Flood Control by Weir Design Using HEC-RAS Model: The Case of Al-Musandaq Escape

Tabarak W.Mahdi, Ali N.Hillo

1Department of Civil Engineering, College of Engineering, University of Wasit, Iraq.
E-mail: twaseem@uowasit.edu.iq, dralinasser@uowasit.edu.iq

Abstract. Proper flood control plays an important part in designing hydraulic structures and environmental safety measures. However, in Iraq, a clear understanding either of the estimation or management of the magnitude of flooding is yet to reach a higher level. This has resulted in grave and frequent damage to much property and life in Maysan town. Therefore, this study was focused on the Flood Hazard control; in the River Tigris at the downstream of Al-Kut Barrage to the Al-Musandaq Escape, by adopting the HEC RAS model. Here, information related to the hydrological and topographical Digital Elevation Model (DEM) data were used as the input data. The hydrological data enabled the estimation of the flood depth of the river, for April 2019. All the geometric data were prepared by the HEC-RAS model. The unsteady-state model simulation was performed employing the input data. In this study, the best method for flood control and management is to design a weir having an optimal level, the optimum level that does not permit the passage of a flow that exceeds 700 m$^3$/s to the city of Maysan during the flood season and a flow that is not below 250 m$^3$/s during the dry season, is 9.406 m.

Keywords: HEC-RAS; GIS; Flood; Weir.

1. Introduction

The most significant natural disaster might be the flood, with more natural hazards than other hazards that affect more people than all-natural disasters combined. [1],[2]. Moreover, the possibility of floods will rise due to climate change [3]. Social-civil conflicts [4], environmental issues [5], and economic losses [6] are connected to floods. Maysan city in Iraq is an example of flood lands suffering from severe flood events causing ongoing environmental, economic, and social damage. Many hectares of arable land are swamped, crops are destroyed, and houses are destroyed. The inundations need to be recognized and the consequences of the proposed acts to suggest flood control measures evaluated. In situ flood control is a simple solution flood management [7]. Flood observations in situ aren’t available always, however. For flood research, other researchers use Data for remote sensing. [8],[9]. However, in the cloudy skies, there are typically flood events that limit the use of remote sensing data. Also, observation-based flood research is applicable just for a particular flood occurrence [10]. Therefore, such observation-based maps cannot analyze predicted flooding incidents or the systemic operation of the flood. The use of computational models allows flood events to be simulated, taking into account various scenarios. Therefore, Models numerical are critical resources for the understanding of flood occurrences, flood risk assessment, and flood control planning. Previous research has shown that numeric models are applicable for developing danger maps taking into account different techniques in flood management. [11,12] or to recreate past flood events [13]. There are now numerical models with diverse capabilities and developers available; some are free, while others require a license to be purchased. The HEC-RAS
model Established by the Engineers’ Corps of the Army (USACE) is one of the Hydraulic Models most common. HEC-RAS is free software that has been successfully used for flood studies [14,15] with a comfortable graphical user interface. Besides, it is under continuous development and improvement by USACE. The current study aims to control the April 2019 flood event in Maysan city using the HEC-RAS-v5.0.7 1D and HEC-GeoRAS (Geospatial River Analysis System). A 1D numerical simulation of the April 2019 Maysan flood occurrence was Executed with the HEC-RAS-v 5.0.7 and the daily flow of the Tigris river.

2. Study Area and data

2.1. Study area
The reach of Tigris River is situated between downstream of Kut Barrage and Al-Musandaq Escape, Figure.1, and is about 160 km long. kut Barrage is the primary cross-regulator for the Tigris River flow regulation. At the downstream of Kut Barrage, the elevation of the river levee is as high as 20m. This elevation progressively decreases to 9m at near the Al-Musandaq Escape. The average longitudinal surface slope of the water is around 4cm / km. Within the reach under study, there is one flood escape to protect the reach understudy from flooding, especially since the reach has a mild slope and runs within a flat area. The Al-Musandaq escape is this flood escape. The Al-Musandaq Escape is located about 87 km downstream of the Kut Barrage on the right side of the reach. This escape connects the Tigris River with Uda Marsh [16] with an earth channel of 400 m maximum width. The authorities opened this escape to discharge 1800 m$^3$ / s during the flood of 1974 to reduce flood pressure on the downstream range, Ministry of Irrigation previously (IMI).

![Figure 1. The River Tigris located between the Kut Barrage downstream and Al-Musandaq Escape (GIS software)](image)

2.2. Data
Geographical data providing a geographical overview of the region and flow data providing details on the flow of the Tigris River is the main data forms. The geographic data from the Shuttle radar topography mission (SRTM) with a grid cell size of 90 m was based on the digital elevation model (DEM) figure 2. The research-based on an area between downstream of the Kut Barrage (with the coordinates of 32° 29′ 00″ N latitude, and 45° 50′ 00″ E longitude) up to the Al-Musandaq Escape (with the coordinates of 32° 30′ 00″ N latitude, and 46° 25′ 00″ E longitude). Data for the flow were based on daily data of the Tigris river at Kut Barrage station provided by the IMI. The cross-sections were surveyed, 62 major cross-sections were measured along the Tigris River from D/S Al-Kut Barrage - Al-
Musandaq Escape by GPS (Global Position System). The cross-sections photo is shown in figure 3. The first and last cross-section for the Tigris river and Al-musandaq Escape was shown in figure 4. The study simulated the floods between April 01, 2019, and April 30, 2019. Figure 5 shows the flow discharge of the Tigris river.

Figure 2. DEM model picture for the study area (global mapper)

Figure 3. cross-sections along reach the river
Figure 4. cross-sections: (a) The first cross-section at Tigris river, (b) The final cross-section at Tigris river, (c) The first cross-section at Al-musandaq Escape, (d) The final cross-section at Al-musandaq Escape

Figure 5. The flow discharge of the Tigris river

3. **Theoretical Basis**

3.1. *One Dimensional Unsteady Flow*

The study focused on the unsteady state and gradually varying flow of the simulation model, which depends upon the finite difference in the solutions of continuity and momentum. Equations (1) & (2) are used to simulate the River Tigris flow of water. The HEC-RAS 1-D unsteady flow simulator measurement engine [17] is as given,
\[
\frac{\delta A_T}{\delta t} + \frac{\delta Q}{\delta x} = q
\] ...................................................(1)

\[
\frac{\delta Q}{\delta t} + \frac{\delta V Q}{\delta x} + gA \left( \frac{\delta z}{\delta x} + S_o + S_f \right) = 0
\] ......................... (2)

Where,

An indicates the cross-section (m²), V refers to the cross-sectional averaged velocity (m/d), Q represents the flow in cross-section (m³/d), g is the gravity acceleration (m/s²), and x shows the distance along the channel (m)

\[\frac{\delta z}{\delta x}\] = water surface slope implies the water surface slope, So means the bed slope; Sf is the energy slope, t equals the time (day)

3.2. Weir

The HEC-RAS is capable of simulating flow at the hydraulic controls in various ways. Bridges, culverts, inline structures, lateral structures, and SA/2D area connections can all function as hydraulic controls. They effectively break down the conservation equations used between the cross-sections in a 1D reach and/or cells in a 2D area with empirically derived (and usually very stable) equations. The weir equations can be used to define the flow over an obstruction and are available with all the five hydraulic controls identified above. However, several options must be considered when selecting a simulating weir flow in the HEC-RAS. The HEC-RAS approaches weir flow for three different cases: Ungated Inline Weirs, Ungated Lateral Weirs, and Gated Weirs. They all begin with the same standard equation. (3),

But in each of the three cases the weir equation is applied slightly differently.

\[Q = C L H^{0.63}\] .......................................................(3)

Where, Q is the discharge (m³/s), C refers to the weir coefficient, L represents the weir crest length and H indicates the energy head over the weir crest.

4. Methodology

4.1. HEC -RAS Model Development

To model floods in the Tigris River Basin, HEC-RAS and HEC-GeoRAS (Geospatial River Analysis System), an extension of HEC-RAS, were used. The HEC-RAS model was established by the Hydraulic Engineering Centre, Part of the U.S. Army Corps of Engineers Institute of Water control. [16]. In 1965, Several river modeling programs were developed at the research institute. In 1995, the first version of the HEC-RAS model was released to analyze the rivers, streams, and channels. The HEC-RAS software is an integrated system that can simulate the water flow in rivers and channels by employing a numerical model [18], as this software is one-dimensional, it implies the lack of any direct modeling of the hydraulic influences of the transverse profiles. [19]. To simulate and produce flood inundation depths, the most important HEC-RAS model is to estimate the water surface profiles of flood events. As per the HEC- RAS manual, the water surface profile measurement is based on the 1D energy equation [20]. In this analysis, the model was built by real values with the help of the GIS environment, three steps were taken to run hydraulic or hydrologic modeling (HEC -RAS). These steps include Data Pre-processing, Data Modelling Phase, and Data Post-processing [21]. The first step in designing the HEC-RAS hydraulic model is to define the directory in which the researcher wants to function and enter a title for the new project. Then it imports the cross-sections from the excel file that were measured by GPS, and edited in the geometry edit window figure.6 [22]. In the new HEC RAS project, flow data from the river,
all RAS layers, and the manning coefficients were established step by step according to the HEC-RAS manual to successfully simulate unsteady-state flow. In the current study, when the output data of the program was exported to RASmapper. Results were showed into Rasmapper after running in HEC-RAS[23] The following procedures have been carried out to achieve the purpose of the analysis, as shown in Figure 7 below.

![Figure 6. Edit geometry window in the HEC-RAS model](image)

![Figure 7. Flow Chart of the Tigris River Flood Modelling](image)
4.2. HEC -RAS Model Calibration

The most sensitive parameter is Manning’s roughness coefficient in river simulation. Calibration of Manning’s roughness coefficient value of the river must be attempted by simulating these flows using the HEC-RAS model along with the study distance. Calibration is an inverse mathematical problem since it attempts to evaluate the original and local parameters that describe a function from unique variables from a given measurement data set. The calibration of hydrodynamic models has historically been performed manually. By changing the parameter sets, the calibration method minimizes the objective function; showing the river and taking into account the ranges of the parameter values for the flow state. The most widely used objective function is the correlation coefficient (r) Equation (4)[24] between simulated and observed data.

\[ r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2(\sum y^2 - (\sum y)^2)}} \] ............... (4)

where, \( n \)= number of data points, \( x \)= observed flow, \( y \)= simulated flow

5. Results and Discussion

5.1 HEC-RAS Calibration and Validation

For the main channel and its flood plain, different Manning’s \( n \) values were assumed to investigate and evaluate their impact on water surface elevation. The range of these values tested ranges between (0.021-0.031) for the Tigris River and between (0.02-0.028) for Al-Musandaq escape. To compare the simulated and observed flows, the \( r \) test was used. The comparison of simulated and observed flows for values of Manning’s \( n \) is shown in Figure 8. Manning’s roughness coefficient ‘\( n \)’ was 0.031 for the river Tigris and 0.028 for the Al-Musandaq Escape. The values of \( r \), are 0.995 and 0.991 for calibration and validation respectively, which were in the acceptable range. Figure 9 shows a graphic comparison of the correlation between the observed and simulated flow data, indicating that the model demonstrated very good performance in fitting correlation.

![Figure 8. The comparison of simulated and observed flows for values of Manning's n: (a) Tigris river in comparison, (b) Al-Musandaq escape n comparison](image-url)
Figure 9. Statistical parameter of unsteady flow calibration: (a) the Tigris river, (b) Al-Musandaq Escape

5.2 Results of one-dimensional mathematical model
To get a clear perception of the inundated flood depth for April 2019, the HEC-RAS was simulated for the discharge values of the River Tigris at the Al-Kut barrage d/s up to the Al-Musandaq Escape. GIS based preliminary: The current study showed the output map of the depths of the flood inundation prepared by simulation of the HEC-RAS based on the Digital Elevation Model (DEM). As shown in Figure 10, the map reveals the flood depths in the area under study, in the event of a flood. Evidently, the maximum height of 7.3 m can be observed on April 13, when the flood peak was achieved., the very high flood risk depths are identified in dark blue.

Figure 10. Flood hazard depth map

5.3 Weir design
A weir was designed in front of the Al-Musandaq Escape at station 23+410, as shown in Figure (11). The parameters were entered in the inline structure weir window, where the distance is 20 m, width is 10 m, and the weir coefficient is equal to 3.1. Several scenarios were conducted to achieve the optimum level that does not permit the passage of any flow exceeding 700 m$^3$/s into the city of Maysan during the flood season and no flow below 250 m$^3$/s during the dry season; the scenarios were performed for four peak flows, namely, (4000, 2500, 1050, 533, and 250) m$^3$/s. After implementing the many scenarios, the optimum level for designing a weir that does not allow the passage of more than 700 m$^3$/s drainages to the city of Maysan and no less than 250 m$^3$/s is 9.406 m.
6. CONCLUSION

In this study, the 1D HEC-RAS model was used to generate the inundation model in the Tigris River floodplain. For the further generation of the flood hazard depth map from the model's inundation data, the Geographical Information System was used. In April 2019, calibration and validation of the 1D HEC-RAS model were carried out where the roughness coefficient 'n' of Manning was the main calibration parameter. The flow data from the Tigris river was used for calibration and validation. A strong correlation between the observed and simulated flow data was seen as a result. For Manning's roughness coefficient 'n' 0.031 for the River Tigris and 0.028 for the Al-Musandaq Escape, the result showed a strong correlation between the observed and simulated flow results. The correlation coefficient, r is 0.995 and 0.991 for calibration and validation respectively, which were found in the appropriate range. In this analysis, the 1D HES-RAS model was used to generate the Tigris River floodplain flood inundation model. The best method for flood control and management is to design a weir having an optimal level, the optimum level that does not permit the passage of a flow that exceeds 700 m$^3$/s to the city of Maysan during the flood season and a flow that is not below 250 m$^3$/s during the dry season, is 9.406 m.

Recommendations

It recommends the following suggestions for future studies:

- Development Al-Musandaq system to perform the flood operation functions for the distribution of water from the Tigris River to the Marshlands of Maysan city.
- Studying the possibility to use the Al-Musandaq escape for irrigation of some areas adjacent to the path for the winter season only to meet the population's needs.

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