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HYDRAULIC MODELING APPLIED TO THE DETERMINATION OF SANITARY PROTECTION ZONES FOR LAKE BUHUI

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Abstract

In order to assess the impact of deforestation on the water quality of Lake Buhui, runoff modeling was conducted for the slopes of the lake's tributary catchments, with particular emphasis on the spatial configuration and morphological characteristics of the small hydrographic basins. Lake Buhui, the first artificial lake in Romania, has a storage capacity of approximately 610,000 m³ and is situated at an elevation of 640 m. Lake is additionally supplied by groundwater sources originating from crystalline schists and limestone formations, as well as by four karst springs located in the western sector of the lake, below the mean water level. Runoff generation from the slopes within the studied catchments was simulated using the rainfall–runoff (RR) module of the MIKE 11 modeling system, under the assumption of a representative annual rainfall regime. The simulation results obtained for all tributaries of Lake Buhui are presented in the form of hydrographs corresponding to forested slopes and degraded pasture areas. Furthermore, the results allow for the delineation of the lake's protection zone.

Key words*: hydraulic modeling, protection zone, deforestation.*

INTRODUCTION

The management of surface water resources in specific geomorphological settings, particularly karst landscapes, requires a rigorous understanding of both technical storage capacities and localized hydrographic behavior. On a historical and structural scale, the engineering of artificial reservoirs represents a foundational milestone in regional development. A primary example of this paradigm within the Central and Eastern European territory is the Buhui Reservoir. Situated on a limestone substratum at an altitude of 640 meters above sea level (a.s.l.), it holds historical and technical significance as the first artificial lake constructed in Romania. Engineered and executed between the years 1905 and 1908, the primary objective of this hydrotechnical structure was to secure the continuous public water supply for the mining town of Anina. Geometrically and morphologically, the reservoir extends across a surface area of approximately 11 hectares, bounded by mixed forests of silver fir (*Abies alba*) and European beech (*Fagus sylvatica*). The basin displays a mean longitudinal length of 1.1 km, a transverse width of 0.7 km, and an average operational depth of 8 meters, retaining a total base water volume of approximately 610,000 m³. While the Buhui Reservoir acts as the primary and critical infrastructure backing the municipal drinking water network, the systemic grid relies on a multi-source layout. This network integrates six supplementary sub-surface and karstic spring catchments, namely Colonovățul Mare, Colonovățul Mic, Valea Terezei, Kraksenthal, Grota Morii, and Jitin. Under hydrological drought regimes, the minimal recorded discharge drops to 20 l/s, whereas peak operational flow reaches up to 60 l/s. From a functional standpoint, the infrastructure is entirely decoupled from hydroelectric power generation, serving exclusively as a supply, ecological, and flood-mitigation system. Flood risk management is achieved dynamically via flood-wave attenuation within the storage basin, leveraging a dedicated attenuation volume of 198,706 m³ located between the spillway crest elevation and the maximum water retention level (MWRL). Hydrological calculations indicate that during a high-return period flash flood event with a 1% probability of exceedance (a 100-year flood), the peak upstream inflow reaches 41.3 m^3/s. Through basin retention over

the spillway crest, the downstream outflow is mitigated and downscaled to 26 m^3/s. This specific flood control framework is designed to protect localized riparian targets, preventing the flooding of the adjacent forest road leading to the Buhui Grotto. To ensure downstream ecological continuity and sustain lower catchments prior to the primary water intake, the dam maintains a continuous mandatory ecological flow calibrated at 150 l/s.

From a technical perspective, the structural behavior of the system is governed by a rigorous set of natural, constructive, and operational elevation parameters: Thalweg: 636.50 m, Bottom Outlet: 637.00 m, Intake: 639.00 m, Minimum Operational: 644.00 m, Spillway Crest/NWRL: 650.00 m, MWRL: 651.80 m (BWBA, 2008).

This research paper provides a modern evaluation of the Buhui Hydrotechnical Node, examining its structural composition, its complex karstic hydrographic basin (including its 3,200-meter underground course through the Buhui Cave), and its long-term operational resilience. By analyzing the interplay between the historical earth-core masonry dam and contemporary water management needs, this study delivers an optimization framework for historic infrastructure operating within vulnerable karstic hydrogeological ecosystems.

MATERIALS AND METHODS

Our capacity to execute numeric modelling of natural systems has progressed exponentially over the past two decades. Within the last decade, high-performance computing power has scaled to the threshold where desktop supercomputers are a reality, allowing for the inclusion of highly sophisticated parameters and processes within numeric models. The computational tools currently available for data analysis, spatial visualization, and rendering are beyond the imagination of previous generations of engineers. However, as predictive modelling capabilities have expanded, a concurrent reduction in field data collection has occurred, particularly concerning foundational hydrological gauging networks. While modern researchers undoubtedly enjoy access to massive, high-technology spatial datasets - such as multi-spectral satellite remote sensing data - the collection and maintenance of basic, traditional, ground-based historical datasets have severely deteriorated.

A precise quantification of water runoff pathways is essential for resolving practical engineering challenges and ensuring the rational, sustainable utilization of water resources. This principle is a core requirement within complex watershed planning strategies and integrated water resource management (IWRM) frameworks across varying temporal scales. In this context, datasets derived from direct, long-term hydrometric observations remain irreplaceable, as they allow for the empirical definition of characteristic water runoff parameters. Naturally, the water runoff regime displays high spatial and temporal variability across seasonal boundaries and consecutive water years. This variance scales proportionally when comparing catchments with divergent physico-geographical and morphological characteristics. Conversely, within catchments characterized by homogenous physico-geographical conditions, the variations are driven primarily by micro-climatic factors, mean basin altitude, and the forestation density of the drainage basin. Appreciable differences in volumetric discharge can be recorded between hydrometric gauging stations that monitor watersheds situated in entirely different physico-geographical regions. However, when these volumetric values are normalized against catchment surface areas with similar physical and geographic baselines, the resulting variance in specific water runoff indices is minimized.

The formulation of Source Water Protection Plans via integrated catchment-level management and localized resource planning within water intake zones represents a baseline best practice established by the European Union. This policy recognizes that anthropogenic activities inside sanitary protection perimeters can induce severe, long-term negative impacts on public health and downstream municipal consumers (Chapra, 2008).

Within the Romanian legislative framework, sanitary and hydrogeological protection zones are strictly regulated under Government Decision No. 930/2005, which approves the special norms regarding the character and

dimension of sanitary and hydrogeological protection zones for water sources. This legal framework establishes three hierarchical protection tiers:
Zone I: Sanitary Protection Zone with Severe Regime;
Zone II: Sanitary Protection Zone with Restriction Regime;
Zone III: Hydrogeological Protection Perimeter.
For surface water intakes established within natural or artificial lakes (reservoirs), Zone I (Severe Regime) mandates the following minimum strict physical dimensions:
Radial Water Incline: A minimum radial boundary of 100 meters on the water surface, measured outwardly from the exact coordinate of the water intake structure.
Riparian Bank Margin: A minimum radial boundary of 25 meters on the physical shoreline where the active intake infrastructure is anchored.
Lacustrine and Shoreline Perimeter: The entire surface area of the lake matrix must be protected, complemented by a continuous, compulsory 5-meter-wide buffer strip along the entirety of the bounding shoreline.
The integrated hydrological and hydrodynamic modeling framework within the MIKE 11 (DHI) software suite relies on the dynamic, bi-directional coupling between the rainfall-runoff component (MIKE 11 RR), driven by the NAM (Nedbør-Afstrømnings-Model) conceptual core, and the non-steady open-channel routing engine (MIKE 11 HD). Conceptually, this co-simulation architecture transforms discrete meteorological input series, such as continuous temporal arrays of precipitation and potential evapotranspiration stored within .dfs0 time-series files, into physically routed volumetric discharge vectors within the river network. This cross-domain data synchronization is managed by the centralized simulation editor (.sim11), which dynamically couples the spatial river network topology (.nwk11) with the physical catchment parameters parameterized inside the hydrological project file (.rr11), including basin surface areas, initial soil moisture thresholds, and infiltration capacities. Mathematically, the link between the two computational modules is established by injecting the simulated catchment runoff directly into the non-linear Saint-Venant equation of continuity, which governs the conservation of fluid mass in a one-dimensional system. This hydrologic feed is introduced as a dynamic lateral boundary inflow term that is continuously updated at each temporal integration step Delta t by the coupled NAM engine, which mathematically partitions the effective rainfall into three interconnected sub-surface and surface water transport pathways: rapid overland flow traveling across slopes to generate flash-flood hydrograph peaks, interflow moving through unsaturated upper soil layers with a medium structural velocity, and baseflow or saturated groundwater drainage that sustains the baseline ecological and operational drafts of the watercourse during drought periods. In terms of spatial allocation, the engine allows this generated runoff volume to be routed either as a point-source inflow discharged into a single georeferenced junction node simulating a distinct secondary tributary, or as a distributed inflow spread uniformly across a specified longitudinal span of a river branch or reservoir shoreline, where the routing engine divides the cumulative catchment discharge by the length of the targeted reach segment to obtain a continuous lateral flow per linear meter.
A major technical advantage of this integrated software architecture is its ability to perform differentiated temporal harmonization of the computational grid during predictive simulations. While the rainfall-runoff engine processes long-term historical meteorological series using a large, computationally inexpensive time step, the onset of an extreme, high-intensity precipitation event automatically triggers the hydrodynamic core to adjust its runtime temporal resolution via an adaptive time-step configuration. This automatic reduction of the computational interval to seconds or fractions of a second ensures strict compliance with the Courant-Friedrichs-Lewy numerical stability criterion during periods of rapid hydraulic acceleration - such as gravity discharging over frontal spillways or pressurized routing through enclosed subterranean karst conduits - thereby preventing matrix divergence and mass balance errors without inflating the computational cost of the long-term hydrologic background simulation (DHI, 2017).

RESULTS AND DISCUSSIONS

Lake Buhui is the first artificial lake realised in Romania, retaining a total water volume of approximately 610,000 m³ (Figure 1). Situated at an elevation of 640 m above sea level (a.s.l.), the reservoir spans a surface area of about 11 hectares, with an average longitudinal length of 1.1 km, a transverse width of 0.7 km, and a mean operational depth of 8 m.

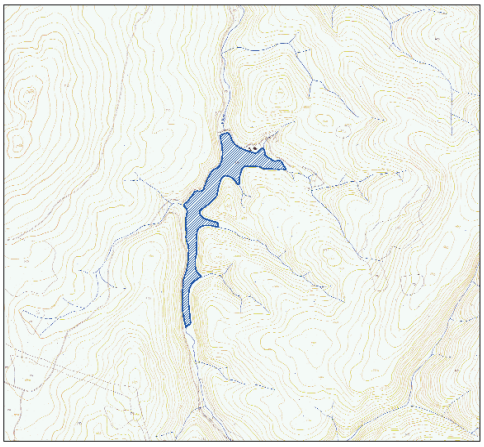


Figure 1. Lake Buhui plan layout

The primary hydrologic inflows sustaining the Buhui Reservoir comprise the following components:

The Buhui Brook: This main watercourse discharges into the Buhui impoundment at a specific location known as "Clocitoare". Originating from a source on the right flank of Lake Buhui, it flows along a surface reach length of approximately 700 m before its confluence with the reservoir.

Secondary Tributaries: In addition to the main brook, five low-discharge streams drain into the perimeter of the lake boundary. Three of these streams are located near the mouth where the Buhui brook enters the reservoir, while the remaining two drain the left flank of the lake, running adjacent to the local forestry road. During summer low-flow periods, several of these minor streams undergo complete drying or exhibit minimal seasonal discharge.

Sub-surface Catchment Inflows: The reservoir is further recharged by subterranean springs originating from crystalline schists and limestone formations. This includes four specific sub-aquatic karst springs located on the western flank of Lake Buhui below the active water surface level.

To execute the numerical hydrological simulations across the catchment, the following boundary conditions and physical boundary parameters were implemented into the computational domain:

Precipitation Distribution: A uniform and constant rainfall intensity was assigned across the entire geographic surface area of the hillslope matrix (Pronk et al., 2006). The monthly rainfall distribution over a one-year period is shown in Figure 2.

Pedological Homogeneity: A single, uniform soil class was mapped across the entire hillslope gradient - specifically categorized as a typical Hapludalfs (comprising multiple sub-types). This soil profile is defined by a medium-to-heavy texture with low permeability, placing it within Hydrologic Soil Group C under standard classification frameworks (Gomi et al., 2002).

Land Use Conditions: Vegetative cover was assumed to be uniform across the hillslope surface area, evaluated under two distinct land-cover scenarios: dense forestry cover versus a post-deforestation state characterized by degraded pastures.

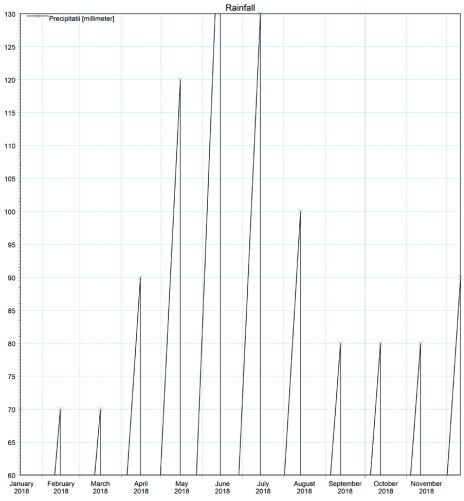


Figure 2. Rainfall one year - 1100 mm

Baseflow Configuration: The continuous background baseline flow was parameterized in accordance with the field-surveyed discharge

data of the sub-surface and karstic tributaries.

Initial Interception Storage: The baseline initial interception and depression storage capacity was set at 20 mm for the forested land-use scenario and downscaled to 1 mm to simulate the low retention capacity of the degraded pastures.

The numerical simulation of hillslope runoff generation across the targeted watersheds was performed using the integrated MIKE 11. The Rainfall-Runoff (RR) module was executed under a non-steady framework based on the regional pluviometric data recorded over a continuous one-year hydrological simulation window.

The simulation results obtained using the MIKE 11 RR module for all the tributaries of Lake Buhui are presented in Figures 3, 4, and 5 through overlaid graphs comparing forested hillslopes and degraded pastures.

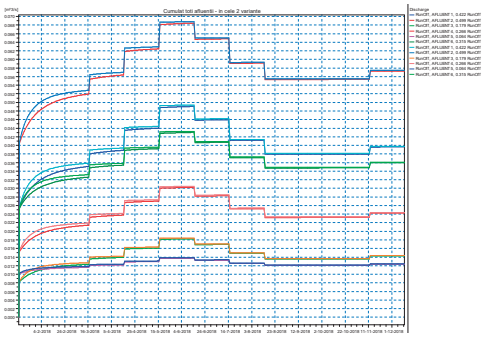


Figure 3. The simulation results

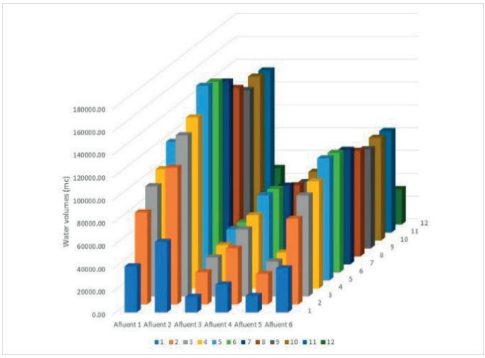


Figure 4. Water volumes - forested hillslopes

To mitigate the risks of accelerated erosion and potential contaminant transport identified in the runoff simulations, a strict spatial delineation of the catchment area is required. Based on these hydrological risks and local karst vulnerability, the critical boundaries around the reservoir perimeter have been mapped (Figure 6).

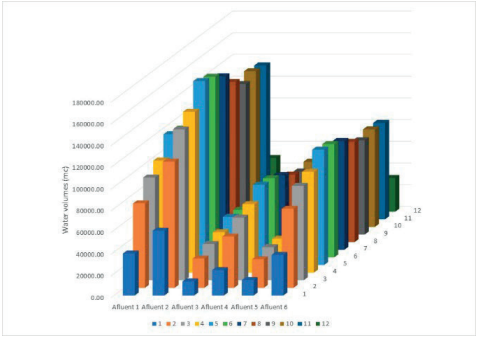


Figure 5. Water volumes - degraded pastures

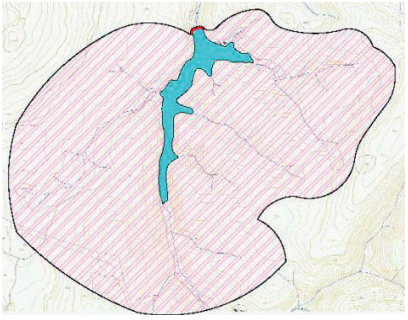


Figure 6. Sanitary and hydrogeological protection zones

The comparative analysis of the simulation scenarios highlights the critical role of vegetative cover in regulating the catchment's water balance. On the forested hillslopes (Figure 4), the high initial interception capacity significantly attenuates peak discharge, ensuring a sustained, gradual baseflow to the reservoir. Conversely, the simulation for the degraded pastures (Figure 5) indicates a rapid hydrological response characterized by accelerated surface runoff and elevated peak volumes, driven by the low retention capacity of the altered terrain. Furthermore, the restrictions implemented within the sanitary and hydrogeological protection zones outlined in Figure 6 are essential to safeguard the subterranean karst springs and surface inflows against anthropogenic degradation, ensuring the long-term ecological stability of the Buhui catchment.

CONCLUSIONS

The Water Framework Directive (Directive 2000/60/EC-WFD) establishes the foundational European paradigm for water policy, mandating the long-term sustainable management of aquatic ecosystems alongside human and economic water security. While the baseline chemical and ecological status of the raw water matrix within the Buhui Reservoir is categorized as "good" under WFD criteria, this investigation targeted a critical anthropogenic stressor: the qualitative degradation of the lacustrine ecosystem induced by intensive, unregulated forestry exploitation within the catchment area. To evaluate this phenomenon, spatial and temporal field campaigns were executed across varying seasonal and hydro-meteorological regimes to analyze the dynamics of turbidity and Biochemical Oxygen Demand (BOD5) at two strategic monitoring boundaries: the primary upstream reservoir inflow zone of the Buhui Brook and the downstream spillway structure (Directive 2000/60/EC, 2000).

The empirical data collected during the monitoring campaigns reveal a direct causal link between localized deforestation and the disruption of baseline hydrochemical and sediment fluxes:

Sediment Transport and Turbidity Level: A statistically significant increase in turbidity values was recorded at the downstream spillway zone relative to the upstream catchment inflow. This spatial gradient serves as a direct indicator of accelerated mechanical weathering and pluvial soil erosion across the deforested hillslopes. The removal of the root matrix and the canopy layer reduce the initial interception capacity (from 20 mm to 1 mm), leading to enhanced rain-splash erosion and the subsequent gravity-driven transport of fine-grained terrigenous sediments into the lacustrine body.

Organic Loading and BOD5 Kinetics: Conversely, the spatial distribution of BOD5 exhibited a downward trend, with lower concentrations recorded at the spillway zone compared to the primary upstream inflow.

Under the framework of the Water and Wastewater Master Plan for Caraș-Severin County, the Buhui Reservoir is designated as the sole, non-redundant drinking water source for the combined Anina and Steierdorf urban agglomerations, serving a population equivalent exceeding 10,000 PE. Given this high operational dependency, the formulation of an empirical Source Water Protection Plan for the Buhui catchment is a critical public health requirement. Implementing a formalized protection strategy provides the necessary engineering and administrative safeguards to preserve compliant raw water quality parameters, shield the intake infrastructure 639.00 m from shock-loading events, and mitigate medium- to long-term environmental risks to human health.

A critical policy misalignment exists between the empirical findings of this study and current statutory frameworks. The specific regulations governing sanitary and hydrogeological protection zones in Romania, established by Government Decision No. 930/2005 (HG 930/2005), enforce strict physical perimeters for Zone I Severe Regimes (e.g., a 100-meter radial water boundary from the intake). However, this legal framework fails to incorporate restrictive clauses or thresholds regarding commercial forestry operations within the wider hydrogeological boundaries (Government, 2005).

Because this research identifies intensive logging as a severe driver of watershed degradation, relying solely on standard sanitary buffers is insufficient to protect vulnerable karstic aquifers. Therefore, a specialized strategic forestry management plan must be developed for the Lake Buhui perimeter to limit timber harvesting within the catchment. To ensure the sustainability of this resource for future generations, immediate logging bans should be implemented within the catchment, alongside proactive preventative measures to protect this high-quality reservoir.

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REFERENCES

Banat Water Basin Administration (BWBA) (2015). Water and Wastewater Master Plan for Caraș-Severin County: Development strategy for catchment sources in Anina and Steierdorf agglomerations, Banat Water Basin Administration, Timișoara, Romania, *Tech. Rep*. MP-CS-2015.

Chapra S. C. (2008). Surface water-quality modeling. Long Grove, IL, USA: Waveland Press.

DHI, MIKE 11: 1D Surface water hydrodynamic and rainfall-runoff modeling user guide, Danish Hydraulic Institute, Hørsholm, Denmark, 2017.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, European Parliament and Council, *Official Journal of the European Communities*, L327, 2000.

Gomi, T., Sidle, R. C., & Richardson, J. S. (2002). Understanding Processes and Downstream Linkages of Headwater Systems: Headwaters differ from downstream reaches by their close coupling to hillslope processes, more temporal and spatial variation, and their need for different means of protection from land use, *BioScience*, 52(10), 905–916, https://doi.org/10.1641/0006-3568(2002)052[0905:UPADLO]2.0.CO;2

Government of Romania (2005). Government Decision No. 930 of August 11, 2005 on the approval of Special Norms regarding the character and size of sanitary and hydrogeological protection zones, *Official Gazette of Romania*, Part I, No. 749.

Pronk, M., Goldscheider, N., & Zopfi J. (2006). Dynamics and interaction of organic carbon, turbidity and bacteria in a karst aquifer system, *Hydrogeol J* 14, 473–484 (2006). https://doi.org/10.1007/s10040-005-0454-5