Advanced Hydroinformatic Tools for Modelling of Reservoirs Operation

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Abstract. Reservoirs are used to control water flows through downstream waterways: downstream water supply, irrigation, flood control, canals and recreation for hydroelectricity generation. Operation policy is essential for reservoir operation because the impact of the operation on the environment, society and economy is significant. In the context of climate change, special attention should be paid to the following functions of reservoirs: flood control through retain water during high rainfall events to prevent or reduce downstream flooding - in this case the reservoir should be as empty in order to retain a larger volume of precipitation and runoff; water supply and irrigation, especially in periods of drought - in this case the reservoir should be as full in order to ensure the necessary volumes of water. A special attention should be given to electricity generation; a reservoir built for hydroelectricity generation can reduce the net production of greenhouse gases when compared to other sources of energy. Therefore, developments of reservoirs operating regulations are very important. The advanced hydroinformatic help to develop these regulations for different scenarios of dangerous hydrological phenomena: heavy and abundant rainfall; rapid snowmelt and drought. Such a tool is MIKE HYDRO Basin software, developed by DHI – Institute for Water and Environment. MIKE HYDRO Basin is a multi-purpose, map-centric decision support tool for integrated river basin analysis, planning and management. This paper contains also a case study: modelling of operation of three reservoirs (Gozna, Valiug and Secu) located in Superior Barzava hydrographic basin.

1. Introduction
Reservoirs were arranged to balance the flow in river catchments, to retain the water volumes during high flows and releasing their again during low flows. Most reservoirs are part of complex hydrotechnical arrangements: different types of reservoirs (dammed reservoirs, bank side reservoirs etc.), surface runoff, soil erosion and sediment transport control works and measures, bypass channels, natural and manmade channels, dikes and river control works etc. Reservoirs are used to control water flows through downstream waterways: downstream water supply, irrigation, flood control, canals and recreation, hydroelectricity generation. Some reservoirs have several uses, and the operating rules may be complex. Operation policy is essential for reservoir operation because the impact of the operation on the environment, society and economy is significant.

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water from precipitation and runoff; water supply and irrigation, especially in periods of drought - in this case the reservoir should be as full in order to ensure the necessary volumes of water.

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2. Advanced hydroinformatic tools
Hydroinformatic (or water informatics) result from a combination between modelling tools and Information and Communication Technologies (ICT), resulting a single methodological approach dealing with physical, social and economic aspects of sustainable water management.

Hydroinformatic is an interdisciplinary field, which exceed traditional definition of water/environmental science and engineering, informatics/computer science (including artificial intelligence, data mining and optimization techniques) and environmental engineering, has applications in various areas of water management, including:

- development and application of decision-support systems, used by involved authorities and stakeholders in water and environment domain;
- simulation and optimization models able to provide solutions to water engineering problems;
- computational tools and techniques and their effective application to managing risk and uncertainties associated with water systems, especially in context of climate changes;
- cross-disciplinary complex system approaches to water resource management (integrated water resources management);
- to improve understanding of water systems functioning, including technical, socio-economic and environmental issues. [1]

Advanced hydroinformatic tools are those tools whose modelling technologies achieve their full potential in terms of practical application. The advanced tools integrate the hydraulic and hydrological models with new hydroinformatic technologies including, in principal, the following elements: standards for “open” modelling systems, logical modelling techniques, knowledge base system, systematic calibration, advanced optimization methods and decision methods. [2]

The recent output of research activities is a fifth generation modelling environment, which make possible a combined access to powerful features, like: standard interfaces to GIS, giving the user access to necessary specific data; a choice of alternative and compatible hydrological and hydraulic modelling system; graphical interface; utilities for model calibration, validation, verification, optimization and decision making; enable specialists from other involved fields (agronomists, ecologists, meteorologists etc.) to access integrated hydrological and hydraulic data and knowledge resources in efficient and responsible way. [2]

The most known advanced hydroinformatic tools for reservoirs operation modelling are:

- MIKE HYDRO Basin, developed by DHI – Institute for Water and Environment. MIKE HYDRO Basin is a multi-purpose, map-centric decision support tool for integrated river basin analysis, planning and management. MIKE HYDRO Basin uses a simplified mathematical representation of the river basin, including the configuration of river and reservoir systems, catchment hydrology and water user schemes. [3]
- MIKE HYDRO River, developed by DHI – Institute for Water and Environment. MIKE HYDRO River is new generation river modelling package - successor of the world-known MIKE 11 river modelling system. MIKE HYDRO River is top quality river modelling, covering more application areas than any other river modelling package available. It enables to model a variety of tasks related to river hydraulics, water quality, flooding, forecasting, navigation as well as catchment dynamics and runoff. [4]
- HEC-ResPRM Prescriptive Reservoir Model program, developed by Hydrologic Engineering Center’s, US Army Corps of Engineers, is a reservoir system operations optimization software
package developed to assist planners, operators, and managers with reservoir operation planning and decision-making. HEC-ResPRM uses network flow optimization to suggest an idea of the best outcome that can be expected for the system based on any particular prioritization of the system objectives and given inflow time-series. [5]

- HEC-ResSim Reservoir System Simulation software, developed by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints. The software simulates reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support. HEC-ResSim can represent both large and small-scale reservoirs and reservoir systems through a network of elements (junctions, routing reaches, diversion, and reservoirs) that the user builds. The software can simulate single events or a full period-or-record using available time-steps. HEC-ResSim is a decision support tool that meets the needs of modellers performing reservoir project studies as well as meeting the needs of reservoir regulators during real-time events. Dam Safety Program Management Tools (DSPMT) - U.S. Army Corps of Engineers. [6]

- WAFLEX – developed by H.H.G. Savenije, in 1995, has been applied extensively, especially in southern Africa and South America.

- Water Evaluation and Planning system (WEAP) – developed by Stockholm Environment Institute.

3. MIKE HYDRO Basin

MIKE HYDRO Basin advanced hydroinformatic tool developed by DHI – Institute for Water and Environment. MIKE HYDRO Basin is a multi-purpose, map-centric decision support tool for integrated river basin analysis, planning and management. MIKE HYDRO Basin uses a simplified mathematical representation of the river basin, including the configuration of river and reservoir systems, catchment hydrology and water user schemes. MIKE BASIN can be used for providing solutions and alternatives to water allocation and water shortage problems, improving and optimizing reservoir and hydropower operations, exploring conjunctive use of groundwater and surface water, evaluating and improving irrigation performance, solving multi-criteria optimization problems, establishing cost-effective measures for water quality compliance. The results of modelling can facilitate a decision support tool that links hydrological, engineering, water quality, agronomic, and other information in an integrated framework. Routing assigned to a river node and applied to flow leaving that river node. The Basin module support three routing options: [3]

Linear reservoir routing - distributes flow leaving the river node over all time steps; delay parameter K (the linear routing time lag), must be specified. The delay parameter K specifies the time for the incremental flood wave to traverse the river between the selected river node and the next downstream node. Its value estimated as the observed travel time of the flood peak between the nodes. For a pulse inflow, outflow peaks after a specified time given by the time lag, and then decays exponentially. The formula used is:

$$Q_o = \left(1-x/\left((dt)/K\right)\right) \cdot q_i + x \cdot s \quad \text{with} \quad x=1-e^{-dt/K}$$

where $Q_o$ is outflow from the node, dt is time step length, $q_i$ is inflow to the node, s is storage in the subsurface, and K is the linear routing time lag (or delay parameter).

Muskingum method - is a commonly used hydrologic routing method for handling a variable discharge-storage relationship. This method models the storage volume of flooding in a river channel by a combination of wedge and prism storage. During the advance of a flood wave, inflow exceeds outflow, producing a wedge of storage. During the recession, outflow exceeds inflow, resulting in a negative wedge. In addition, there is a prism of storage, which formed by a volume of constant cross section along the length of the prismatic channel. Assuming that the cross-sectional area of the flood
flow is directly proportional to the discharge of the section, the volume of prism storage is equal to KQ, where K is a proportionality coefficient, Q is the discharge, and the volume of wedge storage is equal to KX(1 - Q), where X is the shape parameter. The total storage S is therefore the sum of two components:

\[ S = KQ + KX(1 - Q) \]  

Wave translation algorithm - uses a cyclical buffer with ‘slots’ for every time step. The inflow at a time step put into the current slot, and the corresponding earlier inflow that was stored in that slot pulled out. The index of the current slot cycles within the buffer, such that a new inflow always replaces the ‘oldest’ previous inflow. The number of slots in the buffer is equal to the number of time steps that a flow delayed. The number of slots is computed as floor \( dt/K \), where K can vary among reaches, and dt \([\text{time}]\) is the simulation time step. The latter must be constant during a simulation; for months, a standard month length (30 days) assumed. A good estimate of K can be the travel time of a distinct hydrograph peak between the selected river node and the next downstream node.

MIKE HYDRO Basin module used only to calculate flows, not water levels, because module is not a hydraulic model and thus cannot use for proper flood modelling. [3]

4. Study case
The Superior Barzava – Timis - Nera hydropower system is the oldest hydrotechnical system in Romania, early planning occurring in the early nineteenth century with a great development in the last 140 years (figure 1). The entire network of hydraulic and hydropower facilities belonging Resita Steel Works. [7]

![Figure 1. Geographic location of studied reservoirs](image)

Gozna reservoir (figure 2) is located on Barzava River, upstream of the Valiug village, was realized between the years 1951-1953. Gozna reservoir is the water accumulation lake with a maximum retention level at elevation 597 metres above sea level (m. a.s.l.) with a catchment area of 80,08 km\(^2\), of which 14,54 km\(^2\) in the river Nera catchment (where the discharge is captured through the coast channel Nera).

Reservoir characteristics: \( V_{\text{total}} = 12,053,400 \text{ m}^3 \) (between thalweg level and dam weir level) \( S_{\text{lake}} = 66,02 \text{ ha} \) (at dam weir level).

A network of permanent and temporary valleys, some of which are active, favour the transport of very heterogeneous coarse silt quantities, drains the entire hydrographical basin. Without manifest in depth, landslides are active in the deforested areas; the forest occupies 80% of the catchment.
Figure 2. General scheme and capacity curve of Gozna reservoir

Valiug reservoir (figure 3) is located on the River Barzava downstream of village Valiug, is a reservoir with a maximum retention level at elevation 504,50 m. a.s.l., with a catchment area of 80 km², of which 52.7 km² belong to Gozna reservoir. The lake put in function in 1909.

Figure 3. General scheme and capacity curve of reservoir Valiug

Reservoir characteristics: \( V_{\text{total}} = 1206000 \text{ m}^3 \) (regardless of the silting, the effects of which are not known, since no measurement could be made) \( S_{\text{lake}} = 12.06 \text{ ha at level 505.50 m.} \) Arrangement consists of two dams, joined together by a rock conglomerate which can be compared with an island. Characteristic note of the area is the appearance of steep hillslopes, check some frequent landslides, which sometimes becomes the key issue when accompanying the valleys line. Where floodplains covered with vegetation (covering 70% of the basin) are present active landslides, including ravines of detachment.

Secu reservoir (figure 4) is located on the River Barzava, about 7 km upstream from Resita, with a basin area of 165 km², of which 91.4 km² belong Gozna and Valiug reservoirs, in upstream. The lake put in function in 1963. Reservoir characteristics: \( V_{\text{total}} = 11236000 \text{ m}^3 ; S_{\text{lake}} = 105.67 \text{ ha (at dam weir level).} \) In the catchment area, meet silt and regressive erosion, collapse of banks and alluvial cones extensions, afforestation of 85%, represented by deciduous forests.
The input data in MIKE HYDRO Basin are (figure 5):
- river network - river nodes (table 1)
- location and characteristics of reservoirs and water user
- river branches catchments characteristics (area, land use)
- time series of precipitation, evaporations from reservoirs, water demand.
Table 1. River network

| Identifier | Branch | Chainage [m] | Type                      |
|------------|--------|--------------|---------------------------|
| N1         | Barzava| 0.00         | Regular                   |
| N12        | Barzava| 16466.50     | Catchment, RoutingMethod   |
| N16        | Barzava| 13345.64     | Regular                   |
| N17        | Barzava| 16914.30     | Regular                   |
| N2         | Barzava| 10000.00     | RoutingMethod             |
| N3         | Barzava| 12230.00     | Reservoir,Catchment,RoutingMethod |
| N4         | Barzava| 15460.00     | RoutingMethod             |
| N5         | Barzava| 16220.00     | Reservoir, RoutingMethod   |
| N6         | Barzava| 28520.00     | RoutingMethod             |
| N7         | Barzava| 31770.00     | Reservoir,Catchment,RoutingMethod |
| N8         | Barzava| 34770.00     | Regular                   |

The chosen rainfall-runoff model was UHM (Unit Hydrograph Method) and routing method for reservoirs was linear reservoirs method.

5. Results and discussions

The results from simulation with MIKE HYDRO are show in figures 6, 7, 8, 9, 10 and 11. Based on simulation results of accumulation operation with advanced hydroinformatic tools can prepare operating regulations of accumulations for various scenarios (heavy rain, rapid snowmelt, and drought), also can know the available volume of water for new users.

![Figure 6](image-url)
Figure 7. Inflow water discharges in nodes

Figure 8. Outflow water discharges in nodes
Figure 9. Unallocated, inflow and outflow water discharges in reservoir Valiug

Figure 10. Unallocated, inflow and outflow water discharges in reservoir Secu
6. Conclusions

The important steps in integrated water resources management are the policymaking, planning and management. Development of adequate reservoirs operating regulations is very important for planning and management, especially in context of climate change. Must be identified the goals that need met and to specify problems to be resolved to achieve these goals. The identified strategies for problems solve must thank all the factors involved.

Therefore, it needs different planning and management scenarios. The most adequate instruments to find the answer to these scenarios of water resources are advanced hydroinformatic tools. Through comparing the results obtained by its use, can make a technical and economic analysis of various management strategies. Finally, result the most efficient and convenient management plan that meet sustainable development principles.

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