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Original Research

The effect of the islands on the nature of the flow of the Tigris River Using HEC-RAS

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ABSTRACT

Erosion and sediment deposition are among the main processes controlling river hydraulics and the stability of hydraulic structures. This study investigates these processes downstream of the Al-Kut Barrage, where mid-channel islands influence the natural flow behavior of the Tigris River. A one-dimensional steady-flow hydrodynamic model was developed using HEC-RAS to simulate flow conditions and to evaluate the hydraulic response of the river to the virtual removal of these islands under different discharge scenarios. The model was calibrated and validated using observed field data from the study reach. Several Manning's roughness coefficients were tested, and the optimal value was found to be n = 0.03, which provided the best statistical performance. The calibration results showed an excellent agreement between observed and simulated water surface levels, with a Nash–Sutcliffe Efficiency (NSE) of 0.998, and very low error values (RMSE = 0.008 m and MAE = 0.008 m), confirming the high reliability of the model. Simulation results indicate that the existing mid-channel islands have a relatively minor influence on flow conveyance and flood wave attenuation. After modifying the cross-sections and virtually removing the islands, the simulated discharge decreased by 3.59 m^3/s (approximately 0.34%), reflecting a slight improvement in wave dissipation and flow delay. Although the hydraulic impact of island removal was limited, the findings emphasize the importance of continuous monitoring and periodic maintenance of the Tigris River channel to maintain hydraulic efficiency and minimize sedimentation effects downstream of the Al-Kut Barrage.

Keywords: Erosion–deposition, Tigris River, Kut Barrage, HEC-RAS, river modeling, flow simulation, island removal.

1. Introduction

Megastructures with several uses are often referred to as dams, such as water supply, irrigation, recreation, flood control, and electrical production. Its impoundment system has enormous potential energy that might be used to benefit people. However, there would also be a chance of an unexpected breakdown in containment, which could result in downstream property and human casualties [1, 2]. Dam failure disasters have happened all around the world since 1960; thus, there needs to be a plan in place for when dams break, how to prevent them, and how to mitigate their effects dams [3]. Dams are distinct in their architecture due to a combination of factors, including but not limited to their size, diversity, and connection to the field's hydrology and geology. Internal erosion of the embankment or foundation is a leading cause of dam failure. The process of soil and rock degradation caused by seepage and groundwater flow is known as internal erosion. Seepage flow within the dam is possible; however, it can lead to internal erosion in some situations. Dam bodies and foundations might develop ducts or big holes as a result of gradual internal erosion. As time goes on, erosion keeps creating holes, which allow water to seep downstream. Large holes or pipelines might weaken the dam's stability and eventually cause it to collapse .Half of the time, pipes are to blame when water-retaining infrastructure like dams fail[4, 5]. Al-Kut lies 180 km south of Baghdad, according to some sources [6]. The eternal Tigris River splits it in half as it flows through it. Two rivers, the Al-Dujaila and the Al-Gharraf, originate at the Kut Dam[7]. The AL-Kut Dam, located in Wassit Province's AL-Kut city, was built in 1939 to provide water storage and raise the Tigris

River's water level [8].In order to keep the development wheel turning and accommodate the growing population and increased urbanization, it is critical to construct additional bridges across the Tigris River and its tributaries within the city. This is necessary since the town is expanding, the population is increasing, and there are not enough bridges already [9].

Thanks to recent advances in modeling and computer science, even the most complex equations may now be solved. We no longer require expensive and time-consuming physical models. Particularly crucial are the calibration and deployment of accurate computer models to particular regions [10, 11]. Users are able to do one-dimensional river hydraulic assessments using the software developed by the Hydrologic Engineering Center, known as HEC-RAS (River Analysis System). In July 1995, the program was initially made available to the public and could be used to calculate one-dimensional steady flow of water surface profiles. Multiple features for steady flow analysis were included in subsequent releases. From basic to sophisticated river systems with many different kinds of hydraulic structures, HEC-RAS can model them all[12].

This study uses a calibrated one-dimensional HEC-RAS model to emphasize the hydraulic function of the mid-Channel Islands in the Tigris River downstream of the Al-Kut Barrage. This study specifically assesses the hydraulic effects of practically eradicating central river islands throughout a specified 12-kilometer distance, in contrast to earlier research that mostly concentrated on flood danger maps or the effects of hydraulic structures. Results show how much of an impact island removal has on flow conveyance and flood wave behavior, quantitatively speaking. Consequently, this research adds to the current body of knowledge by elucidating the necessity for integrated river management methods and the limited efficacy of island removal as a standalone flood prevention tool.

2. The Aims of the Research Project

Simulate and analyze the flow characteristics and natural erosion–deposition processes downstream of Kut Barrage using numerical modeling (HEC-RAS and ADC) under various discharge conditions, identify critical erosion zones, and recommend suitable protection and management measures.

2.1. Methodology

In order to achieve the aforementioned objectives, the following steps were taken: Reviewing existing literature and data that are pertinent to the study's focus on the Tigris River. Collecting all available hydrological data and river cross-section data is one of the many things that will be part of the Tigris River research. Visiting the river's real location to record its current state [13].To mimic its flow in the research region, we are presently developing a one-dimensional HEC-RAS Tigris model. The HEC-RAS model must be validated and calibrated. Discovering how the natural erosion of mid-channel islands downstream of the dam is influenced by currents and flow velocity

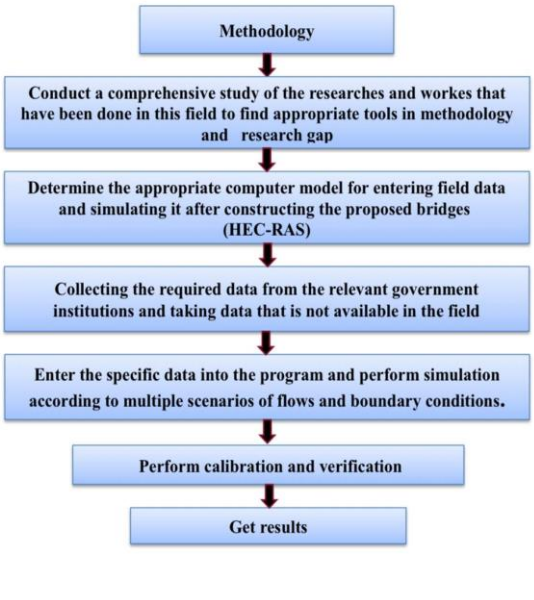


Figure 1. Methodology

2.2. Description of the Reach study

The Kut Barrage in Wasit Governorate is one of the most important hydraulic structures on the Tigris River, as it contributes to regulating the flow and distributing water to irrigation projects and the southern provinces of Iraq[14, 15]. Constructed between 1934 and 1939 under British supervision, it is considered the oldest control structure on the river. The study area is located southeast of Kut City, extending from the point immediately downstream of the barrage to the end of the middle island located within the coordinates (32°30'17" N – 32°31'980" N) and (45°49'07" E – 45°52.’664" E), with a total reach length of about 12km. Figure 1 represents the aerial image of the study area, showing the selected river reach and the surrounding features. This area was chosen due to its importance in analyzing flow characteristics and riverbank erosion processes.

Figure 2. Study area

3. Input data

The geometric information for the study reach encompassed a digital elevation model (DEM), river flow, and affected length cross-sections.

3.1. Modeling of Digital Elevation (DEM)

The Digital Elevation Model (DEM) is a digital or 3D representation of the surface of a terrain, created from the data on terrain elevation. This data is essential for formulating the mathematical models for the area of study. The DEM data identifies the elevations on the Earth's surface and can locate the natural and relevant features on it. The Shuttle Radar Topography Mission (SRTM) data have emerged as reliable global elevation data over the past decade because they are freely available, homogeneous, and consistently accurate when compared with other global elevation datasets. The present study explores the hydrological modeling using the SRTM digital elevation model (DEM). In this study, the DEM image in raster format has been drawn from the SRTM website on April 14, 2019. Figure 3.1 reveals the DEM of the Tigris River from downstream of the Al-Kut Barrage to the middle island located 12km downstream.

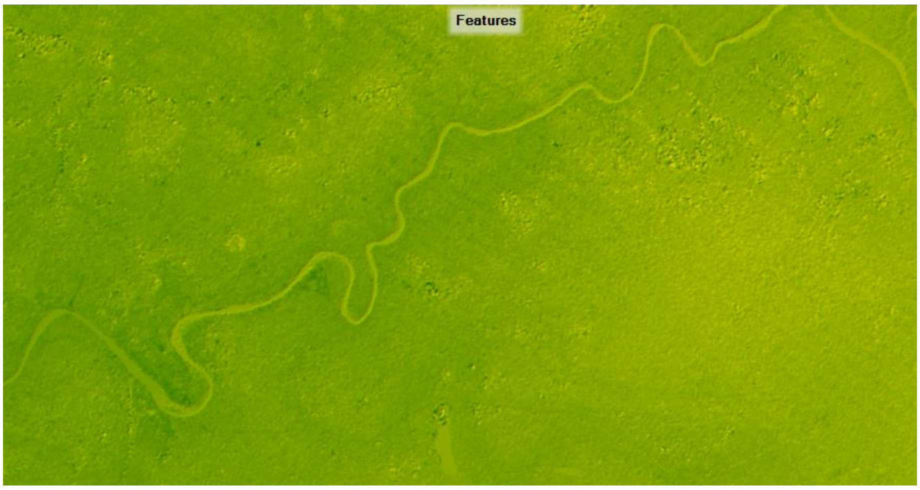


Figure 3. DEM for the study area

3.2. Cross-section

Cross-sections of the Tigris River were obtained from the Irrigation Department in Kut, extending from downstream of the Kut Barrage to the central island to 12km, recorded in an Excel file and subsequently input into the HEC-RAS program within the Edit Geometry window. The figures presented below are instances of the cross-sections.

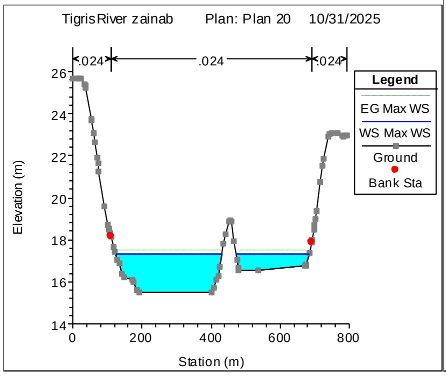


Figure 4. Cross-section situated at station (81+70)

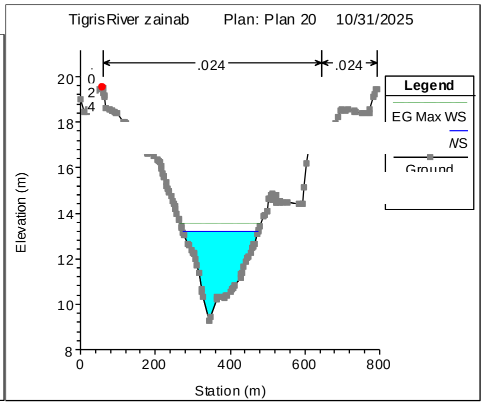


Figure 5. Cross-section located at the station (79+591)

3.3. Interpolation of the Cross-section

Important cross-sectional data may be derived by extrapolating from any two survey sections. When evaluating the energy gradient, the shift becomes impossible due to a substantial change in the velocity head; interpolated cross-sections are employed to generate regular intervals.

3.4. Create Terrain

After downloading the DEM, a terrain is generated in the Ras Mapper window. Visit the WGS84/UTM ZONE 38N spatial reference webpage to download the project's projection file.

3.5. Boundary conditions (unsteady flow data)

Hydrographs of stages and flows, rating curves, precipitation, normal depth, and other boundary conditions may be easily linked to one- or two-dimensional flow areas. The Al-Kut Water Resources Division utilized a single hydrograph collected in April 2019 as the limiting factor for their research. Figure 3.4 displays the flow hydrograph within the research region. A normal flow with a slope of 0.0005 defines downstream boundary circumstances, while this hydrograph depicts upstream boundary conditions.

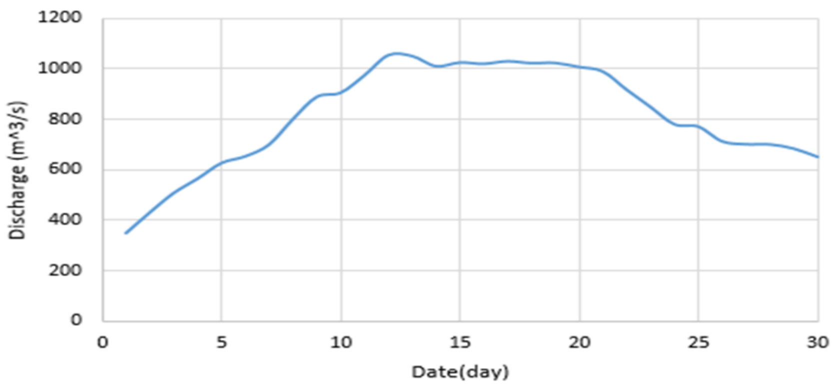


Figure 6. Flow measurements taken along the Tigris River

3.6. One-dimensional HEC-RAS model

Data management is the first step in the hydraulic modeling process using HEC-RAS. In this stage, the actual geographical elements are displayed by the application of GIS techniques such as spatial registration and georeferencing. Data calibration and compilation procedures are enhanced while the study's intrinsic geographical feature attributes are maintained (8). The GIS procedures were finished using Ras Mapper, which is included with HEC-RAS 6.7. The next step is to input the data. Information on the spatial geometry of the river system was initially fed into the model. Among the geographical input data are a digital elevation model (DEM) of the watershed, the channel, the river's cross-sectional geometry, and the surface roughness of the floodplain, as measured by Manning's roughness coefficient. The geometric data utilized to run the hydraulic model mostly consisted of survey cross-sections and the digital elevation model that was subsequently generated. Figure (3.7) shows the completed river network, which was created by connecting 17 cross-section geometries in the Geometry Edit box. The network extends from upstream to downstream.

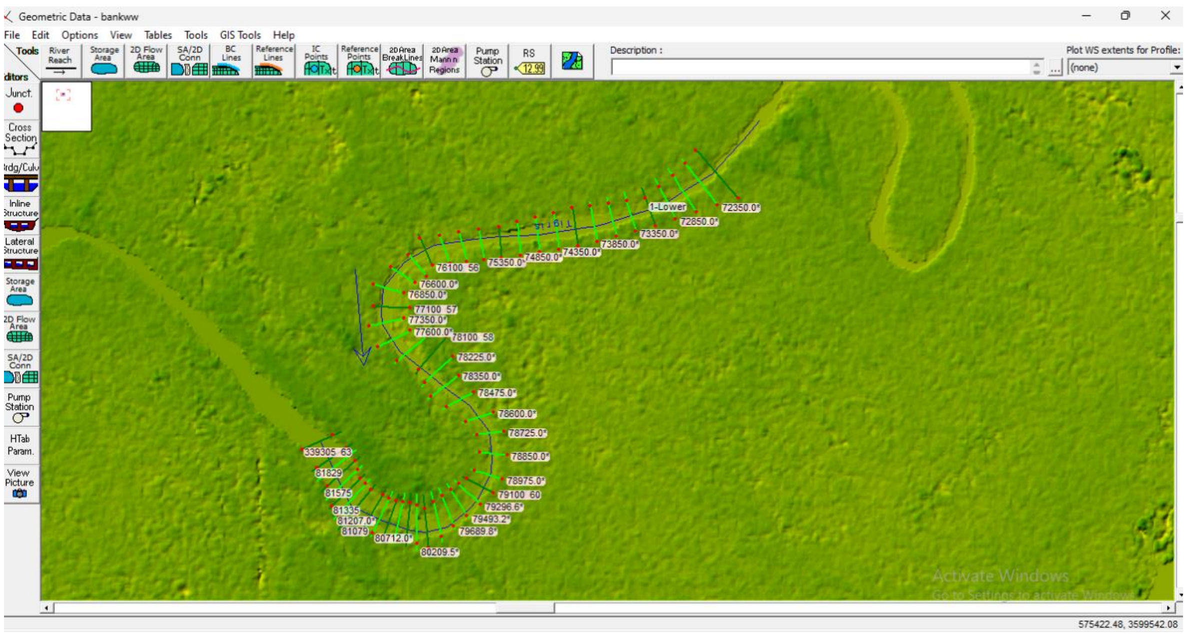


Figure 7. Editing Geometry in the HEC-RAS Models

3.7. Model Calibration for HEC-RAS

The Manning's roughness coefficient is the most important parameter when simulating rivers. These flows need to be modeled with HEC-RAS and the study distance in order to try to calibrate the river's Manning's roughness coefficient value. Because it uses a given set of measurement data to find the independent variables that define the function's original and local arguments, calibration is an inverse mathematical problem. Hydrodynamic model calibration has always relied on human intervention. By showing the river, changing the parameter sets, and taking the ranges of parameter values for the flow scenario into account, this calibration approach minimizes the objective function R, which represents the value of the correlation between the two sets of data: one simulated and one observed. The MAE, NSE, and RMSE are some of the statistical measures employed.

$$\mathrm{MAE} = \frac{\sum_{i=1}^{N} |O_i - F_i|}{N} \tag{1}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N} (O_i - F_i)^2}{N}} \tag{2}$$

$$NSC = 1 - \frac{\sum_{i=1}^{N} (O_i - F_i)^2}{\sum_{i=1}^{N} (O_i - \bar{O}_i)^2} \tag{3}$$

The number of data points (N), the mean of the predicted water demand (Fi), the average of the actual water consumption (Oi), and the number of observations (N).

4. Results

4.1. HEC-RAS Calibration and Validation

The model calibration results indicate excellent performance. Manning's roughness coefficient (n) was applied to the main channel and related floodplain to study and assess its effect on the water surface level. Tested values for the Tigris River ranged from 0.025 to 0.033[16]. The optimal value was determined as n = 0.03, which produced the highest agreement between observed and simulated data. The Nash–Sutcliffe Efficiency (NSE) reached 0.998, indicating an almost perfect model fit, while the r-test confirmed excellent correlation with an R-value of 0.998. Error analysis shows very low discrepancies, with a Root Mean Square Error (RMSE) of 0.008 m and a Mean Absolute Error (MAE) of 0.008 m, confirming the high accuracy and reliability of the hydraulic model. Figures 8 and 9 provide comparisons of actual versus simulated flows for different Manning's n values and visually demonstrate the model's high correlation performance.

Table 1. Estimates from statistics

N value	NSE	RMSE	MAE
0.025	0.181	0.301	0.097
0.027	0.115	0.26	0.0102
0.029	0.508	0.194	0.128
0.030	0.998	0.008	0.008
0.031	0.987	0.031	0.031
0.033	0.932	0.071	0.066

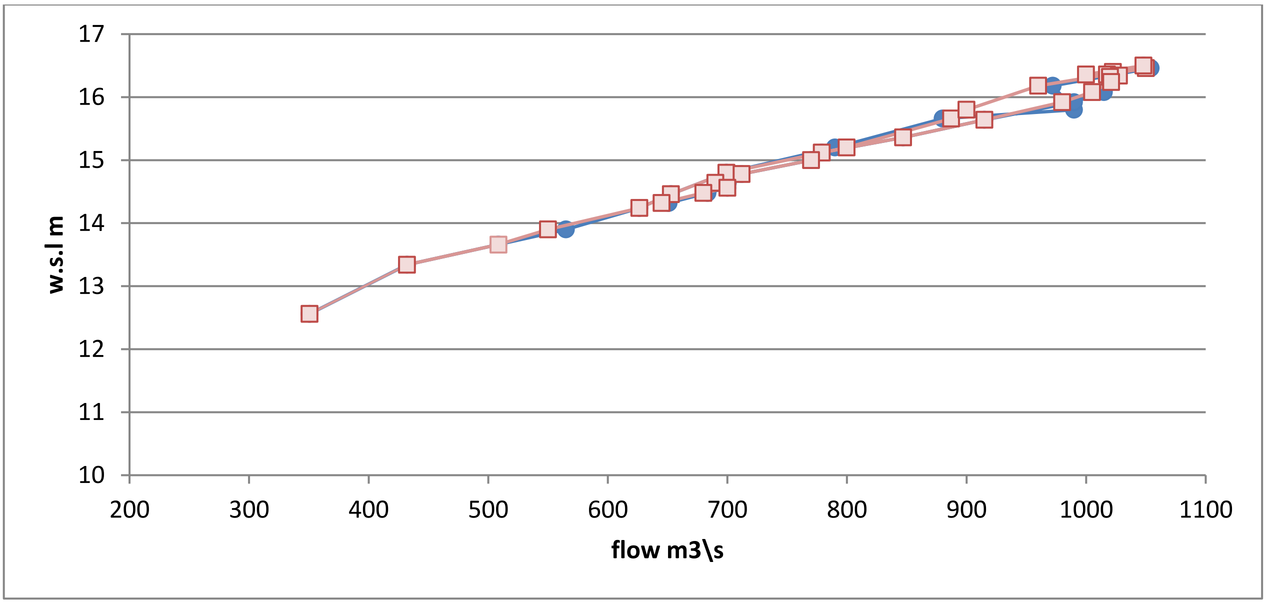


Figure 8. Data that has been simulated

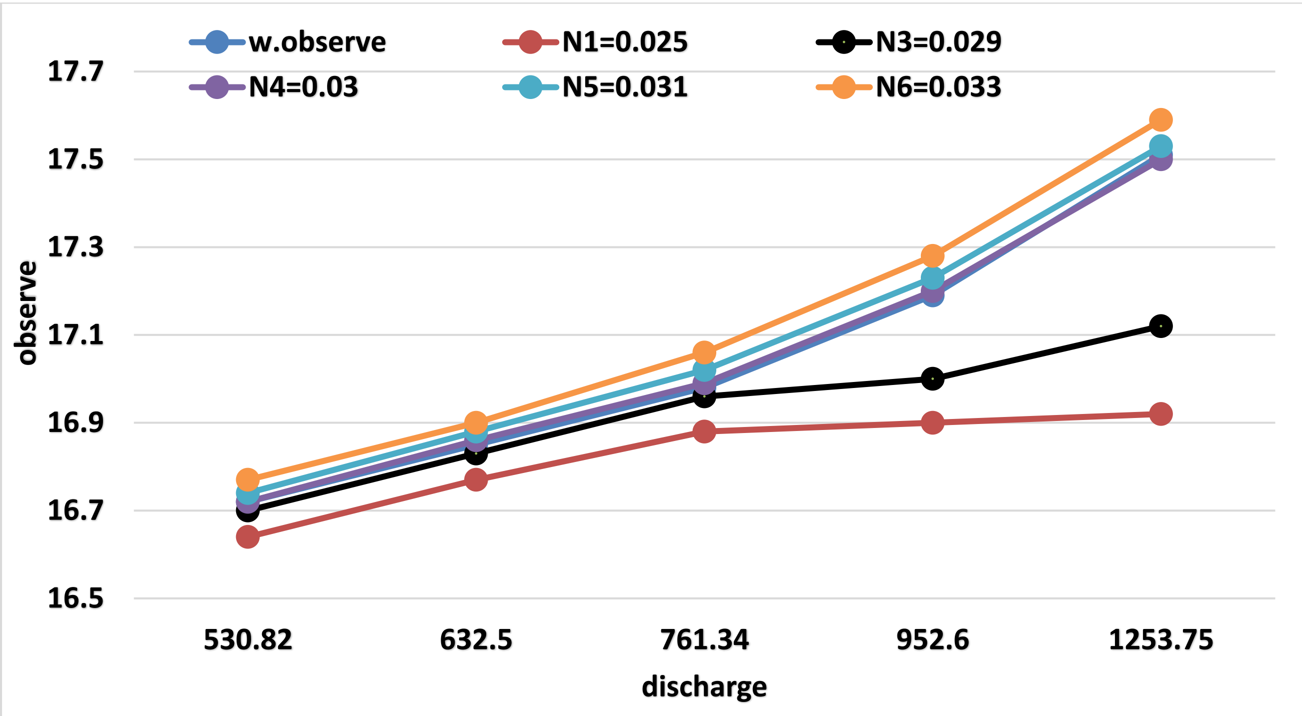


Figure 9. Simulated data

4.2. Stage and flow hydrographs

The hydraulic conditions at the research area's outlet were defined by a stage-discharge relationship at station (339+305), which served as the downstream boundary condition. Figure (10), which shows the peak discharge of 1051.55 m^3/s, corresponds to the highest recorded water level at this station, which reached 18.63 m. The results show that the flood wave didn't go away entirely along the study reach, but there was a slight decrease in discharge of about 2.68 m³/s. This is mostly because the modeled river segment was not very long.

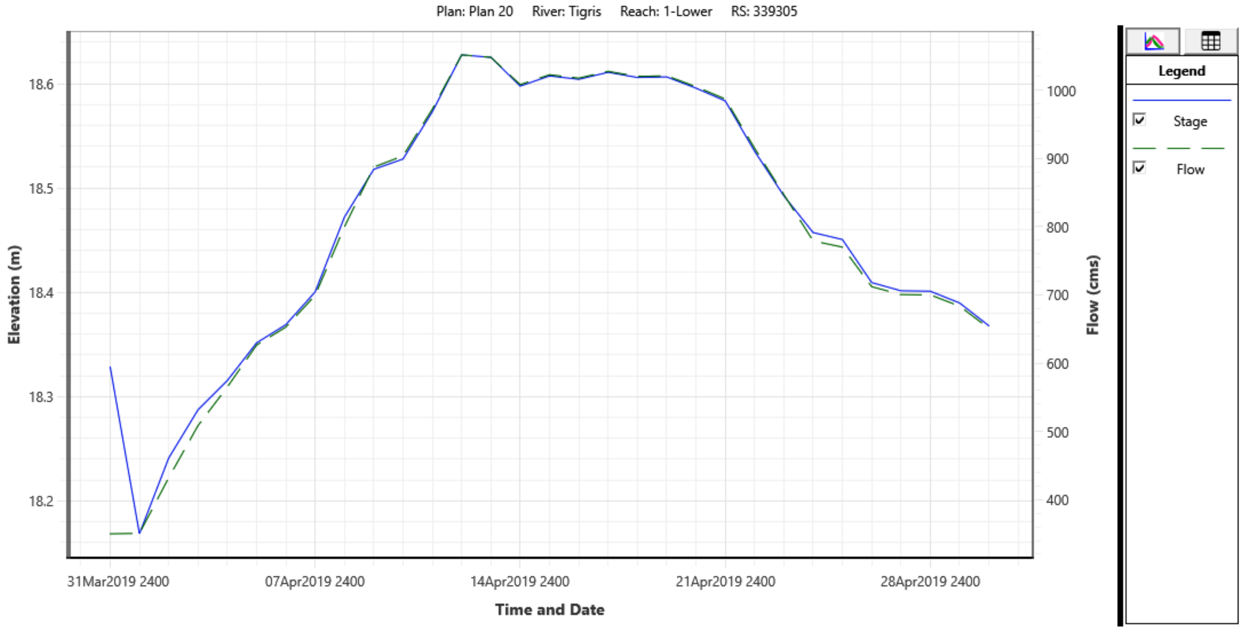


Figure 10. The stage and flow hydrographs at the station 339+305

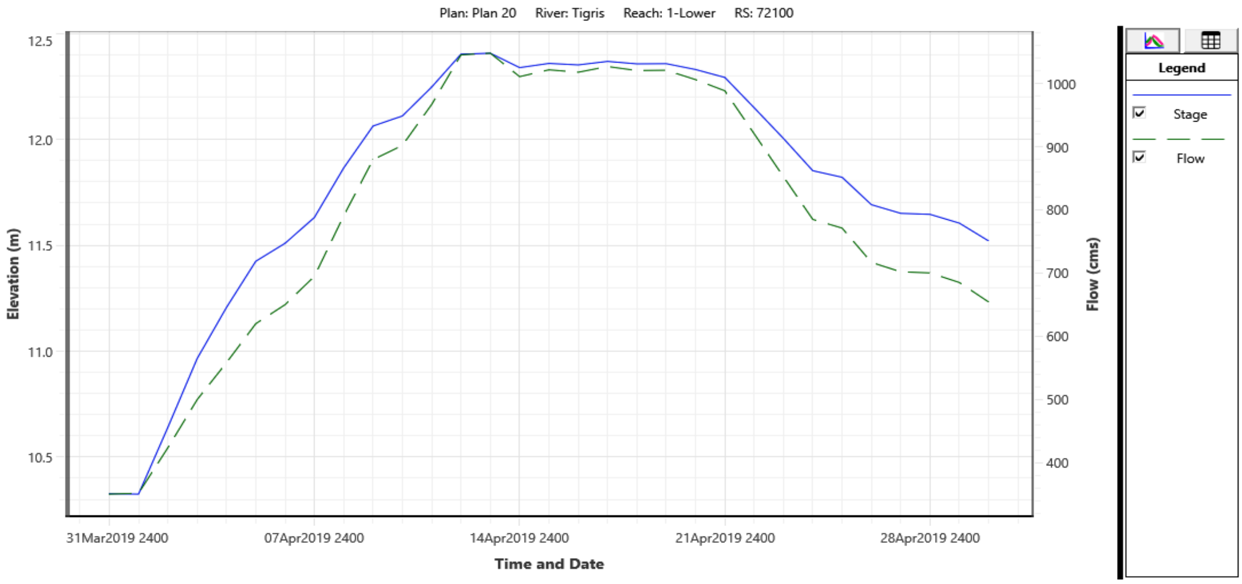


Figure 11. Hydrographs of the stage and flow at the 72+100 station

During the flood event on April 12, 2019, the upstream boundary condition was defined at station (72+100) using a flow hydrograph that reflects the temporal fluctuation of discharge. As indicated in Figure (11) the greatest discharge during the event was 1051.55 m³/s, and the measured flow was 1047.87 m³/s on that date. The purpose of this hydrograph was to model the propagation of a flood wave from its source upstream into the research area.

The results above show that the flood wave did not dissipate or disappear, but rather decreased by an amount of 2.68 m3\sec. Due to the small size of the study area, we will optimize the cross-sections of the central islands within the study area and observe the difference this optimization makes to the flood wave effect in the study area.

4.3. Modification of Cross Sections of the Reach

It was shown that the current capacity of the reach of Tigris River on d\s of Kut barrage d \s and is limited to 1052 m 3 /s when there are no lateral inflows. These flow discharges form nearly half of the flood discharge of 1988. More than thirty years of low flow within the reach, due to the lack of periodic maintenance, are the main cause of the deterioration of the capacity of this reach of the Tigris River. Therefore, it is a very important issue that should be given utmost attention to recover the capacity of the river to accommodate expected flood discharges. The strategy to recover the capacity of the river reach is to identify side bars along the reach and modify the cross sections at their locations. Then, specifying the cross-section causes choking to the flow, and modifying these cross-sections one by one. Figure 4.6 shows satellite images of the two islands along the reach of the study area, according to the sequence of each image listed in Table 4.2.

Figure 12. Hydrographs of the stage and flow at the 72+100 station

Table 2. Locations of the islands and the sidebars along the reach.

Sample	Type	Station
1	Island	81+079
2	Island	80+837
3	Island	80+587
4	Island	80+336
5	Island	80+083
6	Island	74+100

The cross-sections of the Tigris River at these islands were modified by reshaping them into appropriate cross-sections. Figures (4.6), (4.7), (4.8), (4.9), (4.10), (4.11) show the modified cross-sections.

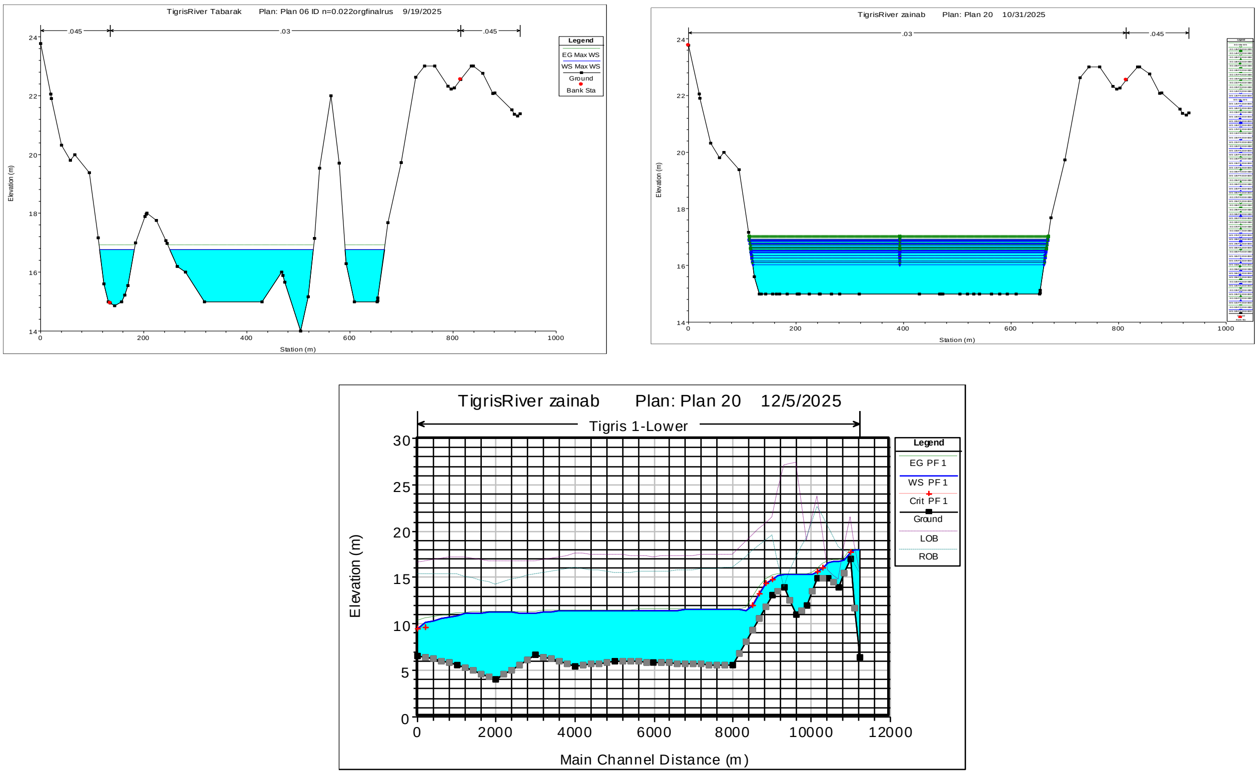


Figure 13. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 81+079

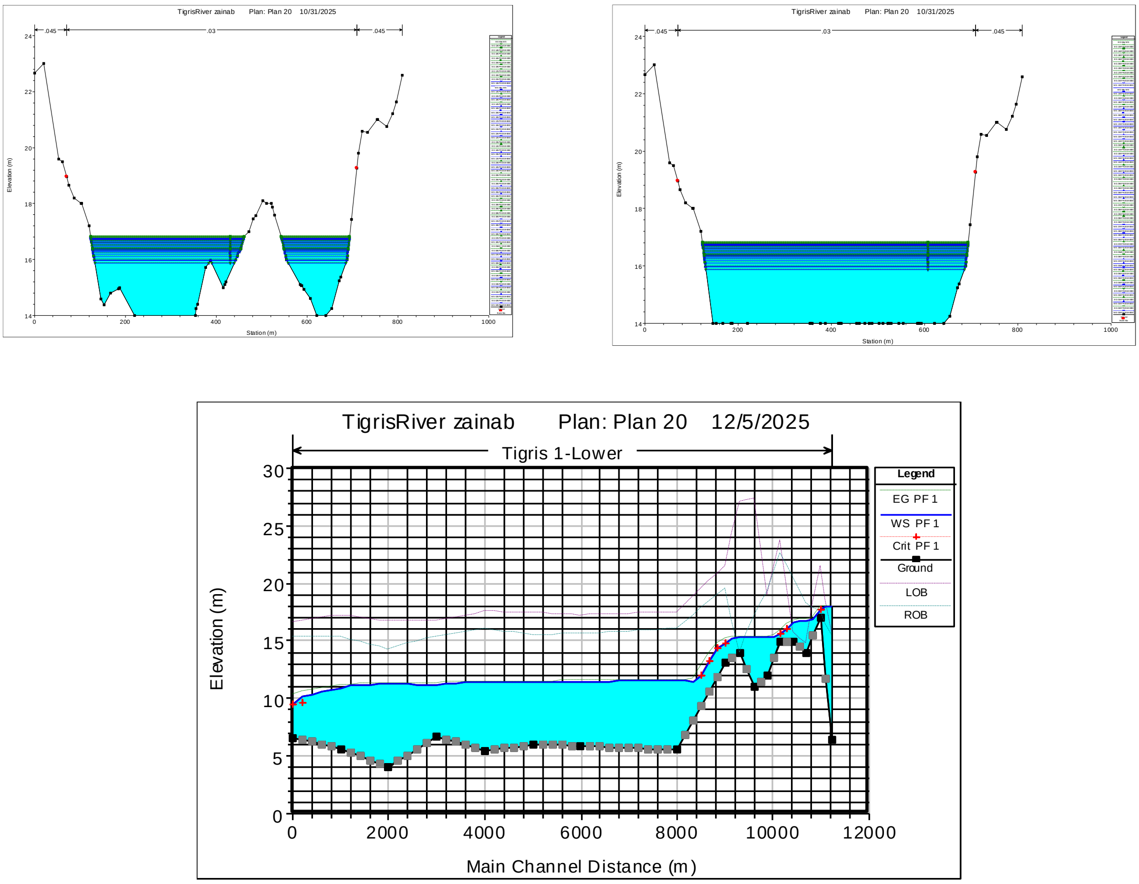
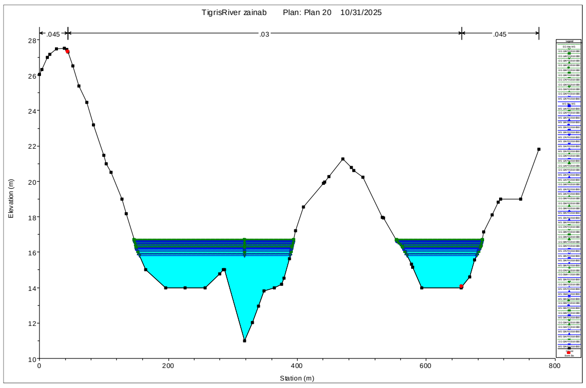
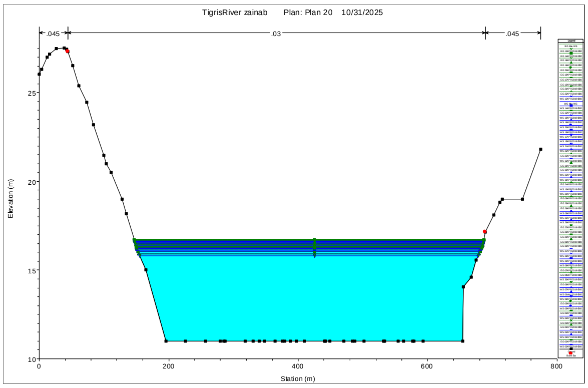


Figure 14. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 80+837





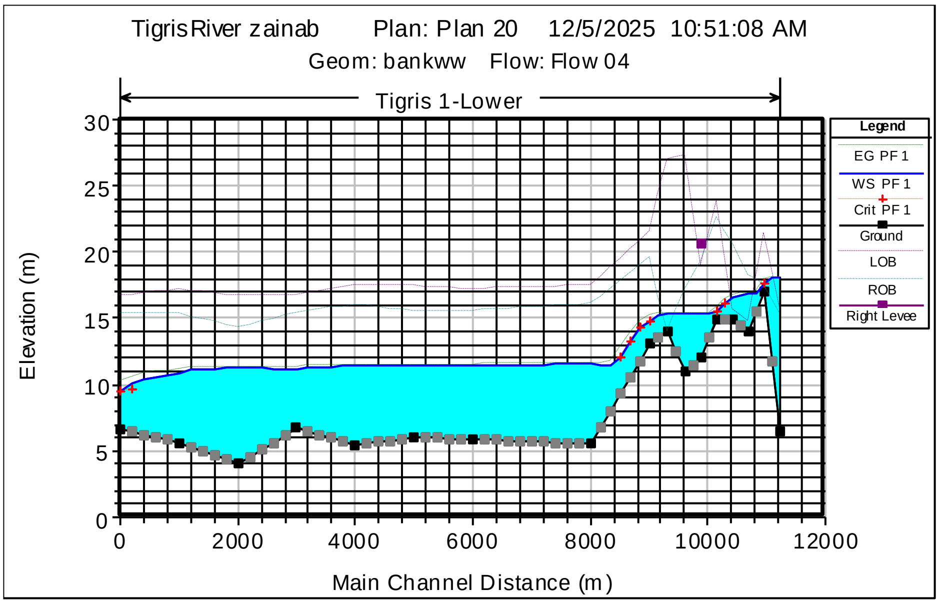
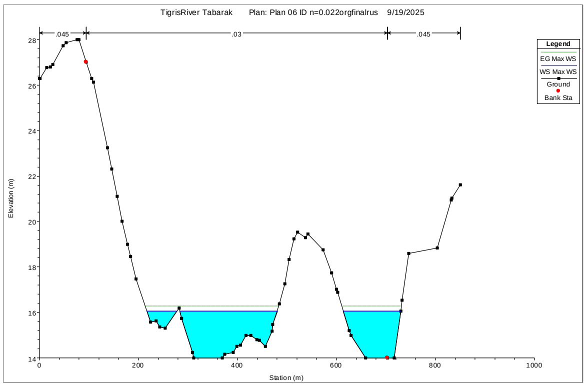
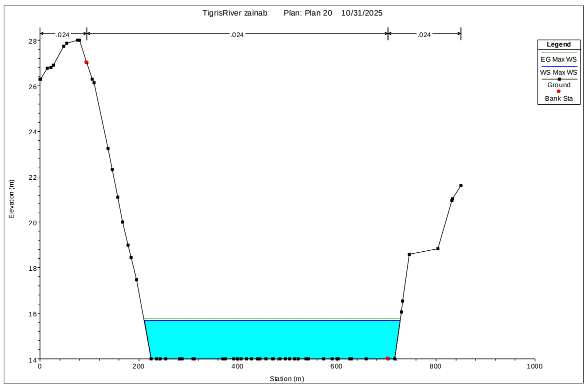


Figure 15. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 80+587





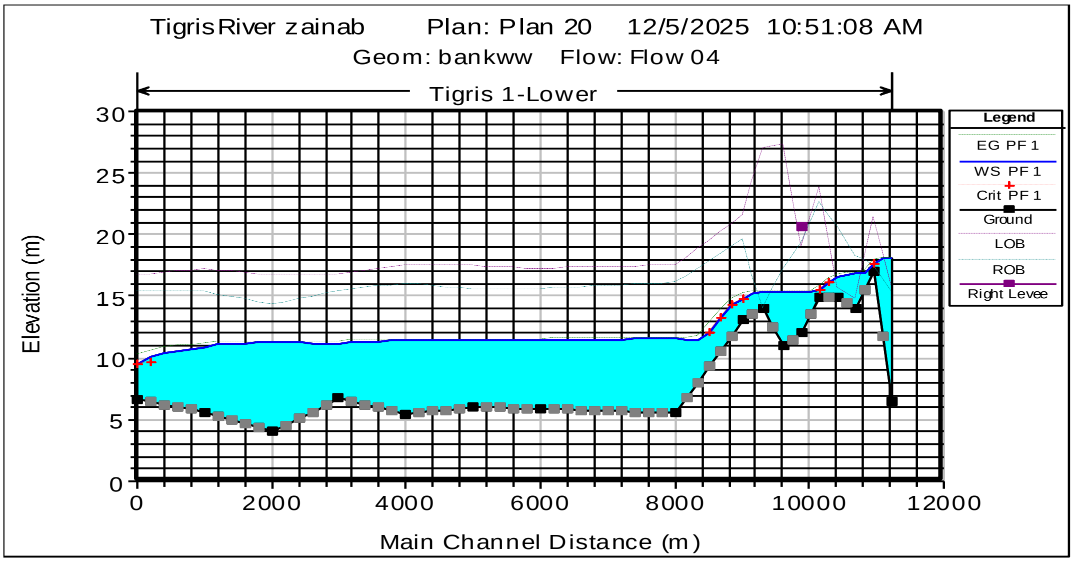
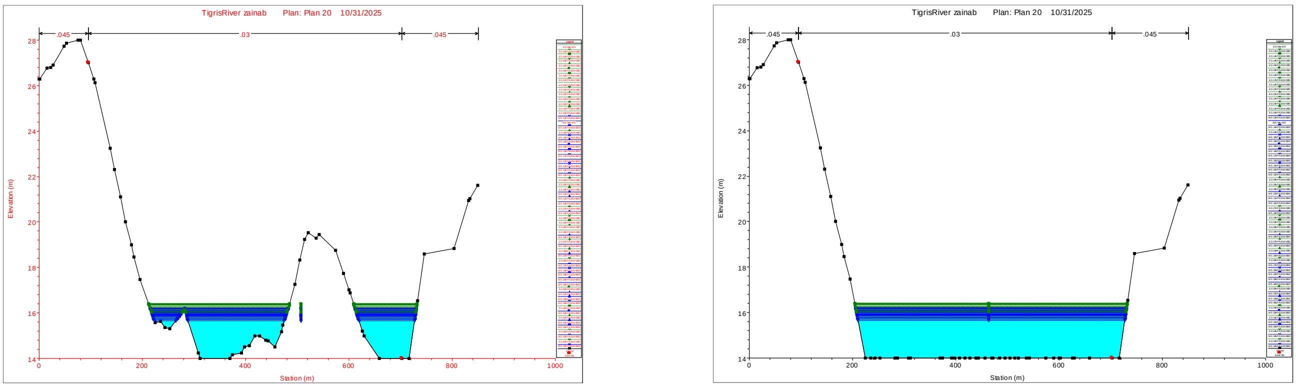


Figure 16. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 80+336



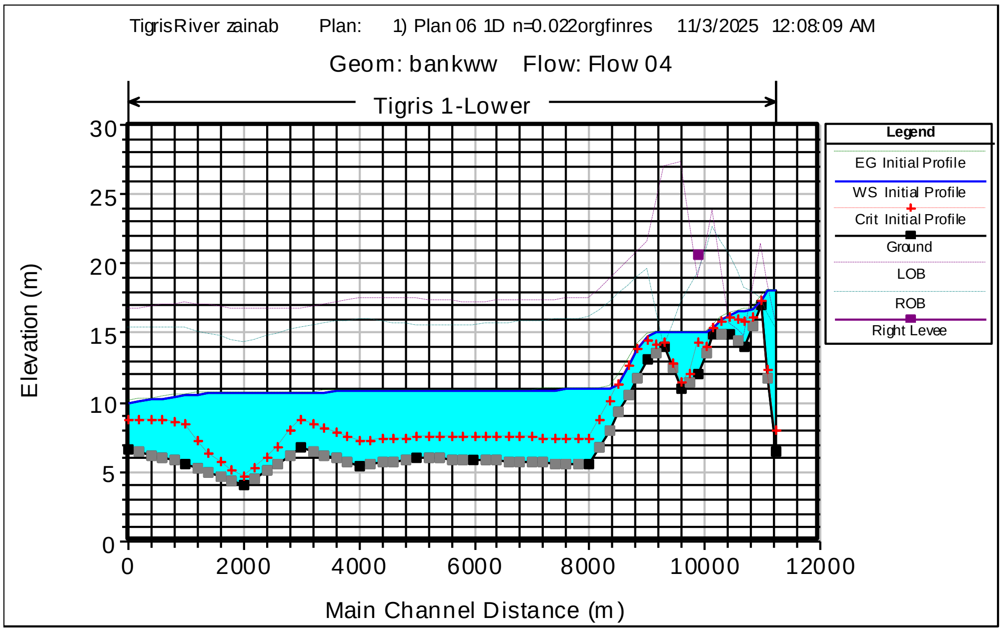
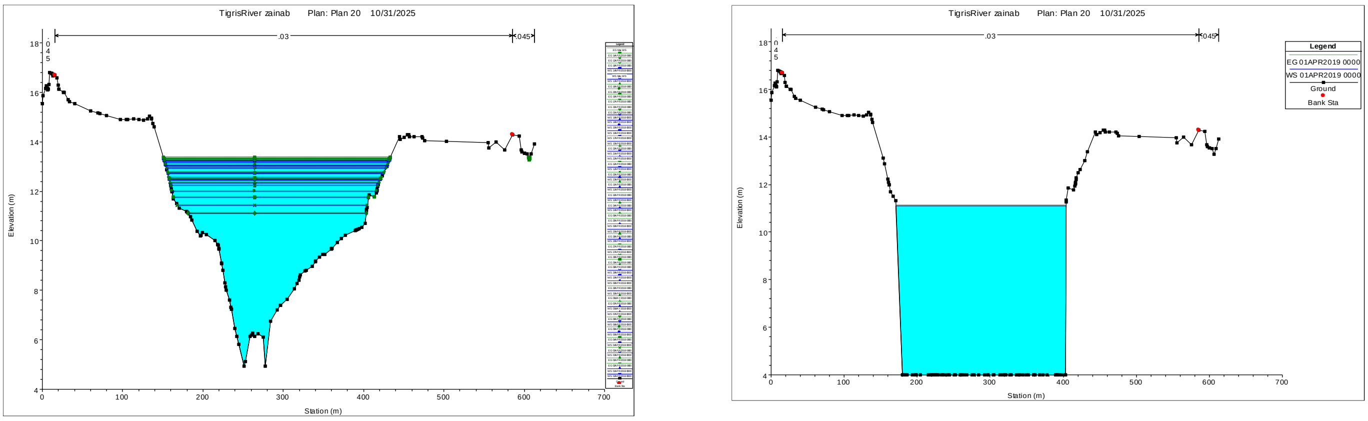


Figure 17. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 80+083



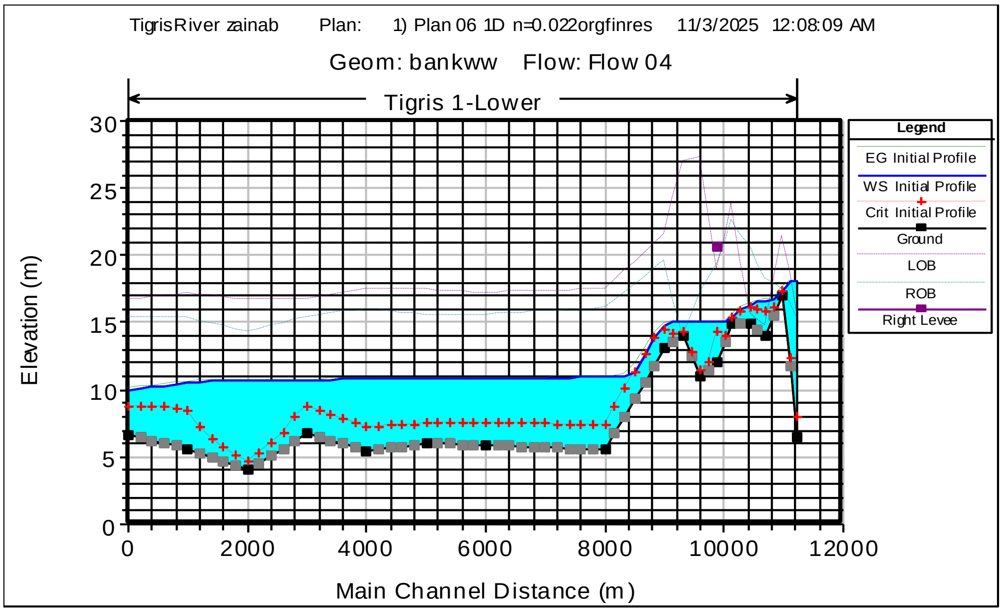


Figure 18. Modified Cross Section with Energy Grade Line and Water Surface Profiles at station 74+100

The results of the model, operated with modified cross-sections of the islands, revealed that the flood wave was slightly dissipated and delayed its arrival at station 72+100. Figures (10) and (11) indicate the results of the hydrograph flow and stage, where for station 339+305 at the downstream of the Kut Barrage, the flow was 1051.55 on April 12, 2019, and the stage was 18.22 on April 12, 2019; at station 72+100, the flow was 1047.96 on April 13, 2019. The flow is 3.59 m2/s less than the flow in the original cross-section of the river, and the stage is 11.79 on April 13, 2019. Therefore, the process of removing the islands is a slight improvement and a positive indicator (wave dissipation and delay), but the decrease in flow is very small (~0.34%), so the process cannot be described as "completely successful" if the criterion is ample flood protection.

5. Discussion

The findings of this study suggest that the HEC-RAS model can reliably replicate the hydraulic dynamics of the Tigris River within the 12 km study reach, evidenced by the robust correlation between observed and simulated flow data. This validates the appropriateness of the chosen Manning's roughness coefficient and the employed calibration and validation methodology. The elimination of the center islands caused a minor decrease and postponement of the flood wave, attributable to alterations in flow distribution within the river channel. Nonetheless, the total decrease in discharge was minimal, suggesting that the existence or elimination of the islands exerts a relatively insignificant impact on large-scale flood mitigation within the research area. These data indicate that whereas island removal may result in localized hydraulic enhancements, it does not substantially mitigate flood risk independently. Consequently, dependence exclusively on this strategy is inadequate for efficient flood protection, necessitating supplementary flood management measures to attain significant flood risk mitigation.

6. Conclusions

Determining the impact of removing the central islands in the Tigris River within the 12 km research area using the HEC-RAS software.

The following deductions were made in light of the current study's findings:

• For validation and calibration, we used the Tigris River's flow measurements. The outcome was a robust correlation between the anticipated and observed flow rates. There was a strong correlation between the simulated and observed river flows for the Tigris River, which has a Manning's roughness coefficient 'n' of 0.03. It was determined that there was an acceptable range for both the calibration and validation correlation coefficients (r), with a value of 0.998.

• The volume of flows did not change between the first and last sections, but it decreased by 3.59 m3\sec, an amount compared to the results in which the intermediate islands were still present.

• Also, in general, the central islands present in the study area affect the amount of flood wave, so the process of removing the islands is considered a slight improvement and a positive indicator (wave dissipation and delay). Still, the decrease in flow is very small (0.34%), and therefore, the process cannot be described as "completely successful" if the criterion is protected from large floods.

The HEC-RAS model proved reliable in simulating the hydraulic behavior of the Tigris River within the 12 km study reach. Removing the central islands resulted in a slight reduction and delay of the flood wave; however, the overall decrease in discharge was very small and insufficient to provide effective protection against major floods. Therefore, while island removal may lead to minor local hydraulic improvements, it cannot be considered an effective standalone flood mitigation measure.

Declaration of Competing Interest

The writers of this work declare that they have no competing interests with respect to its publication.

Funding Information

No organization provided funding for this study.

Author Contributions

The research problem was proposed by the author to Dr. Ali N. Hillo. Zainab Saeed collected the recent relevant articles and organized them in a clear structure. The authors discussed the work with Dr. Ali N. Hillo. The design, results, and final version of the study were suggested and completed by Zainab Saeed Al-Rubaie..

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