# IAHR Fluvial Hydraulic Challenge 2021 Group #3

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## 1. Summary

The IAHR Young Professionals has organized the Fluvial Hydraulics challenge in order to promote international and interdisciplinary collaboration among young professionals and academics working at institutions across the globe in the hydro-environment field. The challenge is aimed at the numerical modeling of a 65 km stretch of the Red River and its confluence with the Black and Atchafalaya rivers, located in the southern United States in the state of Louisiana. The challenge consisted of modeling the Red River and analyzing the hydraulic characteristics with the tool HEC-RAS 2D by the United States Army Corps of Engineers (USACE). For the challenge, much of the base information was previously provided such as: Orthophoto of the study area, Bathymetry in .txt format with different sampling spacing (10-50m), Daily discharge data at stations L and D 1, ORCS and ACME and Daily water level data at Simmesport station. Preliminary to modeling in HEC-RAS, we proceeded to generate the raster of bathymetric elevations with the supplied .txt file, this process was necessary for the creation of the terrain file within the HEC-RAS model. This assignment was performed using ArcGIS 10.8 software, in which a raster of cell size 10x10 meters was defined as output in .tif format. We define the 2d flow areas and geometric parameters of the hydrodynamic model, through RAS Mapper. For the initial testing, a grid size of 20 meters was defined for the fluvial challenge.

Another fundamental parameter in the definition of the geometric characteristics of the project is the assignment of Manning's roughness coefficients, so as an initial reference value for the modeling, a value of 0.025 was defined as representative for multiple meandering rivers worldwide and with conditions similar to the Red River (Mississippi River, Magdalena River, etc.).

The modeling was carried out under the conditions of unstable flow using the values of flow and stage hydrograph: Discharge will be assigned at L&D 1, Acme, and ORCS, provided in LD_1.txt, Acme.txt, and ORCS.txt. Tailwater will be assigned at Simmsport, provided in Simmsport.txt. For this challenge, the boundary conditions were used: Flow hydrograph and Stage hydrograph, which are used to enter flow into the 2D area. Additionally, an EG slope of 0.0025 was defined for each upstream boundary conditions. The time series data showed that time intervals for all four stations is 86400 seconds, equivalent to 1 day and the modelled time for this simulation was defined to 1 year (365 days). Within the Unsteady Flow Analysis, the configuration of computational values necessary for the modeling is defined. For the challenge the following initial values are defined for the modeling: Computation Interval (15 minutes), Hydrograph output Interval (1 day), Mapping output Interval (1 day), Detailed output Interval (1 day). After the computational calculation of the proposed model, the results are visualized in RAS Mapper for velocity, depth, water elevation, among other additional results throughout the simulated time or verifying maximum and minimum values.

# 1 Location and study area

The challenge is aimed at the numerical modeling of a ~65 km stretch of the Red River and its confluence with the Black and Atchafalaya rivers, located in the southern United States in the state of Louisiana. The sector of interest is bounded upstream by the Red River's upstream gate and dam #1, a site of interest for navigation on the river. The sector is bounded downstream in the vicinity of the city of Simmesport, LA.

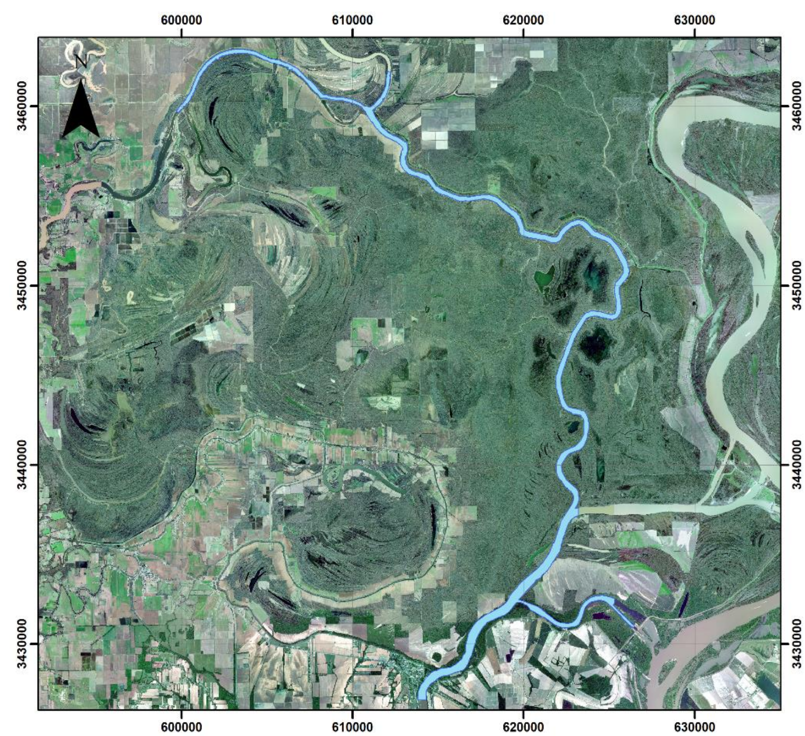


*Figure 1. Study area location*

# 2 Input data management and preprocessing

A fundamental component of the generation of numerical models within computational hydraulics is the preprocessing of information collected in field (bathymetry and ADCP surveys, etc.) and secondary information (water levels and discharge records, satellite images, etc.). For the challenge, much of the base information was previously provided and is listed below:

- Orthophoto of the study area
- Bathymetry in .txt format with different sampling spacing (10-50m)
- Daily discharge data at stations L and D 1, ORCS and ACME
- Daily water level data at Simmesport station

Both the bathymetry and the orthophoto were in the Projected Coordinate System NAD_1983_UTM_Zone_15N, so this coordinate system was maintained for the entire project. Additionally, with the aid of an SRTM satellite image of terrain elevations, it was possible to verify a concordance in the elevations of the bathymetry and the DEM, so it is assumed that the elevations provided, water levels and discharge rates are in the international metric system (SI).

## 2.1 GIS processing

With all the engineering guesses made, we proceeded to generate the raster of bathymetric elevations with the supplied .txt file, this process is necessary for the creation of the terrain file within the HEC-RAS model. This assignment was performed using ArcGIS 10.8 software, in which a raster of cell size 10x10 meters was defined as output in .tif format (Figure 2). A review of detailed satellite images in Google Earth Pro shows that there are different river structures, assuming that their main purpose is to stabilize the riverbed and ensure navigation; additionally, there is a bridge in the vicinity of Simmersport. As detailed information on the geometric characteristics of these structures is not available, they were not considered for the present challenge; however, a complete river hydraulics study should include them for the evaluation of hydrodynamic and morphological trends of the channel under these modifications, as in the case of bridge piers and spurs.

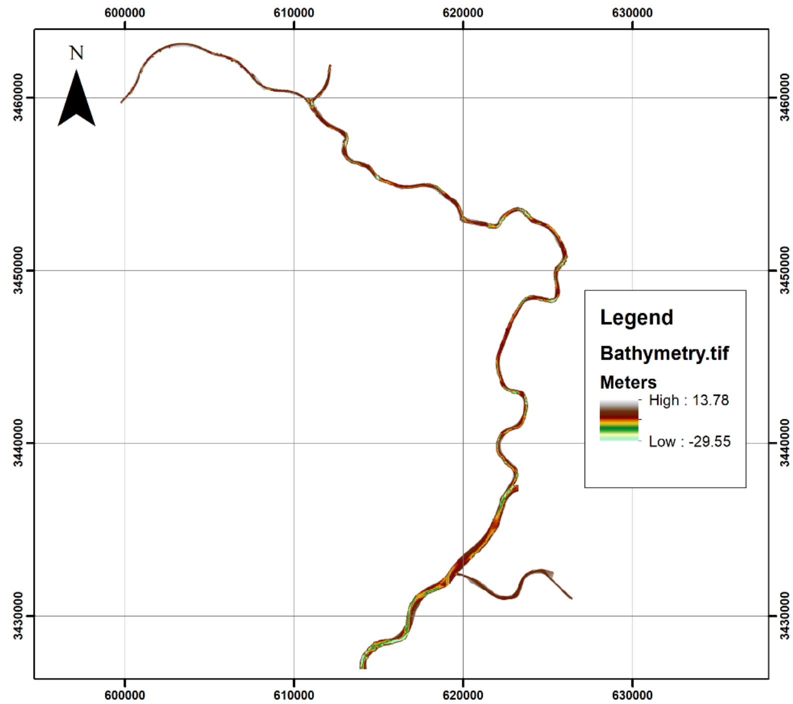


*Figure 2. Bathymetrical elevations raster*

With the bathymetry points, a polygon containing all the data points and delimiting the river channel was also generated. This polygon will be used as the boundary and computational domain of the hydraulic model.

# 3 HEC-RAS model set-up

## 3.1 Terrain definition and 2D flow areas

RAS Mapper allows the definition of most of the geometric parameters of the hydrodynamic model; in this window, the elevation information of both the terrain and the riverbed is introduced first. For the fluvial challenge, the .tif of the bathymetry provided and processed previously is entered with a rounding precision of 1/32 and maintaining the resolution of 10 meters. Additionally, the projection for the project is defined within HEC-RAS maintaining the projected coordinate system NAD_1983_UTM_Zone_15N. The result of the input and detail of these parameters generates a .hdf terrain file which is readable by the model and allows to assign the elevations to the cells that were generated later.

In RAS Mapper the supplied orthophoto was also added and the representative 2D flow area for the Red River was generated from the polygon shapefile created in ArcGIS previously. In order to import the polygon and simplify the manual drawing of the flow area in RAS Mapper, the polygon is exported as points on the vertices, their x and y coordinates are obtained, and then in the Geometry editor in the Storage Area/2D Flow Area Outlines window, the coordinates of each of the vertices of the polygon are entered. When this process is completed, HEC-RAS generates a computational domain joining each of the vertices.

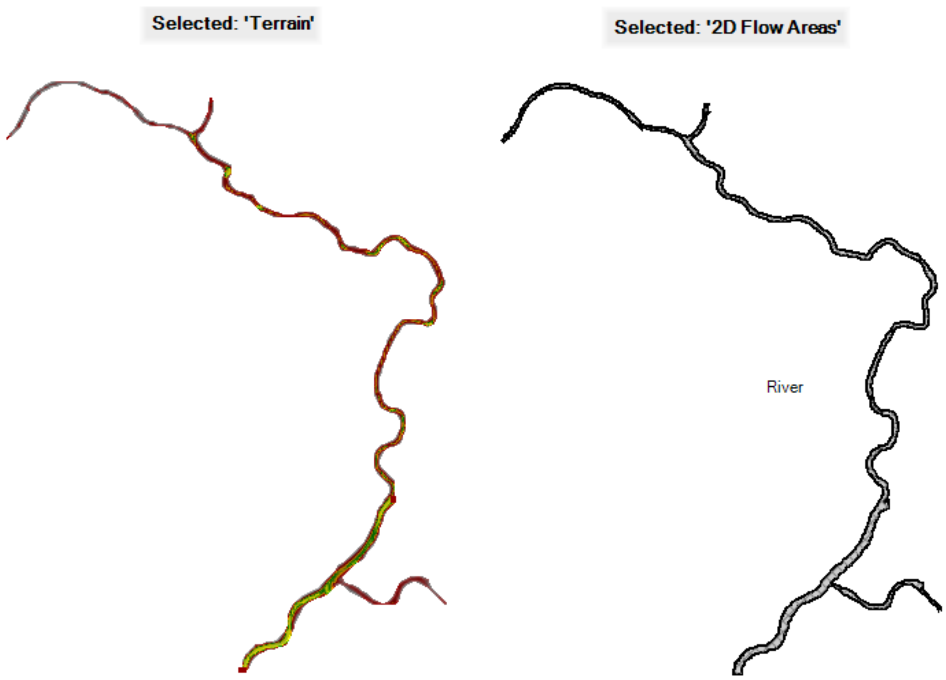


*Figure 3. Terrain and 2D flow areas generated in RAS Mapper*

Within RAS Mapper the parameters of the 2D flow area are edited, mainly the size of the cells or their x and y spacing is defined. It is well known that cell size is a critical parameter in hydraulic simulations, especially in convergence of the model. Topographic features influence the hydraulic flow behavior, so better approximating reality as the resolution increases. For the initial testing, a grid size of 20 meters was defined for the fluvial challenge. Cells stats are shown in Table 1.

*Table 1. 2D flow area cells stats*

| Parameter | Value |
|---|---|
| Number of cells | 61069 |
| Max cell size | 949 m2 |
| Min cell size | 301 m2 |
| Average cell size | 415 m2 |

Another fundamental parameter in the definition of the geometric characteristics of the project is the assignment of Manning's roughness coefficients. This empirical coefficient varies according to cover, vegetation, land use, type of terrain, etc. And it is an essential parameter in the process of water level calibration in different modeled scenarios. Different values of Manning's roughness have been proposed by a variety of authors to approximate a coefficient for natural streams considering the time of bottom sediment, irregularity, variation in cross section, effect of obstacles, vegetation and degree of sinuosity (Chow, 1959). As an initial reference value for the modeling, a value of 0.025 was defined as representative for multiple meandering rivers worldwide and with conditions similar to the Red River (Mississippi River, Magdalena River, etc.). This value will later be modified in the sensitivity analysis of the results. It should be noted that the modeling performed within the present challenge was carried out only for the representative area of the active channel; the floodplain was not considered in terms of elevations, coverage, land use and roughness.

## 3.2 Boundary lines and conditions

The two-dimensional model of HEC-RAS allows to assign the boundary conditions around any point of the DEM. The modeling was carried out under the conditions of unstable flow using the values of flow and stage hydrograph: Discharge will be assigned at L&D 1, Acme, and ORCS, provided in LD_1.txt, Acme.txt, and ORCS.txt. Tailwater will be assigned at Simmsport, provided in Simmsport.txt

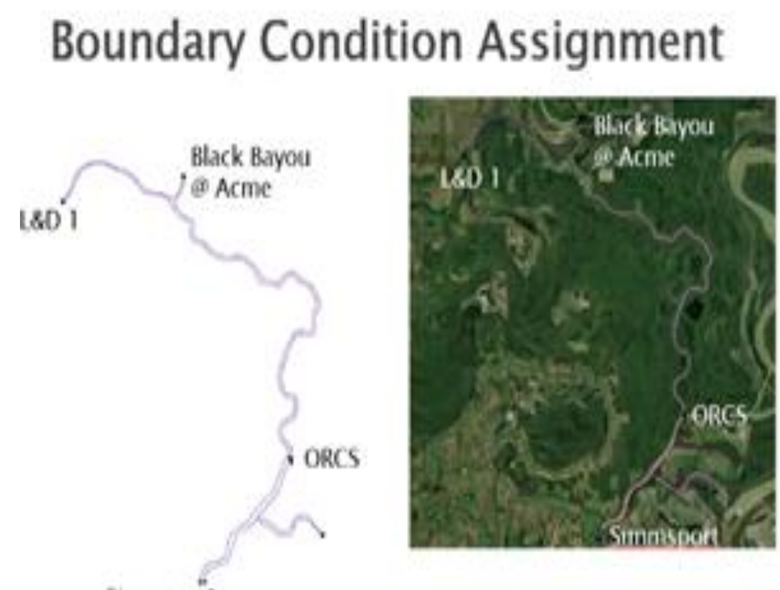


*Figure 4. Boundary conditions assignment*

Next, we go on to define the boundary conditions, which define the water behavior of a model at its limits. Within the Geometric Data window, the boundary conditions within the bathymetry were digitized as polylines, using the SA / 2D Area BC Line tool. With this tool, what we do is establish the lines where the boundary conditions will be located on the mesh.

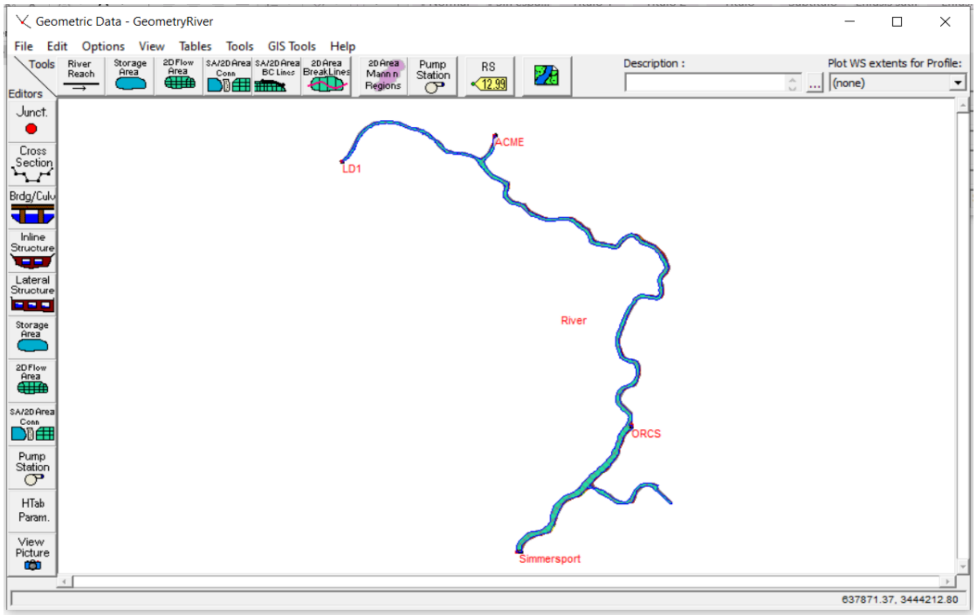


*Figure 5. Boundary conditions for Red River model*

After digitizing the boundary conditions, recorded time series for each line were added. This process is performed in the Unsteady Flow Data window, in which different types of boundary conditions can be entered according to the available information:

- Stage hydrograph: allow to define water level throughout the simulation window (outlet).
- Flow hydrograph: allow to define discharge flow throughout the simulation window (inlet).
- Rating curve: relates the incoming or outgoing flow with water surface elevation in the boundary conditions in 1D models (inlet/outlet)
- Normal depth: defines energy slope at boundary conditions (outlet).

For this challenge, the boundary conditions were used: Flow hydrograph and Stage hydrograph., which are used to enter flow into the 2D area. Additionally, an EG slope of 0.0025 was defined for each upstream boundary conditions, enabling the model to calculate upstream water depth. A previous analysis of the time series data showed that time intervals for all four stations is 86400 seconds, equivalent to 1 day. Considering this value, all timer series were time spaced defined to 1 day within HEC-RAS model.

Other particular condition necessary in hydraulic modeling in HEC RAS is that the simulation only can be performed for a time window that contains data for all boundary conditions. So on, considering the registered values at Table 2, the modelled time for this simulation was defined to 1 year (365 days). Additionally, just for modeling purposes a start date of January 01, 2010 at 00:00 hour was considered due to the scarce information, and assuming that provided data started at the same time.

*Table 2. Boundary lines time windows*

| Boundary line | Time window (days) |
|---|---|
| L&D 1 | 365 |
| ARME | 882 |
| ORCS | 1216 |
| Simmersport | 1194 |

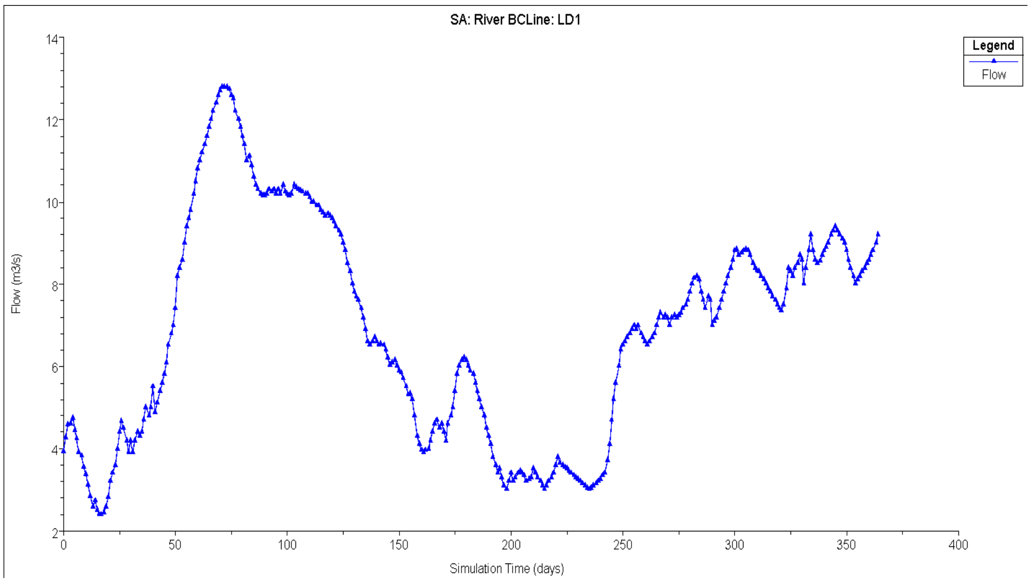


*Figure 6.Discharge series for LD 1 station*

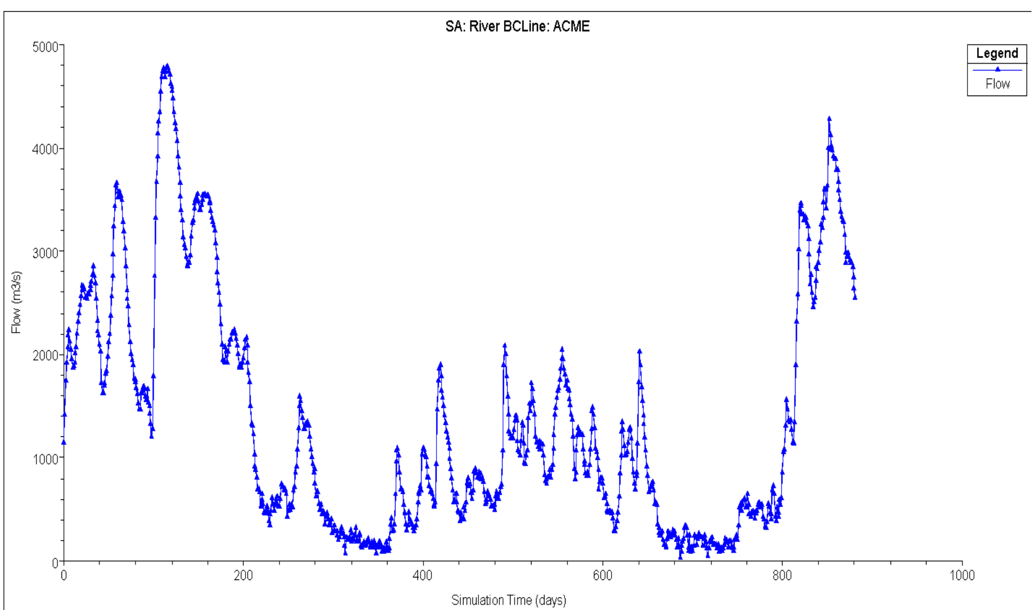


*Figure 7. Discharge series for ACME station*

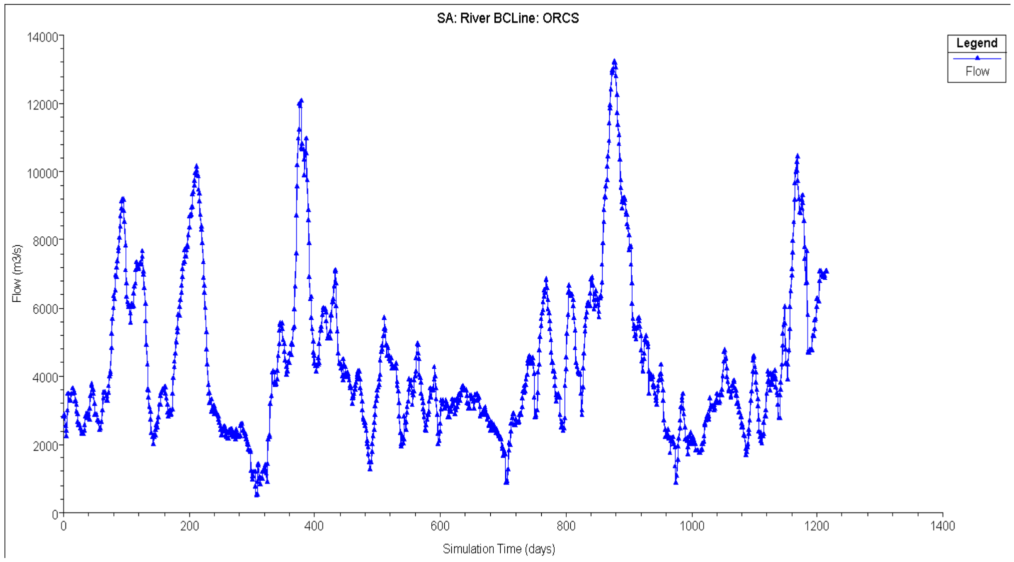


*Figure 8. Discharge series for ORCS station*

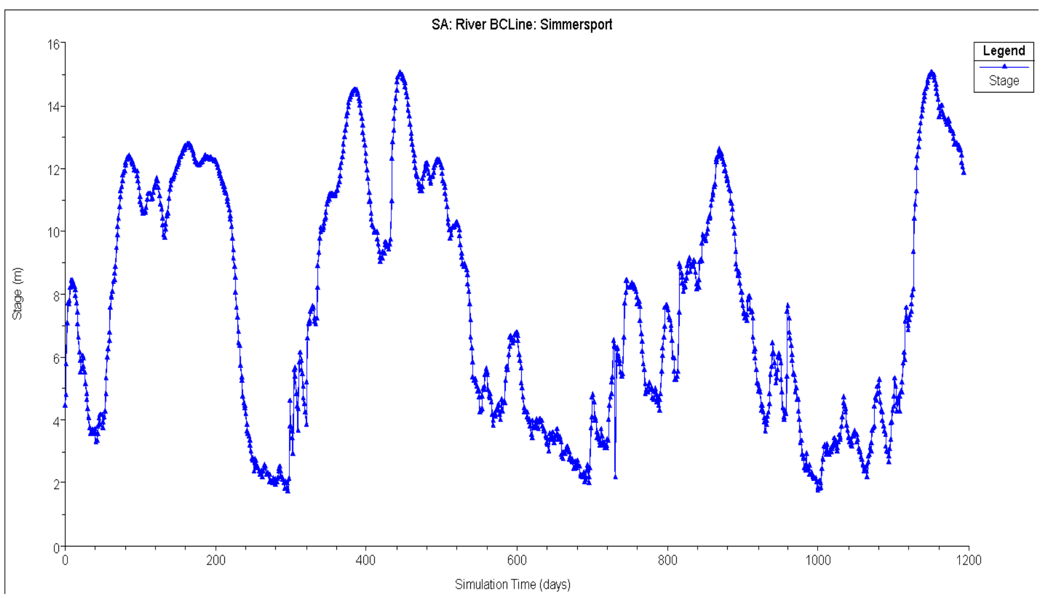


*Figure 9. Water stage series for Simmersport station*

## 3.3 Computational parameters

Once the computation time is defined, it is necessary to perform an unsteady flow analysis. In the Unsteady Flow Analysis window, the programs to be run in HEC-RAS for the challenge were defined: Geometry processor, Unsteady Flow Simulation and Floodplain Mapping. Additionally, the modeling time windows equal to those defined in the boundary conditions are assigned again.

Within the Unsteady Flow Analysis, the configuration of computational values necessary for the modeling is defined. For the challenge the following initial values are defined for the modeling:

*Table 3. Computation settings*

| **Parameter** | **Value** |
|---|---|
| Computation Interval | 15 minutes |
| Hydrograph output Interval | 1 day |
| Mapping output Interval | 1 day |
| Detailed output Interval | 1 day |

Additional computational parameters were defined for the simulation, these parameters were set by default for initial computational process evaluation as seen in Figure 10. For the fluvial challenge, the set of equations was defined to Diffusion wave for the first try (USACE, 2010).

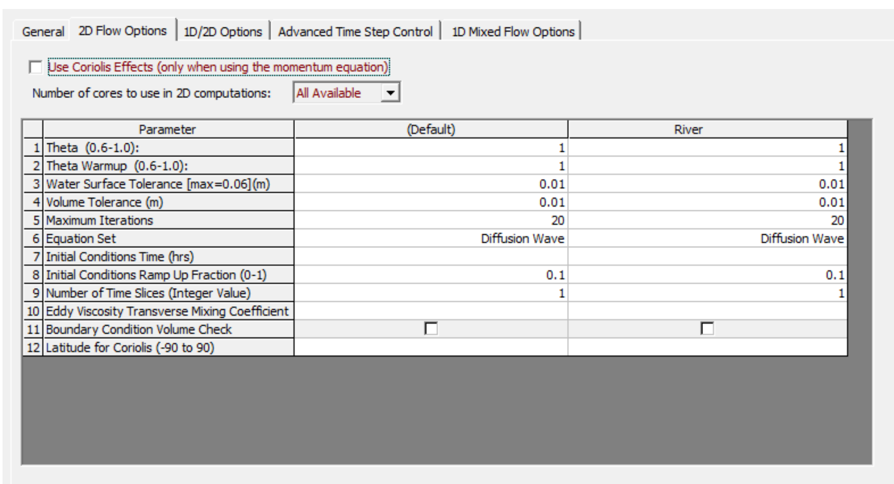


*Figure 10. Unsteady computation options and tolerances*

## 3.4 Initial results

After the computational calculation of the proposed model, the results are visualized in RAS Mapper for velocity, depth, water elevation, among other additional results throughout the simulated time or verifying maximum and minimum values. This tool allows the visualization of results throughout the entire simulated period (365 days) and the extraction of point values such as points, cross sections or for the entire longitudinal profile from which results were also extracted to verify the quality of the simulation. Figure 11 and Figure 12 shows the results of the modeling for the elevation of the water surface, showing a fluctuation of about 8 meters throughout the year.

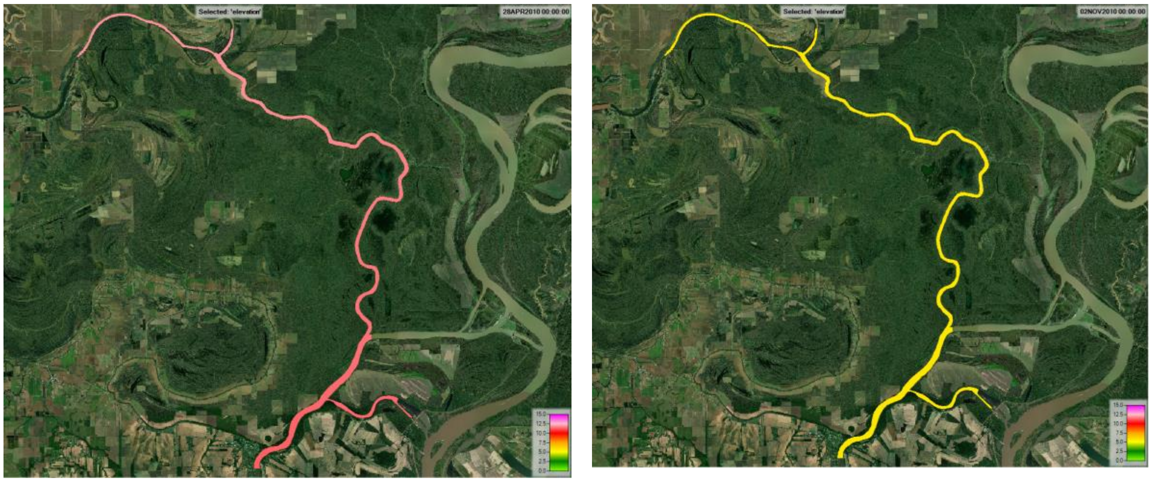

*Figure 11. Water surface elevation results for high and low discharge*

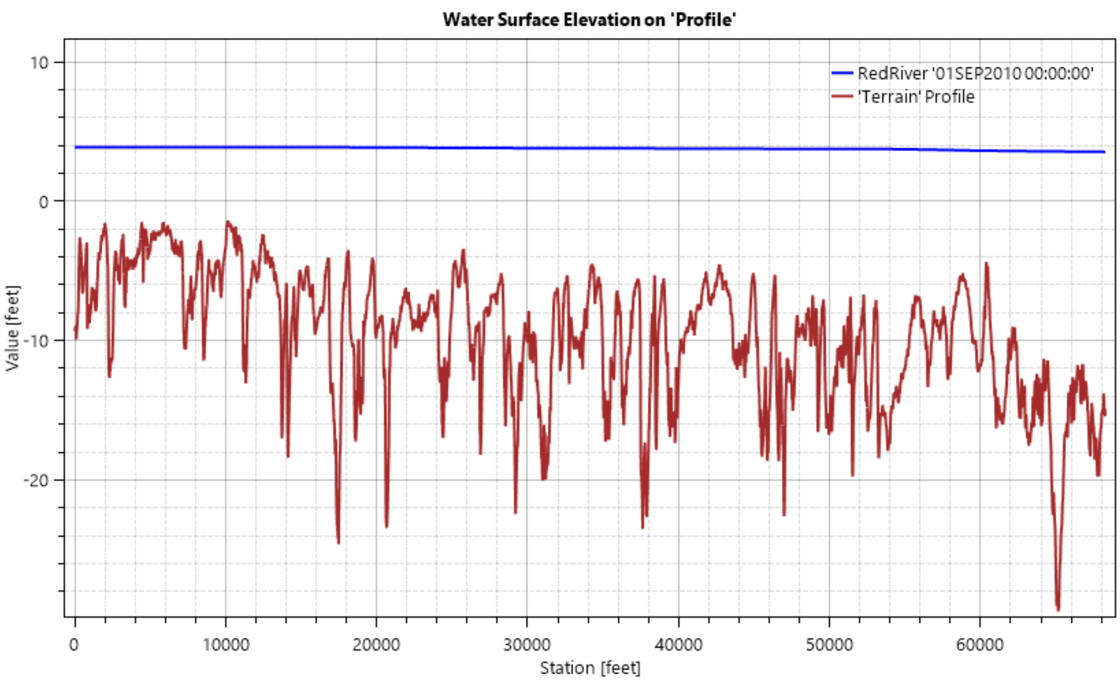


*Figure 12. Water Surface elevation profile result example (low discharge)*

Figure 13 shows the results of the water depth variation for the entire modeling. This figure also presents the results for low and high flows and shows the zones in which there are greater depths in the river and zones which would or would not be covered by water.

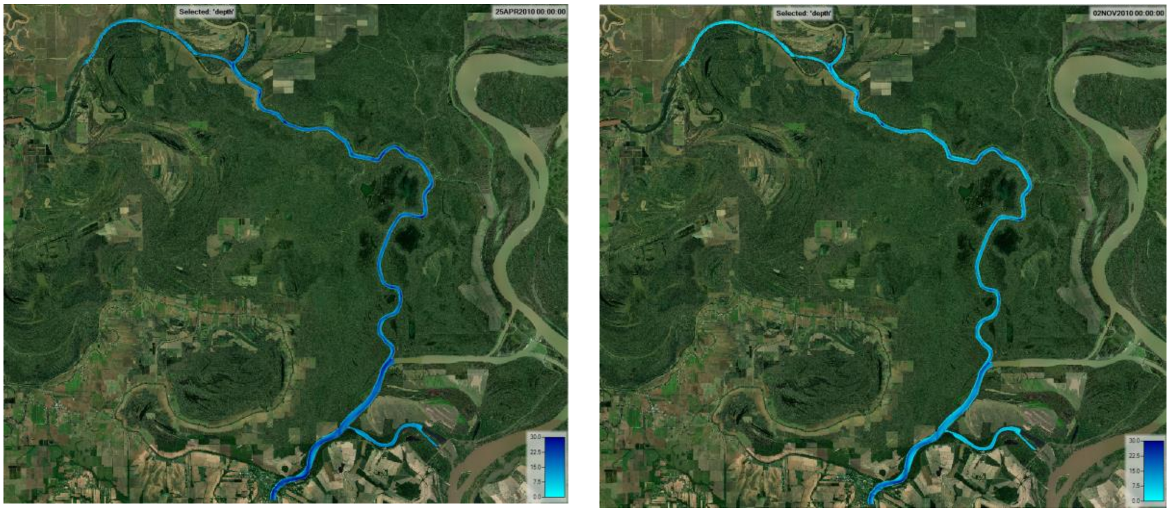


*Figure 13. Water depth results for high and low discharge*

Figure 14 and Figure 15 present the results of flow velocities for the entire computational domain. Like the other variables, it is highly dependent on the hydrological fluctuations in the computational domain and on the flow inputs from the tributaries (ACME and ORCS). The maximum velocities reach about 2m/s and are concentrated downstream of the confluence of the Atchafalaya river. RAS Mapper allows the visualization of streamlines at different sampling size and longitude, also, flow vectors can be displayed for local hydrodynamical behavior characterization.

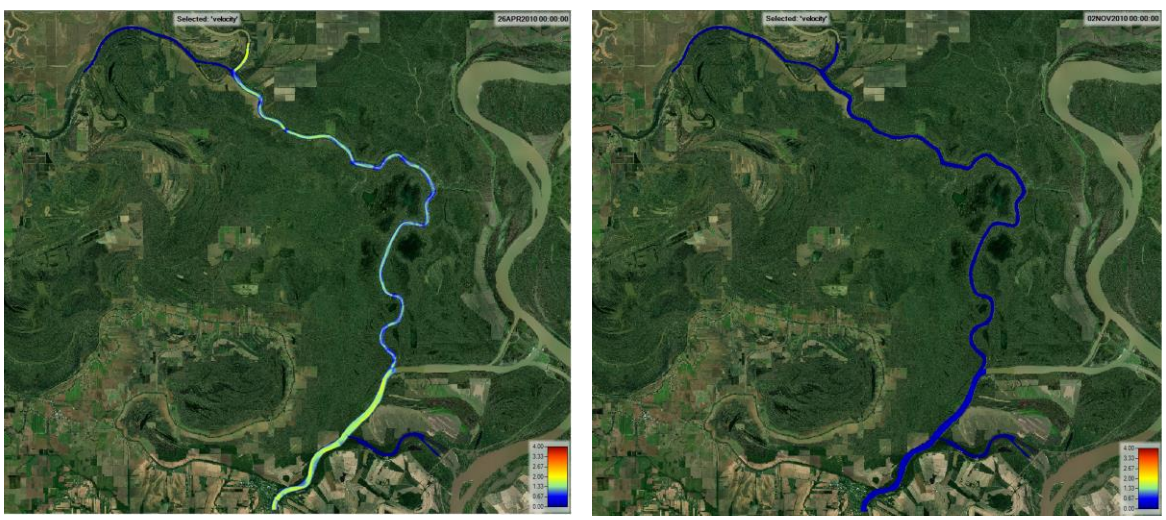


*Figure 14. Velocity results for high and low discharge*

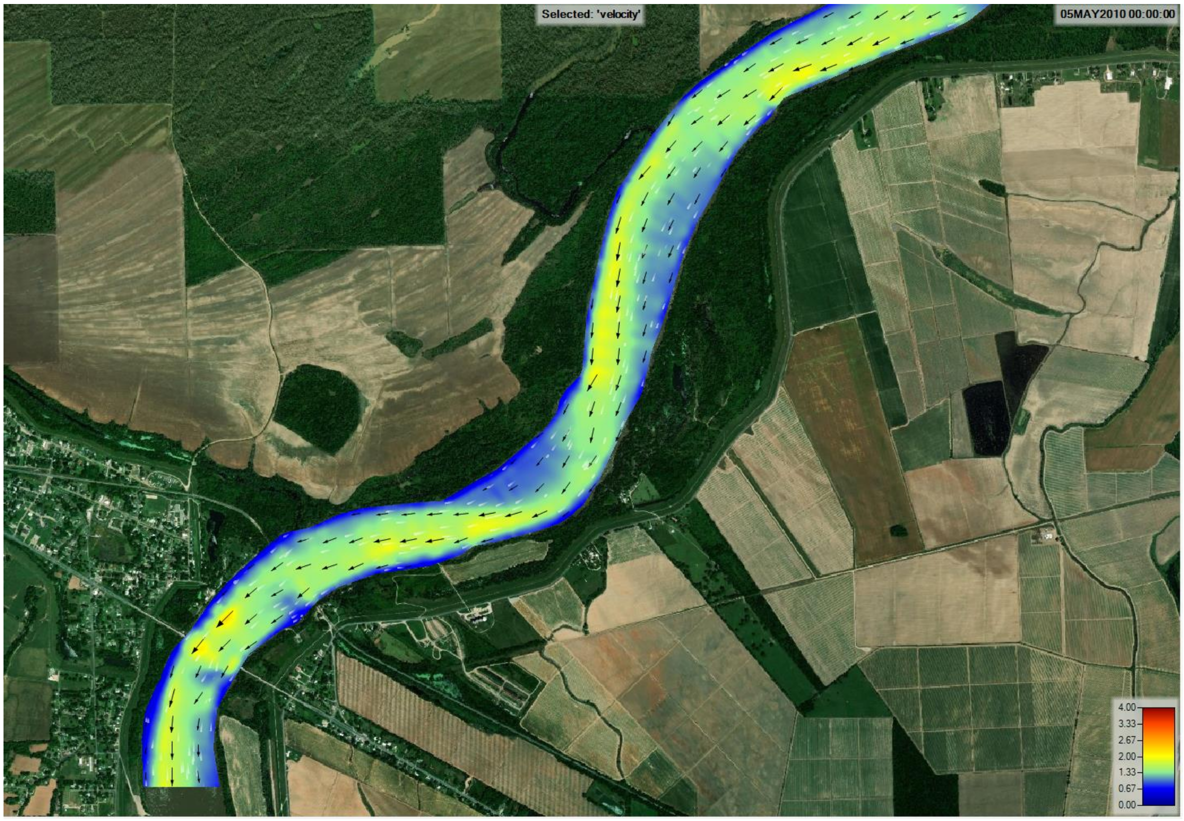


*Figure 15. Velocity results near to Simmersport*

HEC-RAS has the DSS viewer for simple results visualization of flow discharge and stage. Figure 16 shows the results of discharge at each boundary conditions, and the hydrological transit generating the total discharge at Simmersport.

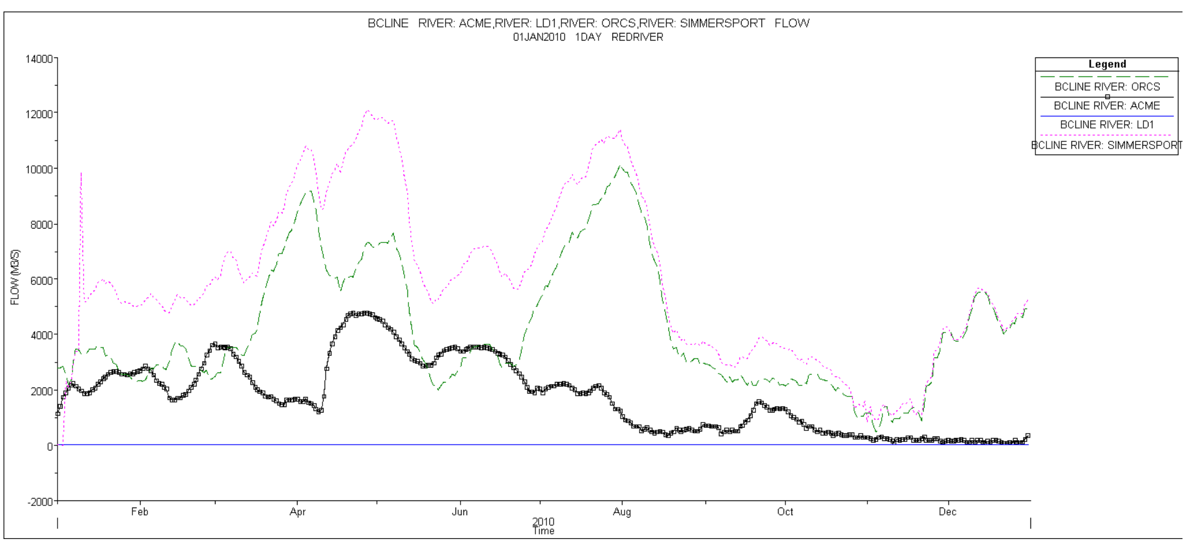


*Figure 16. DSS flow discharge results for boundary conditions*

State of the art HEC-RAS version 6 allows the generation and visualization of more results specially design for 2D modelling. Some group participants worked with version 5.0.7 for the challenge so special results are not showed as initial results.

# 4 Sensitivity analysis

## 4.1 Grid size

A standard two-dimensional computational mesh was initially generated using cell sizes such as 10, 20, 25 and 50 meters for 2D storage area in the model. The model showed errors in computing mesh when 30m cell size was used. In this project, the comparison of the computational time and the downstream velocity at 4 locations (shown in Figure 17) for all the above cell sizes is presented.


*Figure 17. Locations at downstream for results comparison*

The Table 3 shows the computational time for various grid sizes and the number of cells created for the river. The results show that the computational time increases with the decrease in cell size.

The Figure 17 shows the velocity at four downstream locations for all the mesh sizes. From the results, it is concluded that the larger grid sizes are appropriate when the water surface slope is flat and not changing rapidly. It was also observed that the velocity variations at the center of the river were captured well by 10, and 20m grid size (based on the animation results). For other grid sizes, the variation in velocity is not significant visually. The water surface elevation and depth of red river changes rapidly. Smaller grid size is required to capture those changes. Since flow movement is controlled by the computational cell sizes, smaller cells may be required to define significant changes to geometry and rapid changes in flow dynamics.

*Table 3. Computational time for various grid size and the number of cells created for the river*

| Grid size | No. of grid cells | Computational time (hh:mm:ss) |
|---|---|---|
| 50 | 8184 | 00:04:40 |
| 40 | 13042 | 00:11:36 |
| 30 | 23610 | Error computing mesh |
| 25 | 34331 | 00:26:10 |
| 10 | 220402 | 2:30:36 |

## 4.2 Computational interval

In a computational numeric model, the time step or computational calculation interval is required to ensure the proper calculation of variables and model stability. HEC RAS allows the definition of computational interval from 0.1 second to 1 day, the decision of which depends on grid size, set of numerical equations, hydrological variations, terrain obstacles, etc.

As a sensitivity analysis, different computational times were tested for the evaluation of results and total computational times as seen in Table 4 and Figure 16 for a grid size of 20 meters. The results show that the reduction of the computational interval increases the stability of the calculation, ensuring correct calculations between cells along the domain at the expense of the exponential increase of simulation time. The contrary is the scenario when the computational interval is set to the maximum value (1 day) making the simulation unstable with multiple errors; for a 12 hours computational interval, simulation time was completed in ~3 minutes, but multiple accumulated errors along the modelled year generated inconsistent results.

*Table 4. Summary of computational interval testing*

| Cell size (m) | Computational interval | Time (min) | Cell | WSE | Error | Multiple computationas messages until |
|---|---|---|---|---|---|---|
| 20 | 1 min | 254 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 20 | 5 min | 49 | 18161 | 54.13 | 49.127 | 3-Jan-10 |
| 20 | 10 min | 28 | 19378 | 28.83 | 91.54 | 6-Jan-10 |
| 20 | 30 min | 25.15 | 19378 | 39.07 | **** | 20-Jan-10 |
| 20 | 1 hour | 21.17 | 54093 | 11.64 | 0.0106 | 27-Apr-10 |
| 20 | 2 hour | 15.11 | 2976 | 11.63 | 0.011 | 31-Dec-10 |
| 20 | 6 hours | 5.18 | 2976 | 11.63 | 0.0331 | 31-Dec-10 |
| 20 | 12 hours | 3.33 | 16675 | 762.16 | **** | 31-Dec-10 |
| 20 | 1 day | Unstable | | **** | **** | |

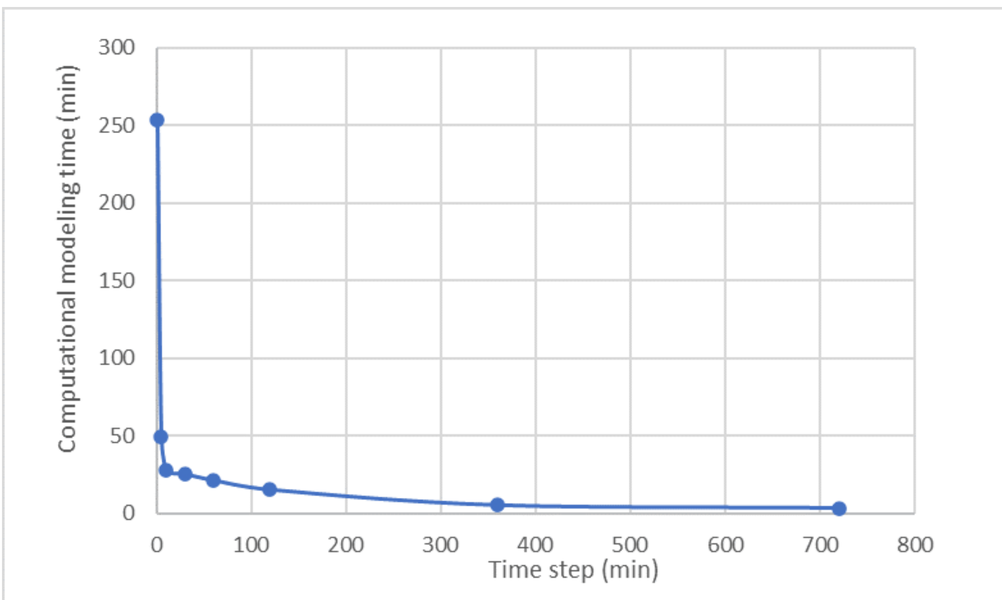


*Figure 18. Computational modeling time varying time step*

Evaluating the results, it can be said that the optimal computational time step is defined between 10 to 30 minutes, considering the total computational modeling time ~25 to 30 minutes with low number of computational messages for the first days of the simulation, as part of the warm up process.

## 4.3 Manning roughness

Manning's roughness coefficient directly influences the elevation of the water surface along the computational domain. This parameter is one of the main variables to be used in the model calibration process and to adjust the modeled results with the observed ones. To evaluate the sensitivity of this parameter, different simulations were carried out in order to estimate the change in the water level along the river, changing its value between 0.02 and 0.05, which are ranges of Manning's coefficient values for channels under different conditions of alignment, bed material and size, etc. Since there is no gauging station within the study area that reports water stage data other than the downstream condition, the process is illustrative but no calibration to actual conditions was performed. Figure 16 shows the variation of the water sheet for the different roughness values assigned; these results were taken for the date corresponding to the middle of the time window (July 31) to be modeled (assumed as an arbitrary date since there were no dated measurements in the data provided for calibration). Upstream, near station LD1, the variation of the water sheet has a range of 122 centimeters. Near the downstream condition (Simmersport) the variation of the results obtained was 10 centimeters, considering that the model is forced to a stage downstream condition, this variation is expected to be none.

From Figure 17 it is observed a significant variation near to the station K53, where water slope increases, and reducing downstream variation in water level surface changing the roughness coeficient. This location is the confluence of the Red River with the Atchafalaya River, generating a significant variation in terrain profile and discharge time series. These results presented are representative for the analyzed date, the variation could be greater or lower depending on the hydrological variations around the year. It should be noted that the modification of the roughness value did not substantially modify the computation time of HEC-RAS but it is a critical parameter in the calibration process of the results.

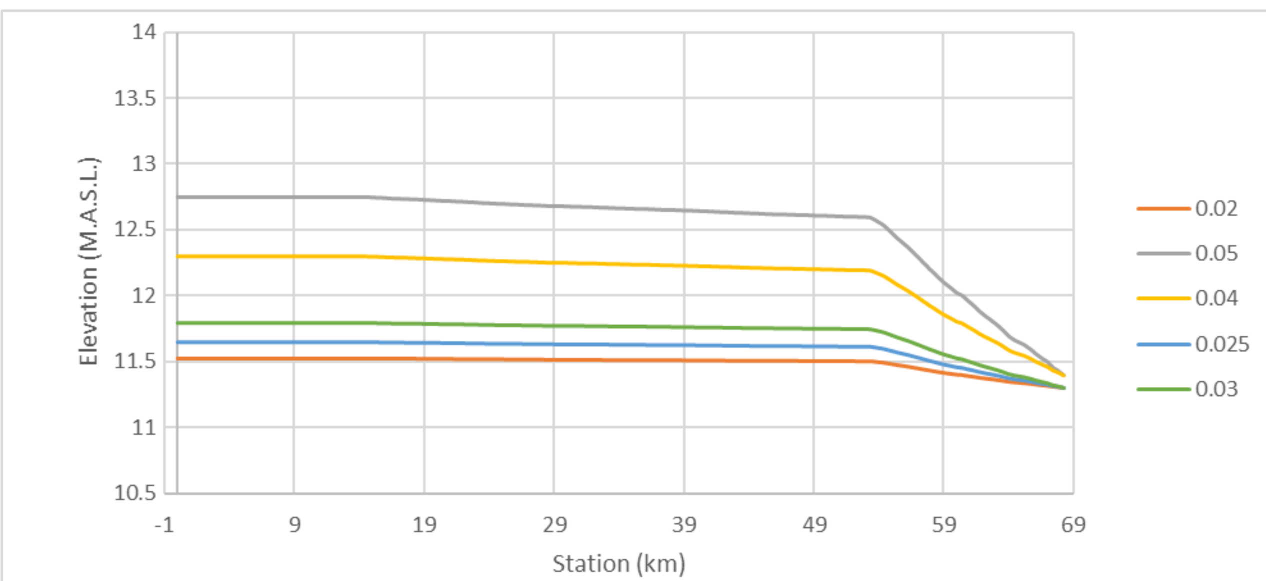

*Figure 19. Water surface elevation sensitivity results*

The ADCP information provided was not considered because at the time this report was written, the WinRiver II application for visualization and export of results in ASCII format was not available. However, if sufficient information and software are available, the calibration process of levels and velocities can be performed.

## 2. Conclusions

The fluvial challenge proposed by IAHR first allowed the integration of different engineers passionate about water resources and especially on issues related to rivers. The development of this activity generated the curiosity to explore a numerical model that in the case of this group 2 of the 3 participants have not worked with before. HEC-RAS is one of the most widely used softwares for the design and evaluation of artificial channels, natural channels and flood conditions, sediment transport and water quality. This shows the need to learn about this model and exploit its qualities in different case studies and problems.

This challenge allowed the hydrodynamic modeling of the Red River in the southern United States, using the information provided by the IAHR team to proceed with the assembly, parameter adjustment, simulation and interpretation of results over a simulated window of 1 year. It was possible to appreciate the hydrological variability in the boundary conditions provided and how this mainly affects the results of water surface elevation, depth and velocity, representative variables in any study of river hydraulics. Additionally, a sensitivity analysis was performed to observe how both computation times and simulation results change when changing several of the basic modeling parameters such as Manning's roughness coefficient, cell size and time step, identifying that it should try to handle optimal modeling parameters, but that many times it depends on a trial and error process to identify which parameters are more susceptible to create excessive computation times or errors within the calibration process.

Although multiple engineering considerations were made throughout the challenge due to the scarcity of several of the data for a complete river hydraulics study, the results obtained and the sensitivity analysis performed allow the identification of optimal modeling parameters, and the detailed knowledge of the HEC-RAS tool. We consider that the activity was performed according to the expectations of the evaluators regarding the development of both technical and professional skills in the generation of a computational model of such a large magnitude, which represents a challenge in many aspects and the dedication of the participants to complete it.

## 3. Team management and soft skills

We adopted collaborative teamwork to complete this project. Our team members have differing skill sets with varying areas of expertise. With our diverse set of skills, we were able to problem-solve as a group. We worked together as equals to come up with solutions and we made decisions together. In addition to completion of the project, we learnt new skills from each other.

We are all located in different time zones. Hence, we used various modes of communication such as Whatsapp group chat, weekly zoom meetings, google drive and google docs. The frequency of our communication increased towards the end of the project.

The important characteristics observed in our team were trust, tolerance, patience, and self-awareness that helped completion of this project. These characteristics negated conflicts within our team. This project helped us establish a professional network.

| Team member name | Lessons learnt |
|---|---|
| Thays | Communication and writing skills |
| Francisco Gomez | Teaching HEC-RAS, and communication skills |
| Queen | Learning HEC-RAS, managing the meetings |

# 4. References


Chow, V. Te. (1959). *Open-channel Hydraulics*. McGraw Hill.

USACE. (2010). HEC-RAS River Analysis System. In *User's Manual, Version 4.1* (Issue November).