-layer consist of business logic servers such are KiTSM (KISTERS Time Series Manager) and KiDSM (KISTERS Distribute Service Manager) and finally client applications on the top of the system (SKED, BIBER) Figure 16.

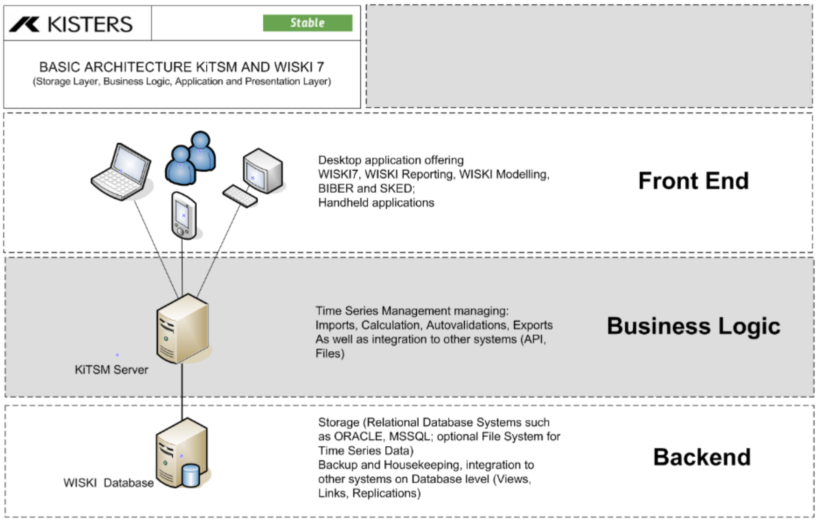

Figure 16: Basic architecture of WISKI7

In order to meet demands of approx. 40 clients the following hardware was installed:

- Oracle – HP ProLiant DL380R05 Intel Xeon E5450 with 2 processors, 8 GB of RAM and 5 x 147 GB SAS HD
- KiTSM – HP ProLiant DL380R05, Intel Xeon E5450 with 2 processors, 16 GB of RAM and 3 x 147 GB SAS HD
- KiDSM – Virtual machine, Intel Xeon E5645 with 4 processors, 4 GB of RAM and 200 GB HD

Entire business logic is places in the middle layer where are placed two major components of WISKI system – KiTSM and KiDSM server.

KiTSM is the “brain” of the entire system where all the user defined operations and tasks are processed. Client applications in the top layer are conceived more like GUI for end users so they can more easily create tasks and operations and KiTSM is the one which really operates them. In this way the system gained two major improvements. First is system scalability, which means that system and its components are independent and can be ungraded and expanded. The other one is economic viability because in this way the client machines are less impacted and therefore can be with lower resources.

KiDSM server is used for automation of some processes which are repeatedly needed to be done like collecting and disseminating hydrometeorological data. Also it is used for providing the data for different models. Depending on the model settings the data can be provided hourly, daily, monthly or even quarterly at exact time. On the data flow chart (Figure 17) it can be seen that data acquisition is conducted by hardware manufacturer: for SEBA it is DEMAS and for OTT it is HYDRAS3. Data gathered in that way is forwarded to the ftp where once when detected KiDSM machine copies them on the local file system and import them into the WISKI Oracle database.

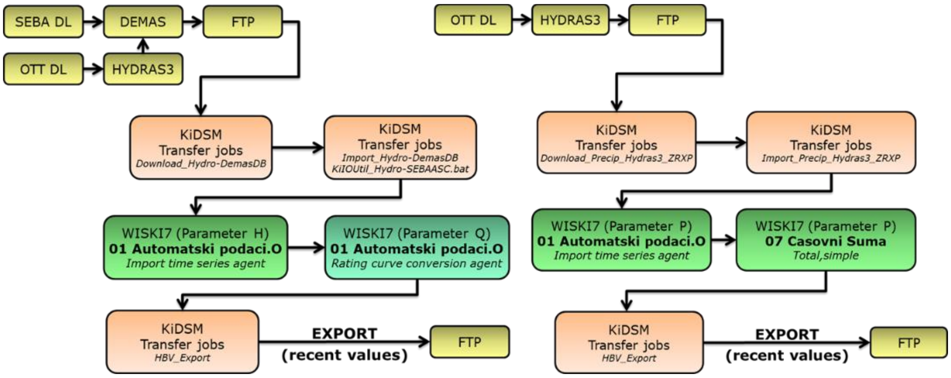

Figure 17: Data workflow for the hydrological and meteorological data

Once the data is available in the WISKI, time series agents convert water level into the discharge using latest rating curves. In that way data is ready to be exported again on ftp, and once again KiDSM does the transfer job. Similar logic is used for meteorological parameters with one exception but instead of using agent for rating curve conversion, agent for calculating hourly totals is used for precipitation and agent for calculating mean hourly values for air temperature. Again, KiDSM takes over the role and transfer the data on the ftp. Once all necessary files are available on the ftp, batch procedures take them over and copy them on the local file system where they are used as input for the model.
The collection of hydrometeorological data starts at 6:00 AM every day and finished at 6:25 AM. The KiDSM make the time series available on ftp at 6:45 AM for the hydrological model.

3.2 WFLOW-HBV

The wflow_hbv [8] is distributed hydrological model based on the original HBV-96 model. The model code is written in Python using PCRaster library [9] together with other libraries for scientific computing. Input to the model are hourly-accumulated precipitation, mean hourly temperature and potential evapotranspiration. They can be imported either as time series or as gridded maps. If the data is station based then Inverse Distance Weighting or Thiessen polygons method is applied. For the specific catchment, it is necessary to prepare static maps: digital elevation map, land use map and soil type map in chosen spatial resolution. Those maps enable model parameters to have different values for various combinations of the soil types and land use classes.
Twenty-one model parameters controls all hydrologic processes in the model. Three major routines manipulate with water in the model: precipitation routine, soil moisture routine, runoff response routine and routing routine (Figure 18).

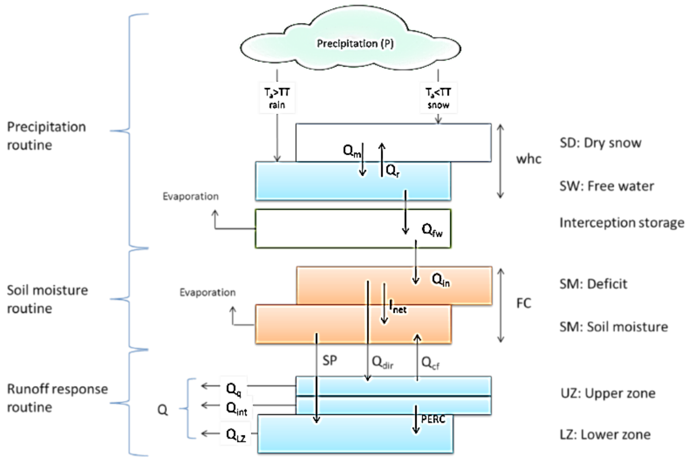

Figure 18: Scheme of the wflow_hbv model

Precipitation routine manipulate with snow accumulation and snowmelt together with interception and evaporation from the vegetation. Precipitation is identified as snow if the air temperature is below defined treshold, otherwise it is classified as rainfall. The distribution of the runoff is modeled with the soil moisture routine and runoff response routine.

Soil moisture routine define the portion of water volume that stay in soil and complements the soil deficit and the volume that forms the direct runoff. Infiltrated water percolate in time toward two reservoirs: upper and lower reservoir. Upper reservoir transforms the quick runoff and lower reservoir transforms the base flow. Unlike the original version, wflow_hbv uses the kinematic wave as method for river routing. Output from the model are maps of all system variables like snow water equivalent, water in snow, interception storage, soil moisture, surface water and water level.

The catchment area for Kolubara River is defined with hydrological profile Draževac on the 250x250 m grid with hourly time step. Static maps are prepared using digital elevation maps from SRTM DEM [10]. The vegetation type for the analyzed basins was taken from Corine Land Cover 2000 [11] and soil types from ESDC [12]. The parameters are determined empirically, using available discharge data.

3.3 WRF-NMM MODEL

The Weather Research and Forecasting (WRF) model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. The basis of numerical weather prediction system of RHMSS lies on WRF-NMM model. Instead of non-hydrostatic approach, usually applied to the synoptic situation, hydrostatic model is expanded to include the non-hydrostatic processes, maintaining beneficial characteristics of the hydrostatic models. High resolution treats vertical processes, the non-hydrostatic dynamics, with the inclusion of the non-hydrostatic modules in the model [13]. The vertical coordinates in WRF-NMM model is a hybrid sigma-pressure coordinate that follows the terrain in the lower layers. Above the mountain, hybrid coordinate increases the vertical resolution. As vertical coordinate, over 420 mb, hydrostatic pressure is used. The equation system in WRF-NMM model consist of adiabatic equations in no viscous form that are analogous to hydrostatic equations, except for non-hydrostatic pressure. The grid of the model is in geographical projection, translated in the way that the centre of the domain is at the intersection of the equator and the Greenwich meridian. Computational model grid is semi-staggered Arakawa 4x4 km E grid with nested domain of 1.33 km.

3.4 DATA INTERFACES

Depending on the type of the simulation, in the preprocessing phase it is necessary to interpolate either 1) observed point based meteorological data or 2) forecasted precipitation, temperature and potential evaporation data from WRF-NMM, to the resolution of the hydrologic model. The meteorological and hydrological observations for last twenty-four hours are exported from WISKI database using KiDSM tools.

The time series are stored in separate (zrxp) files, one for each precipitation and temperature sensor or hydrological station. Forecasted hourly precipitation, temperature and potential evapotranspiration data for three days in advance are stored in one file in NetCDF-CF format. The locations of the sensors are listed in files and available in models directory. According to these lists, python script open the files with observations and perform spatial interpolation. The script produce twenty-four maps, one map for each hour. The gridded data are saved into the PCRaster (map) file format. The grid resolution of the WRF model is usually not the same as grid resolution of the hydrologic model. After the interpolation, the maps are also saved into seventy-two PCRaster maps, one map for each hour.

Workflow of the hydrometeorological chain begins with the simulation of the wflow_hbv model with hourly precipitation and temperature data, observed in last twenty four hours. Those data update variables of the hydrologic system and system creates initial state. Maps with forecasted meteorological parameters are then used to determine future discharge values.

4. SIMULATION OF THE FLOOD IN MAY 2014

In April 2014, after the installation of the automatic rain gauges at Majinović and Štavica, the WISKI database has started to collect the precipitation and temperature data. Exported aggregated data were digested by wflow_hbv model. The model has started to perform the runoff simulations every morning, first with the observations for previous day and, after the termination of the WRF-NMM model, with forecasts. The model was roughly calibrated, using the parameters from the daily IHMS/HBV model. Floods in May 2014 were the first challenge for this hydrometeorological chain. Here, first simulations of one extreme hydrometeorological event are presented (Figure 19.)

The results showed sudden rise of the river discharge on all tributaries of Kolubara River (
Figure *20*). The warnings about massive flood wave were disseminated to all relevant institutions.

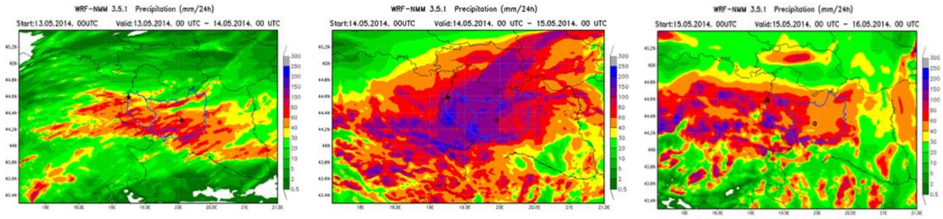

Figure 19: Forecast from WRF-NMM for May 12, May 13 and May 14 2014

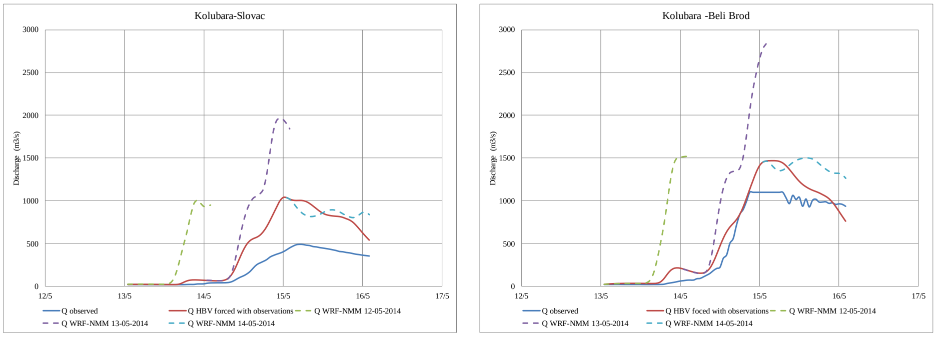

Figure 20: Forecasted discharge at river profiles Slovac and Beli Brod compared with observed discharge and discharge simulated with observations

5. CONCLUSION AND DISCUSSION

Experimental flood forecasting chain created for Kolubara River basin is just the first step in the creation of the multicatchment flood forecasting system. The model chain for Kolubara is providing promising results, and an additional effort need to be done in the future in the improvement of the model parameters with new observations. In addition, there is a strong need for the enlargement of the monitoring network and use of remote sensing data.

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СИСТЕМ ЗА ОПЕРАТИВНУ ПРОГНОЗУ ПОПЛАВА НА СЛИВУ РЕКЕ КОЛУБАРА

Резиме: *Честе поплаве на реци Колубара условиле су неопходност формирања аутоматизованог оперативног ситема за прогнозу поплава. Систем се ослања на хидролошке и метеоролошке податке у реалном времену који се преко WISKI информационог система прослеђују дистрибуираном хидролошком HBV моделу.*

Вишедневне прогнозиране вредности падавина и температура на сливу, доступне из модела за прогнозу времена, користе се за прорачун будућих протицаја на двадесет профила реке Колубара. Као пример рада овог система коришћена је ситуација из маја 2014. године када су слив ове реке задесиле катастрофалне поплаве.

Кључне речи: *прогноза, поплаве, хидролошки модел, ХБВ, Колубара*