WORKFLOW AUTOMATION FOR ANALYZING RAW RESULTS FROM HYDRAULIC MODELING USING QGIS AND PYQGIS

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This paper presents a semi-automated methodology, based on the use of the open-source software QGIS, to extract results of hydraulic model simulations performed in HEC-RAS. QGIS is recognized for its analysis power, with a wide variety of free libraries available. The study is based on the exploration of the Model Designer combined with Python scripts (PyQGIS). The proposed approach brings great benefit to hydraulic modelers around the world, significantly reducing the processing time and extraction of maximum water level results from a water level raster obtained following complex hydraulic processing. The proposed methodology, in addition to reducing the analysis time, also has the component of increasing flexibility regarding the way and location of extracting the results, thus increasing the analysis power and understanding of extreme hydraulic phenomena. Looking at a larger scale, the proposed analysis can also increase the connectivity between software, having a great contribution for hydraulic modeling and making the results much easier to extract and interpret in a 3D technical analysis, at a macro level in the field of hydraulic constructions.

Keywords: HEC-RAS, QGIS, Python, PyQGIS, Flood Modeling

1. Introduction

Numerical modeling techniques are widely used in engineering applications, offering critical support for solving complex computations involving large datasets tasks that are often impractical to address through conventional methods [1]. These techniques enable the simulation of the dynamic behaviour of complex physical systems and provide the capability to simplify and solve complex mathematical relationships.

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Mathematical modeling is currently used across a wide range of fields and applications. Among these are climate and meteorological modeling [2], which rely on advanced techniques to predict and analyse climate change; civil engineering [3], where it is used for the analysis and optimization of structural performance; aerospace engineering [4], which involves complex models for fluid dynamics and aerodynamics in spacecraft design; and energy engineering [5], where modeling techniques support the optimization of power grids, energy transport simulations, and performance evaluation of energy systems.

Regardless of the field of application, mathematical modeling has proven to be an indispensable tool in the analysis and management of complex systems [6], offering precise, efficient, and scalable solutions.

Numerical hydraulic models [7], particularly those used for simulating fluvial [8] and pluvial [9] flood events, are based on complex differential equations that describe the movement of water along river channels, drainage networks, and urban surfaces. The primary equations underpinning hydraulic mathematical models include the Saint-Venant equations [10], the continuity equation, the Navier-Stokes equations [11], and the Green-Ampt equation [12]. These equations enable a better understanding and prediction of water behaviour under various hydraulic, hydrological, and climatic scenarios.

Given the high level of complexity involved in solving these sets of equations and their critical role in sustainable water resources management, specialized software tools have been developed to improve modeling accuracy and reduce computational time. These tools support more effective water resource planning and decision-making, integrating the spatial variation of hydraulic parameters into a GIS environment. Notable examples include HEC-RAS [13], developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center; MIKE by DHI [14]; Flood Modeller by Jacobs [15]; and TUFLOW by BMT Commercial Australia Pty Ltd [16].

This study will focus on the hydraulic modeling software HEC-RAS, a computational tool capable of performing steady and unsteady flow calculations in both one-dimensional (1D) and two-dimensional (2D) approximations, as well as sediment transport simulations.

In the context of accelerating climate change [17], the deterioration of existing hydraulic infrastructure, and the growing need for efficient integrated water resources management, computations using HEC-RAS have become increasingly complex. This complexity arises from the large volume of data involved—whether based on long-term observed records, statistically generated datasets spanning several decades, or from the need to develop advanced two-dimensional (2D) models over extensive areas with a high number of computational cells (calculation grids).

All these factors, combined with the need to analyse a large number of climate change scenarios in order to ensure viable long-term solutions, can result in the generation of extensive datasets containing vast amounts of information. Consequently, the time required for analysis, verification, interpretation, and result extraction increases exponentially. Moreover, in the absence of well-defined algorithms, the likelihood of unintentional human error becomes significantly higher.

HEC-RAS software (developed by Hydrologic Engineering Center, US Army Corps of Engineers) is undoubtedly a powerful tool for hydraulic modeling [18]. This has been demonstrated over time by the large number of users, the quality of the results and the continuous improvements introduced through annual updates. However, it has also shown limitations in terms of flexibility when managing large volumes of data, particularly regarding to processing and result visualization. In many cases, additional processing using external software is required to overcome these constraints [19].

QGIS (Quantum Geographic Information System) comes to aid both in terms of improving the quality of hydraulic modeling results and in automating the processing of large volumes of data. QGIS is an open-source Geographic Information System (GIS), used for analysing, visualizing, and processing geospatial data. The main advantages of this software are that it is a flexible and powerful platform, compatible with numerous data formats, and it has advanced capabilities for automating processes using Python programming language (PyQGIS). This makes QGIS [20] an essential tool for engineers.

The objectives of this article are the integration of QGIS workflows with Python to enhance the post-processing of hydraulic modeling results. Specifically, to address the following: automation of data processing, optimization of flood scenario evaluation and facilitating decision-making processes.

2. Materials and methods

2.1 Numerical modeling component

HEC-RAS modeling software gives users the possibility to perform one-dimensional and two-dimensional unsteady flow river hydraulic computations, sediment transport modeling and water temperature analysis [21]. HEC-RAS is widely used for flood inundation studies because of its reliability, accessibility and user-friendly interface.

Hydraulic numerical models require detailed analyses of the studied area. This is also the case of HEC-RAS 2D modeling software. The development of a model involves several successive steps and is built upon several general components, including hydrological data (historical or synthetic), digital terrain models, and structural elements Fig. 1.

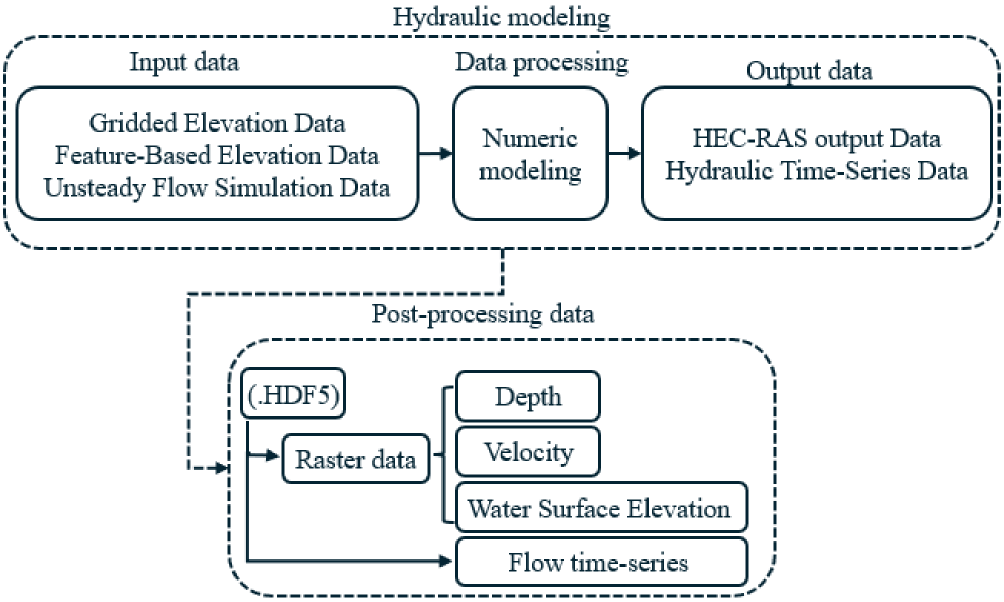


Fig. 1. Hydraulic model result data types

2.2 Modeling results analysis component

As illustrated in Fig. 1, the post-processing stage may involve various output formats. Among these, raster files are widely utilized due to their versatility in representing results from HEC-RAS simulations. These files encode critical hydrodynamic parameters, such as maximum flood depth and water velocity distribution, which are essential for flood risk assessment and disaster management. Government agencies and stakeholders frequently rely on this data to inform sustainable development strategies and establish emergency response plans.

Raster (3D) file format type present significant challenges, particularly in terms of large file sizes and software compatibility. Accessing and interpreting this data requires specialized Geographic Information System (GIS) software and domain-specific expertise, which can limit accessibility for non-experts.

Moreover, the substantial storage and processing requirements associated with raster outputs can impede efficient data exchange [22].

To mitigate these constraints, a common approach is to extract and reformat relevant raster data into a tabular form. This transformation enhances accessibility, allowing a broader range of users to interpret and utilize the data effectively without requiring advanced GIS proficiency.

Extracting data in a tabular format for large studies is a very time-consuming process. To address these challenges, this paper proposes an optimized methodology using QGIS interface and Python, to enhance efficiency, automate workflows, and reduce the risk of human errors in hydraulic modeling result post-processing.

QGIS is an open-source software which provides a wide range of functionalities for raster processing and analysis. However, certain tasks require repetitive operations or batch processing, which can be time-consuming if performed manually. To address this need, the Model Designer in QGIS has been developed, allowing users the possibility to automate geoprocessing workflows through a graphical interface. Thus, it gives the possibility to build geoprocessing workflows and generate Python scripts to further customize or automate it using PyQGIS API [23].

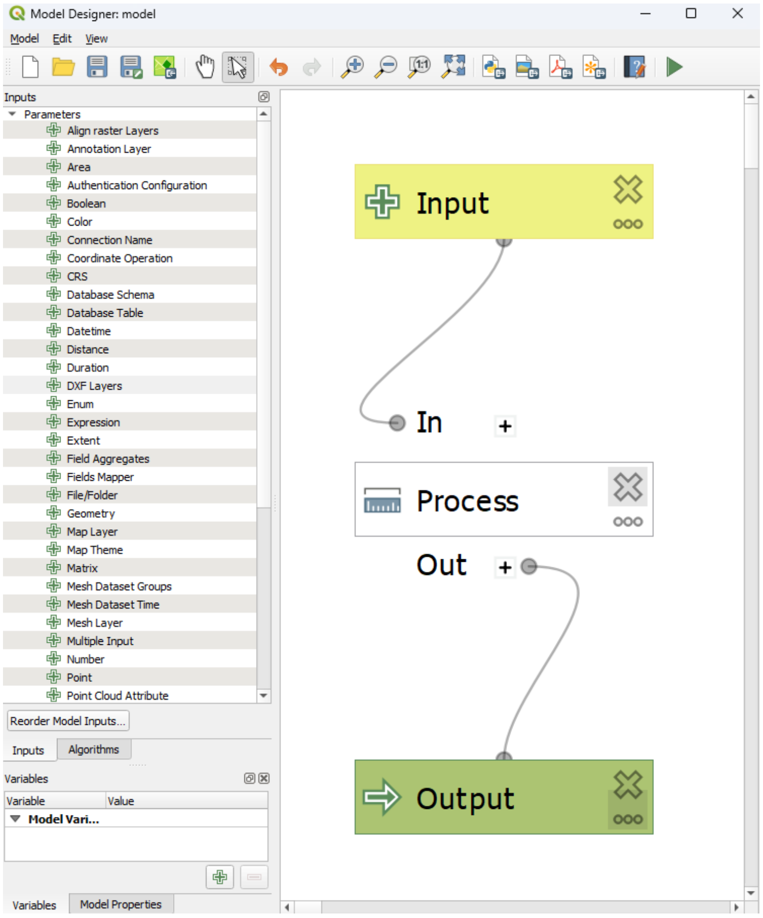


Fig. 2. Model designer graphical interface (example for the simplest workflow)

3. Săcele Dam failure case study

To illustrate the objective of the paper, a study case of flooding model was selected along Târlung River. Săcele dam is located on the Târlung River approximately 3 km upstream of the town of Săcele and about 12 km from the city of Brașov, it controls the runoff from a significant drainage basin, and it plays a crucial role in regulating both low flows during drought periods and flood discharges during peak flow events. The Târlung River is part of the Olt River Basin.

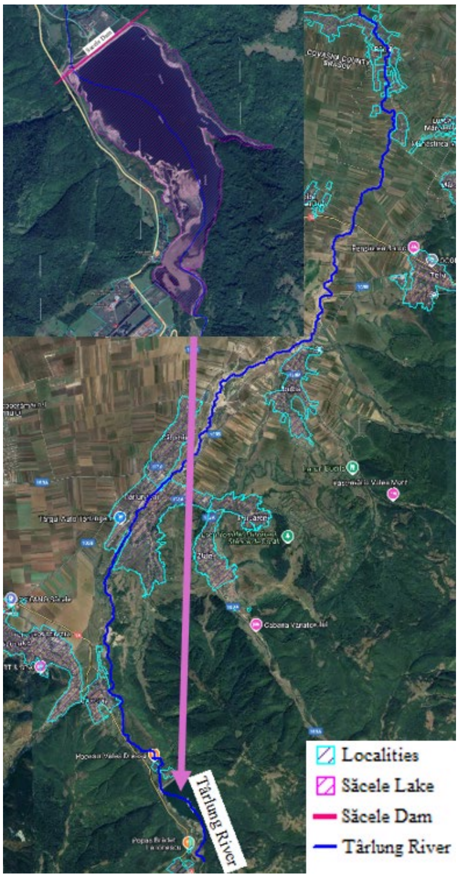
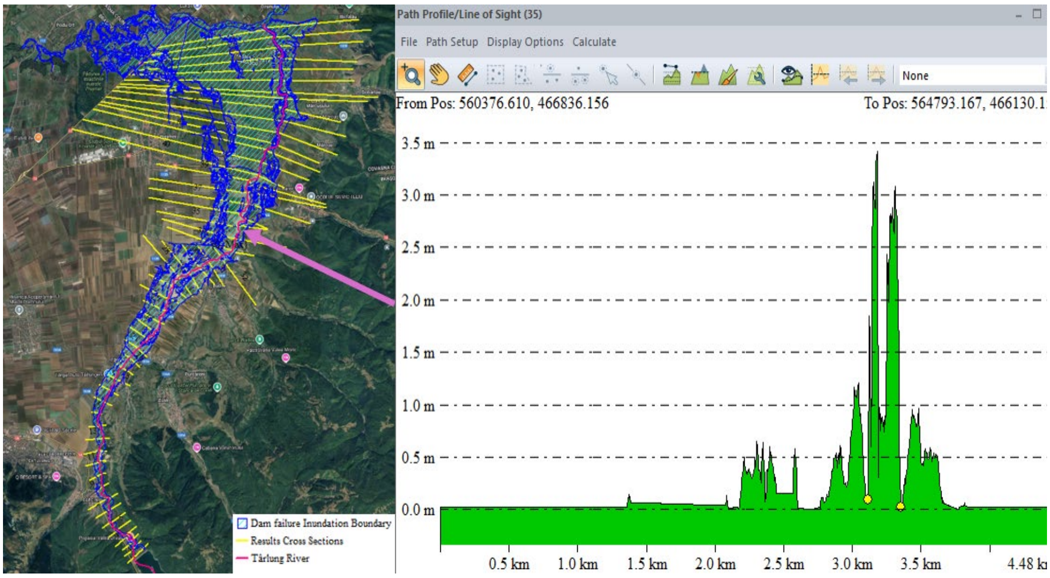


Fig. 3. Săcele Dam

Numerical studies assessing the potential consequences of dam failure or other extreme events must be conducted with thorough and precise analysis of the hydraulic results. This requires careful examination of large areas and systematic organization of results to ensure that relevant stakeholders, such as authorities, can make well-informed and sustainable decisions [24].

Traditional workflows require the manual extraction of key parameters for each simulated cross-section, including cumulative distance, peak flow, thalweg elevation, maximum water level, maximum velocity, average velocity, maximum depth, average depth, minimum propagation time, and cumulative propagation time.

Some of these parameters can be extracted automatically if locations of interest are pre-defined during the numerical model set up phase using the database system HEC-DSS provided by the US Army Corps of Engineers [25]. In real case studies, it is impossible to anticipate all locations of interest beforehand. Therefore, suboptimal manual work is induced into project workflows, to address this issue the present study suggests the use of Model Builder from QGIS.



a) b)

a) Inundation extent (blue line) and cross sections (yellow lines),
b) Local depth in an example cross section

4. Method

The Model Designer is a powerful tool that enhances automation by allowing users to customize workflows with a high degree of flexibility. As illustrated in Fig. 2, it enables the configuration of one or more processes based on a given input, with the option to select specific output types depending on the scope of the project. In the case of Săcele dam failure study 54 cross sections of interest were analysed using Model Designer. This approach helped engineers to manipulate big amounts of data in a short time, therefore dedicating more resources on results interpretation.

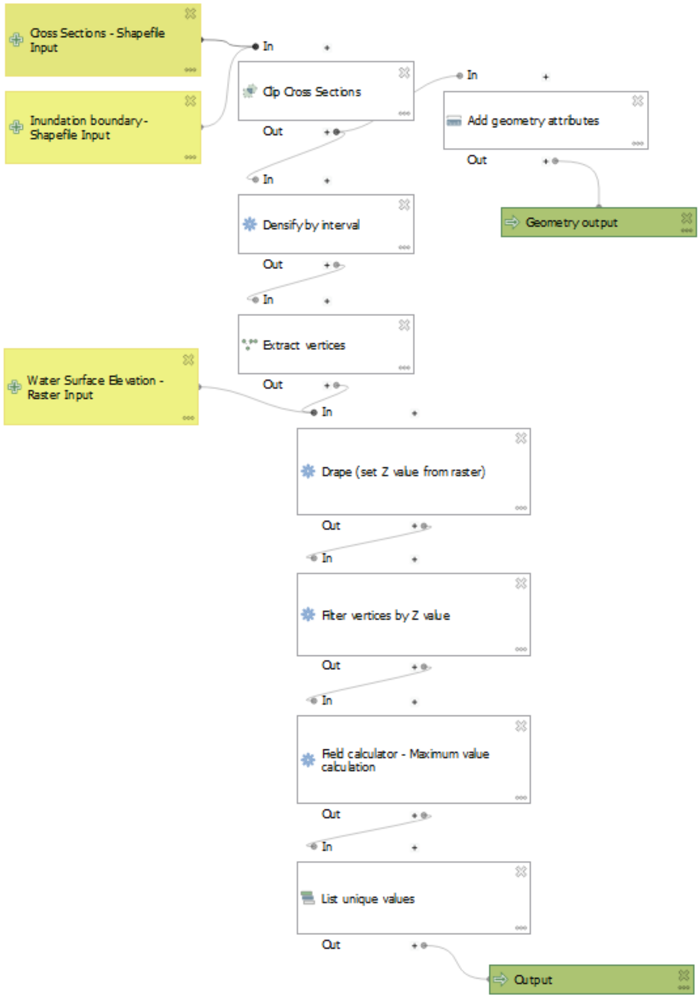


Fig. 4. Algorithm structure in Model Designer

The Model Designer offers flexibility through integration with the QGIS Python API, enabling users the ability to optimize and customize their workflows. It can be used as a standalone QGIS feature or serve as a foundation for further code development. PyQGIS library holds a variety of modules that expose QGIS functionality.

For the proposed workflow, the following classes and functions of PyQGIS were used from its Processing Framework Core: QgsProcessing, QgsProcessingAlgorithm, QgsProcessingContext, QgsProcessingFeedback and QgsProcessingMultiStepFeedback, QgsProcessingParameterVectorLayer QgsProcessingParameterRasterLayer, QgsProcessingParameterFeatureSink and QgsProcessingParameterDefinition.

5. Results and discussions

The proposed workflow flowchart is illustrated in Fig. 5 for the Săcele dam failure case study. For each step of the procedure the used function from PyQGIS is shown in parenthesis.

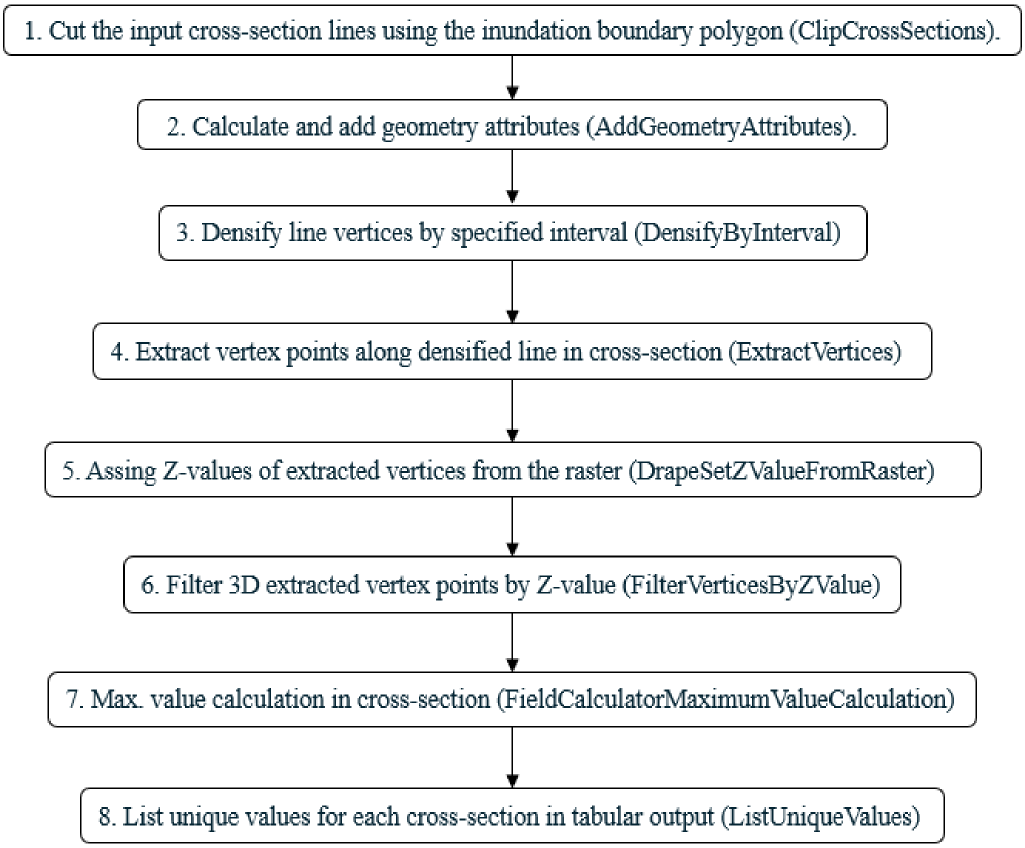


Fig. 5 Flow chart of the QGIS used workflow (and functions)

First step of the process it to clip (cut) the input cross-section lines using the inundation boundary polygon (or polyline). It ensures that only the segments of cross-sections that intersect the inundated area are retained for further analysis. This spatial filtering is essential to restrict calculations (e.g., elevation extraction) to only the flooded or affected zones.

Second step calculates and appends geometry-based attributes (e.g., length) to each clipped cross-section line using an ellipsoidal calculation method. It enhances the dataset with geometric metrics.

The next step (3) is to increase the number of vertices along each clipped cross-section line by inserting additional points at regular intervals, every 0.1 m (*densify by interval* function). It is a preparatory step that ensures sufficient sampling resolution before draping elevation or hydraulic values from raster surfaces.

The following step (4) converts each densified line into a series of individual points by extracting all vertices from the geometry. This enables raster value sampling at specific locations along each cross-section.

The next step (5) assigns Z-values to the extracted vertex points by sampling data from a raster surface. Each point receives a Z-value based on the raster pixel value at its location, effectively "draping" the points over the raster.

The following step (6) filters the 3D points (with Z-values set from the raster) to exclude those that do not meet a minimum value threshold. In this case, it retains only points with a Z-value greater than zero.

Field calculator is a tool used to create, update or manipulate attribute data in a vector layer based on expressions or calculations. The next step (7) calculates the maximum Z-value for each profile line (identified by its NAME attribute) and stores the result in a new field. For the water surface elevation in the cross-section - called NIV_MAX, for eg. - this represents the peak value of the dataset sampled from the corresponding raster.

The final step (8) extracts and organizes the unique combinations of specified attribute fields from the dataset in this case, the profile NAME and its corresponding maximum value NIV_MAX (in m above sea level – m.a.s.l.). The result is a simplified, tabular output containing only one entry per cross-section.

The example in Fig. 5 presents a workflow for a specific case of optimization that extracts maximum values of water surface elevations in a cross section from a raster type file. The execution time of the proposed process is reduced to a matter of seconds, in contrast to manual data extraction, which is significantly more time-consuming and labour-intensive. The use of the QGIS Model Designer offers a high degree of customizability, enabling tailored workflows suited to specific project needs.

Table 1 and Table 2 present examples of typical output data generated during the hydraulic post-processing workflow of flow, water level elevation, velocity, water depth and propagation time.

Table 1

Sample Results from Hydraulic Simulation – Flow Characteristics and Cross-Sectional Metrics

Cross Section	Cumulative distance	Peak flow	Thalweg elevation	Maximum water level	Maximum Velocity	Average velocity
[number]	[m]	[m^3/s]	[m.a.s.l.]	[m.a.s.l.]	[m/s]	[m/s]
1	0	11052.951	699.356	720.18	12.61	5.8
2	72.4	11064.51	695.19	716.63	13.26	6.05
3	849.23	11193.332	689.26	708.28	9.01	5.52
...	...	...	...	...	...	...
54	26383.5	2266.71	501.98	508.47	1.84	0.65

Table 2

Sample Results from Hydraulic Simulation – Depths and Propagation Times

Cross Section	Maximum water depth	Average water depth	Minimum propagation time	Cumulative propagation time
[number]	[m]	[m]	[min]	[min]
1	20.67	5.26	0	0
2	17.88	9.02	1	1
3	16.24	5.4	0	1
...	...	...	...	...
54	5.97	1.94	5	120

Building upon the previously presented model, future developments aim to incorporate batch processing of multiple raster datasets and the aggregation of various result types into a single output, this will facilitate practical scalability and will optimize result processing for large datasets in real-world projects. Typical engineering workstations are adequate for most applications. However, extremely large-scale simulations involving multiple high-resolution rasters may require optimized hardware configurations to ensure optimal performance and efficiency.

Automating data extraction in this way enhances efficiency, reduces the potential for human error, and significantly decreases processing time. This allows engineers to allocate more effort toward complex analytical tasks, while also facilitating access for users with limited GIS expertise or without licensed GIS software. Presented model is not dependent on a particular coordinate reference system, however, maintaining consistency across all input files as standard practice is recommended.

An additional advantage of QGIS lies in its PyQGIS API, which allows users to convert graphical models into Python scripts, providing a foundation for further customization and automation. The integrated Python console enhances this functionality by offering a development-ready environment, complete with a wide range of built-in libraries and tools.

6. Conclusions

This paper demonstrates how open-source GIS tools, particularly QGIS combined with Python scripting (PyQGIS), can significantly enhance the post-processing of results obtained from HEC-RAS simulations. Through the automation of key steps such as geometry extraction, raster draping, and statistical aggregation, the proposed workflow reduces processing time from hours to seconds and minimizes the risk of manual error.

The use of QGIS Model Designer facilitates structured, repeatable workflows and enables users to convert visual models into Python code for further customization. This flexibility allows the integration of various hydraulic result types (e.g., velocity, depth, water level) and supports batch processing of raster data — a major advancement for studies involving large or complex modeling domains.

By applying this workflow to the Săcele Dam failure scenario, the utility of such automation is clearly demonstrated. Engineers were able to efficiently process and extract hydrodynamic parameters for dozens of cross-sections, redirecting valuable time and resources toward interpretation and decision-making. Moreover, the methodology improves accessibility for professionals without specialized GIS training or access to proprietary software.

Future developments will focus on expanding the workflow's capability to handle multiple raster types simultaneously, aggregate multiple hydraulic indicators into unified outputs, and further streamline result integration for decision-support systems.

Data Availability Statement

The data is owned and made available for the creation of this article by S.C. AQUAPROJECT 395 S.A., Romania (https://www.aquaproiect.ro/). Restrictions apply to the availability of these data 396 according to the AQUAPROJECT policy.

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