2D River Modelling With Usace Hec_Ras 5.0.7: Simulation for Operation, Flood Events and Dam Breaks

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July 2020

BBA.CA

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Executive Summary

The practice of 2-Dimensional River Modelling has been conducted in the industry for almost 30 years. In the beginning, the application was very expensive and complicated due to limitations on the technologies. Over the years, as both computer technologies and modelling theories evolve, design engineers are able to create 2D River Model in regular office computers using specialized software.

A 2D River Model can be used in numerous applications such as infrastructure planning, dam safety study, and flood scenario prediction. It has several advantages compared to the conventional 1D model in terms of accuracy and workability. Furthermore, georeferenced 2D models can produce better visual results, which makes it easier for designers to communicate with nontechnical stakeholders and integrate as part of emergency planning exercises.

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Introduction

There are many numerical river modeling techniques to simulate different hydrological events. However, it is critical to choose the most applicable method based on project needs and the nature of the river itself. As budgets and expectations vary from projects, engineers should be able to select the most economic approach based on initial assessment without compromising desired accuracy of the model. For example, a simple 1-Dimensional River Model using HECRAS or MIKE 11 will be sufficient when the target reach has a rather uniform cross section, small width to length ratio, and limited pooling and flood plain area. A sophisticated 3- Dimensional computational fluid dynamics (CFD) model should be employed when complex structures are involved in a small study area and the response of the structure is very sensitive to the fluid behavior.

A 2-Dimensional River Model is a better solution when the study area involves river structures, long reach, fish spawning, and irregularities in the channel geometry. Compared to a 1D model, which interpolates terrain between selected cross sections and defines a flow direction, a 2D model is constructed with meshes that contain elevation data of the entire study area. As a result, irregularities and obstructions within the bathymetry can be captured, and water can travel between these meshes solely based on kinematic and potential energy, which is a more realistic representation of nature conveyance. Apart from that, a 2D model requires less computation time to produce relatively accurate results, while a CFD model can take months to set up, run, and calibrate, especially when the scope of study area is massive.

While there is a lot of 2D River Modelling software available on the market, such as HEC-RAS and TELEMAC, this paper will mainly focus on 2D River Model features in HEC-RAS. Detailed introductions include model geometry, boundary condition, numerical stability, and model calibration and validation.

Capability and Advantages

There are several advantages of 2D River Modelling:

- Georeferenced visualization that makes it easier to interpret the results with nontechnical participants;
- Fewer engineers' inputs and judgements compared to 1D River Modelling;
- Capable of modeling complex hydraulic structures and flow patterns;
- Accurate results with less time consumption compared to CFD models.

The following paragraphs will discuss some basic features in HEC-RAS 2D modelling. The order of introduction follows the conventional procedure of creating a 2D River Model.

Terrain

Traditionally, geometric data, such as river bed elevation and river structures, are imported, created, and modified in HEC-RAS Geometric Editor. However, HEC-RAS 5.0.7 has made some significant improvement, which allows users to easily manipulate the geometric features in RAS Mapper. The first step of creating a 2D model is importing a georeferenced terrain file that contains all elevation data within the study area. The topography can be either original land survey results or modified surface exported from other software like CIVIL 3D. Figure 1 demonstrates a typical terrain layer in the RAS Mapper, which is an edited surface exported from CIVIL 3D.

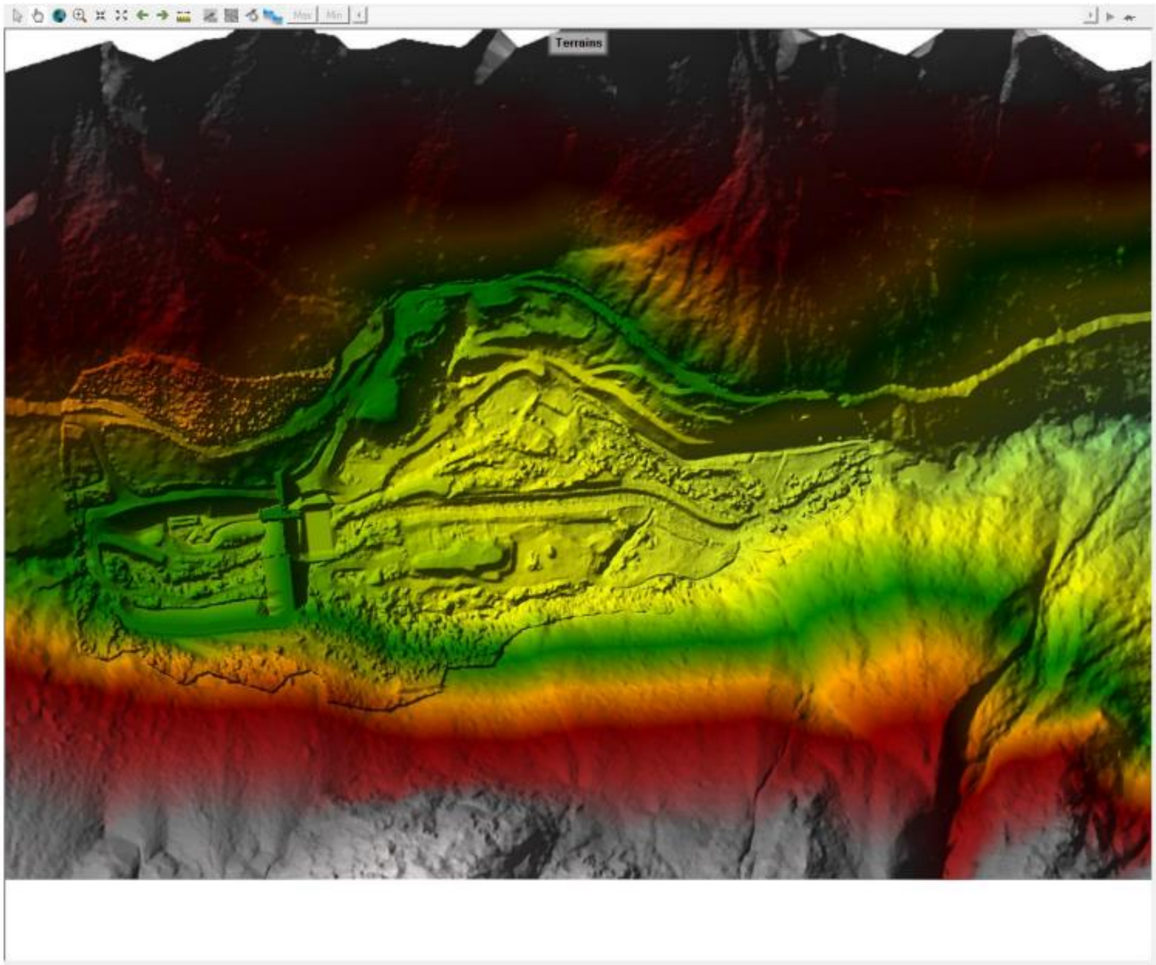

Figure 1: Typical Terrain Layer in RAS Mapper

Additional map layers, such as satellite images and survey images, can be added to assist users to verify or modify the imported terrain. Figure 2 shows a map layer of survey photographs on top of the terrain. This feature is also critical when defining manning's values in the model, which will be covered in Manning's n Land Cover section.

Figure 2: Additional Map Layer of Site Images (60% transparency)

By creating a hypothetical 1D river reach, structures like levees, dam, and buildings can be added onto the existing terrain. This feature can be a very handy tool when engineers want to quickly test the feasibility of their preliminary designs without using civil designer software, such as CIVIL 3D. Figure 3 and Figure 4 demonstrates the basics of this method.

Figure 3: Creating Hypothetic 1D River Reaches

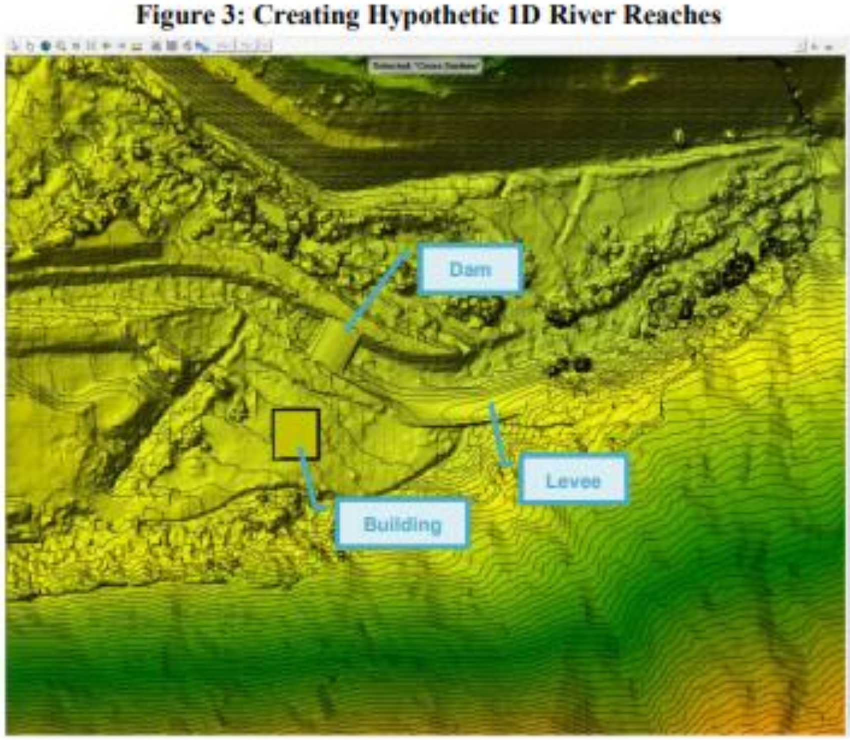

Figure 4: Terrain Modification Results

2D Flow Area

A 2D flow area is the receiving body where water can travel freely based on kinetic and potential energy. An ideal 2D flow area should enclose all regions where flow can possibly reach. This includes the main channel bed, tributary channel, overbank, and flood plain. Inversely, a 2D flow area should not include the area where water cannot reach, such as high ground and remote zones. These areas could result in unnecessary computation time and bad meshes. An example of a 2D flow area is shown in Figure 5.

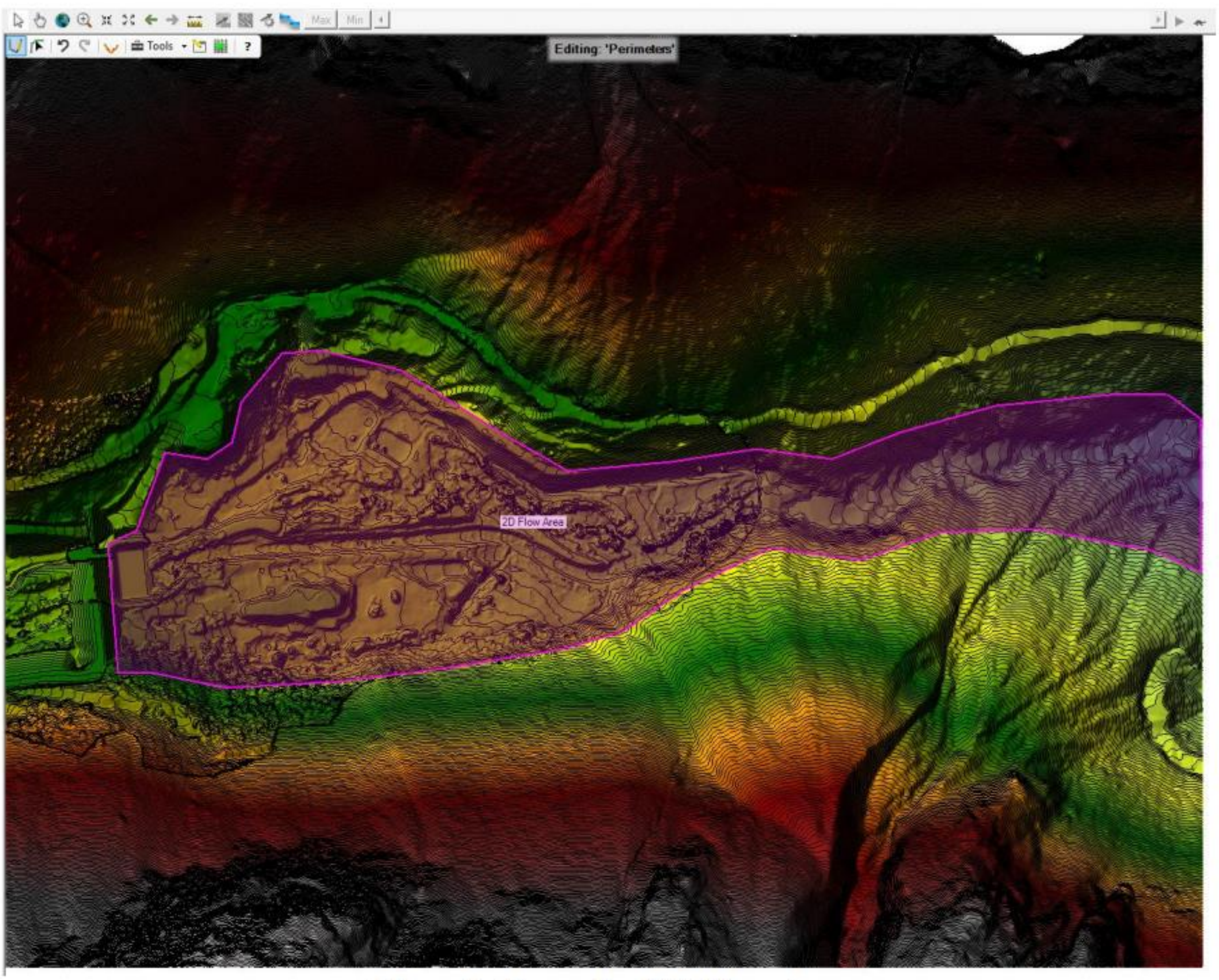

Figure 5: Example of 2D Flow Area

After defining the 2D flow area perimeter, mesh size should be input so that the flow zone can be divided into small cells that automatically store the elevation values at their location based on associated terrain layer. Mesh size has significant influence on computational speed and results accuracy. Therefore, several different mesh sizes and combinations should be tested in order to achieve the desired accuracy and avoid numerical instability. Conventionally, the bathymetry region is more critical to the flow behaviour, where finer meshes are recommended. The overbank and flood plain area have less impact on the results, therefore coarser meshes are acceptable to reduce the computational time. Furthermore, finer meshes are expected in some locations, such as the areas of interest, obstructions in the channel, and areas near river structures. Overall, it is up to the engineers' judgement to choose the most appropriate mesh configuration that optimizes both efficiency and accuracy. An example of generated mesh is shown in Figure 6. Compared to the overbank area, the channel bed is divided into finer meshes (1.0 m) using the refinement area function in RAS Mapper. Additionally, finer meshes (0.5 m) are created using break line function around the pink line where a bridge of interest is located.

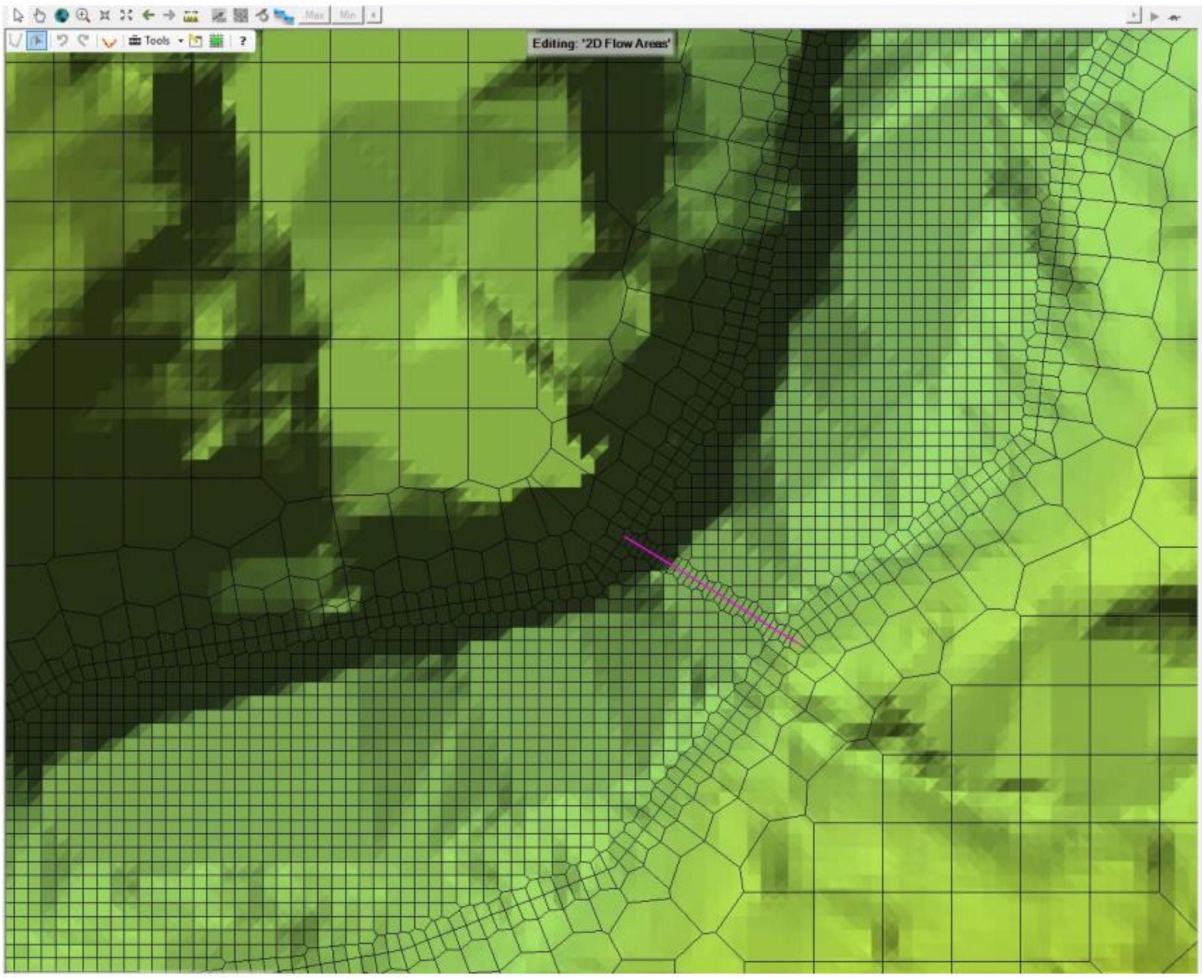

Figure 6: Example of Mesh Generation

In general, the mesh quality is crucial to numerical stability and computational time. Therefore, more refinement areas and break lines are recommended to allow for a smooth transition between different sizes of mesh zones. These refinement techniques can effectively minimize the number of error meshes and skewness.

River Structures

The river structures can be defined in Geometric Editor, which include weirs, culverts, gates, and bridges, as shown in Figure 7. River structures can either be placed within the 2D flow area or act as a connection between the 2D storage area and flow area. Apart from the river structure itself, a breach scenario can also be simulated within the structure by entering the breach parameters. Engineers shall refer to the HEC-RAS Users Manual (USACE, 2016) for detailed instructions.

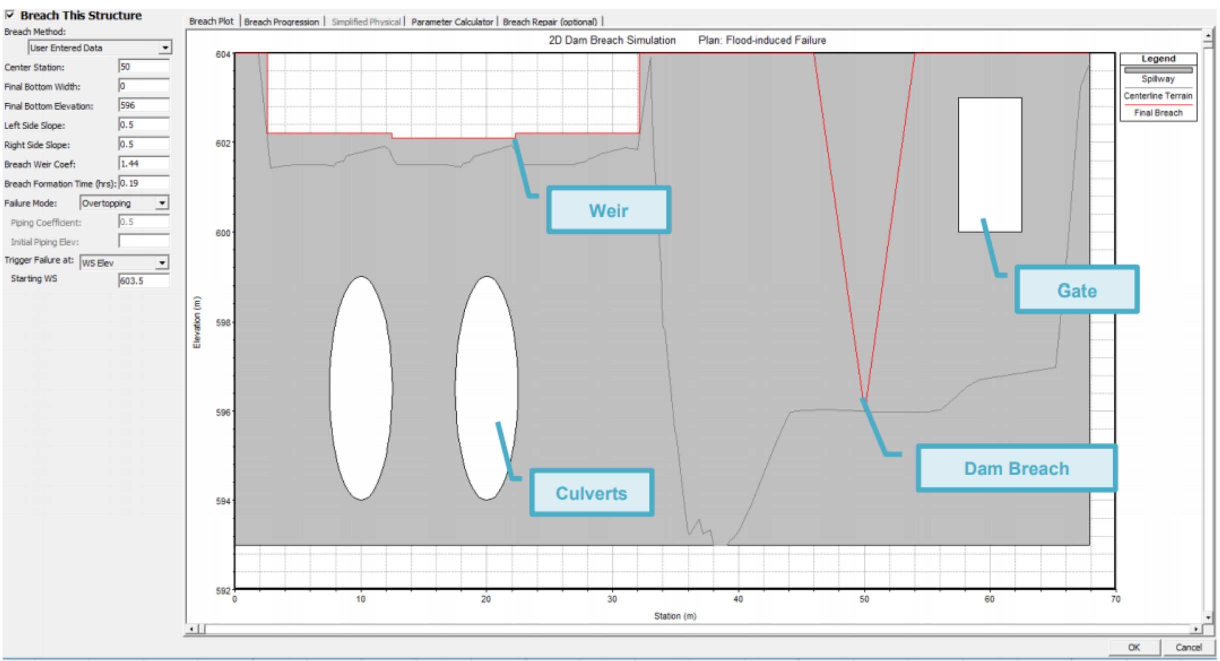

Figure 7: Example of River Structures and Breach Scenario

2D Storage Area

A storage area option can be used for a headpond, detention pond, or lake, etc. It is usually treated as the upstream/downstream boundary conditions for either the source of water or final destination. An example of a 2D storage area is presented in Figure 8. The relationship between volume and water surface elevation is required to define the storage characteristics. HEC-RAS is able to automatically generate the Volume-Elevation curve based on the provided topography, as shown in Figure 9, or the engineers can input the data manually.

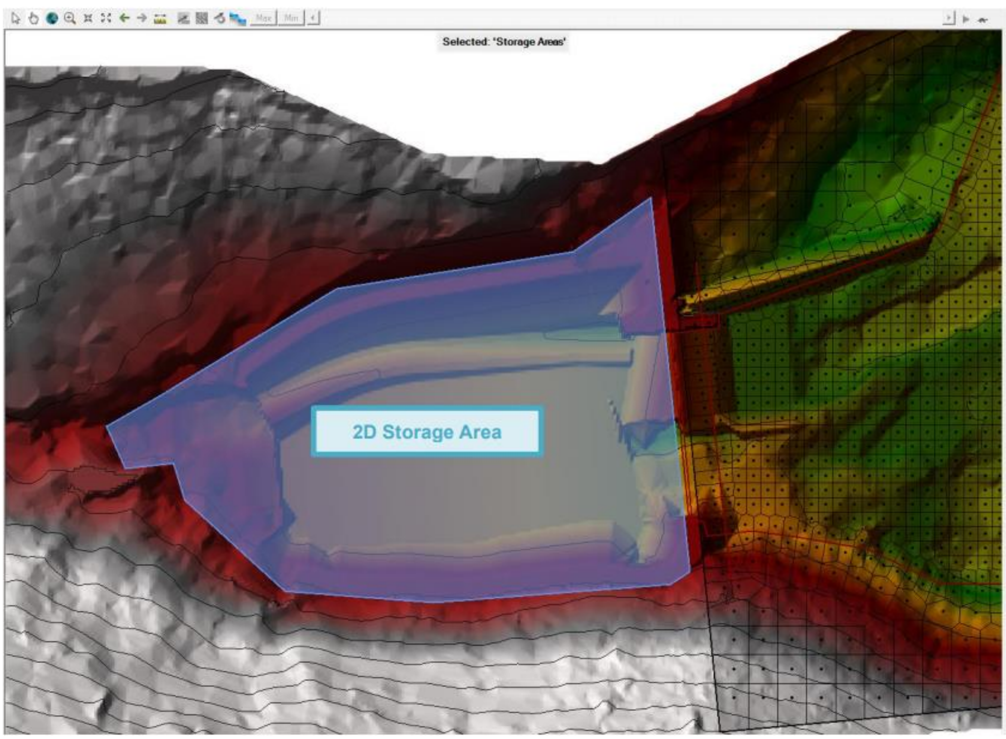

Figure 8: Example of 2D Storage Area

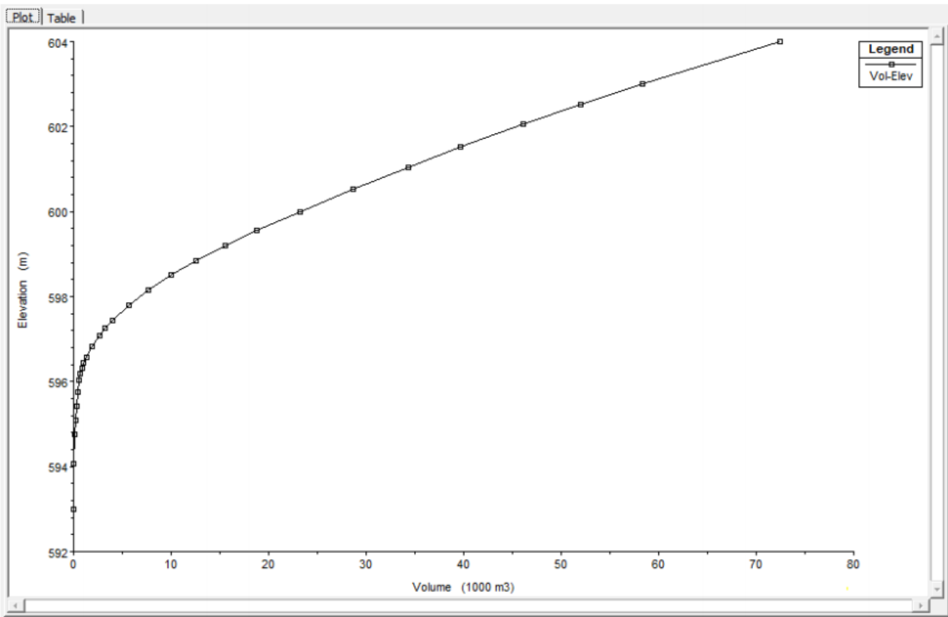

Figure 9: Volume-Elevation Curve Generated by HEC-RAS 5.0.7

Manning's n Land Cover

Another great advantage of the 2D river model is that users can define specific manning's n values (also known as surface roughness) anywhere within the 2D flow area. While in a 1D model, manning's n can only be defined in the main channel and left/right overbanks. Sometimes, flow depth and velocity can be very sensitive to manning's n in a narrow and meandering channel. Therefore, comprehensive distribution of manning's n in the flow area is necessary to achieve the desired accuracy. As mentioned in the previous section, satellite images in RAS Mapper can be very helpful to separate different manning zones. A typical scenario with a complicated surface roughness condition is shown in Figure 10, in which multiple vegetated islands and side creeks are presented.

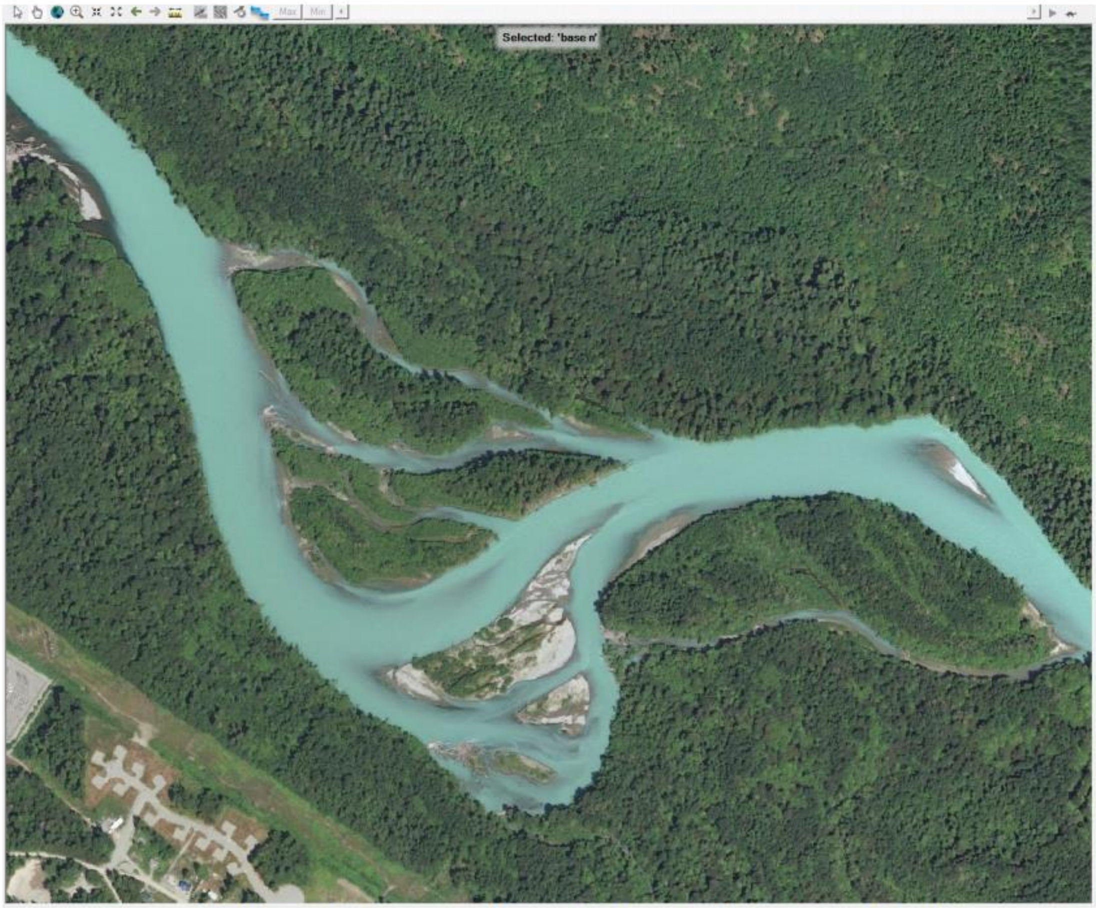

Figure 10: Typical Channel with varied Surface Roughness Condition

Based on satellite images, engineers will be able to map out different surface roughness conditions with polygons. By using the Land Cover function in RAS Mapper, new layers of Manning's n Land Cover can be created according to these polygons' geometry, as shown in Figure 11. After specifying the manning's n in each Land Cover layer, surface roughness within the 2D flow area will be overwritten with the engineers' defined values.

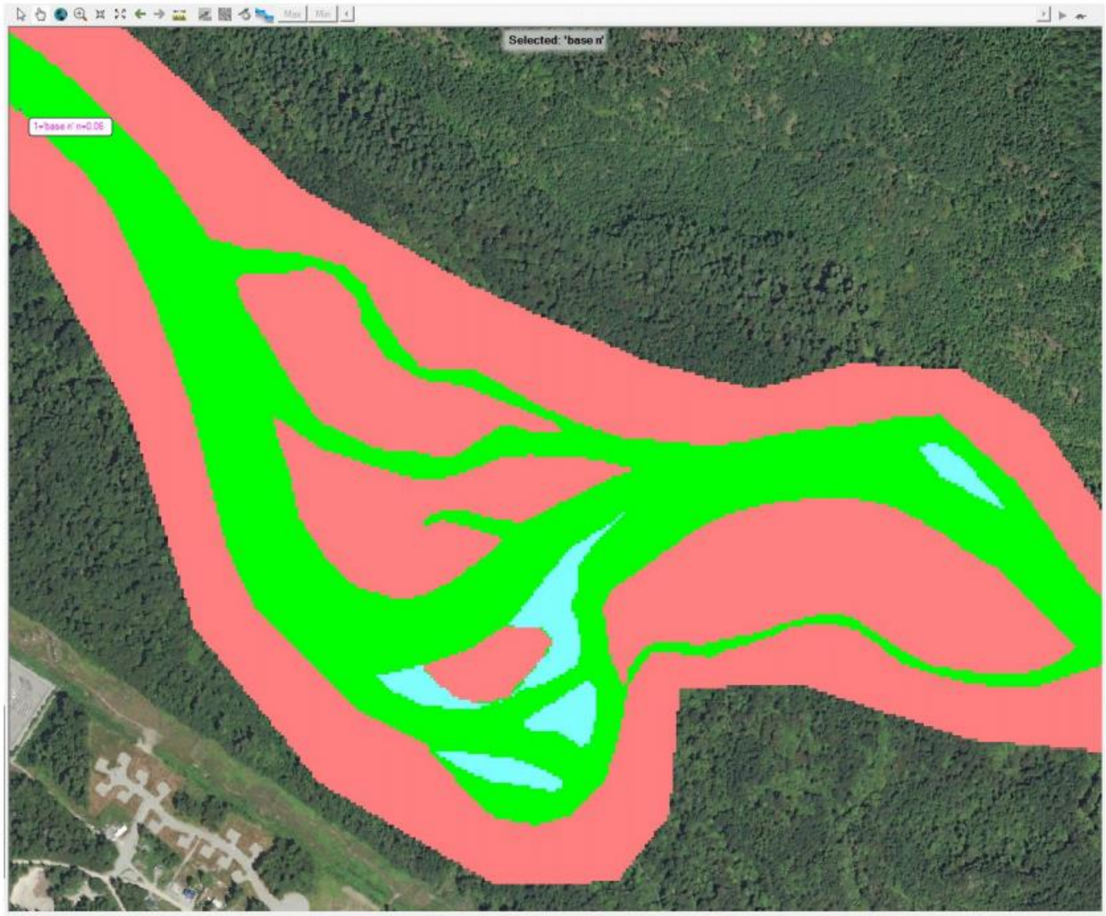

Figure 11: Example of Manning's n Land Covers

Determination of the manning's n value requires experience and generally involves several calibration iterations. Simulation results are usually compared with flow gauge data, field measurement of water depth, and images of flow boundary in this iterative process.

Boundary Conditions

Generally, system boundaries are defined as a channel inlet, outlet, and storage areas. Several options are available for boundary condition types, such as hydrograph, normal depth, precipitation, and rating curves. Engineers shall refer to the HEC-RAS Users Manual (USACE, 2016) for detailed instructions.

Numerical Stability

The selection of mesh size and time step is a balance between achieving good numerical accuracy while minimizing computational time. To avoid numerical instability during the

simulation, the computational time step needs to be adjusted according to the mesh size defined in the 2D flow area. By satisfying the Courant Condition below, numerical stability can be achieved.

$C = \frac{V\Delta T}{\Delta X} \leq 1$ (USACE, 2016)

Where:

C = Courant Number
V = Flood wave velocity
ΔT = Computational time step(s)
ΔX = Average cell size

In order to get a more accurate and stable wetting front, a maximum Courant number of 1.0 is recommended given that the 2D flow area was completely dry initially. (USACE, 2016) Although engineers can manually adjust the time step to satisfy the Courant Condition, the HEC-RAS simulation plan has a "Courant Dependent Time Step" option. This adaptive computation method allows the system to automatically adjust the time step according to predefined Courant criteria.

Results Processing

Simulation results can be viewed in RAS Mapper. A list of computed result parameters are shown in Figure 12. Additionally, flow animation can be displayed for unsteady flow analysis.

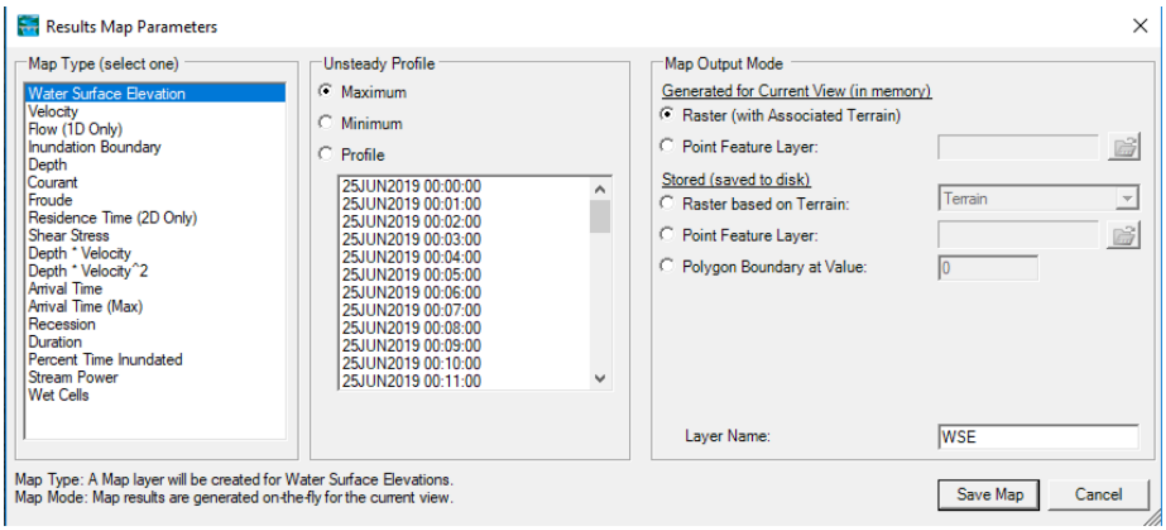

Figure 12: List of Result Parameters

An example of computed water depth results is presented in Figure 13.

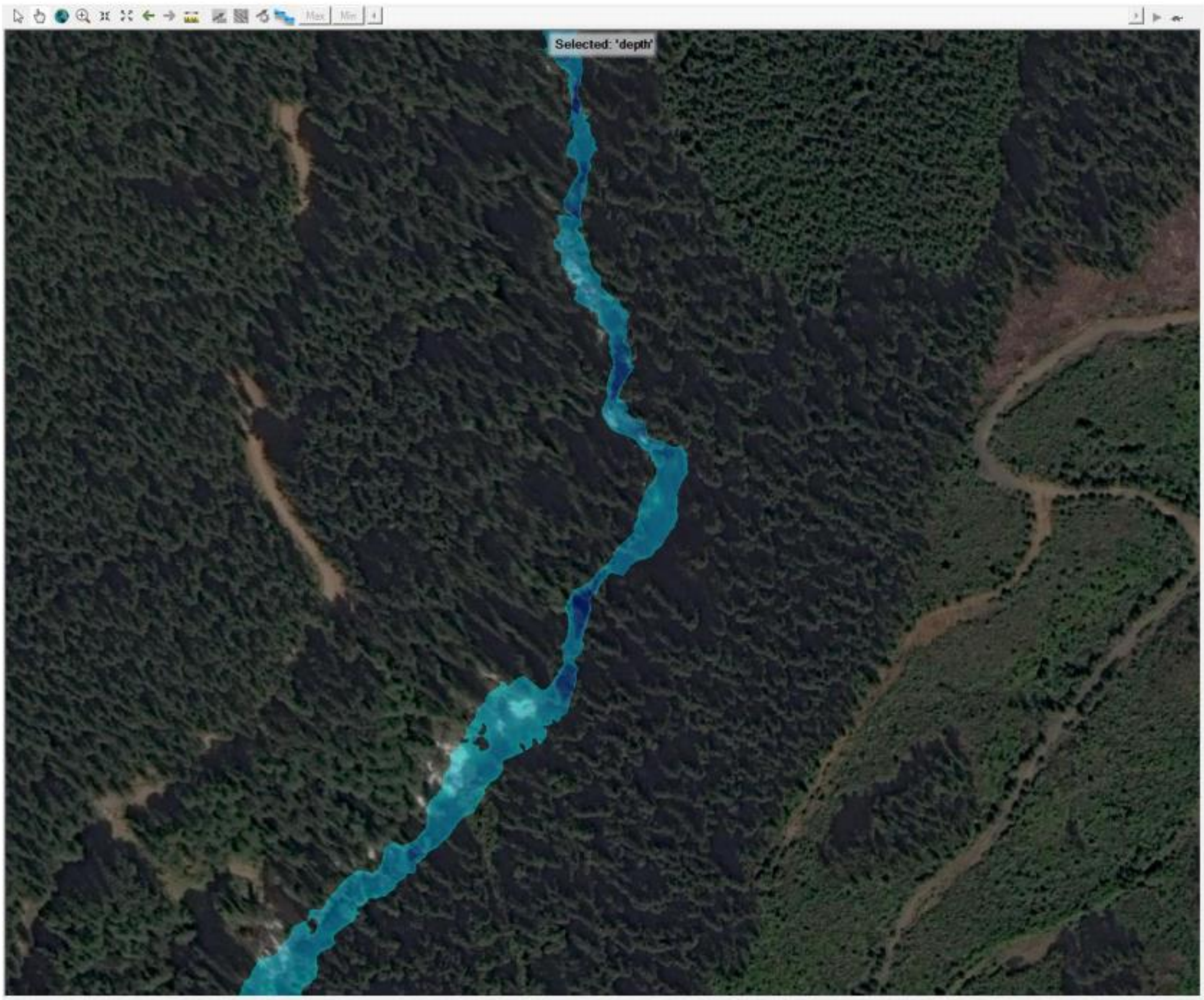

Figure 13: Example of Water Depth Result

Apart from the listed parameters, the particle tracing and static velocity arrow functions are also available to examine the legitimacy of the results, as shown in Figure 14 and Figure 15.

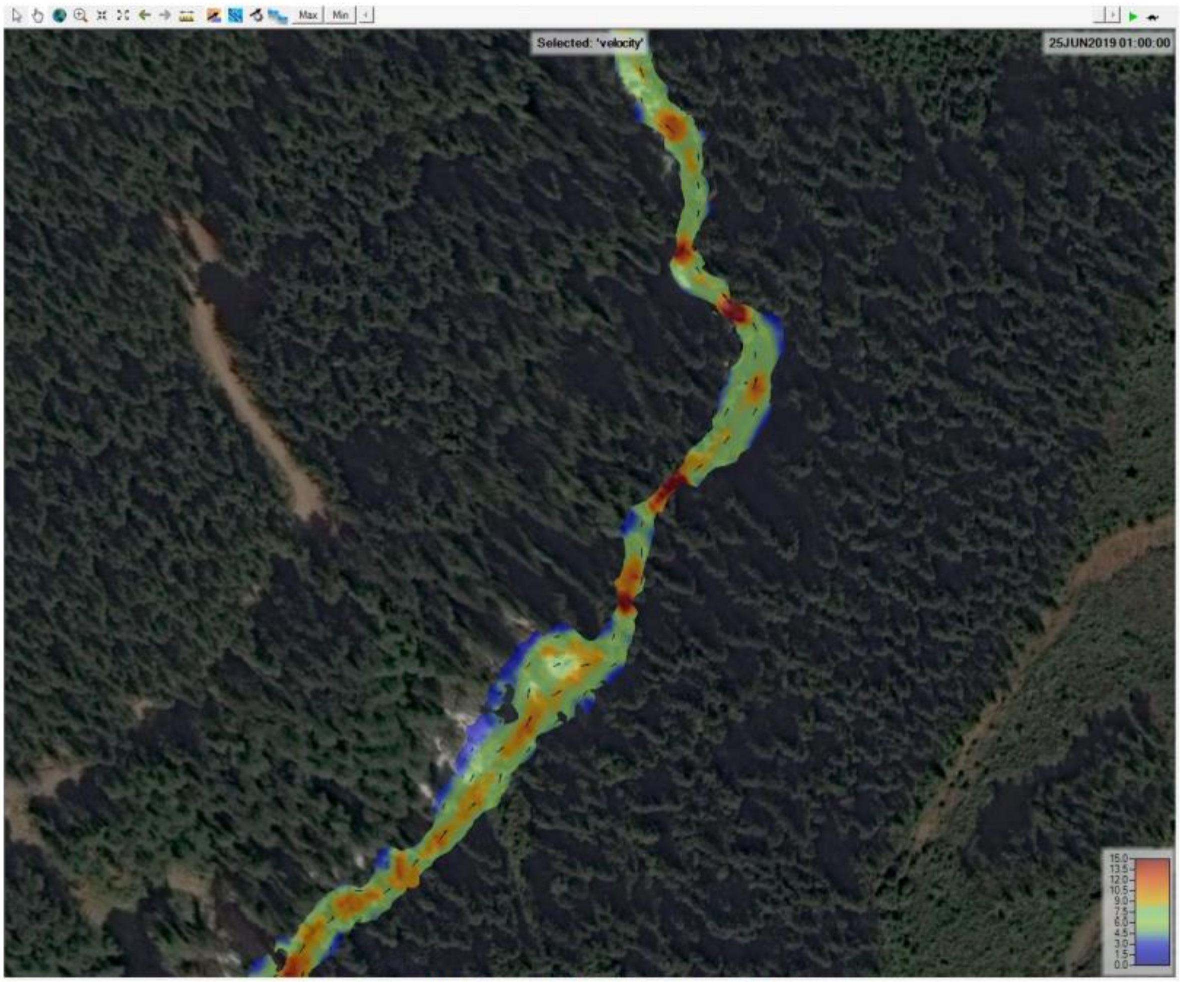

Figure 14: Example of Static Velocity Arrows

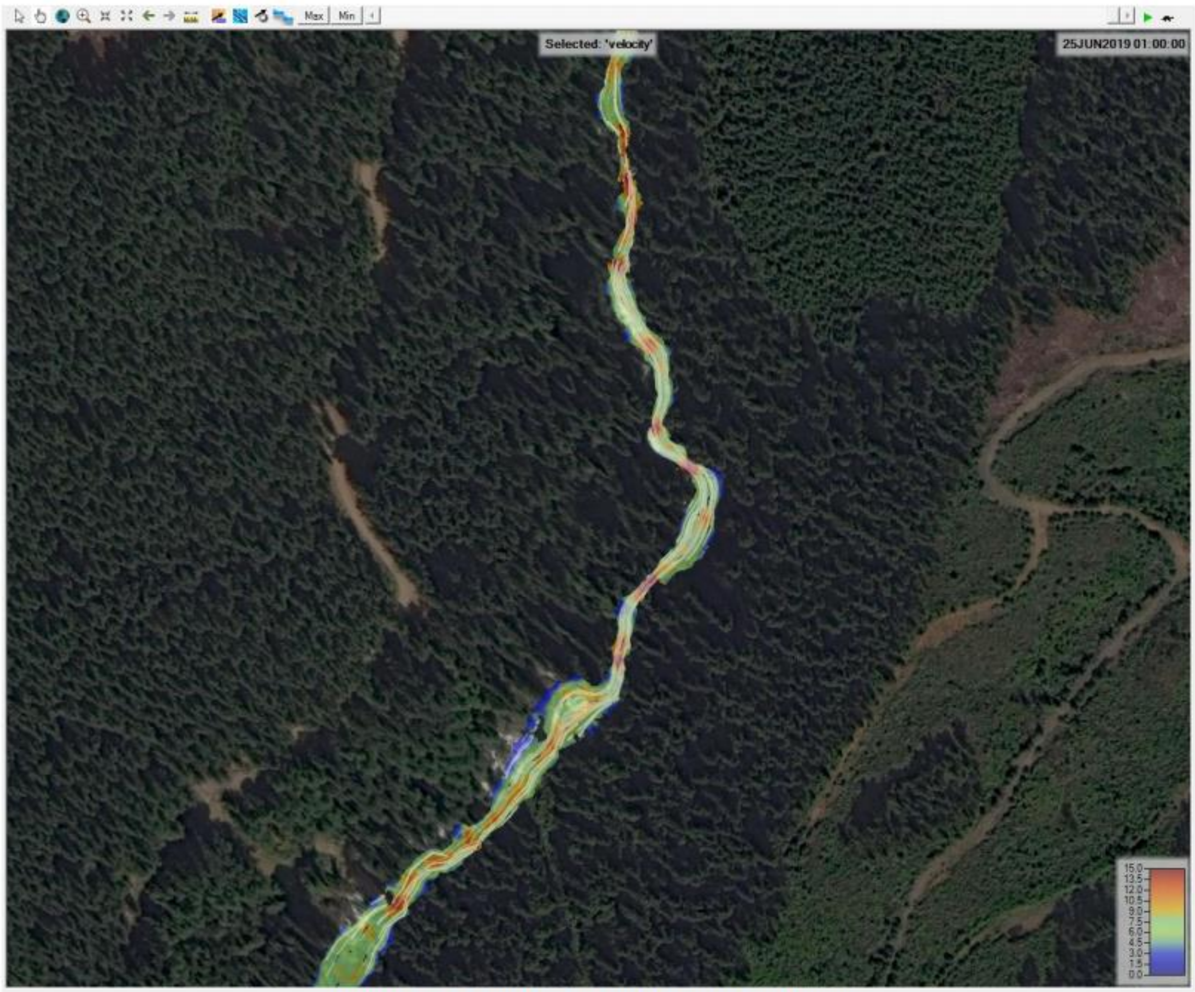

Figure 15: Example of Dynamic Particle Tracing

If the flow behavior is interested in a specific location, a profile line can be created to display the desired parameters at the locations of interest, as shown in Figure 16.

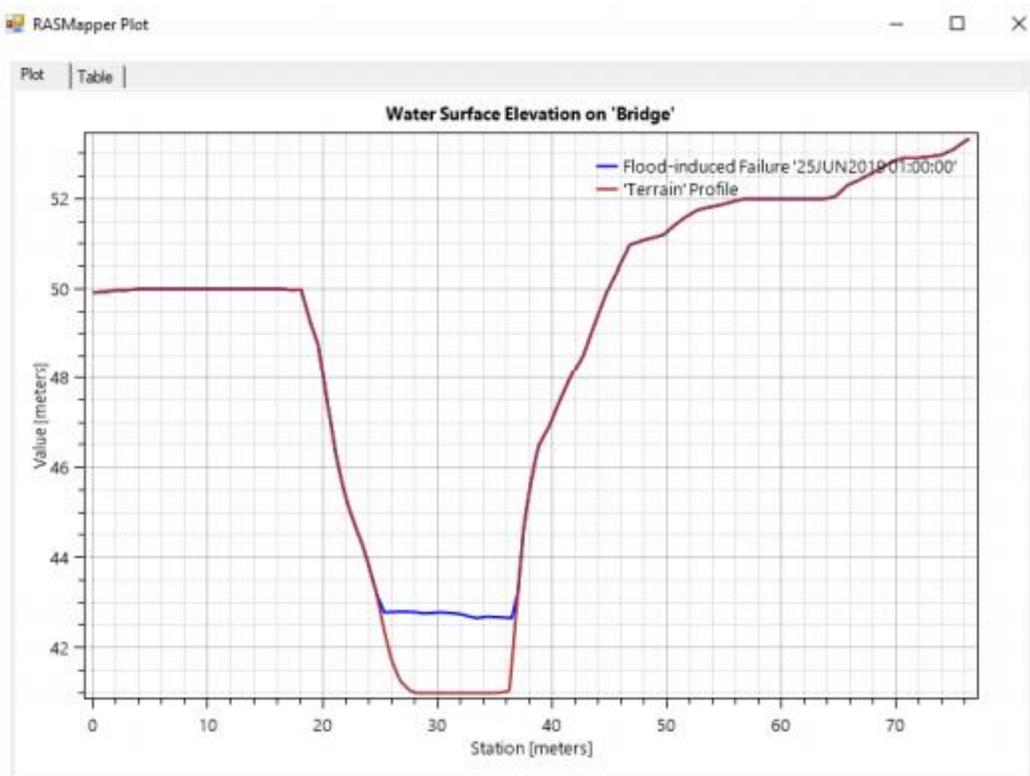

Figure 16: Water Surface Plot at Specific Location

Besides what have been shown above, there are more options available for result processing as described in the HEC-RAS Users Manual (USACE, 2016).

Model Calibration and Validation

Several approaches can be used to calibrate and validate the simulation:

- Mesh quality
  - Check for error points, aspect ratio, multiple centers, skewness, and other criteria.
- Sensitivity analysis

    - Conduct the simulation by changing only one parameter and keep the rest of the parameter the same to see how results vary from such a modification.

- Compare results with other available information

    - Compare the simulation results with site measurements, flow gauge data, photos, etc. Adjust the model accordingly if needed.

Conclusion

This paper summarizes some basic features in solving hydrological events using 2D River Modelling. Although this paper only introduces the modelling procedure using HEC-RAS 5.0.7, other river modelling software has similar capability to conduct the simulation. This methodology is recommended when the study river has relatively complex flood patterns that cannot be accurately represented in 1D river models. By conducting the simulation, important flow characteristics, which include water depth, velocity, hydraulic jump, pooling, flow attenuation, and an inundation map, are made available to the clients and designers. Additionally, this methodology has extensive applications, such as major flood events, dam break, and normal dam operation. It is also a very powerful tool for engineers to effectively test their designs in both the preliminary and final stage.

About the Author

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Ms. Shahraki has over 18 years of experience in structural and civil design and directing the construction of hydropower plants and appurtenant hydraulic structures, substations, thermal power plants, mining facilities and petrochemical plants. She designs and optimizes various types of steel and concrete structures such as power plants, pump stations, intake structures, dam bottom outlets, equipment foundations, supports and pipe racks, using applicable codes and standards. She uses CSI (SAP 2000, ETABS, SAFE) codes for structural analysis and Mathcad for stability analysis and detail design of structural elements. Moreover, Ms. Shahraki has extensive knowledge of AutoCAD CIVIL3D, Hec-Ras which she applies for her work on preliminary engineering, conceptual layout, excavation drawings, hydraulic designs and finish grading of plants.

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