OPTIMIZING THE OPERATION OF A RESERVOIR WITH COMPLEX USES CASE STUDY FOR HYDROTECHNICAL SYSTEM VÂRȘOLȚ

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ABSTRACT: - Optimizing the operation of a reservoir with complex uses. Case study for hydrotechnical system Vârșolț. Water reservoirs play an important role in ensuring water resources, especially in the case of watercourses that have a strong torrent character with high flow variations and which requires flow regulation and water reserves. But few reservoirs have only one role. In the operation of reservoirs with complex uses, conflicts often arise, in particular, on the priorities of satisfying various uses and the distribution of water resources over time. These conflicts cannot always be solved by the level of the market economy, or by moment interests or local interests. Solutions are even more complicated when the reservoir is part of a complex hydrotechnical system. This paper work proposes some general solutions for the optimization of the operation of a hydrotechnical system (operating regulation, support system of the exploitation decision) and, as a case study, the optimization of the operation of the Hydrotechnical System Vârșolț.

Keywords: reservoir, hydrotechnical system, conflicts, running optimization, operating regulation.

1. INTRODUCTION

1.1 Purpose and need to optimize the exploitation of reservoir with complex uses

Water reservoirs are designed to achieve:
- a stock of water for use;
- regularizing flows and mitigating floods;
- providing a water level quota for water capture;
- a drop for hydropower and hydromechanisms;
- a minimum depth for navigation;
- water shine for fish farming, recreation, sports;
- ensuring the conditions for carrying out water quality processes;
- limiting the speed of the watercourse to reduce the capacity of erosion and transport of alluviums.

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In many cases, reservoirs have multiple uses, and their different interests conflict. The purpose of optimizing the exploitation of a reservoir with complex uses:

- efficient use of water resources to meet the water requirements in the area;
- negotiating or renegotiating contracts with water recipients by establishing the debts that can be delivered;
- preparing the operational basis for optimal operating decisions in all possible situations;
- solving conflicts.

1.2 Conflicts occurring in the exploitation of a multi-use reservoir

In the use of water resources in general, and in the exploitation of multi-purpose reservoir, in particular, conflicts occur not only among the various users but also between different uses (Richard, 1995).

Solutions to solving these measures are not always simple because the various uses of water resources sometimes have competing interests (Alvarez, 1992), and satisfying the requirements of these uses can create conflicts. These conflicts can be grouped as follows:

- conflicts related to the uneven distribution of water resources in space;
- conflicts related to the development of upstream water users whose waste water discharges affect downstream water abstraction;
- conflicts related to priorities for water use satisfaction, especially during droughts;
- conflicts related to the use of accumulated water stocks, especially when reservoirs in the same pool have different administrators with different interests.

1.3 Legal Provisions

The current national water legislation, which is a transposition of the European legislation, in the field, requires that holders of water reservoirs to exploit them safely based of approved regulations (GUO, 2001).

According to the legal provisions in force (GUO, 2012), operating regulations are developed at the level of reservoirs, reservoir systems, hydrographic subbasses, hydrographic basins and contain, for each operating regime:

- state and behavior parameters of the system;
- critical thresholds of status parameters;
- monitoring the status parameters;
- how to determine the operating regime;
- establishing the decision (mode of exploitation):
    - elements of decisions;
    - necessary measures;
    - the duties of the staff;
    - work instructions.

1.4 Short presentation of the Crasna river basin

The Vârşolţ hydrotechnic system is located on the Crasna river and is part of the Someș-Tisa hydrographic basin. The river basin of the Crasna river**,** after (Sofronie and Bayer, 2012), is delimited by lower heights mountains, representing the watercourse separating this basin from adjacent river basins and drained by the Crasna river, a former tributary of the Someş, but which, after the landscaping works, it flows into Tisza river on the Hungary territory. The river has its origin in the contact between Meseş and Plopiş Mountains under Măgurii Priei (997 m) and drains the Șimleu Depression, collecting a series of smaller tributaries (Coliţca, Valea Banului, Mortăuţa, Samoşia), and on the course the lower hydrographic network was largely corrected by embankment and drainage channels, receiving Zalăul, Maja and Marisa as important tributaries.

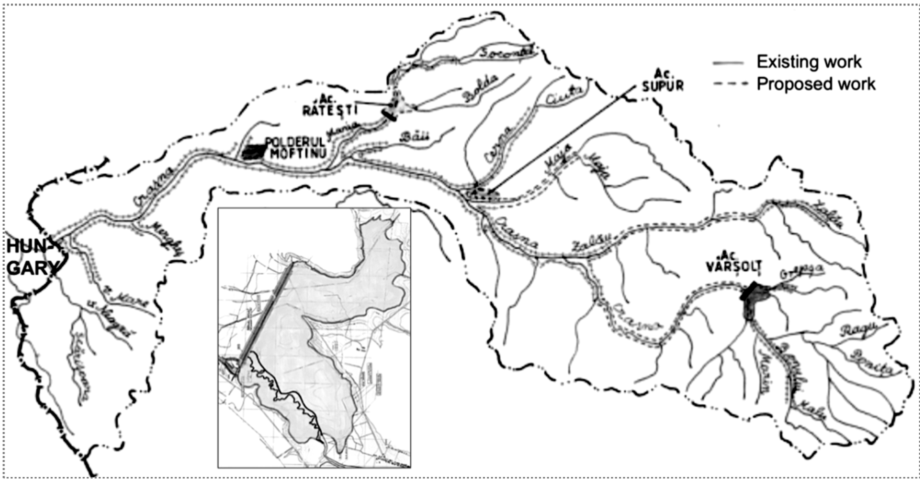


Fig. 1. ***Crasna River Improvement on the Vârșolț Reservoir-Border Sector (Sofronie, 2000). Inset - Crasna reservoir situation plan.***

2. METHODS

2.1 Hydrotechnical system in the systems theory

The hydrotechnical system can be considered:

- an independent and autonomous system, because it is well-bounded by the other river basins by a water catchment;

- a dynamic system because the presence and exploitation of a complex reservoir in the upstream area of the basin has influences throughout its entire downstream area;

- an open system, not an isolated system, because it interacts with both the environment, precipitation and other climatic factors, as well as with the neighboring hydrotechnical systems through inter-basins derivatives, thus a system which influences and is influenced by other systems by material exchange and energy.

A closed system is a system that does not make the environment exchange of matter, but only energy (Levine, 1999).

For simplicity, a reservoir with complex uses or a hydrotechnical system can be considered a closed system in which hydrological processes take place, having precipitations, other climatic factors and inter-basins, and as outputs liquid and solid flows, evaporations and evapotranspiration and water consumption.

By exercising the complex reservoir exploitation it can be considered that the system is a cybernetic one (Giurma, 1993).

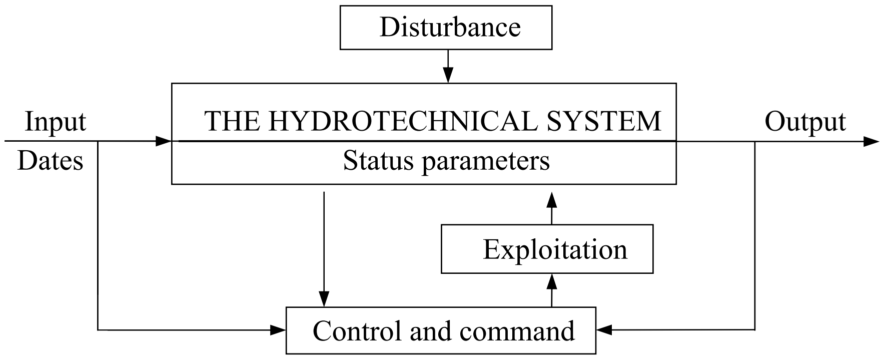


Fig. 3. ***The system for driving and operating a hydrotechnical system***

2.2. Modeling of water management systems

Analysis of water management systems is possible based on systems analysis models, of which the most commonly used (Labadie, 1977) are:

- systemic behavioral patterns: simulation
- alternative assessment methods: optimization

Simulation models are used to:

- determination of management policies for water management;
- establishing strategies for the efficient use of water resources;
- negotiation or renegotiation of supply contracts for water management products and services;
- anticipating the effects (consequences) of system behavior, finding operating and exploitation methods in various situations.

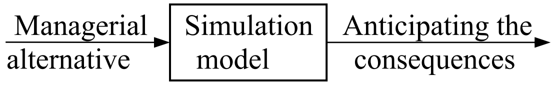


Fig. 4. ***Simulation model***

A simulation model does not find the best operating method, but this problem can be solved using the optimization model [8].

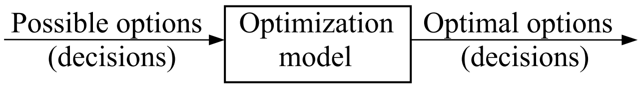


Fig. 5. ***Optimization model***

The best approach to analyzing water management systems [6], is to combine the two types of models in order to find the best managerial methods among the multitude of possibilities.

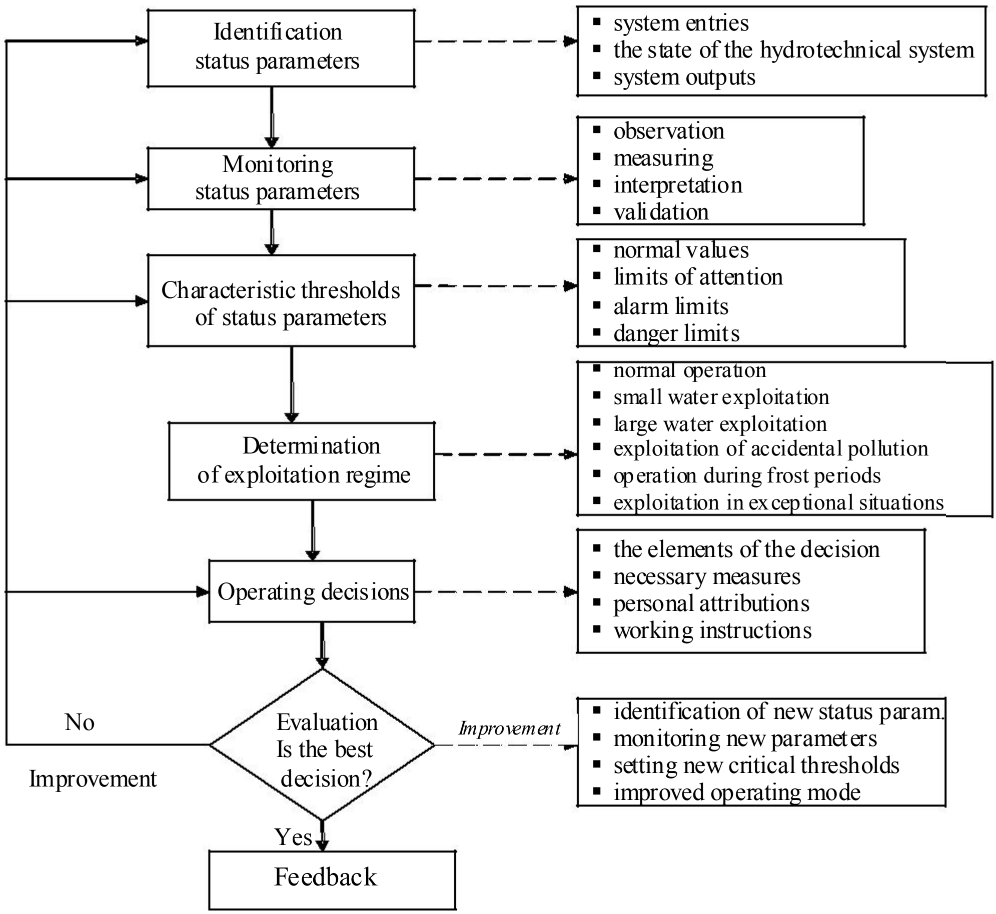


Fig. 6. ***The decision support system for the hydrotechnical system operation regime***

A model for a hydrotechnical system can have inputs and outputs of the type:

- Inputs: - controlled: - monitored inter-basins derivations;
- tributaries monitored;
- measured precipitations;
- operating rules;

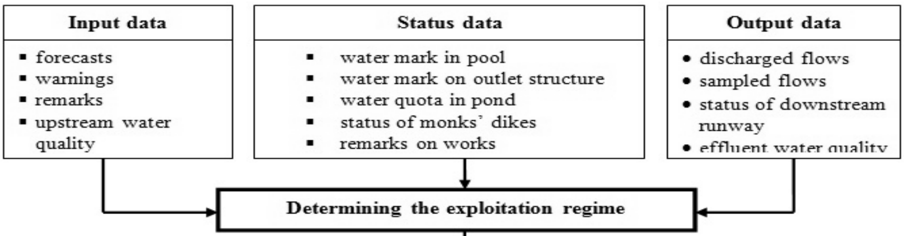
- authorized water demand;

- uncontrolled: - uncontrolled tributaries;
  - climate factors and uncontrolled rainfall;
  - uncontrolled water demand;

- Outputs: - desired: - useful satisfaction;
  - rational use;
  - sustainable development;

- undesirable: - floods;
  - drought;
  - current and accidental pollution;
  - accidents to hydrotechnical constructions.

Determination of the exploitation regime is shown in the figure 6.



Exploitation regime	Decision-making*	- decision-making elements - necessary measures - staff duties
- **normal exploitation**	▪ Chap.6.2* – Exploitation in medium water season	
- **low water exploitation**	▪ Chap. 6.3* – Exploitation in low or scarce water season ▪ The drought plan	
- **exploitation during frosting**	▪ Chap. 6.4* – Exploitation in cold season	
- **exploitation in high water**	▪ Chap. 6.5* – Exploitation in high flood season ▪ Defence plan against flood, frost and accidental pollution	
- **exploitation in case of accidental pollution**	▪ Chap. 6.6* – Monitoring and preventing water quality degradation ▪ Defence plan against flood, frost and accidental pollution	
- **exploitation in special technical conditions and extraordinary situations**	▪ The Warning and Alarm Plan of Baia Mare ▪ Specific technical instructions	

* Note: These are chapters according to the legal provisions, by (GUO, 2012)

Fig. 7. ***Support system for determining the operating regime***

2.3 Optimizing the exploitation of a hydrotechnical system determines:

- Operating rules;
- Operating scenarios for different situations;

• Operating regimes;
• Optimal exploitation decisions:
  - technical instructions;
  - expert systems: dispatcher chart;
  - decision support systems (SSD).
• Operating strategies

3. RESULTS AND DISCUSSION. APPLICATIONS FOR VÂRŞOLŢ HYDROTECHNIC SYSTEM

3.1. Presentation of the Vârşolţ Hydrotechnic System

The Vârşolţ Hydrotechnical System is part of the complex arrangement of the Crasna river and consists of: Vârşolţ reservoir and dam; old maneuver tower with water inlet and outlet; new maneuver tower with water inlet and outlet; the Barcău-Vârşolţ derivation.

The reservoir was originally designed as a non-permanent reservoir with the role of attenuation of the flood waves and flood defense, but was put into operation as a permanent storage with an additional water supply of the Zalău-Şimleu Silvaniei area (Sofronie et al., 2013).

Between 1991-1994 the Barcău-Vârşolţ derivation was executed for supplementation and refreshment of the flowing tributary flows in the Barcău river, with a break in Mortauta stream, and between 1993-1996 a new maneuver tower was made and the old maneuver tower was repaired, both with two compartments, one for bottom emptying, the other for the water pipe.

The main characteristic data of the reservoir are:

- Useful volume: 16,07 million m3;
- Attenuation volume: 23,32 million m3;
- Guard volume: 4,17 million m3;
- Total volume: 39,3974 million m3.

Uses of Vârşolţ reservoir:

- water supply of the city of Zalău and Șimleu Silvaniei;
- regularization of debts;
- control of downstream floods;
- irrigation;
- recreational and sport fishing;
- ensure the flow of servitude on the Crasna downstream of the reservoir.

3.2 The main conflicts that arise in the exploitation of the Vârşolţ Hydrotechnic System are:

- providing a larger mitigation cut in the case of hydrological warnings by pre-evacuation the lake is in conflict with the provision of higher water reserves for water supply;

- the need for dilutions on the Crasna downstream of the reservoir in the case of accidental pollution by evacuating additional accumulated flow rates leads to the reduction of useful volumes of accumulated water;

- the satisfaction priorities of different uses can not be solved by market economy levers, as meeting the requirements for industry to the detriment of water requirements for the population or for maintaining aquatic ecosystems (where much lower benefits are obtained, the tariffs being smaller or null);

- the lack of interest of the upstream water users to invest in ensuring the quality of the discharged waters in conflict with ensuring the quality of the lake water and the interest of the downstream users;

- the lack of interest of some downstream localities to increase the river's transport capacity to floods is in conflict with the increase in the capacity to mitigate floods in reservoir;

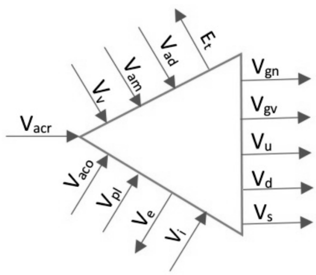
- providing a larger mitigation cut in the reservoir versus reducing the transit of additional flows from the Barcau bypass, with much higher costs;

- postponing the implementation of measures in the containment plan is at the risk of increasing the reservoir deficit and reducing the reservoir rate, with negative effects on ensuring a sufficient decanting of the turbid water or the erosion of material deposited on the lake slopes during the rain.

3.3. The purpose of optimizing the operation of the Vârşolţ Hydrotechnic System

- efficient use of water resources to meet the water requirements in the area;
- negotiating contracts with water recipients by determining the deliverable water debts;
- determining optimal operating decisions in all possible situations;
- flood control downstream;
- ensuring downstream servitude;
- solving conflicts.

3.4. The proposed mathematical model



$$V_{t+1} = V_t + V_{acr} + V_{aco} + V_{am} + V_{ad} + V_{pl} + V_v + V_i - V_e - V_d - E_t - V_{gv} - V_{gn} - V_{uc} - V_s$$

Constraints: $\mathbf{V_{min} \le V_t \le V_{max}}$; $\mathbf{V_{min} \le V_{t+1} \le V_{max}}$; $\mathbf{V_{util} = V_{max} - V_{min}}$

V_t – volume in reservoir at the beginning of month t;
V_{t+1} – volume in reservoir at the end of month t;
V_{acr} – the tributary volume in the lake of the Crasna river;
V_{aco} – vacuum of the tributary water in the Lake of Colitca;
V_{am} – the volume of tributary water in Mortauta
V_{ad} – the volume of water derived from Barcău by the Barcău- Vârşolţ derivation;
V_{pl} – the amount of precipitation falling on the lake;
V_v – the volume of water spilled on the slopes;
E_t – the volume of water evaporated from the lake;
V_{gv} – the volume of water discharged by bottom emptying through the old tower;
V_{gn} – the volume of water discharged by bottom emptying through the new tower;
V_s – the volume of water discharged to ensure the flow of servitude;
V_d – volume of water spilled over the large water spill;
V_{uc} – water volume for water users;
V_e – the volume of water lost through the exfiltration;
V_i – the volume of water infiltrated into the underground lake and springs;

3.5 Optimizing the operation of the Vârşolţ Hydrotechnic System

The objective function is to maximize user water content satisfaction:

$z = \max V_{uc} = \max \{\sum V_u + \sum_i V_{di} + \sum_j V_{gj} - \sum_k V_{dk}\}$

where: $V_{gi} = (V_{gv} + V_{gn})$ - empty water volume from the reservoir by bottom emptying in the "i" situations;

V_{dj} - volume of water discharged from the reservoir through the large water spill in "j" situations.

Optimization goals:

- maximizing water requirements;
- minimizing emptying and spills;
- attenuation of flood waves;
- ensuring the environmental flows downstream of the reservoir;
- minimizing the volumes of water derived from the Barcău - Vârşolţ derivation.

The objective function becomes:

$z = \max \{V_{uc} + V_u - (\sum_i V_{gi} + \sum_j V_{dj} + \sum_k V_{dk})\}$

with restrictions:

- the hydrological balance sheet equation;
- the reservoir limits: $V_{min} \le V_{util} \le V_{max}$ and $V_d \ge 0$; $V_g \ge 0$

3.6 The materialization of the reservoir exploitation optimization

Optimizing the operation of the Vârşolţ Hydrotechnic System is materialized by:

- operating rules;
- exploitation scenarios for different possible situations;

- operating regimes for these situations, which may be:
- under normal operating conditions;
- small water (drought);
- to large waters (floods);
- during periods of frost;
- in case of accidental pollution;
- under special technical conditions and exceptional situations;
- optimal decisions for each exploitation regime by:
- technical instructions;
- operating regulations.

The Operating Regulations contain for each operating regime:
- system status and behavior parameters;
- critical thresholds of status parameters;
- monitoring the status parameters;
- how to determine the operating regime;
- establishing the optimal operating decision, which includes: the elements of the decision, the necessary measures and the duties of the staff.

4. CONCLUSIONS

The management of water resources, vulnerable and limited resources, often subject to unnecessary use and excessive exploitation, often resulting in conflicts between different users, is facilitated by an optimization of the exploitation of hydrotechnical systems considered autonomous, dynamic, open for precipitation, climate factors and anthropogenic actions, but also as cybernetic systems by exploiting multiple use reservoir and water management infrastructure.

The optimization of hydrotechnical system expedition is a useful tool in the management of water resources from reservoirs to solve many conflicts that arise between the different uses, in the paper are presented the applications for the Hydrosystems Vârşolţ, conflicts that can be solved by a Operating Regulation that establishes exploitation regime and optimal exploitation decisions to ensure the satisfaction of water requirements and ecological flows downstream, minimization of emptyings and discharges, minimization of water volumes derived by the Barcău- Vârşolţ derivation and flood waves attenuation.

The applications of optimization of this hydrotechnical system can be successfully extended to many other reservoirs using hydrotechnical complexes or systems.

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