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CROSS BORDER COOPERATION

EAST AVERT Project

TECHNICAL REPORT

FORECAST SYSTEM DESIGN REPORT

2017

The prevention and protection against floods in the upper Siret and Prut River Basins, through the implementation of a modern monitoring system with automatic stations – EAST AVERT Project

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TECHNICAL REPORT

FORECAST SYSTEM DESIGN REPORT

Coordinated by

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Partner 7: Chernivtsi Regional Centre on Hydrometeorology, Ukraine

With the contribution of:

Lead Partner:	*Ministry of Environment, Romania*
Partner 2:	*Prut-Barlad Water Basin Administration, Romania*
Partner 3:	*Siret Water Basin Administration, Romania*
Partner 5:	*"Apele Moldovei" Agency, Republic of Moldova*
Partner 6:	*Dnister-Prut Basin Department of water resources, Ukraine*
Partner 8:	*State Scientific and Technical Centre for inter-sectorial&regional problems of the Environemental Safety and Resources Conservation "EcoResources", Ukraine*

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1. Introduction

There are several well-known general hydrological models currently in use in the UE, U.S. and elsewhere. These models vary significantly in the model construct of each individual component process partly because these models serve somewhat different purposes. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is considered the standard model in the private sector in the U.S. for design of drainage systems, quantifying the effect of land use change on flooding, etc. The National Weather Service (NWS) model is the standard model for flood forecasting. HSPF and its extended water quality model are the standard models adopted by the Environmental Protection Agency. The Modular Modeling System (MMS) model of the USGS. is a widely used model for water resources planning and management works, including a number of those under the purview of the U.S. Bureau of Reclamation. The University of British Columbia (UBC) and distributed hydrologic model (WATFLOOD) are popular in Canada for hydrologic simulation. The runoff routing model (RORB) and WBN models are commonly employed for flood forecasting, drainage design, and evaluating the effect of land use change in Australia. TOPMODEL and SHE are the standard models for hydrologic analysis in many European countries. The HBV model is the standard model for flow forecasting in Scandinavian countries. The ARNO, LCS, and TOPIKAPI models are popular in Italy. The Tank models are well accepted in Japan. The Xin'anjiang model is a commonly used model in China.

The World Meteorological Organization (WMO) sponsored three studies on intercomparison of watershed hydrology models. The first study (WMO, 1975) dealt with conceptual models used in hydrologic forecasting. The second study (WMO, 1986) dealt with an intercomparison of models used for simulation of flow rates, including snowmelt. The third study (WMO, 1992) dealt with models for forecasting streamflow in real time. Except for the WMO reports, no comprehensive effort has been made to compare most major watershed hydrology models.

The data needed for watershed models are hydrometeorologic, geomorphologic, agricultural, pedologic, geologic, hydraulic, and hydrologic. Hydrometeorologic data include rainfall, snowfall, temperature, radiation, humidity, vapor pressure, sunshine hours, wind velocity, and pan evaporation. Agricultural data include vegetative cover, land use, treatment, and fertilizer application. Pedologic data include soil type, texture, and structure; soil condition; soil particle size diameter; porosity; moisture content and capillary pressure; steady-state infiltration, saturated hydraulic conductivity, and antecedent moisture content. Geologic data include data on stratigraphy, lithology, and structural controls, depth, and areal extent of aquifers. For confined aquifers, hydraulic conductivity, transmissivity, storativity,

compressibility, and porosity are needed. For unconfined aquifers, data on specific yield, specific storage, hydraulic conductivity, porosity, water table, and recharge are needed. Geomorphologic data include topographic maps showing elevation contours, river networks, drainage areas, slopes and slope lengths, and watershed area. Hydraulic data include roughness, flow stage, river crosssections, and river morphology. Hydrologic data include flow depth, streamflow discharge, base flow, interflow, stream-aquifer interaction, potential, water table, and drawdown. Each data set is examined with respect to homogeneity, completeness, errors, and accuracy. Storage, handling, retrieval, processing, management, analysis, and manipulation of data are other important issues in data processing. Observed data frequently correspond to different space and time scales, appropriate for river basin modeling.

2. Current situation of Flood Forecasting in Upper Prut and Siret River Basins

Nowadays, Ukrainian Hydrometeorological Center (UHMC) and Chernovtsy Hydrometeorological Center (ChHMC) respectively use operational hydrological models which have been developed more than 25 years ago. These models are conceptual lumped hydrological models which basis structures were developed in 70 th -80th of the previous century. Before the start of "EAST-AVERT" the contemporary numerical weather prediction models was were not used in UHMC for the operational forecasting of for the precipitation in the basins of the Prut and Siret region, that provides supplementary limits to the predictive power of the floods in this region.

The flood management in this region provided by the Dnister- Prut Basin Department on Water Managements (DPDWM) , Chernovtsy (the regional structure of the State Agency of Committee on the Water Management of Ukraine) , did not use the computed maps of the inundation of the near river territories during by flood of the different probability of exceeding, i.e., the flood zoning for this region was absent.

3. EAST-AVERT Integrated Flood Forecasting and Warning System – General Design Structure

In order to satisfy the specific needs for improving the real time forecasting and warning system capabilities in Prut and Siret transboundary River Basins, the following general forecasting system design structure have been proposed by the project partners:

- A detailed spatial and temporal scale hydrological model for the upper part of the Siret and Prut River basins, in Ukraine, in order to provide short-term detailed rainfall-runoff, and flood routing capabilities.

- Also a high resolution local numerical weather prediction model is used to provide adequate, improved quantitative precipitation forecasts.
- For the same area, for the routing and the flood inundation mapping needs, a hydraulic model was implemented.
- Both type of models, for the upper part of Prut and Siret, in Ukraine, are also used for flood hazard maps generation, in this part of the basins.
- A second type of model, a conceptual hydrological rainfall-runoff model was implemented, in order to satisfy the needs of medium term forecasts and scenarios analysis for the Siret and Prut river basins at the entrance in Romania.
- These forecasts will be used both by the partners from Romania and Moldova, in order to optimize the operation of Stanca-Costesti reservoir for flood defense in Prut river basin, and by Romanian partners for optimize the operation of reservoirs on Siret river.
- For the Prut River, downstream the entrance in Romania, a hydraulic model was implemented by the Romanian and Moldavian partners, based on HEC-RAS hydraulic model, including the Stanca Costesti reservoir. This hydraulic model was used for the flood hazard maps generation on Prut River, and will also be used for more accurate real-time forecasts during extreme flood events.

4. Models chain for short term, high spatial and temporal resolution Flood Forecasting developed for the Prut and Siret River basins in Ukraine

The detailed Flood Forecasting system for the Prut and Siret River Basins, in Ukraine, will be based on the chain of the following modelling components:

- The numerical weather forecasting model (based on the customization of the USA open source numerical meteorological model WRF);
- The distributed physically based “rainfall runoff model“ predicting the lateral inflow from watershed to river network, based on the customization of the model / code TOPKAPI-UKRAINE (TOPKAPI-U), developed in the UCEWP on the basis of the well-known distributed model TOPKAPI, developed in the University of Bologna.
- The hydraulic flood routing model based on the full Saint Venant equations describing propagation of flood waves in the river network in 1-D approximation (it was used the customization of the model code RIVTOX, developed in the UCEWP, for Prut and Siret river network.

- The two dimensional model of the river flow in the river channels and the surrounding floodplains based on the numerical solutions of the 2D shallow water equation on the unstructured grid to produce the quality simulation of the flooding zone for the floods of the different probability of exceeding in correspondence with the European Floods Directive.

The main graphical user interface will provides the following functionalities:

- coupling of the model chain by the set-up and processing of the fluxes of the information between the different modules of the modelling system;
- data retrieval from the data bases of the monitoring systems and external modelling system (for the meteorological forecast);
- data transfer from 1D and 2D hydraulic models to the GIS server established within the project to prepare the flood zooming /risk maps by the GIS tools;
- user interfaces for each module of the system;
- date exchange with the transboundary Project's partners;

The meteorological Forecasting System will be based on the Numerical Weather Prediction Model WRF. Weather Research and Forecasting (WRF) Model is a contemporary mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs by several USA agencies and universities. The input data for the regional implementation of WRF can be downloaded from the servers NOMADS of the USA agency http://nomads.ncep.noaa.gov/

Within the EAST AVERT Project the software system will run with four times update per 24 hours, automatic computation of the detailed weather forecast in the areas of the Prut and Siret basin in Ukraine on the basis of automatic retrievals of the global model results from the NOMADS servers, as boundary conditions.

The simulations will be performed on a sequence of 3 nested domains (Fig. 1) with the outer (first) domain having resolution of 27 km, second domain having resolution of 9 km and the inner (third domain) having resolution 3 km (Fig. 1, 2).

Figure 1 - Three nested domains of the WRF model customized for the basins of the Prut and Siret rivers in Ukraine.

Hydrological Rainfall-Runoff Model TOPKAPI-UKRAINE

TOPKAPI model is a fully distributed rainfall-runoff model based on combining GIS data and kinematic wave approach for routing processes. Due to its distributed nature model it is more easy to assimilate the results of numerical weather prediction systems (in our case regional WRF model). Original TOPKAPI model was developed at the University of Bologna. Many research groups around the world have been developed own implementations of TOPKAPI models that were used for hydrological studies and flood forecasting systems. Ukrainian Center of Environmental and Water Projects (UCEWP) developed own code of TOPKAPI model (TOPKAPI-U) and successfully used it before for hydrological studies of Ukrainian rivers of Transcarpathian region. TOPKAPI-U comprises modules that describe processes of interception, evapotranspiration, snow melting and snow accumulation, subsurface flow, overland flow, channel flow. Model is used for flow calculation from upper subwatersheds of Prut and Siret basins and for lateral inflow calculation to river networks for further routing.

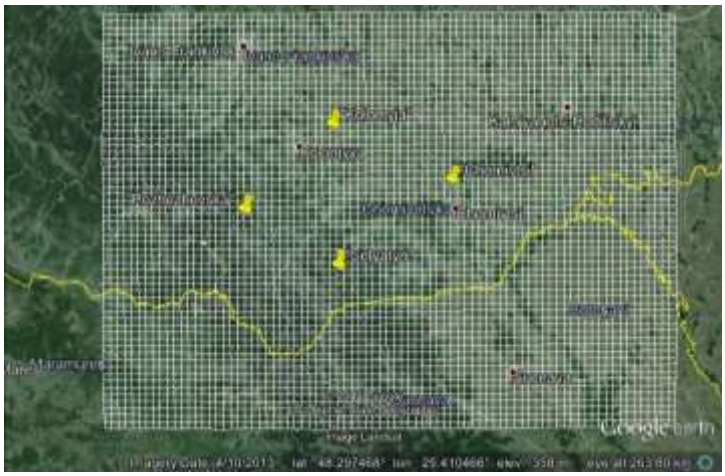

*Figure 2 - Internal domain of WRF- PRUT - UA model, with a grid 3*3 km*

One Dimensional Hydrodynamic Model RIVTOX was developed in UCEWP and is based on numerical solving the full set of the Saint-Venant equations. As any other 1D hydrodynamic model RIVTOX operates with cross-section averaged flow variables like flow velocity, flow depth. As boundary conditions model RIVTOX uses flow calculated by rainfall-runoff model TOPKAPI-U.

5. The medium term hydrological rainfall-runoff modeling system for upper Siret and Prut River Basin

In order to elaborate and provide medium term hydrological forecasts for the upper Siret and Prut river basins, at the entrance in Romania, a second conceptual rainfall-runoff model was implemented.

These medium term forecasts are used in real-time to optimize the reservoirs operation in Siret and Prut River, downstream the entrance in Romania, during the flood events.

This rainfall-runoff model will provide the inflow forecasts to Stanca Costesti, in order to support by scenarios simulations this important reservoir operations for flood management, for real-time decision support.

Also, the short term forecasts elaborated with this system, could be used as a backup in real time, if situations when there are some problems / failure in running the detailed hydrological modeling system for the upper part of Siret and Prut River basins, in Ukraine.

The implementation will be done using the RS-Minerve System - https://www.crealp.ch/fr/accueil/outils-services/logiciels/rs-minerve.html, a freely distributed software that could be used for the simulation of free surface runoff flow formation and routing, in complex hydrological and hydraulic networks using a semi-distributed conceptual scheme. In addition to particular hydrological processes such as snowmelt, glacier melt, surface and underground flow, hydraulic control elements (gates, spillways, diversions, junctions, turbines and pumps) could also be included.

This hydrological forecasting system configuration is based on the Sacramento Soil Moisture Accounting System (SAC-SMA) as rainfall-runoff model, the same model that is implemented and used in HFMS-DESWAT National system in Romania, in order to benefit from the experience in model configuration and calibration, and for a better integration with the existing system (Figure 3).

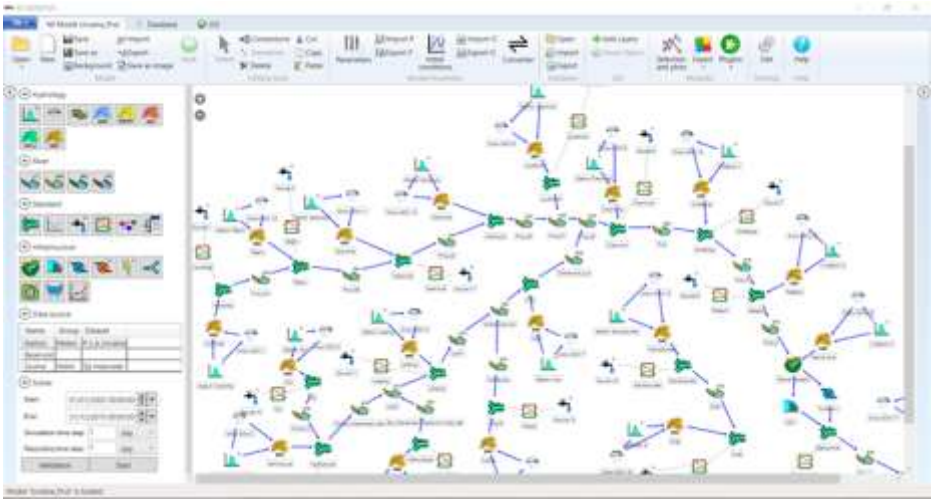

Figure 3 - General structure of the medium term hydrological forecasting system, for Prut and Siret River Basins, within the RS-Minerve modelling system

6. HEC-RAS routing model for Prut River, downstream the entrance in Romania

HEC-RAS is a software which was developed by Hydrologic Engineering Center (HEC), a department of the Institute of Water Resources (IWR) in the U.S. Corps of Engineer's.

The program may perform hydraulic simulations / analysis regarding:

- steady flow;
- unsteady flow;
- sediment transport / mobile bed;
- water temperature /water quality.

With HEC-RAS software hydraulic parameters for steady and unsteady flow for a study area (a river, a certain sector of river floodplains, lakes and dams etc) can be computed. To successfully configure and run the software, accurate and actual input data are needed, consisting in general by:

- topographical data – cross sections, descriptions of built structures (bridges, inline structures, lateral structures, water intakes etc.), situation plans, aerial photos, digital terrain models;
- hydrological data – the value of flow across all areas of interest, flow hydrograph, rating curves, traces of extraordinary floods for models calibration etc.;
- data regarding river scheme;

•information on land use, vegetation coverage and soil in the area of interest in order to determine the roughness coefficients.

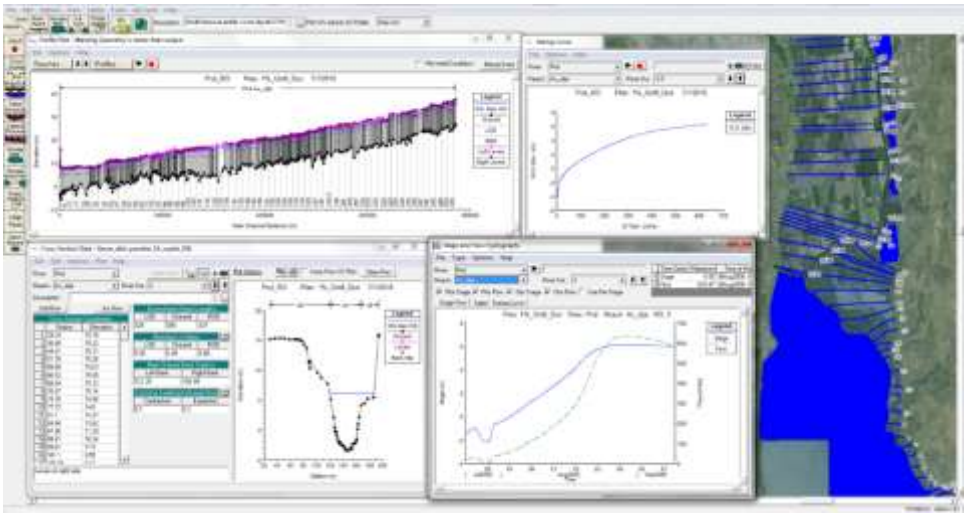

Figure 4 - Example of a Prut River sector analyzed within the HEC-RAS model

The goal of performing HEC-RAS is to achieve results that reflect the real phenomenon as much as possible. To achieve this, it is necessary to calibrate and validate the application. In the end, by running the model multiple output data could be generated and analyzed, in tabular and graphical view: water level for all cross sections, the plot profile containing free water surface level variation, water depths, average flow velocity, the extend of floodplain etc.

For the Prut River, downstream the entrance in Romania, a hydraulic model will be implemented by the Romanian and Moldavian partners, based on HEC-RAS hydraulic model, including the Stanca Costesti reservoir. This hydraulic model will be used also for the flood hazard maps generation on Prut River, and will be used for more accurate real-time forecasts during extreme flood events.

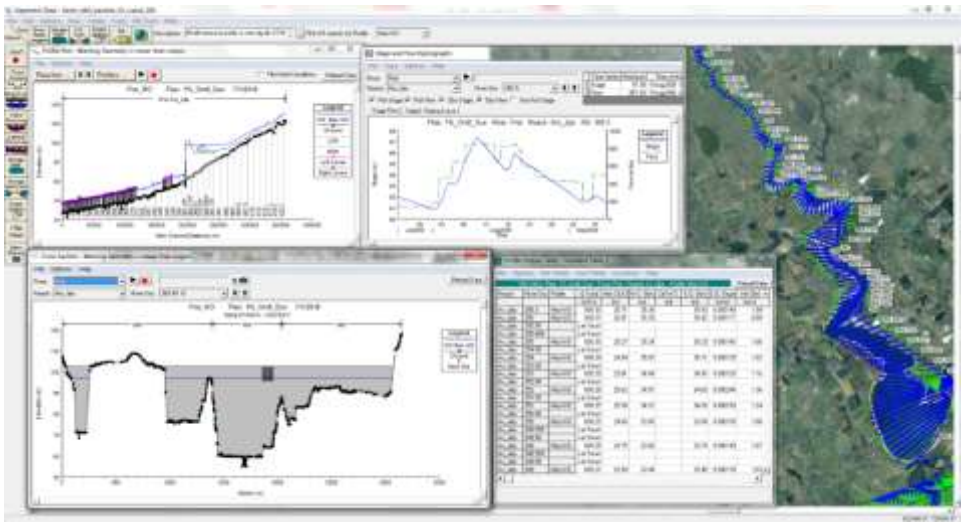

Figure 5 - Prut River - Stânca Costești Dam sector analyzed within the HEC-RAS model interface

7. Conclusions

One of the main objective of EAST-AVERT Project is to improve the flood forecasting and warning systems capabilities in Prut and Siret River Basins by developing a modern integrated monitoring and warning system, better common forecasting procedures, to protect localities and population living in the border areas.

The design of the new integrated Flood Forecasting and Warning System, that will be implemented within the EAST-AVERT Project, make use of multiple hydrological and hydraulic forecasting models, adequate for simulation of hydrological processes at different spatial and temporal scales, and include robust models that could be run in interactive way by the forecaster.

The integrated forecasting system has a modular, flexible, and robust structure in order to allow the Hydrological Forecasts Centers from Romania, Ukraine, Moldova to cooperate in real-time for the hydrological forecasts and warnings elaboration, and in order to be able to elaborate the forecasts products for the upper Siret and Prut River Basins under different type of failure scenarios, of data communication interfaces and/or flood forecasting system components.

The system improved capabilities are based not only on the new specialized hydrologic and hydraulic forecasting models to be implemented, but also on the high resolution and improved accuracy of the regional numerical weather forecasting model, and from the new installed automated stations which provide significantly improved real-time monitoring capabilities for the hydrological and meteorological parameters evolution, within the upper Siret and Prut River Basins.