General platform for hydroinformatics systems – a review of concept

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Abstract: This paper provides insight into the Institute's long-standing engagement in the design and implementation of hydroinformatics systems in Serbia and the region. The introduction provides a definition of the hydroinformatics system and different areas of application, as well as an overview of the best practices in the world. An overview of the general platform that was created based on experience in the development of different systems has been presented here. We have described the functionalities integrated into a single software platform based on mathematical models and computational services. Various practical examples of application by the Institute are presented with the specifics of implementation in line with the purpose and characteristics of the studied systems. The conclusion highlights the role of applied hydroinformatics systems and the effects of application by users. Possible further development and implementation directions in water management and hydropower systems in Serbia and the region have been also presented.

INTRODUCTION

Hydroinformatics is an interdisciplinary field of technology originating from computational hydraulics [1] that focuses on the integration of information and communication technologies with hydrology, hydraulics, environmental science and engineering with an increasing frequency of addressing serious problems of equitable and efficient water use for different purposes. Hydroinformatics includes many state-of-the-art applications of modern information technologies in water management and decision-making. It also takes advantage of the latest IT developments in the field of artificial intelligence (including knowledge-based systems, Machine Learning, evolutionary algorithms, and artificial neural networks), artificial life, cellular and automatic finite state automatons, and others, previously unrelated, sciences and technologies. Hydroinformatic tools i.e., simulation modelling, SCADA, remote detection and GIS, artificial intelligence, etc. are currently used in water system planning.

Hydroinformatics covers the application of information technologies in the water sector in the broadest sense. One of them is Hydroinformatics systems (HIS), which have emerged as a means to create conditions that can help optimal water resources management, as well as to resolve existing and potential conflicts within a certain basin or in a certain region in relation to conflicts of interest or development projects that exist in different countries, local communities, individual companies and other legal or physical bodies. HIS contains information and communication components that are closely related to hydrological investigations and focused on the presentation, manipulation, and distribution of data describing hydrological processes, and supports the decision-making process in all aspects. HIS as a Hydroinformatics system is a term used as a synonym where the hydrological-information system is only a component that is common to most HIS systems and is generally characterized by a single-purpose application while hydroinformatics systems are broader systems that include electricity generation, water supply, irrigation, flood and drought risk assessment, water quality and other artificial activities within the system. The earliest ideas and activities in the development of hydroinformatics at the Jaroslav Černi Water Institute began in the 1970s. Since its establishment, the Institute has been a leader in the application of new technologies and is now a regional leader in the development and application of hydroinformatics systems.

The development and use of the hydroinformatics system in Serbia has provided significant knowledge of the behaviour of the hydropower system in the previous period of exploitation, variant management scenarios in the future, as well as real-time operation, thus providing a platform for adequate decision-making and analysis of the achieved management in relation to the expected optimal.

The hydroinformatics system development and implementation involve the development of a complex software platform, with orientation to: the user (user applications), real-time system execution (services), as well as specialized system management (administrator tools). This system was developed based on the principles of modern service-oriented architecture that contains interconnected software components of different uses built over distributed relational databases. This system provides full and precise data retrieval mechanisms from various sources, their validation, processing and archiving, as well as software components for fast and secure data access by users through specialized applications intended to provide support in system management. This set of components for data management in HIS provides for the development of software for the formation of an up-to-date computational state of the system in "real-time", which would bring HIS as an IT platform for management support closer to the daily operational use with the minimum engagement of human resources.

Trends in the development of modern hydroinformatics systems imply greater flexibility regarding the application of different models. The Open Modelling Interface (OpenMI) was launched at the end of 2005 with the aim of becoming a global standard for connecting models and tools in the environmental domain with a focus on water. Deep Learning (DL) studies have gained significant momentum with the availability of computer resources and the popularity of DL algorithms in many water resource data analyses and hydrology tasks. Xiang and Demir [2] proposed a fully distributed physical rainfall-runoff model, NRM-Graph (Neural Runoff Model-Graph), using Graph Neural Networks (GNN) to make full use of spatial information, including flow direction and geographic data.

In recent years, hydrological studies have increasingly used deep learning models [3], including increased data [4], image synthesis [5] and web-based modelling [6]. Simulation methods that account for feedback from participants are also applicable in water resources management, in the form of serious games [7]. Particularly important is the current trend of "digitalization" of water [8], which should provide the broadest view of the state of water resources in real time, by combining information and models with risk management.

The quantity of data available in modern information systems in the field of hydroinformatics is a challenge for researchers, if viewed with conventional tools. Therefore, it is important to consider the application of Big data techniques in hydroinformatics [9], [10].

This paper contributes to the understanding and concept of HIS, such as functionalities for data management, model management, assimilation in hydrological and hydraulic models, as well as a description of the functionality of decision support tools. Here we give a brief overview of the implemented HISs, their development and treatment of some specific issues such as the management of the catchment area, multi-purpose reservoirs and water resources, hydropower, flood forecasting, i.e., early flood warning and flood management, as well as support in decision-making and design and construction. And then, the conclusion presents some future research directions for the development and implementation of HISs as platforms for supporting the planning and management of reservoirs and amelioration systems, as well as future early warning and flood warning systems.

THE ROLE AND CONCEPT OF A HYDROINFORMATICS SYSTEM

Viewed in a broad sense, the hydroinformatics system is a technical system for water management systems support. It consists of a number of interconnected components of hardware, software, measurement facilities and instruments and users of the system. Narrowly viewed, a hydroinformatics system is defined as an organised set of data and software components, which relies on appropriate equipment and hardware. The system is in the service of specially trained technical persons, for the purpose of optimal system management and monitoring the history of system use.

The HIS concept is based on the following functionalities: data management, modelling, support for operational management and strategic planning (Figure 1).

Reliable data enables simulations to be performed with mathematical models, which enables timely decisions to be made at the operational and long-term levels. It can be said that it is not necessary for each HIS to support both operational and strategic levels of decision-making, especially since such systems are much more often expected to provide real-time information on values that cannot be directly measured or on forecasted measurable values. For example, measuring soil moisture can be performed only at individual locations – pointwise, while by using hydrological models, it is possible to estimate the state of soil moisture in the basin in large areas. , By using meteorological forecasts in hydrological models, such assessments can also be performed for the future period. In contrast to the subject applications, strategic planning mainly requires long historical series that can be extrapolated in various ways for many years into the future, including accounting for climate change, which, for example, enables assessments of the cost-effectiveness of investments in hydropower and water management facilities. Thus, it can be said that each HIS implementation is different and is directly related to the availability of data and observation systems, as well as to the needs of system users.

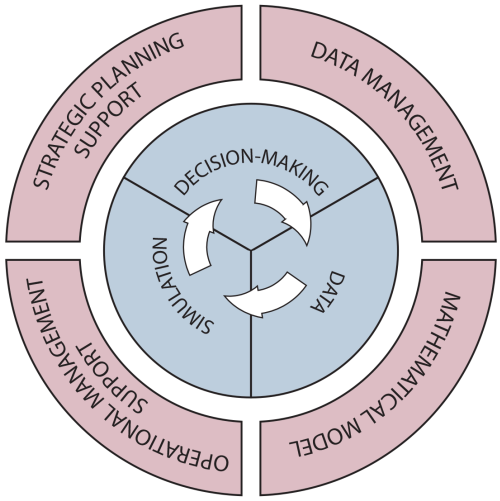

Figure 1. *The concept of hydroinformatics system*

Cyclically related data, simulation and decision-making are the foundations of the HIS concept. This means that data is necessary to perform simulations, while the results of simulations are the basis for decision-making. In doing so, decision-making can also affect the scope of the required data and the detail of the model, so it can be said that these three factors interact with each other during the HIS development and exploitation. The integration of these factors into a functional software system should provide experts with intuitive and efficient tools for accessing and using both observable data and computational values, with the possibility of solving optimisation issues that arise in resolving conflicting requirements in complex hydro systems management. The general structure of the HIS is outlined below, based on which it is possible to implement specific systems in accordance with their purpose.

GENERAL PLATFORM OVERVIEW

The HIS formation and application for a given system implies the implementation of the displayed set of functionalities. Since the basic functionality is data management, certain software components related to the data acquisition, archiving and processing are mandatory factors of all HISs. Also, the functionality of managing mathematical models and calculations is implied in the formation of HIS, regardless of its purpose. Only in terms of the functionality of management support depending on the purpose of the HIS can individual implementations be distinguished, since not all HISs are intended to support decision-making at both management levels: operational and strategic. Based on the experience in the development of various HISs, the experts of the Jaroslav Černi Institute defined the general structure of HIS, as shown in the following figure (Figure 2).

The software components that are executed in the background are logically grouped into three parts: acquisition, central and compute server. User tools are grouped by purpose: data analysis tools, system maintenance tools, operational management support tools and strategic planning support tools. The figure specifically indicates the data flows between the aforementioned units, emphasizing the transformation of data from different sources into validated data, and then data with quality control used in the models in order to obtain computational values. The principles of service-oriented architecture (SOA) [11] are followed in the implementation of the HIS, with the application of modern web technologies following the principles of scalability and robustness.

Data management

Processes related to data management in the HIS take place on the acquisition and central server, while users have access to user and administrator tools where the users access data. The main goal of data management in HIS is to automatically retrieve and translate data from various sources into data and metadata models defined in HIS, as well as to enable data processing and retrieval with quality control information. It is very important that all components involved in data management processes are efficient and reliable, so that at the time the data is needed to support decision-making they can be instantly downloaded and used for computations with the required degree of reliability.

In the data management process, the acquisition server is the entry point to the system. Based on this, the task of the acquisition server, within the system, is to collect measurement data as well as relevant information on the state of the system itself. The number of acquisition servers within the system is not limited. Each acquisition server has a connection to a central server via a data transmission component. Automatic data collection is based on the principle of ETL (Extraction, Transformation and Loading), which provides for the integration of data from a large number of different sources. The implementation of the ETL process is modular and configurable, which provides for easy adaptation to possible changes that occur in the system, and this structure supports the subsequent acquisition of new measurements that are not initially envisaged, resulting from the further development of the system.

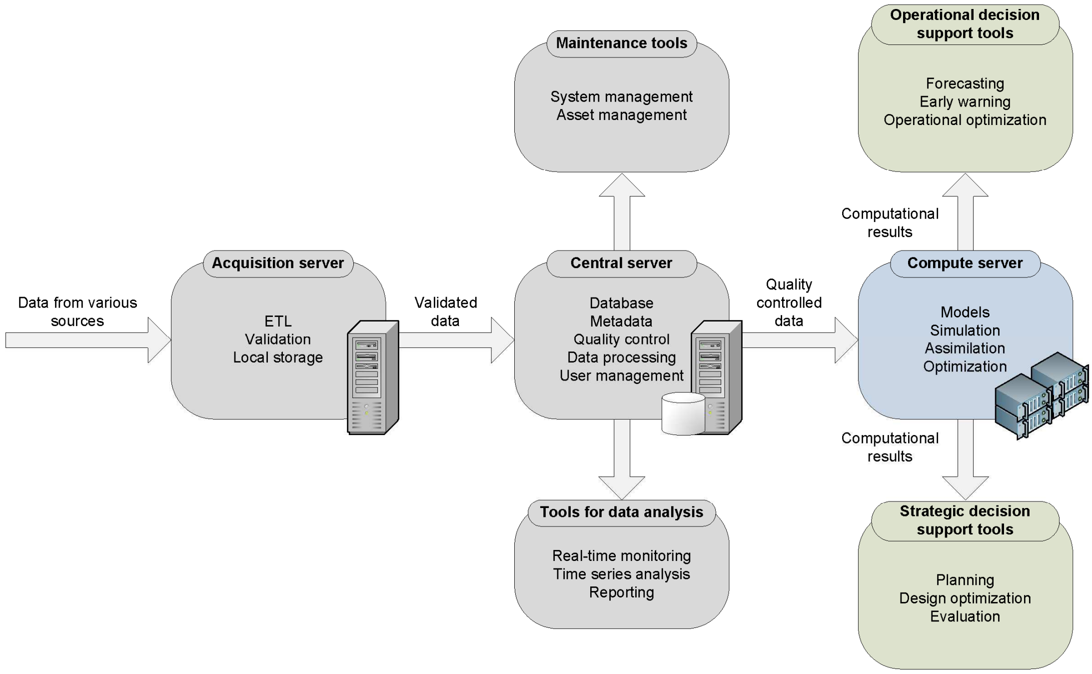

Figure 2. *Structure of hydroinformatics system general platform*

An integral part of the acquisition server, within the data receiving layer, is the data validation process. This process implies that, before registering in the local storage, a check is carried out on each data piece received. The result of this check is a data status that may be either correct or incorrect. This is how the data validation process on the acquisition server can filter the input data and allow the rest of the system to continue to work only with the correct data. Depending on the configuration of the acquisition server, all incoming data can be sent to the central server, or only those that are, in the validation process, assessed as correct.

Upon download and validation, all data is stored in the local data storage. The data stays in the local storage until it is transferred to the central server, after which the storage in the local storage becomes time limited. This means that after a certain period of time defined by the configuration has elapsed, the data is removed from the local storage. This is how the local storage serves as the time-limited redundancy of the collected data on the central server. In case of unforeseen loss of data from the central database, data from the local storage, within a certain period of time, can be sent to the central server.

The central server is a subsystem located in the centre of the information and communication structure and implements the essential functionality of the system. The central server is a fundamental element of the data management process. Since all system elements refer to the central data server, its basic task is to ensure competitive access to its resources, primarily, the central database.

The data reception service is located on the central server, which represents the interface to all elements of the system writing data to the central database, which means that data to the central database can be written only through the data reception service.

The other key service determines the technical quality of the data. The Technical Data Quality Service is designed to determine the usable value of data in the rest of the system and functions on the basis of evaluators that the system administrator can form in accordance with the nature of the data and their purposes. The application of evaluators [12] is needed to achieve robustness. Evaluators only require data from the series to be evaluated for computation purposes. The evaluation of data quality based on values from another time series is also supported (for example, the measured discharge through the power unit that recorded zero production is probably not reliable data). Interpretation of data based on quality evaluation enables users and automated software components to apply their own criteria: whether the data is used, regardless of quality, or whether only data with a quality evaluation higher than the threshold can be used (Figure 3) and similar. The exchange of quality data with other systems is also envisaged, using structured descriptions of schemes [13].

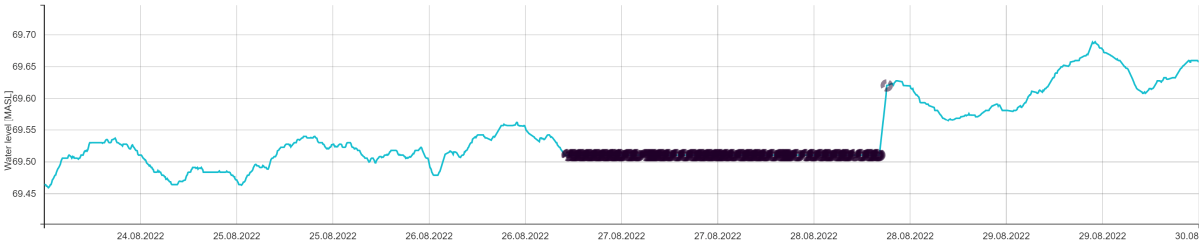

Figure 3. *Data recorded at a hydrological station with discarded data marked (quality of marked data is below threshold)*

Any request that is made from any element of the system to the central server must go through the access management service to verify the corresponding access rights. Access rights to the system have been implemented through several levels. The first and basic level of access to the system, and thus to the data, is the username and password. Each user application contains this level of protection. The next level of protection is the determination of the access right of registered users to certain elements of the system. The third level of protection is defining the access right to data in the system. The fourth and final level of protection is the definition of rights to data in the central database. Authorized professionals (experts) have the right to change the measured data and save the changed data in a central database, with a specific system note.

The data processing and provisioning service is an interface to all elements and subsystems that use data from the central database. All requests for data are made through the data processing and provision service. Data processing is implemented at the client's request and only the original data are stored in the database. Arithmetic expressions and data aggregations may be used in the processing procedure, and information on data quality shall be considered. All processing parameters can be configured via the administrator tools.

The central database is a repository of all data in the HIS because it gathers all time series collected by observation in the system, data on the observation system, documents and data on the functionality of the HIS. The functionality data contained in the central database refer to graphical layers, time charts and user accounts. All data are time-referenced, so it is possible to monitor the history of changes during the use of the system.

The bulk of the central database is data on observation time series. The central database provides for the archiving of relevant measurements into a system that is designed to optimally collect and provide the user with the data recorded at different locations and systems. Also, the implementation of the central database standardizes the exchange of data between users, thus enabling an integrated approach to analysis, decision-making, and research in the area of the broader basin area. There are also data on the quality of measured technical data in this unit, which are set within the system and serve to consider the reliability of data for use in analyses and computations over mathematical models.

The system of observation and data collection is documented in the central database in terms of spatial relations, characteristics of measuring equipment, condition of measuring equipment, etc. Observation system data are recorded in a central database with a time reference, so it is possible to monitor the state of the system over time, from the introduction of entities into the system, through changes in characteristics, to the archiving of entities.

The execution of HIS services and tools relies on data in the central database, both due to the use of time series data and the use of other data used to configure operations and form graphical presentations. The contents displayed in applications (graphic layers, diagrams) are stored in a central database and are related to the respective time references. The operation of the tools and services using these contents is aligned with the data in the database, so it is possible to look at changes in graphic presentations through the period of exploitation of the facility. User accounts and access rights to system resources are also stored in a central database.

In addition to the aforementioned data, the following data are stored in the central database: user notes, user data types, groups, documents, etc. This further facilitates the interpretation of time series data and possible changes in the measuring system that can lead to sudden changes in observed values or interruptions in time series.

In addition to the basic data that is stored in the central database, the metadata database stores data that follows subject data and enables a better understanding of the data in the central database. A metadata model has been implemented in HIS, which includes inheritance by hierarchy, which significantly facilitates the administration of metadata in the system.

User applications for data analysis are formed on the basis of data management mechanisms, the purpose of which is to enable access to data in a uniform manner and with the use of content created in the system by administrators. In particular, panels for real-time data review are formed, as well as layers and diagrams for historical data review. It is also possible to form reports based on data from the central database and the data obtained from their processing.

A special group consists of administrator tools that configure software components and maintain the database and metadata. These tools also enable the maintenance of data on measuring equipment, which significantly facilitates the maintenance of the monitoring system that is under the responsibility of the user.

Model and simulation process management

Various mathematical models can be implemented within the HIS. Hydrological models are most often found, but very often they are combined with hydropower and 1D and 2D hydraulic models. It is also possible to apply material transport models, groundwater flow models and many others related to the movement of water in nature. Due to the nature of the modelled system, it is often necessary to introduce additional models (e.g., hydraulic model of flow through the karst canals for basins with karst, etc.). It is necessary for HIS to enable the connection of models with data, as well as the interconnectivity of models.

The models in HIS have full utility value only if they are implemented in the form of executable modules that enable setting input data, running computations and downloading results through HIS user tools. This functionality is achieved by encapsulating the model files and the executable files of the solver into a wrapper. It implements an interface for computation preparation and running. It is possible to manage the computation and monitor the original solver information via wrapper. Reading the results is also available via the interface, whereby it is also possible to perform various processing and post-processing, before the results are displayed in the tools.

The use of wrappers for executing computations in mathematical models also enabled the application of algorithms for optimisation and assimilation of measured data. In particular, the HIS provides the application of a platform for parallel evolutionary algorithms to solve multi-criteria optimisation problems that occur in the management of water resources. One example is HIS Iron Gate, where it is necessary to align the division of the hydro potential of the Serbian and Romanian sides with the restrictions defined by the rulebook on the use of the complex Iron Gate system, so that the optimisation results are available at the operational level.

In addition to optimisation problems for decision support, it is also possible to implement algorithms of assimilation of measured data into model states on the same platform, so that the reconstructed model state values are better matched with the actual ones, which on the other hand enables better forecasting of the state and output from the model. One of the more recent examples of the application of assimilation is the service implemented in RNU "Kolubara". This implementation involves data on air temperatures, rainfall and levels in river courses collected from the observation network, thus updating the coupled hydrological-hydraulic model of the basin for the needs of early warnings and flood warnings.

All the aforementioned functionalities regarding model and computation management are implemented on the compute server, which is also an indispensable part of HIS. Very often, there is also dedicated high-performance hardware (High-Performance Computing) within the compute server, used to implement computations and solve optimisation problems. The possibility of engaging cloud resources is also envisaged if the procurement and maintenance of the HPC cluster is a too high cost for the HIS user.

Decision support tools

In general terms, HIS contains user-based decision support tools that enable analysis of measured data with quality control and computation results in mathematical models in order to make decisions at the short- or long-term level. Specific HIS implementations may have only operational management tools or only strategic planning tools, depending on the purpose and needs of the user.

Operational management support in HIS relies on real-time model state reconstruction mechanisms and value forecasting in the near future. User tools for this purpose enable quick verification of expert assessments, short-term plans and the formation of alerts on close events. Very often, the values that are crucial for decision-making cannot be directly measured, so it is possible to compute the estimated value through these tools, which on the other hand enables informed decision making. The automated assimilation process that occurs on the compute server enables the formation of an up-to-date state of the model on the basis of which more accurate forecasts can be formed. These forecast values can be used to check the plan, for example, in HIS Iron Gate, the daily production plan at the Iron Gate 1 Hydroelectric Power Plant (HPP) and HPP Iron Gate 2 is thus checked. If there is a need to adjust the plan, the tool can offer alternative plans or enable the plan to be checked as desired. Another possibility of applying the forecast values is in the early warning and flood warning systems, where the forecast values of the level are compared with the threshold or, more precisely, with the actual geometry of the bank and embankment for even more detailed warnings.

To support strategic planning, i.e., decision making at the long-term level, user tools enable analysis to be implemented over long periods of time in order to assess the effects of investments or changes in management rules. It is possible to perform statistical data processing with HIS tools based on long time series and to form relevant hyetographs and hydrographs in order to create hypothetical scenarios. For example, hundred-year and thousand-year water hydrographs for design solutions testing. An example of such tools is the tool for analysing the impact of floods on the highway and nearshore to support the design and construction of the Morava Corridor. The tool enables the initiation of a hydrological model whose results are the input for the 2D hydraulic model. They were used to check the risk zones in the West Morava nearshore, as well as the potential danger for the designed road grade. In terms of estimating the investment effects, mostly hydrological models for decades long computations are applied. This is done by taking into account the results of climate models for different climate change scenarios. The results of hydrological models are then used in hydropower models to assess the efficiency of different technical solutions. An example of such a tool is the strategic planning tool in HIS Drina. It is possible to account for other water consumers (water supply, industry, etc.) in order to estimate annual generation at future hydroelectric power plants in the Drina River basin. The example of the tool for periodic updating of the rules of HIS Prvonek management shows the application of models and optimisation algorithms for assessing the efficiency of the management rules of the multi-purpose reservoir. This tool takes in account changes in water consumption, but also changes in the estimated freeboard resulting from the possible climate changes.

EXAMPLES OF PLATFORM APPLICATION

During the long-standing practice of hydroinformatics systems development, the Jaroslav Černi Institute has developed a number of systems that are in use in various fields of application, the most important of which are: HIS Drina, HIS Vlasina, HIS Pirot, HIS Vrbas, HIS Prvonek, the application of the Early Warning System (EWS) in the Kolubara River Basin, the predicting model of inflow into the "Trebišnjica" system reservoir, as well as the application of the HIS for the analysis of hydrological-hydraulic scenarios along the route of the planned highway of the Morava Corridor. A good example of a review and synthesis of a large number of issues related to the development of hydroinformatics systems to manage the hydropower potential of Serbia is described extensively by Divac et al. [14]. The three main hydroinformatics systems in Serbia are separately highlighted and described in detail. Also, a comprehensive description of the development of the Drina hydroinformatics system has been presented in the paper authored by Milivojevic et al. [15].

Drina river basin management

The Drina River Basin covers the territory of Serbia, Bosnia and Herzegovina, Montenegro and a small part of Albania. The area of the basin is about 19,980 km^2. The need to develop the Drina Hydroinformatics system was imposed by the specific features of the area of the Drina River, as well as because the facilities located in the Drina basin have significant roles in the system of Public Enterprise Electric Power Industry of Serbia (PE EPS). In early 2002, the "Drina Hydroinformatics system" (HIS Drina) Study was initiated by PE EPS and the "Jaroslav Černi" Water Institute.

The objectives of the development of HIS "Drina" were: to integrate hydrometeorological, hydrogeological, hydropower and other data and their availability to users, to support operational management decisions at hydro powerplants, to support the decision-making required for the selection of optimal solutions for water use, protection against water and water protection, to support the process of interests alignment within the basin management, to establish and promote a system for coordination and cooperation, to educate professional staff and to spread information, understanding and public participation in the process of management and protection of the aquatic environment.

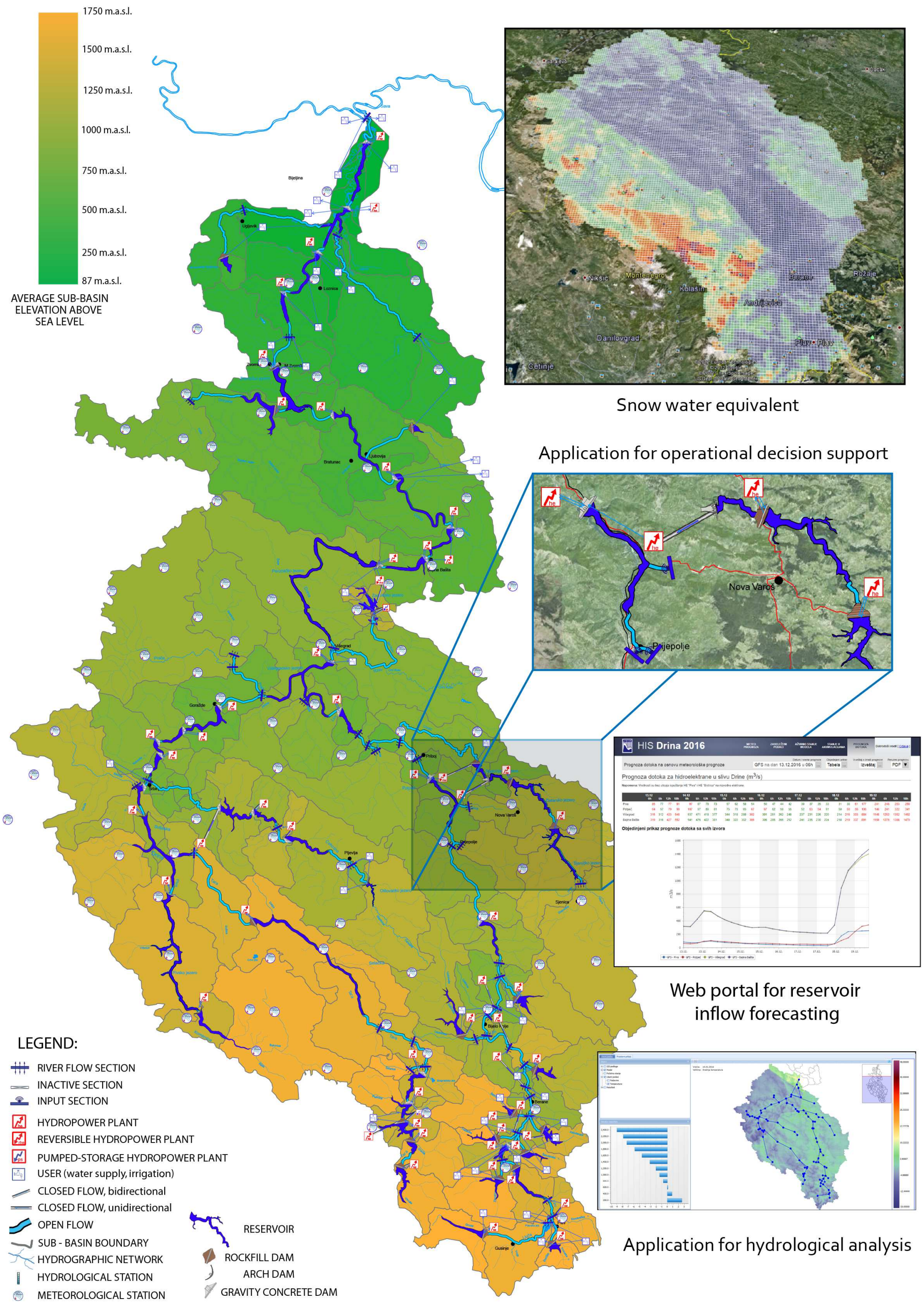

Figure 4. *HIS Drina – schematic model and user tools*

The development of HIS Drina over the years took place through phases during the 2002 - 2017 period. Between 2008 and 2010, it was developed simultaneously through the project "Development and implementation of hydroinformatics systems in order to increase energy efficiency in the hydro-potential management in the Republic of Serbia". Based on the aforementioned project, HIS Drina phase 3.1 started in March 2010 and was implemented and put into operation in 2011. During 2012 and 2013, the software was used jointly, which resulted in a report based on which the terms of reference were designed and then a contract was signed in 2014 for the implementation of HIS "Drina" phase 3b. This phase was implemented from November 2014 to February 2016. After working meetings and the development and installation of software components, the expert council of PE EPS adopted HIS "Drina" 3b as a complete software solution that is successfully implemented in the real exploitation environment in PE EPS.

In order to unify HISs into PE EPS, the system HIS "Drina" 2016 version was formed in 2016. The transition to the new version was not integral, but the development took place partially. The 2016 version of HIS "Drina" consists of the following subsystems: acquisition server of HPP "Bajina Bašta", acquisition server of HPP "Zvornik", central server, user applications for data analysis, user applications for computation management and administrator tools.

There is a layer with simulation models within the central server, which are sued to simulate the processes that are important for water resources management, as well as for the use of hydro potential on the basin.

One of the models within the server is the hydrological model for short-term calculations in the basin [16], which is used as a hydrological prediction model. The time step of this model is 6 hours and is used for making operational forecasts of inflow from the basin and for developing possible scenarios of high water occurrence based on one or more meteorological forecasts. The resulting inflow forecasts can be used in the user application to support operational management and can be published through the management support portal.

Another layer located within the central server is the layer with computational services. Within this layer, among other things, there is a service for the assimilation of measurements. The purpose of this service is to connect the hydrological prediction model and the optimisation service with the available data through the layer with the central server data. The service automatically updates the state of the model using the optimisation service and the data that has arrived updates the state of the basin and stores the obtained values in the database.

User applications for computation management include: user application for strategic planning support, user application for operational decision support, user application for hydrological analysis, and web portal for reservoir inflow forecasting. Application to support strategic planning should be highlighted, because all locations of potential hydroelectric power plants are processed within HIS Drina in such a way that it is possible to perform long-term computations based on the designed characteristics, but it is also possible to test different characteristics of hydroelectric power plants and reservoirs. The results of the computations are possible energy generation at future hydroelectric power plants, taking into account water consumers (water supply, industry, etc.).

The hydrological model developed within HIS Drina, with certain modifications and improvements, was applied within the development of the "Support to Water Resources Management in the Drina River Basin" project – SWRMDRB in 2017 and within West Balkans Drina River Basin Management (WDBRBMP) project – Study of water resources of the Drina River Basin (DRB) in 2020 and hydrological and hydraulic modelling of the Drina River Basin with the reservoir management.

Large-scale hydropower management at Iron Gates I and II

HIS Iron Gate includes two hydropower and navigation systems: HPP Iron Gate 1 and HPP Iron Gate 2, with the system Iron Gate 2 connected to the system Iron Gate 1. These two systems are the most significant hydropower generation systems in Serbia, covering over 50% of hydropower generation, which is approximately 18% of total electricity generation. The management of HPP Iron Gate 1 and 2 systems implies meeting the requirements of the energy systems of Serbia and Romania, as well as a number of restrictions on control sections on the Danube, ensuring the navigation and stability of the river bank. HPP Iron Gate 1 and Iron Gate 2 are significant and complex hydropower and navigation facilities with a great impact on the Danube River levels and flow. In order to maximize the use of hydropower potential regulated by these systems and obey constraints on all control sections on the Danube, it is necessary to possess an operational Hydroinformatics system – HIS Iron Gate. This way it is possible to gain knowledge of the current observations in the system and perform all computations required for the exploitation of these systems.

Observations of the hydrological situation on the Danube and tributaries are implemented at: gauging stations set on the Serbian side owned by HPP Iron Gate (10 sections), gauging stations set on the Romanian side (12 sections), as well as gauging stations owned by the Republic Hydrometeorological Service of Serbia (RHMSS) (6 sections). In addition to the water level, RHMSS gauging stations also provide discharge data on river flow, a functionality that other stations do not have. Level data from the gauging stations belonging to the observation system at the Hydropower and Navigation System (HPNS) Iron Gate are collected and archived in the SCADA database. Data from RHMSS stations are obtained within the hydrological report together with forecasts for the next 5 days.

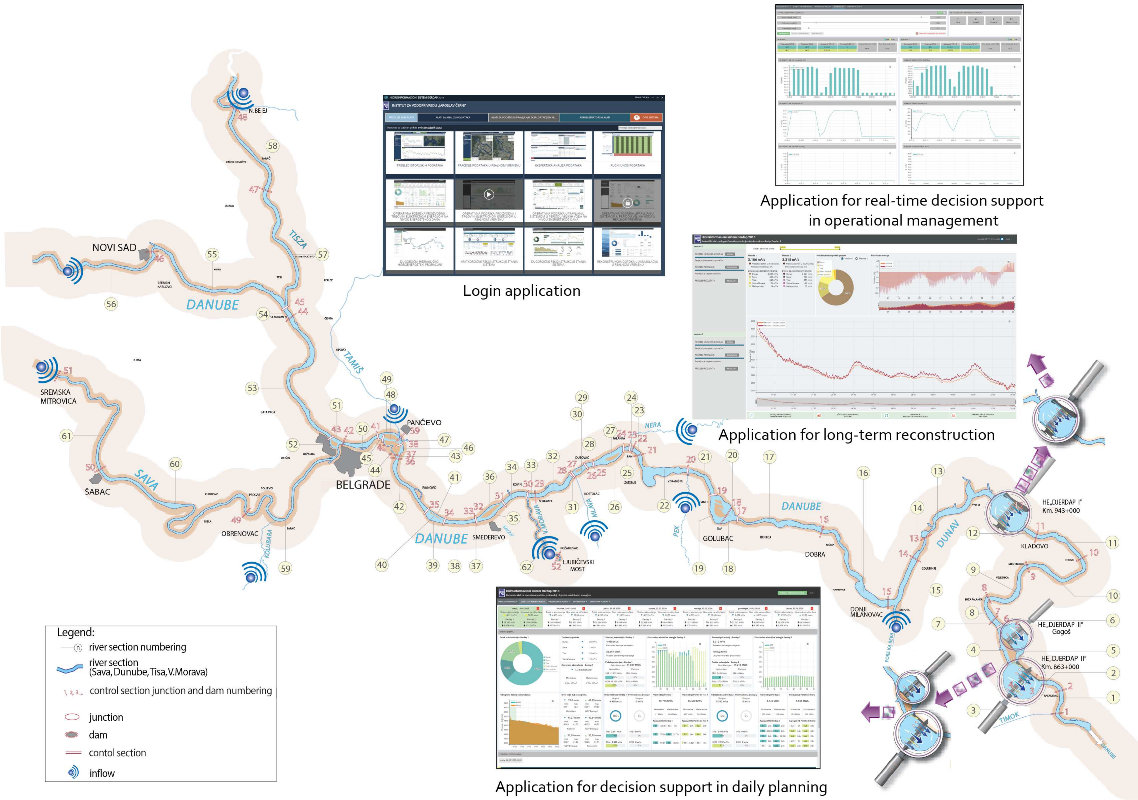

Figure 5. HIS Iron Gate – schematic model and user tools

Active and reactive power measurements are performed on HPP Iron Gate 1 and HPP Iron Gate 2, on each individual power plant unit. Subject data is archived in the SCADA system of respective HPPs. Hourly discharge data at hydropower plants and spillways are computed by the hydropower model and stored in the computational database and loaded when querying this application. So, there's an automatic discharge computation in the background based on 5-minute data. In addition to the computed discharges, information on the number of non-existent data the service use to make computations, as well as the number of low-quality data used to perform computation, is stored. On the spillway dam of the HPP Iron Gate and each field, an automatic measurement of the water gate position on the spillway bay is performed. The measuring equipment on the spillway bays of HPP Iron Gate 2 provides data on the water gate position, as well as on the discharge through the spillway bay. This data is also archived in respective SCADA systems. In total, about 27,000,000 data pieces are downloaded annually into the data management system of HIS Iron Gate.

The hydraulic-hydropower model is a basic part of the complex of specialized HIS programs. The mathematical model of HIS Iron Gate is a model of water movement in a large and complex area, including: water inlet into the system, open channel flows, spilling on spillway facilities at the dams and flow and power generation at hydropower plants. This model allows the reconstruction of the inflow into the reservoir in real-time.

Within this HIS there is also a model for assimilation of levels from hydrological stations [17]. Data assimilation involves setting the computational state of a system such that it reflects, to the greatest extent possible, the measured values at specific locations [18]. Once this state has been set, individual values are obtained as a result of the model at all other locations in the system, and additional values that cannot be accurately measured can be also obtained.

The user tools available within the HIS Iron Gate provide decision support in daily planning, operational management support in real time, as well as long-term and short-term analyses and reconstructions.

Cascade hydropower system „Vlasina“ management

The hydropower system "Vlasina" consists of the reservoir of the Vlasina Lake and Lisina with the system of channels and tunnels, as well as four HPPs: HPP "Vrla 1", HPP "Vrla 2", HPP "Vrla 3" and HPP "Vrla 4". The basin of the Vlasina Lake is located on the catchment divide between the Black Sea and the Aegean basin, and the position of the lake provides an extremely favourable possibility for collecting and accumulating water and has a high hydropower potential compared to the Južna Morava River.

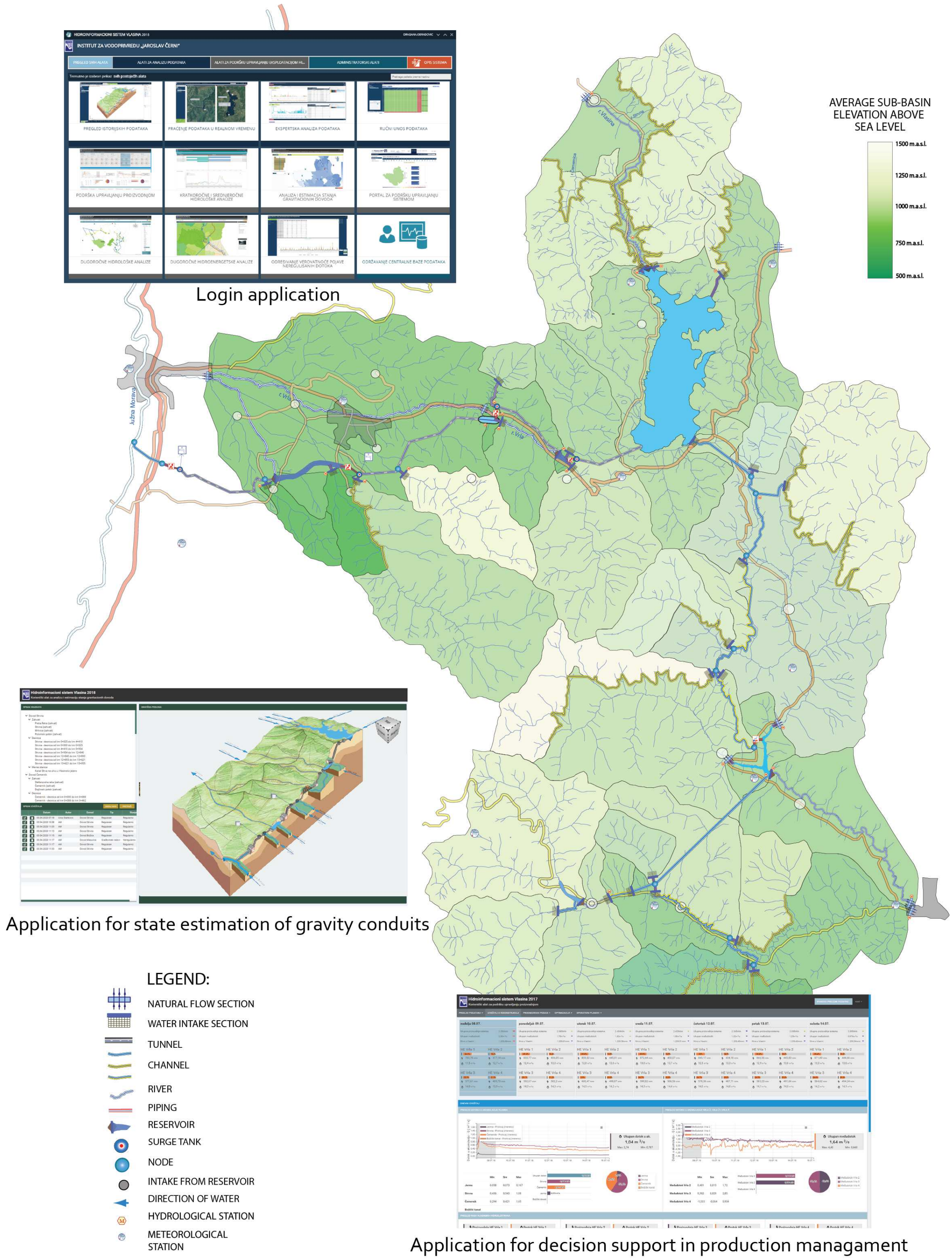

Figure 6. *HIS Vlasina – schematic model and user tools*

The "Lisina" reservoir was built on the Božička River in 1978, and is part of the Vlasina Hydrosystem, as the water is transported from there into the Vlasina Lake. The reservoir is supplied with water from the Toplodolska River, Božica and Lisina and transported to Ljubatske waters. Part of the Božica River waters is caught by gravity conduits and runs off directly into the Vlasina lake. This system is a significant generation facility in the power grid, because it is used for peak power generation and as a cold or rotating system reserve.

Monitoring data are received into the acquisition server from publicly available sources – SCADA, RHMS data, meteorological stations and hydrological stations on the channels. During the 2018 - 2020 period, the monitoring system of "Vlasinske HPPs" was improved via the installation of new automatic meteorological stations. The number of data processed by the acquisition server on a daily basis is approximately 10,000 data.

For the purposes of HIS Vlasina, a compute server with appropriate mathematical models was also developed. Hydrological models (model for long-term computations and model for short-term calculations, i.e., forecast model), hydrological-hydropower model for long-term computations, hydraulic model of the gravity conduits and hydraulic-hydropower model for operational management were also developed. These models are provided with tools for long-term hydrological computations, hydrological calculations and forecasts in under a high-level of uncertainty of the real state of the system, as well as the uncertainty in meteorological forecasts. It is also possible to perform long-term hydrological-hydropower computations in order to analyse the effects of natural and artificial water movements in the basin, and to simulate flow in gravity conduits and water intake on channels and water intake structures.

The assimilation of the level from the gauge on the channels is performed within HIS Vlasina, in order to ensure continuous operation. The problem of the cascade operation, which includes inflows between power plants, is solved as an optimisation problem in order to meet the plan and system constraints, while minimizing the spilling at the dams.

HPP Pirot decision support system

HPP Pirot is located in the village of Berilovac, near Pirot. It is water supply from the Zavoj reservoir on the Visočica River. It is a reservoir hydropower plant with a diversion and a tunnel with a pipeline under pressure and a reservoir for annual levelling. The installed power of the power plant is 2 x 44.5 MW, with an installed discharge of 45 m^3/s.

Figure 7. *HIS Pirot – operative management tool*

From available data sources, which include the SCADA system, HPP Pirot and RHMSS stations, approximately 5,500 data is received daily, which enables monitoring of the system operation, as well as making decisions on management in real time.

In HIS Pirot, semi-distributed hydrological models were implemented: for long-term simulations and for medium and short-term simulations, a hydraulic model for the computation of steady and unsteady flow, a hydropower model for the calculation of volume changes in the Zavoj storage, a hydrological-hydropower model for long-term hydropower simulations and a statistical model for setting the probability of the occurrence of unregulated discharges.

Forecast of inflow into the Zavoj reservoir is the result of a meteorological forecast that primarily passes through a hydrological model that provides the computational values of the inflow.

Within the hydrological model for long-term simulations, physical processes are simulated on a daily basis, whereby the input parameters require the daily rainfall total, as well as the minimum and maximum air temperatures. The hydrological model for medium and short-term simulations is based on physical laws describing the transformation of surface and underground runoff. The hydraulic model is used to check the constraints in the Nišava River. These constraints are defined by the minimum and maximum water level in Nišava River downstream up to the HPP Pirot discharge. The hydropower model computes the volume change in the reservoir by means of the head and the power of the unit. The hydrological-hydropower model is a model of water movement through facilities in the HPP Pirot system and the transformation of water power into electricity at HPP Pirot. The computations obtained from this model are used for simulations and analyses of the multiannual generation plan, the management plan for medium-term periods, as well as for analysing the impact of changes in the system. The statistical model used to set the probability of occurrence of unregulated discharges was used because probabilistic analysis of realized discharges is of great importance for long-term forecasts of the state of water resources. This analysis makes it possible to set annual, monthly and weekly values of discharge series based on different probabilities of occurrence.

Vrbas river basin management

The Vrbas River is the largest in western Bosnia. It is the right tributary of the Sava River on the northern slopes of the Dinaric Mountain range. The basin area of the Vrbas River is approximately 6,386 km^2. The hydrographic network of the Vrbas River is relatively broken in the upper and lower part of the basin, except for parts with expressed karst (such as the Janja River basin, Pliva River, etc.). The most significant tributaries of the Vrbas River are Pliva, Ugar, Crna Rijeka and Vrbanja. In the upper and middle part of the basin, a larger number of karst springs occur.

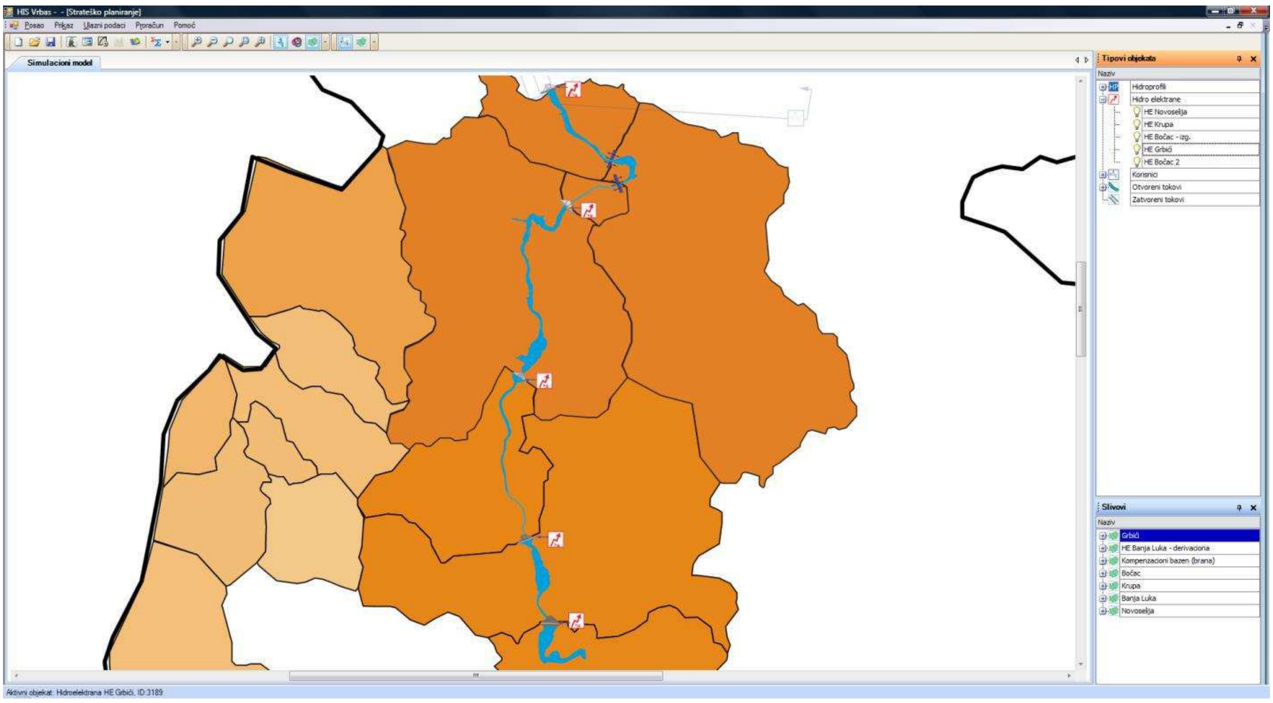

Figure 8. *Using the strategic planning tool for studying potential investments in new hydropower plants*

One of the most important goals of the Hydroinformatics system "Vrbas" implementation is, in the short term, optimal management in the current state of construction. This management is required due to existence of various power companies from different countries, with different interests, in conditions of pronounced unevenness of natural inflows and consumer needs. In the long term, conditions for the multi-purpose use of water in the Vrbas River Basin will be created, both for the engagement of hydropower potential for electricity generation, as well as for water use and other purposes, while reducing the risk and uncertainty related to water resources (pollution, flood protection, etc.).

The hydrological model contained in HIS "Vrbas" enables computation of the water yield from the basin in specific nodes of the hydrographic network, which is an input for further computation of the flow and exploitation of water in a given river system and existing and future reservoirs.

There are two approaches in water resources management in terms of the application of hydrological models: long-term planning and short-term planning, which serves to obtain operational forecasts of inflows into reservoirs. The first approach involves the use of historical series to calibrate model parameters, for its use in long-term forecasts. The second approach involves up-to-date observations of the model state and the system input, together with the current forecasts of the hydrometeorological service. All of the information is entered into a distributed hydrological model that simulates the balance of surface and groundwater in the basin, thus evaluating the model state to improve the forecast of the inflow into the reservoirs for operational planning purposes.

Sequential data assimilation was applied in HIS Vrbas, which implies that only the last observed values are used for the computation, as soon as they are available. This approach leads to discontinuity in the moments observed before and after a specific up-to-date state, but is suitable in cases where the behaviour of the system is predominantly determined by external boundary conditions. The service for the calculation of the up-to-date state in HIS "Vrbas" was implemented in the form of an automated service that can work without the user's influence. A service management tool for the up-to-date state was provided for the purpose of monitoring operations and occasional corrections.

Inflow forecast for storage in a karstic basin

The HPP system on the Trebišnjica River includes the HPP Trebinje I, HPP Trebinje II and HPP Dubrovnik. The basin area of the source zone of the Trebišnjica River covers an area of about 1,150 km^2. Although the entire area is characterized by high infiltration capacity, three zones with highly concentrated infiltration can be distinguished: Gatačko polje, Cerničko polje and Fatničko polje. The high infiltration capacity is due to the karstification of rocks in one part of the basin area; the depth up to which soluble rocks are exposed to the karstification process varies in a wide range.

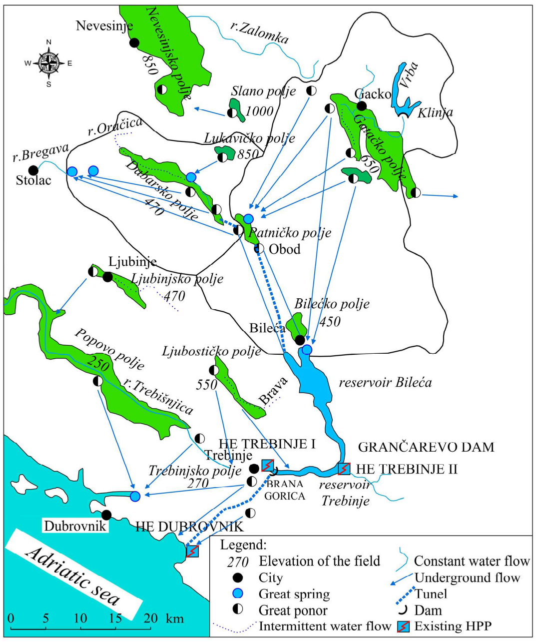

Figure 9. *Surface and karstic flows in the Trebišnjica River basin*

The operational application of the predicting model of inflow into the reservoirs of the "Trebisnjica" system relies on the timely use of systematized and reliable data in order to bring the model conditions closer to the observed values. Data coming into the considered system include measurements from the network of stations (manually entered data, automatic measuring stations, etc.). As the obtained data have different discretization periods, it is necessary to use predefined mathematical relationships to process raw data and create new data.

A hydrological model and a hydraulic model for forecasting the inflow into the reservoirs of Bileća and Gorica were created within the Trebisnjica forecast mode. The hydrological model was distributed and based on physical laws describing the transformation of surface and underground runoff. The input to the hydrological model is an up-to-date model state and a meteorological forecast, and the result is the discharge on the profiles of the hydrological model. The hydraulic model takes the outputs of the hydrological model, together with the up-to-date state of the karst aquifers. Upon completion of the hydraulic model computation, inflows into all hydro sections, runoff from the karst, as well as new states of vertical balance units and the karst component are obtained as a result. Inflows into the reservoirs of Bileća and Gorica are obtained by aggregating the respective inflows from the hydro sections and the karst. Based on the forecast values of the inflow, hydropower plant outflows are set, but also the control effects on tunnels with gates/flashboards that transport water between the karst fields.

Prvonek storage management

The Prvonek Dam is located on the Banjska River, the right tributary of the Južna Morava, with the dam site located approximately 9 km from the mouth to the Južna Morava, at the location of the village of Prvonek. The Prvonek Dam is a regional multi-purpose water management facility, serving the following: water supply for the population and industry of the City of Vranje, the Municipality of Bujanovac and the Municipality of Preševo, flood protection, low water processing in periods of unfavourable hydrological conditions in the basin, as well as electricity generation. The Prvonek dam reservoir is fed by the waters of the Banjska River and the Gradasnica River. The Prvonek dam basin is located at an altitude of between 540 and 1806 m above sea level.

The concept of Prvonek reservoir management is based on the fact that this facility is multi-purpose, and therefore the conservative rules of management must be changed in terms of multi-purpose water use. The practical application of the management principle is solving the optimisation problem of water delivery from the multi-purpose reservoir Prvonek, which will come up with a set of best management rules for hydrological input, reservoir states, user requirements, and other limitations.

A reservoir management hydroinformatics system was formed for the Prvonek reservoir basin. The system is based on the observation network in the basin area and the distributed hydrological model [19]. By running a hydrological model, system components can obtain information on model states based on the observed input data (rainfall, temperature, etc.), which can be used for short-term and long-term analyses in order to improve the operation of the system. Also, the model calculates runoffs from the basin for forecasted input data (meteorological forecast of rainfall and temperatures), so in the system components, forecasted values of inflow into the reservoir can be used for planning the water consumption from the reservoir, preparation for the arrival of the flood wave, etc.

As part of the implementation of the reservoir management system, the rules of reservoir management are defined based on the current values of the headwater level and the inflow into the reservoir. These rules take into account the volume reserves for the acceptance of the flood wave (the so-called freeboard), as well as for the water supply and the eco-friendly flow downstream of the dam. The rules are defined seasonally, based on multiannual series of measurements and application of the hydrological model.

Since changes in water supply requirements (mainly upward trend) occur over time, but also changes in climate patterns lead to the occurrence of concentrated rainfall, it is possible that the initial management rules may become inadequate. That is why an optimisation module has been installed in the system, which enables the verification of management rules and the definition of new rules based on the latest measurement sets.

Tamnava flood early warning system

The need to develop early warning systems for floods in the Kolubara River Basin stemmed from the predisposition of the basin to form the torrent flood. This predisposition refers to geomorphological, hydrological, hydraulic and meteorological conditions. Due to the limited environment required for the implementation of effective flood defence in the zone of critical sites, as well as due to the limited possibilities for structural (investment) measures, PWMC "Srbijavode" estimates that the development of a modern flood early warning system raises the level of preparedness for an effective flood wave response.

The development of an early warning system in the Kolubara River basin was started via a pilot project in the Tamnava River basin. The following software components have been integrated as part of the system development: data management software, mathematical models and computation services, user tools for monitoring the hydrometeorological status in the Tamnava River basin, user tool for analysing and forecasting the hydrological situation, user web portal for information dissemination in the Tamnava River basin and administrator tools.

The monitoring system was further developed by setting up a supplementary network of stations. 3 hydrological and 4 automatic rainfall stations were built in the Tamnava River basin and put into operation within the FEWS "Kolubara" project. One of the rainfall stations includes disdrometer and a sensor for air temperature and humidity measurement. The system also uses data from the existing state network of stations. Around 24,000 data flows into the data management system every day. In addition to historical data, the system receives rainfall and temperature forecasts for the next 10 days twice a day, based on which, by computing the coupled model, discharge and level forecasts are made.

The coupled hydrological-hydraulic model was formed for the FEWS Kolubara, with the aim of forecasting levels along the Tamnava and Ub rivers based on the available rainfall and temperature forecasts in the basin. The model consists of a hydrological model developed in the software package HEC-HMS (Hydrologic Engineering Center – Hydrologic Modelling System) and a hydraulic model developed in the software package HEC-RAS (Hydrologic Engineering Center's River Analysis System). The hydrological model transforms the forecasted rainfall into runoff from independent sub-basins in the Tamnava river basin, while the role of the hydraulic model is the wave transformation along the Tamnava and Ub river flows. These two units are not independent of each other, and the coupling of the model is done through the external boundary conditions of the hydraulic model. For the purpose of a timely response in case of high waters and taking into account the rapid response in the basin, the coupled model works with an hourly time step. Sub-basin discharges, as a result of the hydrological model, are the inputs of the hydraulic model at predefined common nodes where the exchange of flux between the models is implemented. The result of the hydraulic calculation is a forecast level that is further analysed based on the given criteria.

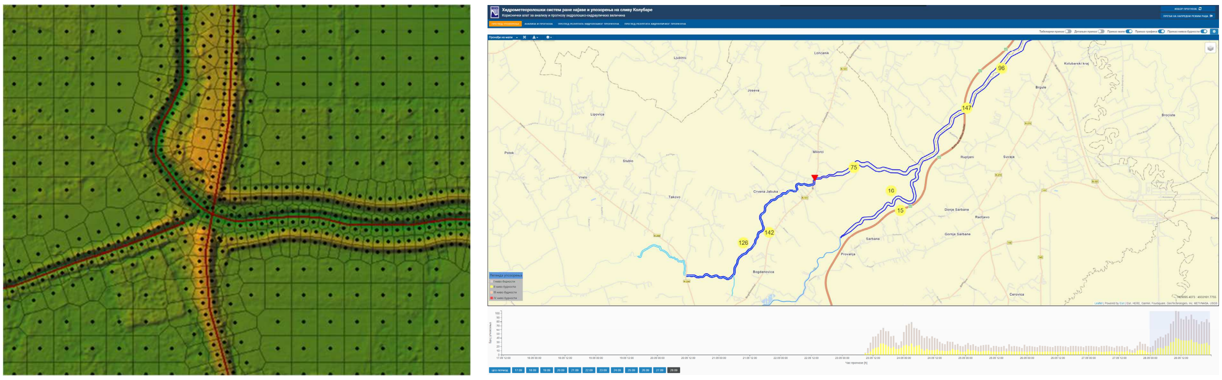

Figure 10. *Hydraulic model of Tamnava river basin (left) and user tool (right)*

The initial state of the forecast model relies on data from rainfall and hydrological stations and is obtained in the process of automated assimilation. The data from the supplementary network of stations (quantity and dynamics of rainfall, temperature) are the input data into the coupled model, while the levels obtained from hydrological stations are the values used to compare with the results of the coupled model during assimilation. The assumption was made that the rainfall quantities and the rainfall dynamics at rainfall stations are correct and cannot be changed during assimilation. To accelerate the assimilation process, virtual stations were introduced, representing fictitious rainfall stations where corrections are made, instead of corrections being made on each individual sub-basin in the model. In addition to the correction of the rainfall quantity and dynamics at virtual stations, the initial value of the soil moisture deficit is also corrected, i.e., the correction of the initial conditions.

The computation management system on the FEWS computation server automatically performs hydrological-hydraulic computations on the basis of measured data, estimated hydrological values and available meteorological forecasts. In the post-processing procedure, based on the results of hydraulic computations, the effect of the results on the state of the system is checked, i.e., it is checked whether the forecasted level has reached the level of the embankment toe, or, if it has already exceeded that level, whether it reaches up to 1 m below the embankment crest at the most endangered site. These results are available to experts through the hydrological-hydraulic value analysis and forecast tool.

A collaborative platform for support in the design and construction of the Moravian Corridor

Since the future corridor of the E-761 motorway from Pojate to Preljina mostly run through the valley of the Zapadna Morava, and a smaller part of the Južna and Velika Morava, within the project of the E-761 motorway, Pojate – Preljina "Morava Corridor", a hydroinformatics system was developed for the analysis of hydrological-hydraulic scenarios along the route of the planned motorway. The route is located almost the entirely in the zone that is exposed to flooding during the period of high waters of the Zapadna Morava, and largely is in direct contact with the river flow. Direct contact means points of intersection and zones where the route of the motorway is close to the riverbed.

The system was developed to support the design and construction for analyses of different scenarios, and existing and designed state of flood protection systems in the current climate conditions, as well as in climate change conditions.

The data management system contains time series of daily rainfall totals at rainfall and main meteorological stations (MMS), mean hourly discharges at hydrological stations (HS), as well as hourly rainfall at MMS and mean hourly discharges at HS.

The hydrological model was developed within the HEC-HMS software package. As the model must simulate a complex river network and generate results on sections that meet the specified criteria (e.g. sections of hydrological stations, river and motorway intersection sites), the delineation of the subject basin is spatially inhomogeneous. This is how a model consisting of 153 sub-basins was obtained. The input data to the hydrological model are synthetic hyetographs obtained for the assumed probabilities of occurrence of rain elements and CN runoff parameter defining losses. The outputs from the model are synthetic hydrographs serving as the input data to the hydraulic model.

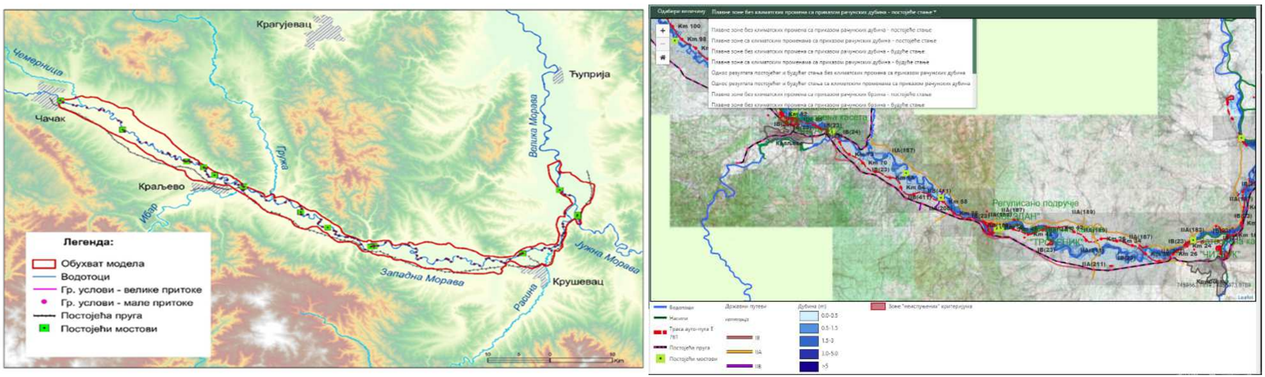

Figure 11. *Moravian corridor schematic model (left) and user tool (right)*

A 2D hydraulic model developed in the RiverFlow2D software (Hydronia LLC - Florida) was used to analyse the impact of different hydrological scenarios on the highway and the river bank. The upstream boundary of the hydraulic model is on the Zapadna Morava 4 km upstream from the mouth of Čemernica River, while the downstream boundary is on the Velika Morava, about 6 km downstream from the bridge in Varvarin. The lateral boundaries of the 2D model include sufficient space for the computation of high water flood zones. A total of about 150 km of the Zapadna Morava course was modelled. For more detailed hydraulic analysis of the planned motorway sections and in the zones of the planned motorway bridges, partial 2D hydraulic models were developed that include micro-locations of the subject sections and facilities.

The application of models and user tools includes the impact of relevant high waters with characteristic probabilities of occurrence of 1%, 2% and 5%, with and without the impact of climate change. Models and tools provide for analyses both in the existing and future state of the construction. Processing of the model results is of the primary importance in terms of possible flooding of protected areas according to predefined criteria, as well as the impact of high (flood) waters on the highway itself, and it is also possible to analyse the impact of hydrotechnical solutions on morphological changes of the Zapadna Morava riverbed.

CONCLUSION

The general structure of HIS is the result of many years of development of HISs, whereby key processes are recognized and various limitations in the application of automated data processing and computing procedures are taken into account. The said experiences have been applied in line with current trends in information technologies to enable effective implementation of HISs in various areas.

Potential applications of these systems can be on impounding reservoirs with high dams, which are numerous in Serbia (over 70). Although many reservoirs were designed for a single purpose use (water supply, hydropower, flood protection, etc.), due to climate change and increasing water and electricity consumption, practically all reservoirs are now used for several purposes. Therefore, reservoir management is becoming more and more complex and the need for modern decision support systems such as HIS is becoming more and more evident. It is thus possible to improve the dynamic resilience of water management systems [20] by developing models and applying HIS.

Similarly, due to evident changes in climate, there are increasingly frequent episodes of intense rainfall that can cause significant flood waves and, consequently, potential material damage and risk to the population. The presented application of HIS in early warning and alert systems provides for population alerting about possible floods on time and for precise identification of weak spots in the flood protection system [21].

More broadly, it is possible to develop and implement hydrodynamic groundwater models [22] in HIS, pollution transport models, agricultural models, etc., in order to enable the analysis of water resource management and to provide support in resolving disputes over water use in complex irrigation systems.

The increasing need for decision support tools in the management of water resources, with the constant development of numerical procedures and hardware platforms, requires the application of a general approach in the development of HISs in order to reduce costs and increase standardization in implementation on different systems. Based on the presented implementations in actual systems, it can be said that the HIS concept presented in this paper is a good basis for further development and expansion to other areas of application in water management.

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Editors

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PREFACE

Institute of Hydrology was established in 1947 within the Serbian Academy of Sciences. The Hydraulics Laboratory was established that same year within the Federal Ministry of Electricity, a predecessor of the later Hydropower Institute created in 1950. These two institutions were soon merged under the auspices of the Serbian Academy of Sciences into the Hydrotechnical Institute Eng. Jaroslav Černi. This Institute merged with the Serbian Water Management Institute in 1959 to create today's Jaroslav Černi Water Institute.

Over the past decades, the Institute has been the backbone of scientific research in the field of water in Serbia and the former Yugoslavia. The international scientific conference Contemporary Water Management: Challenges and Research Directions is organized to celebrate 75 years of the Institute's long and successful history. The Scientific Board selected 26 papers to provide readers with the best view of the current research results, as well as the further scientific research directions and potential challenges in the future. Selected papers are classified into six conference topics according to the corresponding research field, although one should note that most of the presented works is multidisciplinary, which is after all a characteristic of a modern problem-solving approach in the field of water. Hence, the chosen conference topics and corresponding papers represent only one possible way of classification of the presented works.

We wish to express our gratitude to the International Scientific Board and the Organizing Committee of this international conference for their efforts in selecting the papers, reviewing, and organizing the conference. We also wish to express our gratitude to all the authors of selected papers for the time they spent presenting the results of their research in a way suitable for this conference, and for contributing to the celebration of 75 years since the establishment of the Jaroslav Černi Water Institute. Respecting the importance of jubilee and wishing to express gratitude to previous generations of scientific workers, the Honorary Committee was also formed.

Following the path of previous generations, the Institute's present and future staff remain privileged, and under duty and obligation to continue and improve the scientific and research work of the Institute in the years and decades to come.

Belgrade, October 2022

Editors

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