High-Performance Computing Based Decision-Support System for Remediation Works on a Dam

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Abstract. Even in the early years of the Višegrad Dam's operation, water leakage was noted. It was required to stop leaking by inserting granular materials into subsurface holes since further escalation of this phenomena may have had a number of negative implications. However, closing subterranean karst conduits is a very complicated procedure that needs ongoing oversight and management. To assist decision-makers plan their future actions and make the best choices during remediation, we have created a decision-support system that can assess the consequences of the applied technical procedures almost instantly. In order to determine piezometric levels, flow rates, and tracer concentrations for an assumed system design and under specified boundary conditions, the system uses numerical models of hydraulics and mass transport. To get the model states that best match reality, the measuring system's data were routinely and automatically integrated into a numerical model. The system is made to allow conducting all computations and data assimilation on a high-performance computing infrastructure in order to ensure that simulation results are timely provided.

Keywords: high-performance computing · genetic algorithm · decision-support tool

1 Introduction

A water leakage through the karst topography has been observed since the dam of the hydroelectric plant Višegrad was built; it increased steadily from 1.4 m^3/s in 1990 to 14.68 m^3/s in 2009. It was necessary to remediate the dam environment in order to decrease water and energy losses, stop additional erosion, and potentially prevent the dam from collapsing. A variety of different research and remedial operations were carried out, as stated in [1], in order to ascertain the as-yet-unknown geometry of the karst conduits, which serve as the primary channels of water leakage. A sophisticated computational decision-support system (DSS) was needed for the initial investigations as well as ongoing monitoring and control of the remediation process. This DSS had to be able to add an in silico perspective to the problem on top of the in situ experimental investigations as well as combine these two perspectives to create an augmented and comprehensive picture of the issue.

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Many publications that deal with some elements of situations that are comparable have been published in the recent past, although the majority of them are only recommendations for the use of particular methodologies [2, 3]. Several methods have been used to learn about karst development and leakage studies, as can be seen from an overview of these documents: (a) regional and dam site geological mapping [4–9]; (b) boreholes and galleries [4, 8–16]; and (c) geophysical methods [10, 14, 16–18]. To the best of the authors' knowledge, there aren't any papers regarding computational platforms that integrate terrain research, in-situ data, and computational models in an automated, holistic way.

The primary goal of the DSS for the Višegrad dam seepage investigation and remediation was to provide an automated and continuous estimation of the spatial distribution of karst faults, their geometric parameters, and hydraulic properties before and during the remediation process, based on the measurements obtained by the installed monitoring system and deterministic and empirical physical laws. The model was created as a collection of elements for simulating phenomena like sinking upstream the dam, the velocity of the flow at the downstream springs, sodium fluorescein dye tracing, sodium chloride tracing, tomography, etc. that would otherwise only be particularly observed using a system for continuous monitoring or measured through periodic experiments.

The discrepancy between measured and estimated values is a good indicator of how accurately the model captures the behavior of the real system. We may get alternative model findings that diverge less or more from observed data by changing the values of the conduit parameters (the diameters of karst fractures and frictions along the conduits). Given the complexity of the models under consideration, it is obvious that the construction of suitable algorithms is necessary in order to carry out an iterative process this demanding. This issue may be viewed as a mathematical optimization problem that seeks to minimize the discrepancy between calculated and measured values by determining the size and hydraulic characteristics of the conduits within the specified network. Due to the genetic algorithm's (GA) intrinsic universality and resilience, we used it to optimize the highly nonlinear and multi-objective optimization problem. A DSS that automates the process of determining the best suitable model parameters utilizing the concepts and methodologies of high-performance computing (HPC) is used to accomplish the whole simulation-based optimization using GA. Using the DSS throughout the entire remediation process, a series of automated simulations of granulate injection, transport, and deposition were run on a regular basis to determine the ideal granulate mixture and injection speed for sealing cracks.

2 The Concept of Decision-Support System

Figure 1 depicts the high-level idea of the HPC-based computational platform for the analysis and repair of seepage under the Višegrad dam. The foundation of the platform is a hydraulic model developed in accordance with research on the morphology of karst fissures.

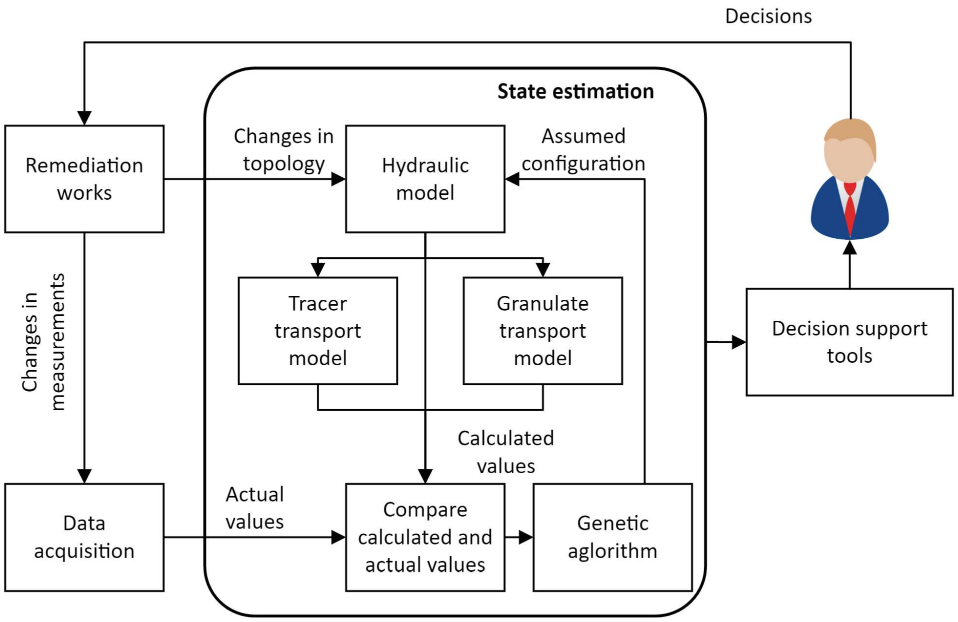


Fig. 1. HPC based decision-support system for remediation works on a dam.

Since the conduits' exact geometrical and hydraulic qualities are unknown, they are first presumed within realistically predicted ranges. The computed flow rates are then utilized to run the tracer transport model, which produces tracer dynamics over time, following the hydraulic simulation on the presumptive model configuration. Piezometric levels, flow rates, and tracer concentrations are calculated and utilized as indications of the quality of the assumed configuration by comparison with measured values. The GA develops ever-better configuration assumptions, performs simulations, assesses their fitness, and chooses the best for the following generation in an iterative process. The amount of the deposited material is determined in each GA iteration based on the previously determined flow rates in order to account for the impacts of the granulated material injection on the hydraulic model. Once the most suitable system configuration has been found, it is made available to the remediation operators through a specially created user application, enabling them to watch the repair process in almost real-time and take the necessary steps.

The DSS is made to run GA and all required computations on high-performance computing infrastructure in order to give continuous estimation of the system status within a reasonable amount of time. The DSS also includes a data management system with automatic quality control, ensuring accurate and timely data delivery for computations. The program for monitoring remediation is a 3D graphical tool that offers all the indications crucial for making decisions in numerical, tabular, and graphical form.

2.1 Hydraulics

Given the intricacy of the seepage under the Višegrad dam, it is obvious that it consists of a few distinct physical processes that are tightly connected and call for an all-encompassing strategy. Fluid movement via subsurface fissures created by stone faulting and erosion over millions of years is the fundamental underlying mechanism. We used a

1D hydraulic model, assuming relatively long conduit lengths compared to their transverse dimensions, to avoid the danger of missing any significant hydraulic events. On the other hand, large cross-sections and flow rates result in high Reynolds numbers, which indicate a turbulent flow regime. The Finite Element Method (FEM) was employed to solve equations relating to turbulent flow. Piezometric levels at the characteristic sites of the system and the fluid velocity and flow rates within every conduit are outcomes of the simulation of the hydraulic model.

2.2 Tracer Transport

We do stationary hydraulic calculations and do not take into account the temporal dimension of the flow since changes in boundary conditions are relatively slow in comparison to flow hydraulics. Tracers are introduced into the critical locations of the systems during tests to learn more about the velocities. We created a suitable computational model of solution transport to simulate the dynamics of the tracer through the system based on the hydraulic calculation findings. The temporal path of tracer concentrations at significant locations along the subterranean network is the outcome of Finite Difference Method (FDM) modeling.

2.3 Granulated Material Transport and Sedimentation

The main sinkholes and many boreholes were filled with inert granular material as part of the dam's remediation. Using the installed monitoring tools, the effects of the granulate injection on the piezometric levels and velocities were observed. However, we had to create a computer model of the movement and sedimentation of granulated material in order to determine the position and volume of the deposited material. The sedimentation model is based on the computation of critical velocities and tangent stresses for the deposition of the granulate within the sloping conduits, using the velocities and flow rates derived from hydraulic simulations as inputs. Critical velocities and tangential strains are computed for each conduit for a specific granulate dimension; these values are then utilized to compute the probability of material deposition within each conduit. Each class of granulate in a granulate mix is calculated separately to determine how much of each class was deposited during the period under consideration.

A hydraulic calculation is made to determine the velocities and flow rates in conduits at the start of each simulation time step. We determine the rate of granulate deposition using the computed velocities and the transportation and sedimentation model, and then we determine changes in conduit diameters and frictions. The computed hydraulic and sedimentation variables are recorded in output files at the conclusion of the phase, and the entire procedure is repeated for the following time step. Up until the simulation time period is exceeded or the system is completely sealed, the iterative process is repeated.

2.4 Estimation of Conduits' Parameters

Prior to starting the remediation, it was required to estimate the geometry and hydraulic properties of the karst conduits using measurements and the output of computational models. Additionally, the sedimentation of the injected granular material changes the size and frictions of conduits during remediation, leading to a variety of various hydraulic system topologies. It is important to perform the hydraulic simulation and compare the outcomes with the measurements in order to compare piezometric levels and water velocities in the expected and actual system design for the identical upstream and downstream levels. Tracer transport is computed, and the estimated concentration time course is then compared with the concentrations acquired by the experiment, in order to determine how well the model complies with tracer dynamics.

3 Data Management

Within the DSS depicted in Fig. 1 a data management system has been built in order to supply accurate and timely data for computations. The system is used to track variables important to the remediation process; while most measures are automated, some are still done manually. The system is made up of an acquisition server and a central database server, both of which include services that have been especially created for them. It is housed at the HPP Višegrad server room.

3.1 Data Acquisition

Data from monitoring systems are gathered via the data acquisition procedure, whether they are supplied in file form (CSV, TXT, XLS, etc.) or manually input by monitoring employees. It is based on the widely used Extraction, Transformation, and Loading (ETL) method, in which data is taken from the original source, converted into a standard data model, and loaded into a data storage.

Groundwater levels, headwater and tailwater levels, as well as water velocity and NaCl sensors at significant karst system exits (underwater springs), are all automatically acquired from the monitoring system on the Višegrad dam. For direct monitoring of levels in karst conduits beneath the dam, various water level and NaCl sensors have also been placed in upstream deep boreholes.

Weir flows, groundwater levels, well levels, and uplift pressures are all measured manually. Throughout the remediation procedure, quantities of inert granules and grouting materials are also tracked and acquired. Control measures, borehole logs, salt tracing studies, tomography experiments, etc. also have manually collected data.

At the acquisition server, acquired data is locally kept before being routinely sent to the central database server. The standard data model for time series, which is implemented in a central database on a relational database system, transforms all measurement data. Together with metadata on measurements, investigations, and remedial operations, additional data is also kept in the central database. The setup of computational models is handled by a specific section of the central database. This section is essential for the real-time application of calculations because it includes information on the most recent state of the computational model that decision support tools use to analyze and forecast the impacts of remedial activity.

3.2 Data Quality Control

To better comprehend the consequences of remediation efforts, all collected data is later employed in computations and optimizations. Even if gathered data may be easily accessible, it is crucial to perform quality control of the data in order to deliver accurate input for computations. The purpose of the quality control process is to assess each measured value's level of reliability in comparison to user-defined criteria, which may use both past values for the same variable and values from a different variable. The criteria is often established based on the properties of the measuring apparatus (such as the measurement range), as well as trend values (such as the moving average) and values of other relevant variables (real or averaged). Data quality mark, which may be any number between 0 and 1, with 0 designating faulty data and 1 indicating trustworthy data, is the outcome of the quality control process.

3.3 Data Processing

The central database server can handle data processing on demand in addition to delivering raw data from the database. This is done using a specialized data processing service that may be set up to produce engineering values based on raw data (for example, the water level determined by the frequency of vibrating wire in a piezometer). Analytical formulae for data processing and aggregation of values across time (minimum, maximum, or average values) are also available. When redundancy is crucial, a special sort of processing may be employed to combine two or more time series from different measurement equipment into a single time series.

3.4 Data Distribution

For the purpose of distributing data to automated software components and decision support tools, a dedicated service is offered on a central database server. Data access through this service requires user authentication, and the data sets to which a user has access are determined by user permission rules. When a user or software component asks a data distribution service for specific data, the service responds with processed or raw data from a database, depending on the request. The request also specifies an acceptable quality level (often 0.5), which can be used to pick data for the response and to analyze it, particularly when aggregating data. This allows for the use of only high-quality data, which is essential for estimating the impacts of remediation efforts.

4 Computational Model

As stated in [1], a 3D geological model is developed based on the known geological structure in order to construct a fictitious network of karst conduits connecting sinkholes and the zone of springs. The comprehensive examination of all accessible geological exploration objects (boreholes), their segmentation, and monitoring of the drilling procedure itself led to the development of the fault distribution in three dimensions. By logically linking the majority of potential fault paths and employing tectonics as the most important component in the early stages of karst fissure formation, the network of conduits is designed.

We established a potential network of karst conduits after positioning all the karst components in three dimensions, which served as the basic topology for mathematical modeling of subterranean flow. Since it represents the collection of finite elements with certain unknown parameters that are generated during the parameter estimation procedure, the fictitious 3D network of karst conduits served as the foundation for all simulations. The proximity of an element to a certain fault structure allowed for the reasonably accurate determination of the approximate ranges of its geometric properties.

4.1 Boundary Conditions

The primary sinkholes are represented by the exterior nodes of the finite element hydraulic model that are located upstream of the dam. The downstream springs are represented by the downstream external nodes, on the other hand. As a result, piezometric levels at nodes that represent sinkholes are equivalent to the upstream water level, whereas levels at nodes that represent springs are equivalent to the downstream water level.

4.2 Tracer Transport Model

Hydraulic calculations may be used to determine the flow rates for an assumed system geometry and specified boundary conditions, after which the dynamics of the tracer injected into certain system sites can be computed. On the other hand, experimental results are also obtained for the kinetics of the tracer insertion and the tracer concentration time course. The parameter estimate method finds the most likely system configuration by comparing the computed and measured tracer concentrations, among other criteria.

5 Data Assimilation

The following indications are used to assess how well an assumed system architecture and associated hydraulic model reflect the actual condition of the subsurface network of fissures:

- matching between the actual and estimated piezometric values;
- matching between the actual and estimated water velocities values;
- matching between the estimated tracer dynamics and the actual concentration time.

The quality of each configuration is assessed by comparing calculated piezometric levels, velocities, and tracer dynamics with measured values for the same boundary conditions (upstream and downstream water levels). Unknown parameters of each configuration (equivalent diameters and frictions of conduits) are determined using genetic algorithm (GA).

5.1 Evolutionary Algorithms

Multiobjective GA is used, as previously described, to estimate the subterranean conduits’ unknown characteristics. The first production of parameter sets (individuals) is where the process of parameter estimates starts. The hydraulic model is simulated based on the parameters specified by each individual, producing piezometric levels and flow rates. Tracer transfer is also computed based on the flow rates. The quality of the considered parameter set (the individual fitness) is determined by comparing the hydraulics and tracer dynamics to the observed values. GA selects the top solutions to be subsequently exposed to processes of selection, cross-over, and mutation, resulting in a new generation of individuals, based on the evaluation of all individuals. Once the computed findings and observed values are sufficiently matched, the preceding process is repeated iteratively, and the parameters are then accepted as the most likely.

5.2 HPC Implementation

We have created WoBinGO [19], a software framework for tackling optimization issues over heterogeneous resources, including HPC clusters and Globus-based Grids, in order to enable speedup of the algorithm execution and to minimize the optimization period to a manageable timeframe. The framework was created to achieve the following objectives: (1) accelerating the optimization process through parallelization of GA over the Grid; (2) relieving the researcher's burden of locating Grid resources and interacting with various Grid middlewares; (3) enabling quick allocation of Grid jobs to avoid waiting until requests for computing resources are processed by Grid middleware; and (4) providing flexible worker job allocation in accordance with the dynamics of the users' requirements. It enables parallel GA population assessment using a master-slave parallelization approach.

This framework includes the Work Binder (WB) [20], which gives client applications interactive access to Grid resources practically immediately. The WB integration into the framework frees the programmer from having to deal about specific Grid computing features and allows them to concentrate entirely on the optimization problem. Additionally, WB offers automatic occupancy flexibility depending on recent and current client behavior, which enhances the usage of the Grid infrastructure. Evaluation of individuals is carried out on Grid computing elements (CEs) with the use of the master-slave parallelization paradigm and WB.

Figure 2 depicts the framework's fundamental structure. The distributed evaluation system based on WB and the optimization master make up the framework. The evaluation pool and the WB subsystem make up the distributed evaluation system. The core evolutionary loop is carried out by the master, while the grid-based assessment procedures are executed by the evaluation system. It should be emphasized that the pool of ready jobs developed and maintained by WB itself is NOT the same as the evaluation pool.

Up to the moment where a generation needs to be evaluated, the master completes the primary evolutionary loop. The master then directs everyone in a generation to the evaluation pool. The master continues the process until the halting criterion is met after each generation's individuals have been assessed and given an objective function value.

An intermediary layer between the master and the WB service is the evaluation pool. It offers generational appraisal of people in asynchronous parallel. The evaluation pool gets people from the master and enqueues them each time a generation has to be reviewed. For each individual in the queue, the evaluation pool launches the WB client.

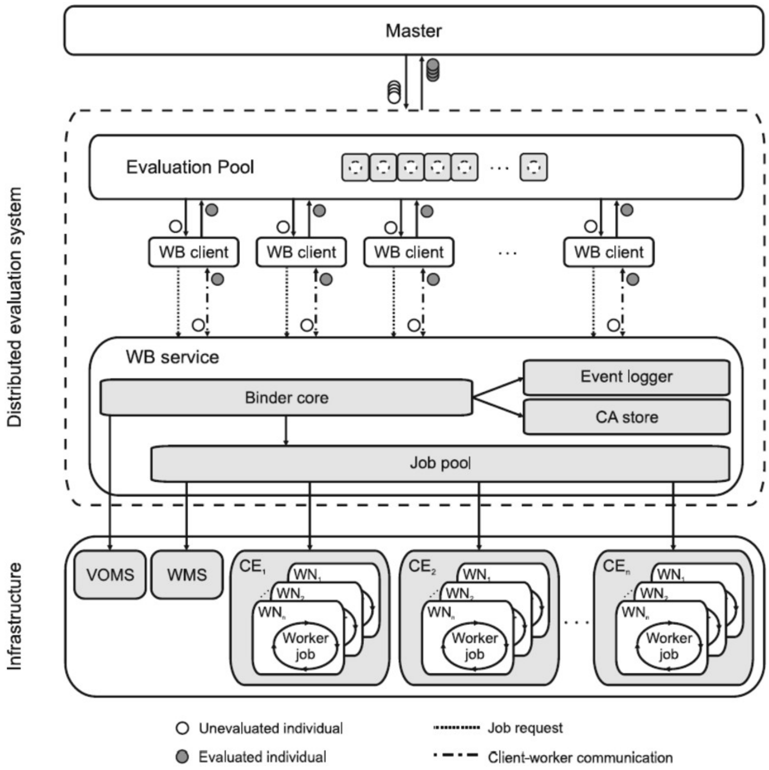


Fig. 2. Structure of WoBinGO framework [19].

When a individual is assessed, the evaluation pool gets the outcome from a WB client and then gives the associated individual an objective function value.

The client, worker, and WB service are the three tiers in which the software components that make up the WB environment are delivered. The WB service's principal function is to keep a pool of available worker tasks on the Grid and connect them to clients that need evaluations. In order to load enough worker jobs into the pool for incoming requests, it submits jobs to the Grid CEs. The client connects to the WB service and makes a worker request. Following a successful coupling between the client and worker, the WB service serves as a relay for traffic between them. The client transmits an individual to a worker for the purpose of distributed evaluation, who then computes fitness value and delivers it back over WBproxy. Following evaluation, the worker re-connects to the WB service and requests further work within the WB-configured job time constraints. The maximum work lifetime imposed by the local Grid site administrator using MDS cannot be exceeded.

6 Decision Support Tools

In order to properly define and coordinate subsequent activities, decision-makers had to move quickly in response to the different obstacles provided by the investigation and remediation of Višegrad dam seepage. To help decision makers make well-informed choices and consider the effects of their actions, specifically developed decision support tools were created. One tool is made especially for tracking remediation efforts in real-time, while the other is made for analysis and planning. Both tools are dependent on calculations made on mathematical models that are a component of the HPC platform, as well as observed data and metadata.

6.1 Real-Time Tracking of Remediation

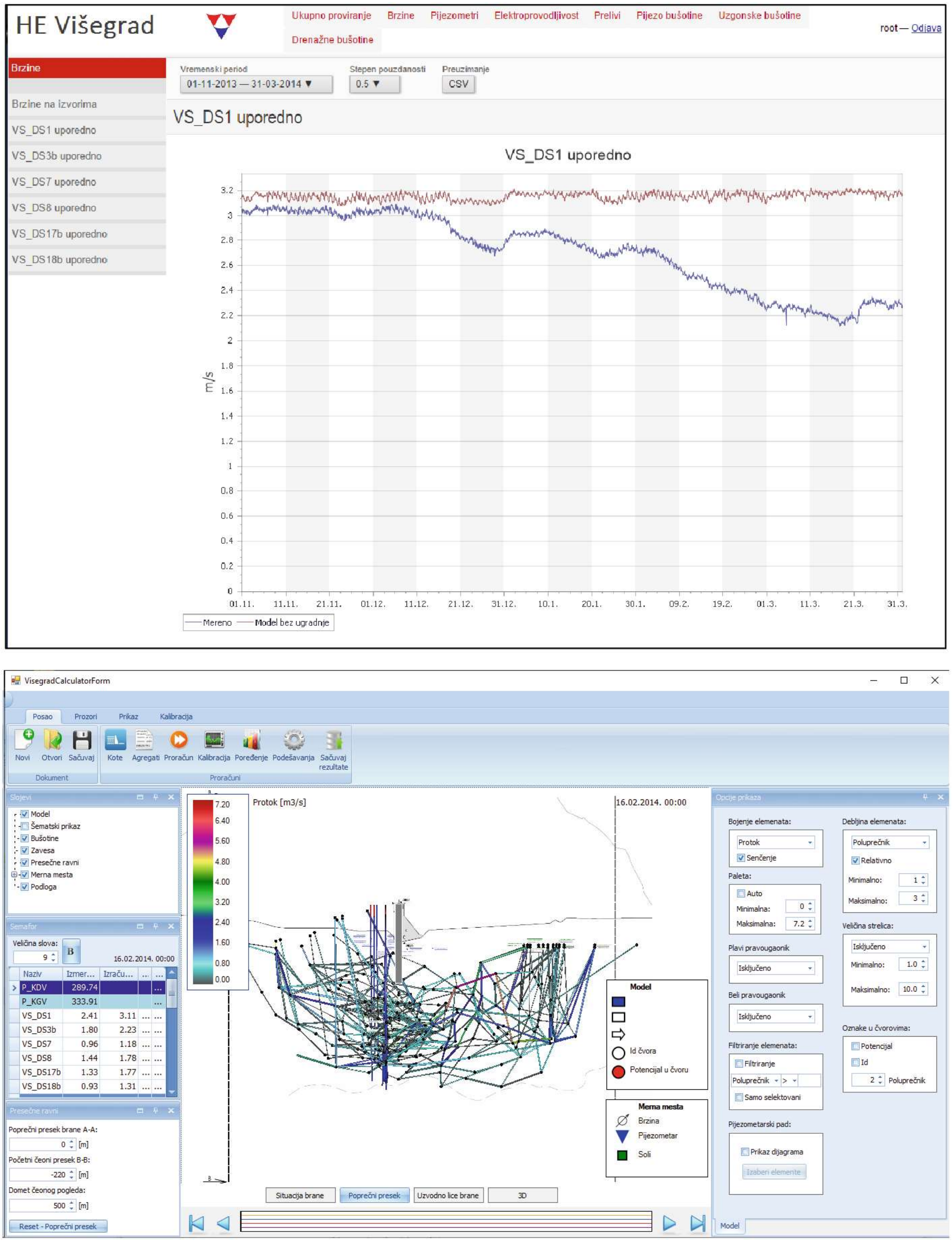
This tool's primary focus is on current measurements because it is intended to help decisions in real-time, but it also offers insight into the outcomes of calculations. This tool also gives data from continuous calculations done on an HPC platform, in addition to the fact that recent values of measured variables may be utilized for evaluating the impacts of remediation activity. By injecting both inert and grouting material into karst conduits, remediation seeks to lower the hydraulic conductivity and effective cross-section of conduits while minimizing seepage beneath the dam. Model parameters had been estimated before the start of the remediation procedure, and a preliminary model configuration had been saved in a central database. Using the starting model and the current boundary conditions, an automatic computation was run continuously during the remediation procedure. In this method, reference values that match to seepage undisturbed by remediation efforts have been supplied. The impacts of remediation on seepage beneath the dam are seen by comparing these reference values to the most recent measurements. On Fig. 3a, reference water velocity at spring DS1 is depicted as the red line, which is essentially constant, as contrast to observed water velocity, which is depicted as the blue line and is significantly decreasing with time due to remediation efforts.

Along with additional data from a central database, such as injection logs for both grouting material and inert granular material, tomography charts, and other data, the tool also offers 2D and 3D representations of measurements, model results, and configurations. Individual injection logs can be reported or the total volume over time can be deduced by data processing. Users may observe the volume of material injected every batch, the volume for each granulation, the borehole, and the depth at which the material was injected in the detailed logs.

6.2 Analysis and Planning

Different scenarios of inert material injection have been routinely simulated during the cleanup efforts. The best parameters for the injection procedure have been determined based on study and are then utilized for planning.

Daily and weekly planning has employed applications for analysis and planning to assist decisions. Inert material injection has been simulated using an updated state of hydraulic model, and boundary conditions have been determined using data on headwater and tailwater levels. Additionally, user-defined parameters included the rate and position of injection as well as the ratio of different grain sizes, which were also examined. The simulation produced findings for conduit flow rates and velocities, piezometric heads, as well as variations in conduit volumes brought on by the deposition of inert material. In this manner, the effects of injection or grouting could be evaluated, and preparations could be made for more work, often lasting up to seven days. In Fig. 3b, conduits with effective sizes and consequent flows are shown in three dimensions.



Vremenski period: 01-11-2013 — 31-03-2014
Stepen pouzdanosti: 0.5
Preuzimanje: CSV

☑ Model
☐ Šematski prikaz
☑ Bušotine
☑ Zavesa
☑ Presečne ravni
☑ Merna mesta
☑ Podloga

Veličina slova: 9
16.02.2014. 00:00

Naziv	Izmer...	Izraču...	...	...
P_KDV	289.74			...
P_KGV	333.91			...
VS_DS1	2.41	3.11	...	...
VS_DS3b	1.80	2.23	...	...
VS_DS7	0.96	1.18	...	...
VS_DS8	1.44	1.78	...	...
VS_DS17b	1.33	1.77	...	...
VS_DS18b	0.93	1.31	...	...

Poprečni presek brane A-A: 0 [m]
Početni čeoni presek B-B: -220 [m]
Domet čeonog pogleda: 500 [m]

Bojenje elemenata: Protok
☑ Senčenje
Paleta:
☐ Auto
Minimalna: 0
Maksimalna: 7.2
Plavi pravougaonik: Isključeno
Beli pravougaonik: Isključeno
Filtriranje elemenata:
☐ Filtriranje
Poluprečnik >
☐ Samo selektovani
Pijezometarski pad:
☐ Prikaz dijagrama
Izaberi elemente

Debljina elemenata: Poluprečnik
☑ Relativno
Minimalno: 1
Maksimalno: 3
Veličina strelica: Isključeno
Minimalno: 1.0
Maksimalno: 10.0
Oznake u čvorovima:
☐ Potencijal
☐ Id
2 Poluprečnik

Fig. 3. a) Real-time tracking of remediation (above), b) Tool for analysis and planning (below).

7 Conclusion

We described the HPC infrastructure for Višegrad dam remediation decision-support system in this work. The DSS's main building blocks include numerical models of hydraulics, tracer transport, and the transit and sedimentation of granular materials. The key component of the DSS was the method for parameter estimation based on genetic algorithm because some of the hydraulic model parameters were known roughly within the ranges determined by geological study. In order to ensure that the results of the simulations best reflect the in situ observations, the algorithm was able to estimate the geometric and hydraulic characteristics of the postulated karst conduits, producing a model configuration that accurately depicts the subterranean network of fissures. The computations were performed in a distributed computing environment as a result of the parallelization method that was used, allowing for daily decision support and parameter estimate within a reasonable time period.

The DSS met every criteria established prior to and during remediation, and it allowed for near real-time monitoring of the impacts of granular material injection as well as the forecasting of hypothetical injection situations during remediation planning. The results' satisfactory degree of reliability was demonstrated by a comparison between the major variables' projected changes and their observed values.

Given that the DSS was created as a modular software-hardware system, the algorithms used are inherently robust, and the parallelization strategy is effective, the DSS is easily adaptable and can be turned into a very potent decision support system for projects of a similar nature. Implementing current HPC techniques, Cloud technologies, and perhaps AI approaches that might aid in modeling poorly-defined physical processes are possible routes for platform upgrades.

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Editors

Disruptive Information Technologies for a Smart Society

Proceedings of the 13th International Conference on Information Society and Technology (ICIST)

Springer

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Preface

This book includes selected high-quality peer-reviewed research papers presented at 13th International Conference on Information Society and Technology held on Kopaonik Mountain, Serbia, on Mar 12–15, 2023. In an era where technology disrupts many facets of our lives, the papers included in this issue exemplify the remarkable ways in which information technologies are reshaping our world, driving innovation, and paving the path toward a smarter, more efficient society.

The selected papers represent a diverse range of topics, all connected by the common commitment to explore information technologies as tools for positive transformation. From e-government requirements specification to advanced machine learning algorithms for river water quality management and from the application of artificial intelligence in healthcare to the analysis of financial markets using social media data, these contributions collectively illuminate the profound impact of information technologies on various domains.

One of the several focal points of this special issue is the intersection of artificial intelligence and public administration. Some papers delve into this area, addressing topics such as the role of AI in public administration and business sectors and the adoption of e-contracting and smart contracts for legally enforceable conformance checking in collaborative production. These papers underscore the potential of information technologies to enhance governance, streamline processes, and promote transparency in the public sector.

Another significant theme explored in this issue is the application of disruptive technologies in healthcare. Whether it's the prediction of coronary plaque progression using data mining and artificial neural networks or the risk stratification of patients with hypertrophic cardiomyopathy through genetic and clinical data features, these studies demonstrate how advanced information technologies are contributing to the diagnosis, treatment, and overall well-being of individuals. The use of technology in healthcare is becoming increasingly indispensable, and the papers presented here showcase the latest trends in this field.

Furthermore, this special issue highlights the importance of sustainability and environmental consciousness in our technologically driven society. From estimating solar power potential for rooftops to optimizing wind production forecasting and analyzing hydropower system resilience, these papers underscore the critical role of information technologies in promoting eco-friendly practices and renewable energy solutions.

The paper review process, organized as a single blind, had two stages. In the first stage, the papers were reviewed to be accepted for presentation at the 13th International Conference on Information Society and Technology. A total of 80 papers were accepted for presentation at the conference. The authors had the opportunity to prepare an improved version of the manuscript for these proceedings. After the second stage of review, 48 papers were accepted for publication in the proceedings.

In conclusion, “Disruptive Information Technologies for a Smart Society” represents a collective effort to explore the transformative power of information technologies in diverse domains. We extend our heartfelt gratitude to all the authors who have contributed their valuable research. Also, we would like to thank the reviewers who, with their expertise and comments, contributed to significantly improving the quality of the selected papers. We believe that the insights and findings presented in these papers will not only advance our understanding of the potential impact digitalization may have but also inspire further research and innovation in the pursuit of a smarter, more connected, and sustainable society.

November 2023

Miroslav Trajanovic
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