Overview of the complex and modular system FLOREON^{+} for hydrologic and environmental modeling

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Abstract

The main goal of the research project FLOREON^{+} (FLOod REcognition On the Net) is a development of prototypal open modular system of environmental risks modeling and simulation which is based on modern internet technologies and platform independency. The system is running in the operative way nowadays. Hydrological issues such as floods are complimented by other environmental analyses and models. These models involve water quality, air quality, erosion and ecological models. The final product of the project is going to be the system offering an online communicational man-machine interface and providing various types of products for decision support. The project results should help to simplify the process of crisis management and increase its operability and effectiveness. The main scopes of modeling and simulation are flood risk, transportation risk and water and air pollution risks. Incorporation of geographic information systems (GIS) is a logical step because numerical models work with geospatial data and effective handling of such data is a crucial factor of efficiency of the whole system.
Keywords: FLOREON+, hydrologic modeling, modular system, GIS.

1 Introduction

Modelling of the water component in the landscape together with consequent environmental aspects becomes frequently discussed activity. Water is both an element and irreplaceable resource in this context.

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The geographic information systems and hydrologic models became more frequently used with the development of informatics in the field of hydrology and environmental issues. These products represent most efficient tools for the hydrologic analyses beyond any doubt. Numerous projects for the improvement of such tools were realized worldwide. Both particular hydrologic and environmental problems were solved together with the design of more complex systems, in which was solved communication of GIS and hydrologic models in the system way. ArcHydro is amongst the most sophisticated projects in that way [1, 2].

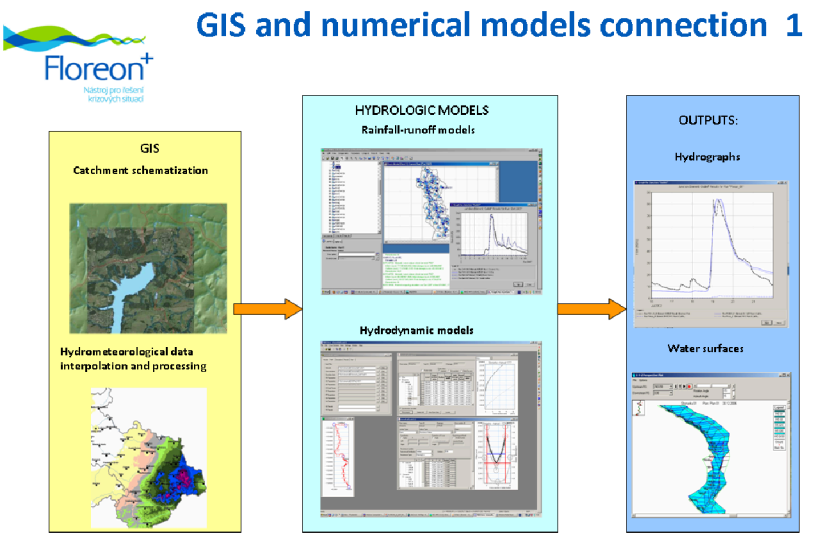

Figure 1: Scheme of GIS and numerical models connection 1.

Our project FLOREON^{+} (FLOods REcognition On the Net) endeavors to achieve such complex solution for environmental issues. The first milestone of this project was the development and operative running of complex decision support and prediction system for hydrologic problems such as floods [3, 5]. Near real-time predictions of hydrographs and flood lakes was the first aim, which was achieved. The project is running in an operative way nowadays. Incorporation of other environmental models is the second phase of the project run, which took this year to complete. Incorporated issues are the following:

- floods,
- water duality and contamination,
- fluvial erosion,
- fluvial geomorphology,
- air quality and pollution,
- traffic management (during natural hazards etc.).

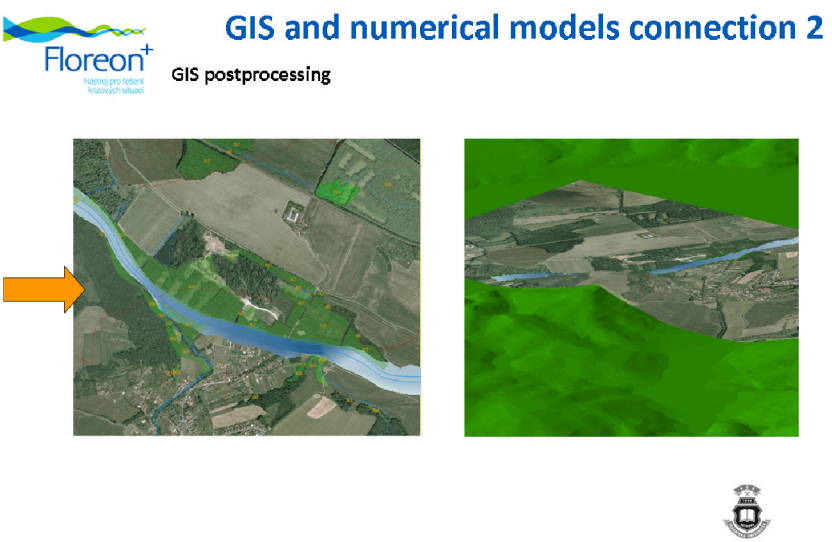

Figure 2: Scheme of GIS and numerical models connection 2.

The most important thing is the modularity of the whole system and using of internet technologies. There are no special requirements for hardware and software equipment together with practical knowledge of users from that point of view. Only an internet browser is required for the ”thin client” of system FLOREON+.

All spheres of interest are solved in the analytic and prognostic way with GIS and numerical models utilization.

Modularity of FLOREON$^+$ is important in two regards: availability of connection of various numerical models and GIS software and mutual substitution and supplement of particular numerical models.

The System is designed as the solution for experts from the range of environmental and hydrological agencies, crisis management, local governments and autonomies and also as provider of information for common citizens. Level of user is differentiated by the user login. A larger amount of detailed information and possibility of affect on the simulation parameters are offered for the expert user. Information about the flood extent and culmination is designed for the laymen.

Most important partners of project are:

- Moravian-Silesian regional authority
- Povod Labe (Labe Basin Management)
- Povod Odry (Odra Basin Management)
- Czech Hydrometeorological Institute
- Agency for Nature Conservation and Landscape Protection of Czech Republic

2 System architecture

The system is based on client - server architecture, so that all computing operations are performed on HPC servers, with that users are made available only to the form for the award and subsequent results. The whole system operates in ”near real time”.

Architecture is being constructed as hierarchically modular. In general terms, the system consists of a few basic modules that can be supplemented or replaced by others or alternative modules. As far as the hierarchy, so much the basic modules can be composed of other modules, for which the same freedom as the basic modules and, in the sense that they may be replaced, supplemented or alternated whenever it's needed.

The modules and their sub-modules must interact with one another in some way to communicate. To ensure the independence of modules, it was necessary to choose the technology that is implementation independent. Currently, the best solution, which was also chosen, appears to be the deployment of Web services. Web services make it easy to interconnect modules and sub-modules through the Internet, the simple interchangeability of modules and standardized form of communication. In particular, thanks to these features makes the system very flexible, distributed implementation and complete independence.

The system architecture FLOREON$^+$ we can look at with a few glances. One of them is to look at the deployment of individual Web services and communication within the system. Here you can see a set of basic modules at the highest level of hierarchy. This is a data storage module (Warehouse), the mathematical calculations module (FloodMathematic), a module for calculating the statistical properties of the results of modeling (Postprocessing), a module for importing GIS data (Geography), a module for the import of meteorological data. The main module, which serves to define and manage the various scenarios in the system, is FLOREON$^+$ module (Coordinator). This module also serves as an interface to access the system from other systems and users for access to the system (for example, using the Web client).

3 Hydrologic modeling

The following GIS software were utilized:

- ArcGIS (ESRI),
- GRASS GIS (OSGeo),
- QuantumGIS (OSGeo),
- IDRISI Andes (Clark Labs).

GIS software serves as geospatial data preprocessor, tool for hydrologic model schematization and development, tool for meteorological data (time series) preprocessing, postprocessing and visualization tool and modeling tool (e.g. scenarios making, hydrologic layers computation).

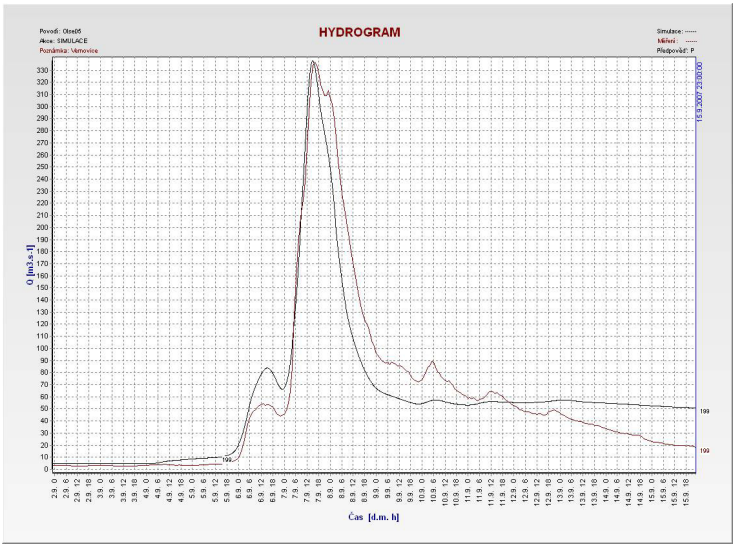

Figure 3: Comparison of simulated and observed hydrograph for calibration period September 2007 in closing profile of Olse basin. Result from HYDROG rainfall-runoff model.

The following hydrologic (rainfall-runoff and hydraulic) models were incorporated:

- HEC-HMS (USACE),
- HYDROG,
- MIKE SHE (DHI),
- HEC-RAS (USACE),
- MIKE 11 (DHI),
- MIKE 21c (DHI),
- GSSHA (USACE),
- DHI ECO Lab (DHI).

Commercial software together with freeware and open source software is used in system FLOREON$^+$ as is obvious from previous list.

We can design various scenarios of using FLOREON$^+$. The decision support making during the extreme floods is the first appropriate scenario. We can divide this scenario to several consequent steps:

1. hydrometeorological data acquisition (both gauges, radar network and NWFS ALADIN) [4],
2. rainfall-runoff modeling and hydrograph prediction,
3. hydrographs handover as the boundary conditions for hydraulic models,
4. water levels modeling and prediction,
5. flood lakes computation in GIS postprocessing.

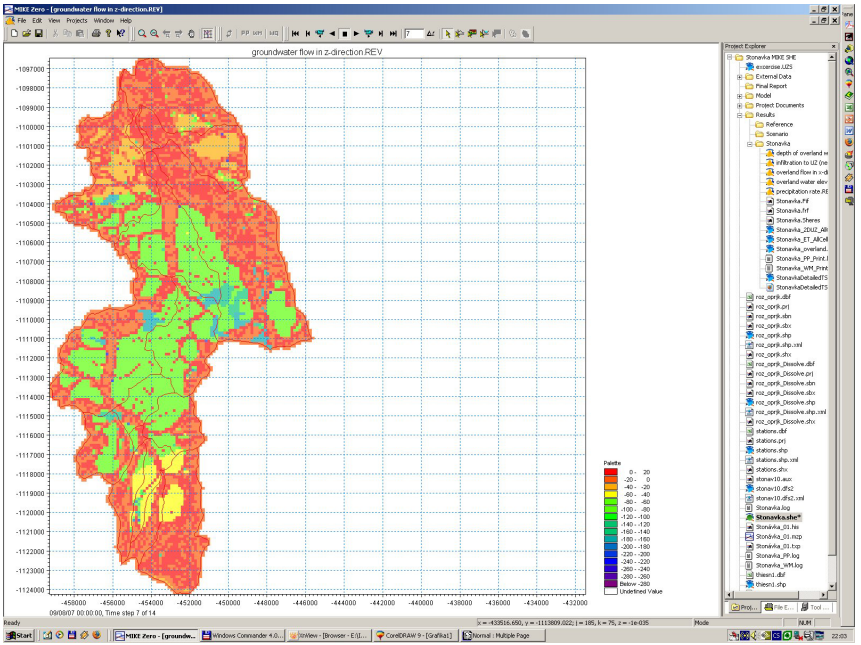

Figure 4: Additional outputs from the fully distributed model MIKE SHE. Grid of the groundwater discharge.

The results obtained from this type of scenario are the information about the flood extremity, flood duration, affected areas and buildings and evacuation particularities (e.g. evacuation routes). This type of scenario is about the application of the data obtained from the near real time operative running of FLOREON+ project.

Long term forecast of environmental changes could be another type of scenario. Changes of land use and land cover, fluctuation of meteorological and hydrological conditions - all these factors affect the hydrologic and environmental conditions in the landscape or basin scale. The changes of sediment yield and water quality are the most important indicators for water management. Typical scenarios are mentioned as follows:

1. analysis and prediction of the land use changes,
2. land use changes impact on the hydrological and erosion conditions modeling,
3. development of GIS layers as the support for evaluation of influence of these circumstances on erosion, sediment transport and accumulation, water quality and water availability for inhabitants, agriculture and forestry,
4. design of further optimization measures for decrease of negative impacts of such changes (e.g. design of detention basins, landscape structure optimization, design of terraces, river channel modifications),

Figure 5: Final output from FLOREON$^+$. Combination of the flood lakes and traffic information.

5. modeling of optimization measures influence in FLOREON$^+$,
6. production of the final GIS layers for decision support.

Dynamical erosion models as SWAT (Soil and Water Assessment Tool) are utilized for the water erosion modeling. Better underpinning of water erosion spatial and temporal continuity, sediment transport and accumulation are amongst the main advantages of such dynamical physical models. Modeling of the various pollutants is the second possibility beside the erosion itself in the watershed scale. Watershed is divided into partial elements (subcatchments) and above mentioned processes are modeled in the same way as the rainfall-runoff relations. Results produced by erosion models could be used in hydraulic models such is MIKE 11 and HEC-RAS for detailed modeling of sediment transport and accumulation in river channel and water bodies. 2D hydraulic models as is MIKE 21c simulate the development of river channels then. Further research is oriented to satisfactory modeling of the rill and gully erosion. Model LISEM is analyzed from that point of view.

Subsequent research is oriented on the water pollution simulation in the more complex way in the watershed scale. Various types of GIS, hydrologic and hydraulic models communication are tested and analyzed. Final solution is oriented to offer the robust tool for the contamination prediction wherever accident is situated. Vulnerability of the watershed to various types of contamination is the other important data set required for such analysis and prediction. The role of GIS and numerical models is irreplaceable in that sense.

The above mentioned examples and scenarios illustrate the using of the system FLOREON$^+$ as the complex system as the decision support system for the operative run and long term planning. Water element remains as the main scope, but our team endeavor and achieves to look at water in more complex way and connected with other environmental problems in the watershed scale. Existing results and further calibration and validation of models bring optimism that our effort has significance.

Figure 6: 3D view of the FLOREON$^+$ results.

Ecological consequences of hydrologic extremes such are major floods and droughts should be analyzed in the proper and efficient way. Combination of GIS and ecological model (e.g. DHI ECO Lab) could be such efficient way. Changes in ecosystem structure, population dynamics, invasive species dynamics and flows of substances and energy in ecosystem are amongst the tasks for solution in these types of numerical models.

Technical solutions for the module of the air quality and pollution is based on the data acquisition from the air quality monitoring, emission data, their subsequent processing in GIS and final short term prediction of air pollution could be processed after the incorporation of NWFS prediction. Analyses of forest health in such cases could be provided by the ecological models again.

4 Conclusion

FLOREON$^+$ is functional, complex and efficient system for hydrologic prediction, modeling of water and air quality, modeling of traffic situation nowadays. These issues are products of operative running of this system and they are combined with the long-term analyses of the human impacts on hydrologic cycle, air quality, erosion and landscape ecology. FLOREON$^+$ is designed as a decision support system for crisis management, hydrologic forecast offices, and local autonomies together with the system of information providing for common inhabitants. All solved themes are integrated in one complex and modular system. Use of high performance computing brings the possibility of satisfy the big amount of users in real time and near real time. The next development of environmental models is oriented to complex modular system development used as the decision support system for crisis management, environmental and urban planning to represent the watershed or administrative district in the complex way. This complexity brings

the tool for experts and information portal based on the only one system. Further migration on the supercomputer helps to achieve that goal.

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