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Applying HEC-RAS Software to Propose a Dam Site Along the Tigris River Between Mosul and Tikrit, Iraq

Alyaa Shakir Oleiwi[1] and Moutaz Al-Dabbas[2]

[1]Department of Water Resources, College of Engineering, University of Baghdad, Jadiriya, Iraq.
[2]Department of Earth Sciences, College of Sciences, University of Baghdad, Jadiriya, Iraq.

[1]E-mail: Alia.s@coeng.uobaghdad.edu.iq.

Abstract. Tigris River is an important water body in Iraq for drinking, agricultural, industrial, and livestock uses. The river flows from Turkey to the Iraqi land at Fiesh-khabour district in the northern part of Iraq and flows into Mosul city. Therefore, this study aims to simulate the flow in the Tigris River using the latest version of the HEC-RAS model (v5.0.7). The calibration and verification of the model showed that the final Manning's roughness coefficients (n) of the main channels for the Tigris River were 0.036 and 0.026 for Mosul and Tikrit sites respectively. The Results illustrated a very good agreement between the simulated and measured stages. The Root Mean Square Error RMSE, MAE, and Nash-Sutcliffe Efficiency Criteria NSE, tests were used for calibrating the unsteady state flow model where it served as a comparison of calculated water levels by the model for each of the Manning index values 'n' with the observed water levels as a function. The final Manning's roughness coefficients (n) of the main channels for the Mosul and Tikrit sites were 0.036 and 0.026 respectively. It's suggested to construct of hydraulic structures such as a dam with a reservoir beside this area to operate water stations and electric turbinate's and other projects built next to the river, such as irrigation projects. Recommended using the simulation of the present study in the future to study the effect of constructing a dam in the Tikrit region. In addition, the current simulation can be used in the future to study the TDS, transportation of sediment loads, or pollution along the river.

Keywords. Hec-ras, Tigris river, Discharge, Hydrodynamic, Simulation.

1. Introduction

There are two essential rivers in Iraq, the Tigris and Euphrates Rivers that are presented as the primary source of drinking water and irrigation. Over the past few years, Iraqi territories have experienced a lack of water resources to meet current and future demands. These shortages are primarily related to the south-eastern Anatolia Project (GAP), Turkey's projects by building many dams on the Tigris and Euphrates Rivers, besides the diversion of many tributaries from the Iranian sides. In addition to the effect of global climate change, which has affected stream flow and the amount of runoff [1]. This climate change has had an impact on the annual flow of the Tigris the Tiger has an average annual flow of 672 m^3/s when entering Iraq from 1960 to 1984, a reduction to 596 m^3/s from 1985 to 2008, and has dropped to 413 m^3/s over recent years [1] and [2]. In addition, during the last few years, the Iraqi environment, in general, has suffered from the pollution which causes high risks both to the environment itself and to its habitable life forms [2]. Many challenging factors were associated with climatic condition change, growing global water demand; including the growing population, coupled with increasing consumption rates, enlargement of agriculture, and industrialization [3].

The hydraulics modelling software (Hydraulics Engineering Centre River Analysis System HEC-RAC) is a widely available source [4]. The HEC-RAS is used to enable hydraulic engineers to analyse the flow of canals and to identify the floodplain of the river. It comprises extensive data input capabilities, hydraulic analysing components, storage, and data management capacities, besides graphs and reports as well as estimating the manning coefficient [5]. The HEC-RAS model is essential to show the change in the water level that varies from one site to another depending on Manning roughness coefficient ‘n’ that varies with the stream bed bathymetry, topography and morphology, and it can provide information on various water depths, velocities, and surface water elevations. In other words, it can be a tool for monitoring water levels for the future and as achieve the water levels under drought conditions [6]. This study deals with the hydraulic evaluation of the Tigris River by applying the HEC-RAS model of Tigris River between Mosul and Tikrit site.

The stretch of Tigris River in the HEC-RAS model started from Mosul at (Badush) to the south of Tikrit city (Table 1). The river was subdivided into two paths depending on the main sites of the Tigris River involving Mosul and Tikrit sites so that the river could be completely covered and notes all the changes in the water levels etc. (Fig.1).

Table 1. The main sites in the river system input in the model.

Sites		Mosul	Tikrit
Location (Inflow)	N	”19.98ʾ4136°	35°04’26.72”
	E	”21.14ʾ9742°	43°32’44.59”
	Indicate point	Badush	Al-Fatha city
Location (outflow)	N	35 ° 09ʾ01.68”	34°20’22.13”
	E	43 ° 26ʾ06.51”	43°47’19.20”
	Indicate point	Makhoul	Tikrit city
Length (km)		228	155

The aim of the research is to use the HEC-RAS 5.0.7 model for the simulation of the one-dimensional unsteady state flow based on the flow rate and water levels under different conditions of Tigris River between Mosul, Fatha, Bijiee, and south Tikrit city depending on Manning roughness coefficient ‘n’. As well as, examining the discharge capacity of the river control system under present conditions to propose a dam construction site at the Fatha within the Tikrit region for future water harvesting to get rid of the future water shortage.

The Geological features play a significant role in the determination of water quality in rivers, such as the type of rocks in the river basin plays a key role in controlling the quantity and quality of the dissolved and suspended load in the river [7]. The geological formations crossed by Tigris River and present within the study area between Mosul and the south of the city of Tikrit (Fig. 2).

According to [9], Tigris River upon entering Iraqi territory flows in the formation of Mukdadiya, Injana, and Al-Fatha formations. These formations are composed of sandstones, siltstone, claystone, marl, limestone, and gypsum. Furthermore, the riverbanks are characterized by the presence of terraces alongside the river. Pebbles come in various sizes and shapes, consisting mainly of silicates, carbonates and less extensive igneous and metamorphic rocks. Beyond the gorge of Al-Fatha, Tigris River runs through the sediment of Al-Fatha Alluvial Fan; deposited by the river. The sediments are substantially the same as the ones on the river terraces. But the top is covered by gypsiferous soil (Gypcrete). The main geomorphological units along the course of the Tigris River are the terraces, anticlinal ridges (such as Khanooqa, and Makhoul anticlines), and erosional pediments [9] and [10]. After Al-Fatha gorge, the Tigris River flows in the Mesopotamian Plain.

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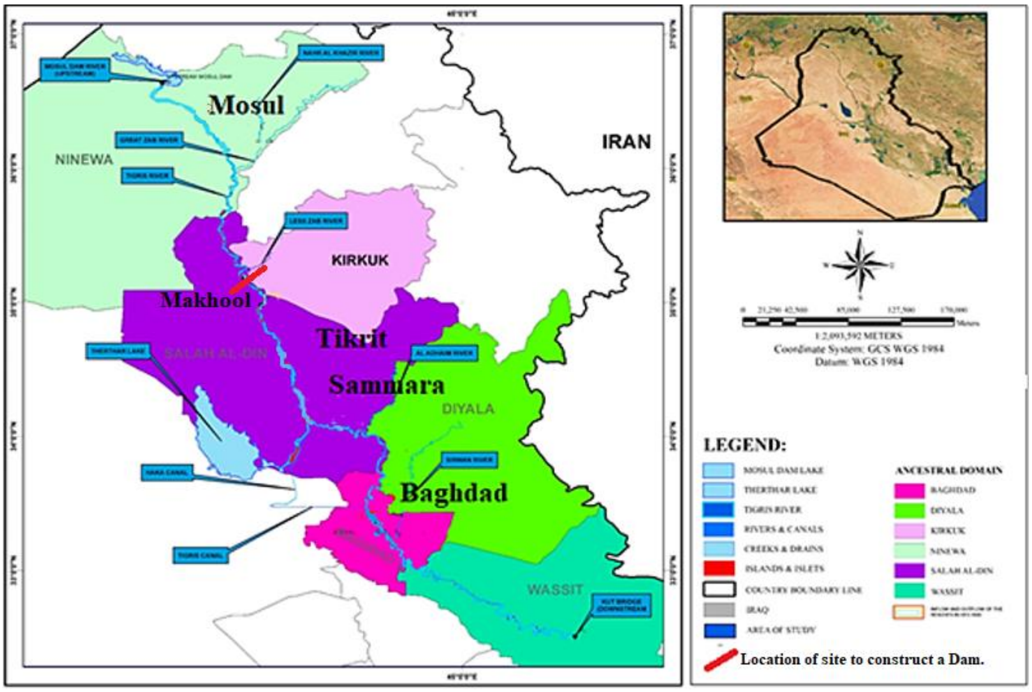

Figure 1. Tigris River stretch of the study area.

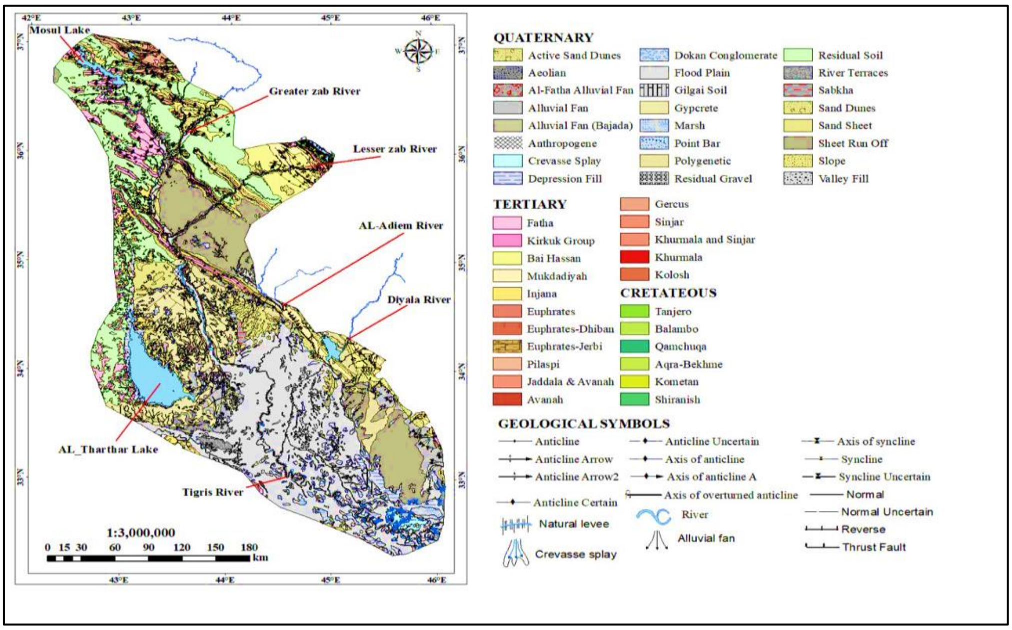

Figure 2. Geological map of the study area, [8].

2. Methods and Materials

*2.1. HEC-RAS *Model Setup**

The HEC-RAS 5.0.7 software was used for the simulation of the one-dimensional unsteady state of the present study under several conditions, the program can model the hydraulics of water flow through natural rivers (Figs.3 and 4). The first part is entered geometric information from the study scope, which included the numerical elevation model (DEM), the cross-sections of the study scope, and the boundary conditions, and the second involved the results of applying the hydraulic (one-dimensional) numerical model in the study area, calibration of Manning's coefficient 'n', and their verification.

The flow is simulated by solving either the full Saint Venant equations or the diffusive wave equations. the present study considered both options the full Saint Venant equations and the diffusive

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wave. Both methods provided the same results, but the simulation solving the diffusive wave equations was faster than the other.

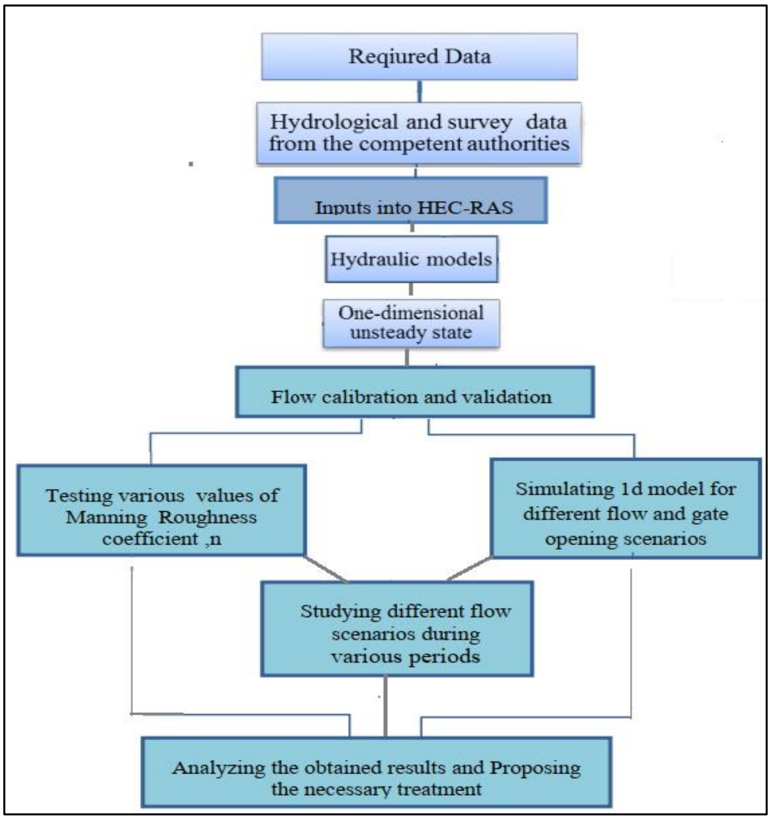

Figure 3. Setups of the HEC-RAS model in the present study.

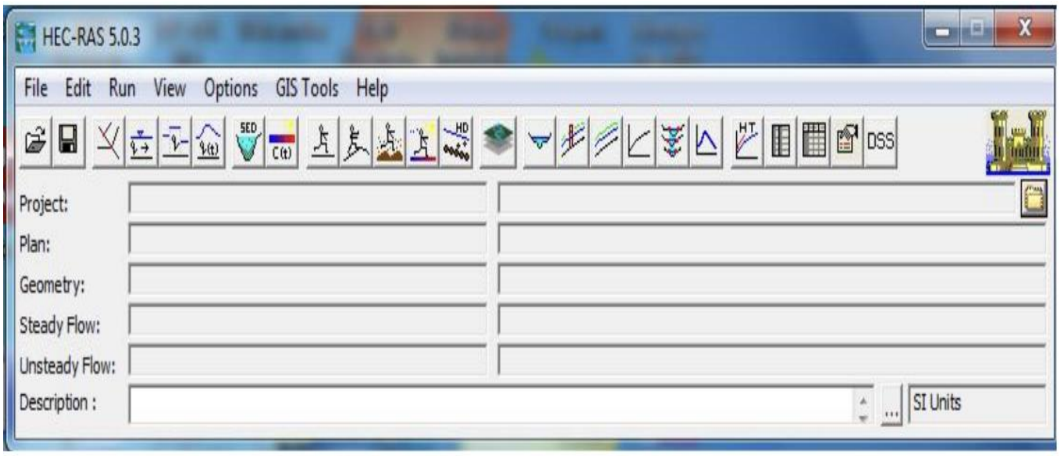

Figure 4. Main menu of HEC-RAS software (V. 5.0.7).

2.2. Geometric Data

The first step is entering the geometric data, which consists of a background map layer, connectivity information for the stream system (River System Schematic), and cross-section data. The cross sections of Tigris River were measured during the period from December 2021 to February 2022 [11]. The required information had been displayed on the cross-section data editor as shown in Fig. (5).

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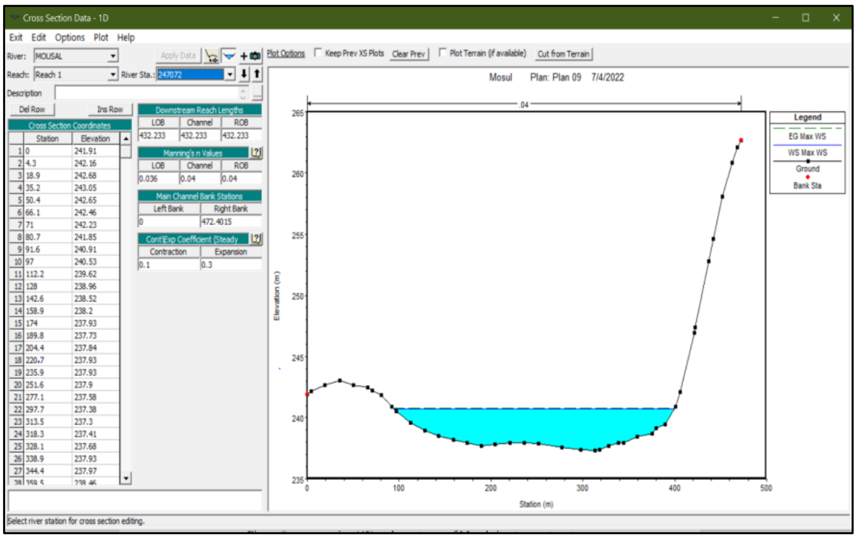

River: MOUSAL
Reach: Reach 1
River Sta.: 247072
Description

Cross Section Coordinates

	Station	Elevation
1	0	241.91
2	4.3	242.16
3	18.9	242.68
4	35.2	243.05
5	50.4	242.65
6	66.1	242.46
7	71	242.23
8	80.7	241.85
9	91.6	240.91
10	97	240.53
11	112.2	239.62
12	128	238.96
13	142.6	238.52
14	158.9	238.2
15	174	237.93
16	189.8	237.73
17	204.4	237.84
18	220.7	237.93
19	235.9	237.93
20	251.6	237.9
21	277.1	237.58
22	297.7	237.38
23	313.5	237.3
24	318.3	237.41
25	328.1	237.68
26	338.9	237.93
27	344.4	237.97
28	359.5	238.46

Downstream Reach Lengths

LOB	Channel	ROB
432.233	432.233	432.233

Manning's n Values

LOB	Channel	ROB
0.036	0.04	0.04

Main Channel Bank Stations

Left Bank	Right Bank
0	472.4015

Cont\Exp Coefficient (Steady

Contraction	Expansion
0.1	0.3

Select river station for cross section editing.

Figure 5. Cross-section data editor of the upstream of Mosul site (Badush City).

2.3. River Reaches

The modeler can develop the geometric data in HEC-RAS software first drawing in the river system schematic. This is accomplished, on a reach-by-reach basis, by pressing the river reach and then drawing in a reach from upstream to downstream (in the positive flow direction), as shown in Fig. (6 and 7).

In some instances, it is required to complement cross-sectional data surveyed by interpolating additional sections between two cross-sectional areas. Typically needed when the change in velocity head is large. That required the first to select the cross-section left (east), and the right (west) cross-section, the number of the interpolation cross sections, and the interval across them. In the present study, the interpolation between cross-sections for the stretch of the Tigris River has been added by choosing the distance of 500 m between one cross-section and another. The unsteady state of flow data is then imported into the HEC-RAS as the required limit conditions. At that time, the HEC-RAS had obtained all the model needed to conduct the hydrodynamic modelling. The latest simulation process was to calculate the unsteady state flow model in the "Run" window.

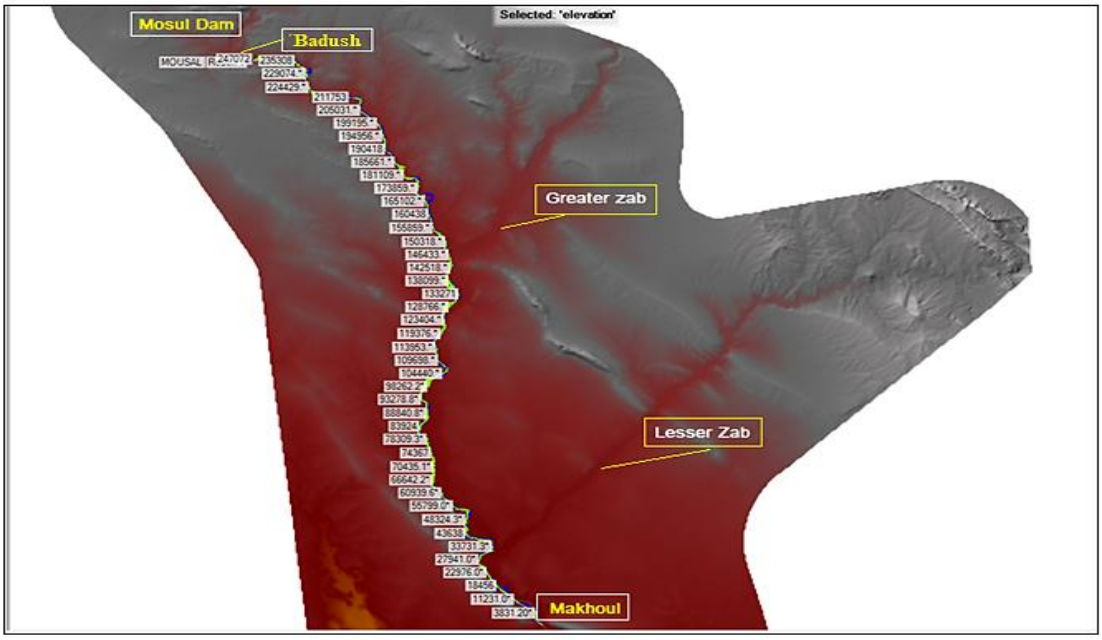

Figure 6. The stretch of Tigris River at Mosul site with the cross sections located between Badush and Makhoul City.

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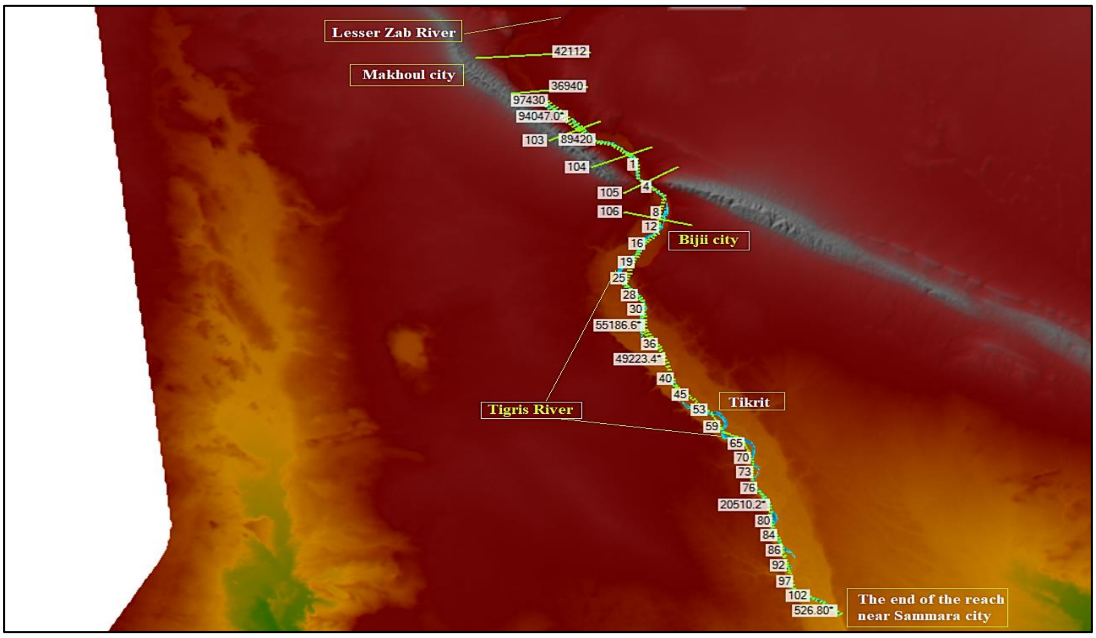

Figure 7. The stretch of Tigris River at Tikrit site with the cross sections located between Al-Fatha and Tikrit City.

2.4. Boundary Conditions

The data of the boundary conditions of the present study involve the daily discharge m^3/sec for upstream and the normal depth for downstream. The daily discharge m^3/sec was brought from the National Centre for Water Resources Management,2022, these hydrographs for the main sites of the Tigris River such as (Mosul and Tikrit sites) for the periods (March/2021 and August/2021) in the case of high and low water level condition (Figs. 8, 9,10, and 11). The boundary conditions on the downstream include normal depth equal to 0.005 m according to the previous studies [11].

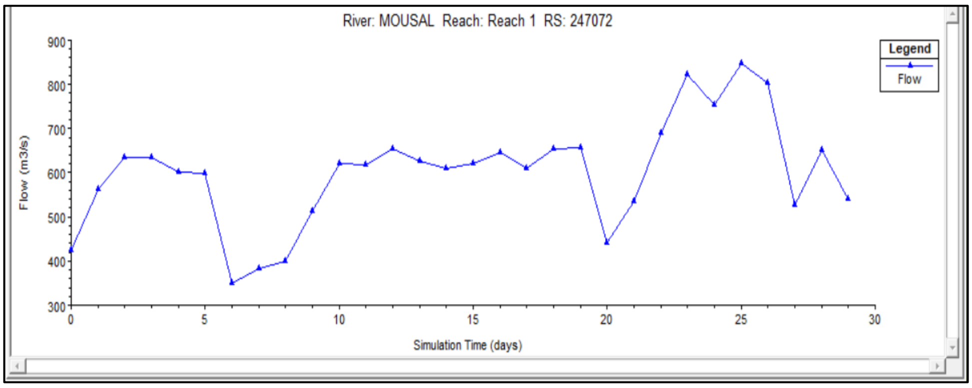

Figure 8. The flow hydrograph of the Tigris River at Mosul station (March,2021).

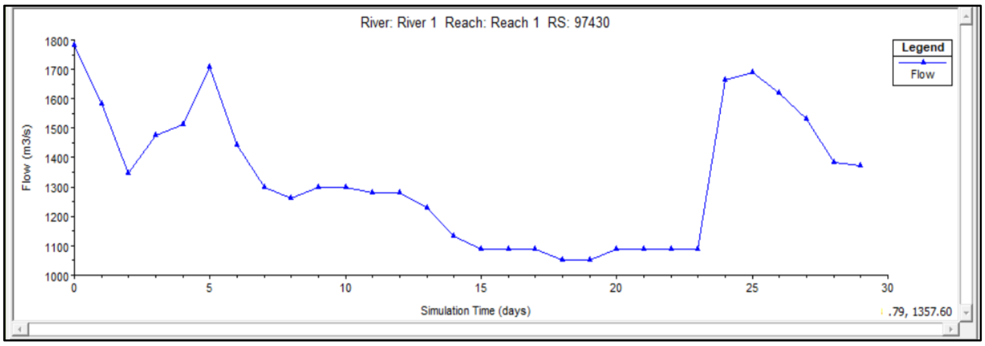

Figure 9. The flow hydrograph of the Tigris River at Tikrit station (March,2021).

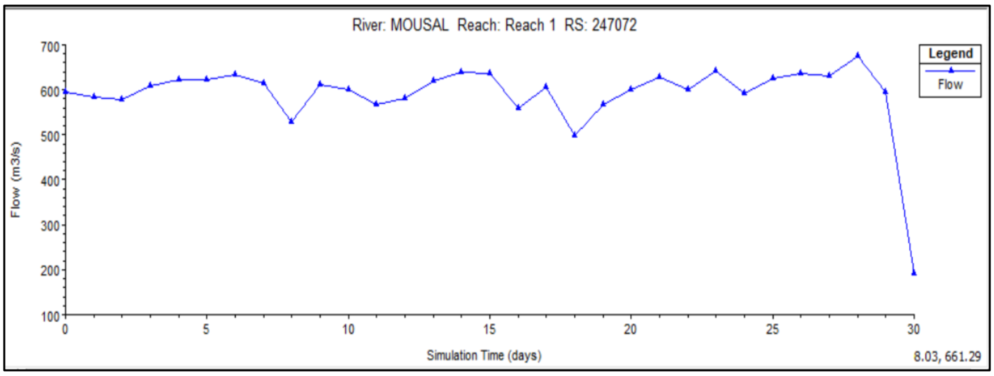

Figure 10. The flow hydrograph of the Tigris River at Mosul station (August,2021).

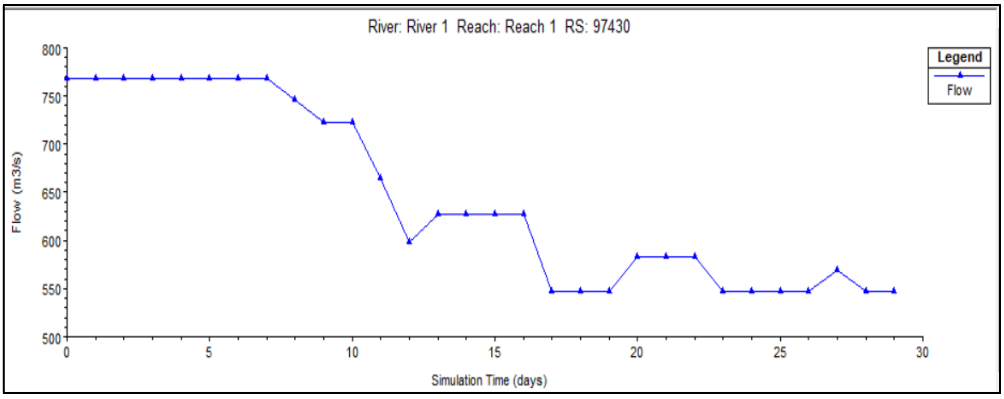

Figure 11. The flow hydrograph of the Tigris River at Tikrit station (August,2021).

2.5. Model Calibration, Verification, and Validation

Model calibration determines the right values of the model parameters by an iterative process of changing the values of model parameters and comparing the model results with the real system than improving the model until the accuracy is judged to be acceptable. Manning's roughness coefficient (n) was considered a calibration parameter for the hydraulic models. Manning's roughness coefficient (n) is a value to describe the resistance to flow due to channel roughness caused by sand or gravel bed, bank vegetation, and other obstructions [12].

One dimensional unsteady state flow HEC-RAS software was calibrated by using one set of observation flow data for the period (August/2021) for Mosul and Tikrit sites (Table 2). The Root Mean Square Error RMSE, MAE, and Nash-Sutcliffe Efficiency Criteria NSE, tests were used for calibrating the unsteady state flow model. These parameters served as a comparison of calculated water levels by the model for each of the Manning index values 'n' with the observed water levels as a function [13].

The Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency Criteria (NSE), and Mean Absolute Error (MAE) which are defined as equations used as assessment criteria to compare the simulated flow and the observed flow at the study stage [14], which applied to simulate the HEC-RAS model in this study, which is the most widely used objective function [15]. For Mosul site, the calibration of the water level of Tigris River showed that the best fit of Manning values 'n' varied between 0.032 to 0.042, and the best fit was 0.036 (Fig.12). As for the Tikrit site, Manning's 'n' values ranged between 0.024-0.032 and the best fit was 0.026 (Fig.13).

Table 2. The observed data of Tigris River flow (m3/sec) and water levels (m.a.s.l), [11].

TIME (day)	Mosul		Tikrit	
	Flow m^3/s	Water Surface Elevation m	Flow m^3/s	Water Surface Elevation m
1	594	240.3	768	103.29
2	584	240.15	768	103.29
3	579	240.1	768	103.29

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TIME (day)	Mosul		Tikrit	
	Flow m³/s	**Water Surface Elevation m**	**Flow m³/s**	**Water Surface Elevation m**
4	610	240.1	768	103.29
5	623	240.1	768	103.29
6	622	240.2	768	103.29
7	633	240.2	768	103.29
8	615	240.2	768	103.29
9	529	240.2	746	103.26
10	611	240	723	103.23
11	600	240.1	723	103.23
12	567	240.1	664	103.15
13	581	240	598	103.06
14	621	240.1	627	103.1
15	639	240.1	627	103.1
16	636	240.1	627	103.1
17	559	240.2	627	103.1
18	606	240	547	102.99
19	499	240	547	102.99
20	566	240	547	102.99
21	601	240	583	103.04
22	627	240.1	583	103
23	600	240.2	583	103

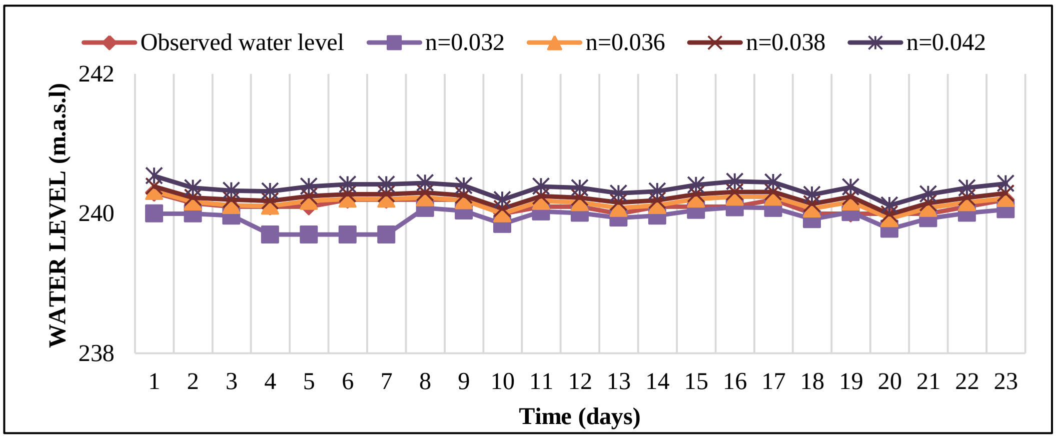

Figure 12. Computed and observed discharge for Tigris River at Mosul site, (August, 2021).

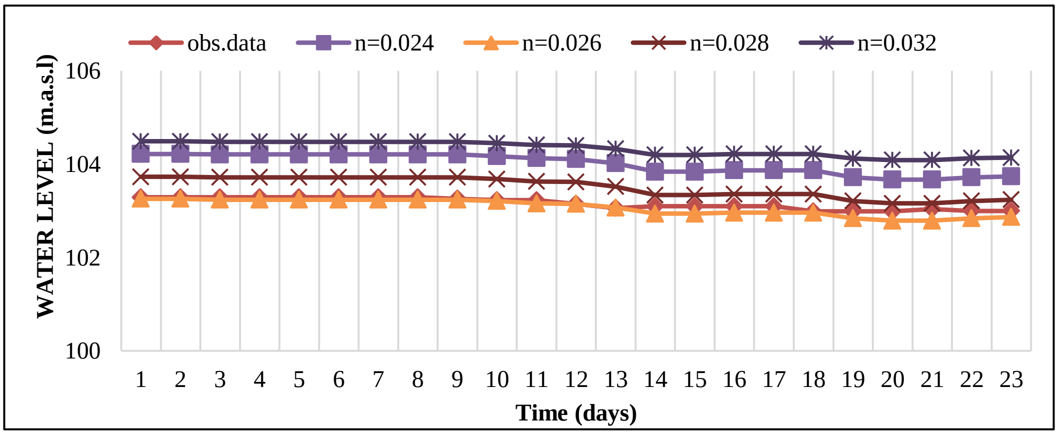

Figure 13. Computed and observed water level (m.a.s.l) for Tigris River at Tikrit site, (August, 2021).

Then, these initial values were modified during the calibration process until a good simulation have occurred between the simulated stage levels and the levels measured stages at the sections of Tigris as shown in Table (3).

Table 3. A Summary of Statistical test of the calibration results for the Tigris River cross-section.

The values of 'n'	R.M.S.E. values	NSE values	MAE values
	Mosul site		
n=0.032	0.224	-5.989	0.01
n=0.036 (Best fit)	0.205	0.323	0
n=0.038	0.242	-1.323	0
n=0.042	0.348	-8.634	0.01
	Tikrit site		
n=0.024	0.854	-49.5	0.847
n=0.026 (Best fit)	0.111	0.152	0.087
n=0.028	0.366	-8.295	0.349
n=0.032	1.171	-94.028	1.17

3. Results and Discussion

3.1. Water Depth Maps of Tigris River

From HEC-RAS software outputs during (August/2021), found that the water depth (m) along Tigris River in the study area ranges between (0-8.2) and (0-6.8) m at Mosul and Tikrit respectively. The water depth varies along Tigris River stretch in the area due to the topography of the area along the river. The water depth at the period (March/2021), found that the water depth (m) along Tigris River ranged between (0-9.6 m) and (0-10.3 m) at Mosul and Tikrit respectively.

3.2. Velocity Maps of Tigris River

The velocity of Tigris River for the period (Augest/2021) varied between (0-1.60) and (0-2.0) m/sec at Mosul and Tikrit respectively (Figs. 14 and 15). Wheres, the velocity of Tigris River for the period (March/2021), varied between (0-2) and (0-3) m/sec at Mosul and Tikrit respectively.

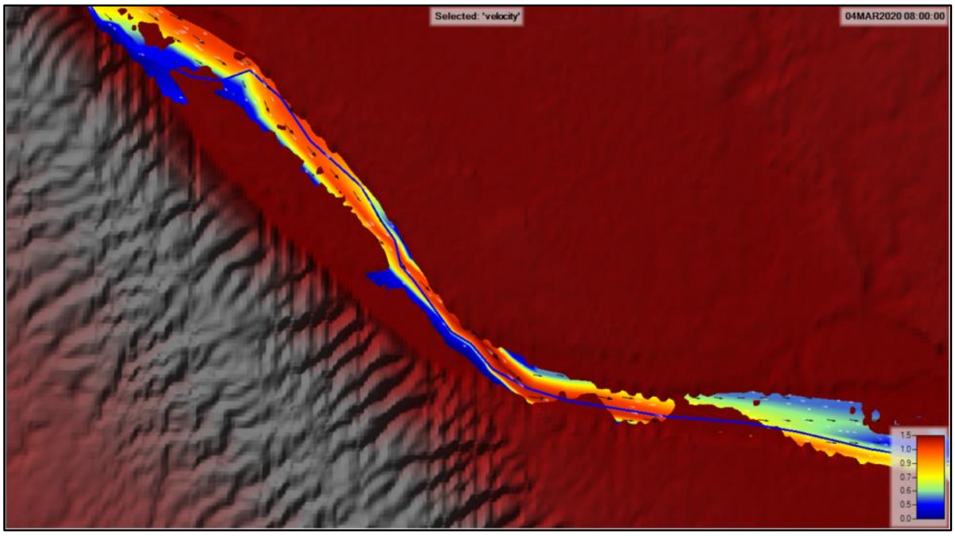

Figure 14. Velocity map at peak flow for Mosul site (August /2021).

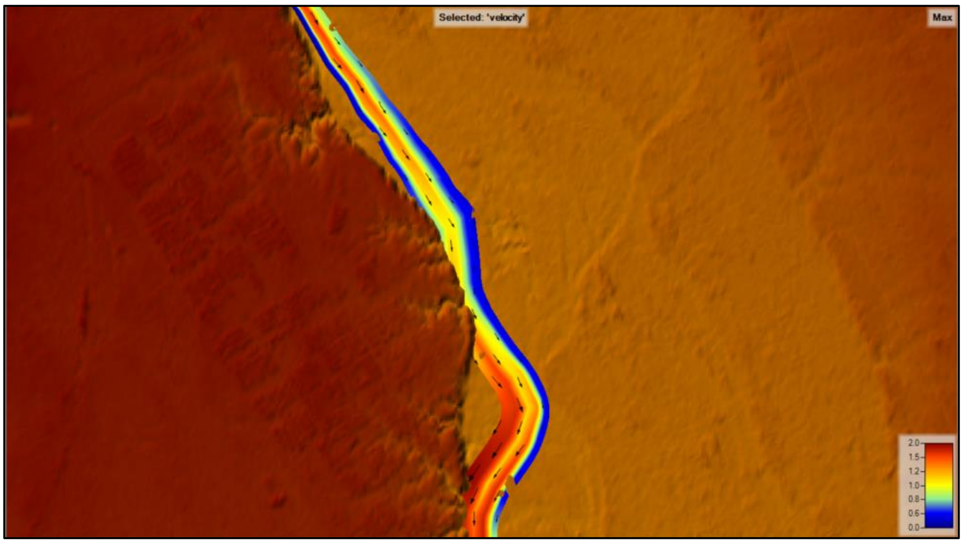

Figure 15. Velocity map at peak flow for Tikrit site (August /2021).

3.3. Water Surface Elevation Profile of Tigris River

The water level for Tigris River during the period (August/2021) for Mosul site were 240.38 and 111.49 m.a.s.l in the U/S and D/S respectively (Fig. 16).

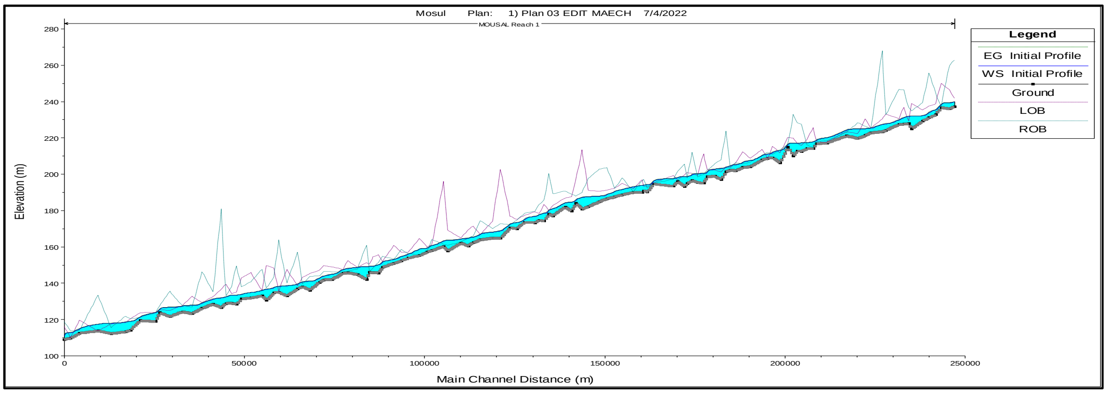

Figure 16. Water surface profile at peak flow at Mosul site (August/2021).

For Tikrit, the water level were 121.05 and 77.07 m.a.s.l in the U/S and D/S respectively (Fig. 17). While, the water level for Tigris River during the period (March/2021) for Mosul site were 240.73 and 111.83 m.a.s.l in the U/S and D/S respectively. For Tikrit, the water levels were 122.14 and 78.26 m.a.s.l in the U/S and D/S respectively.

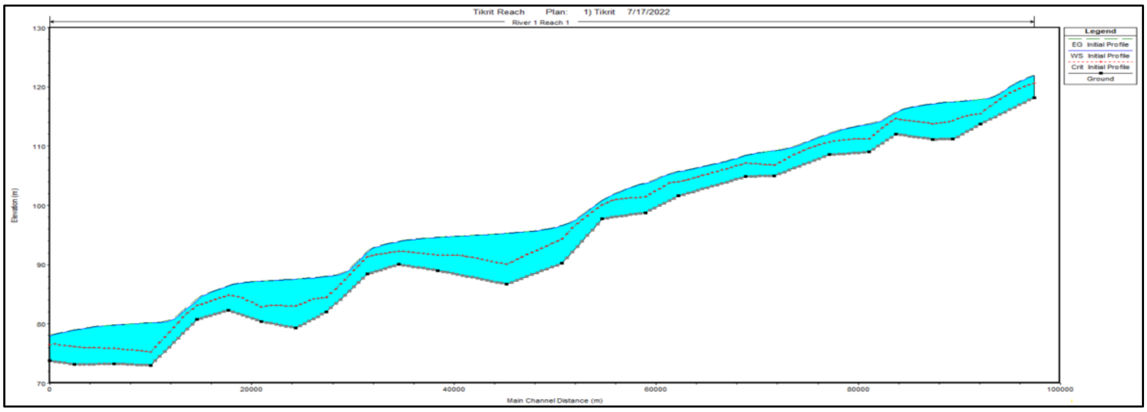

Figure 17. Water surface profile at peak flow at Tikrit site (August /2021).

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3.4. Proposed Best Location of Dam site on Tigris River

It is very important to propose the best location for the dam on the studied stretch of Tigris River. The best-suggested location lies between Makhoul and Al-Fatha (Fig. 18). This area on the left bank (east) of the river was established to be more exposed to flooding comparative to the right bank which shows the demand construct of hydraulic structures such as a dam with a reservoir beside this area to operate water stations and electric turbinate's and other projects built next to the river, such as irrigation projects.

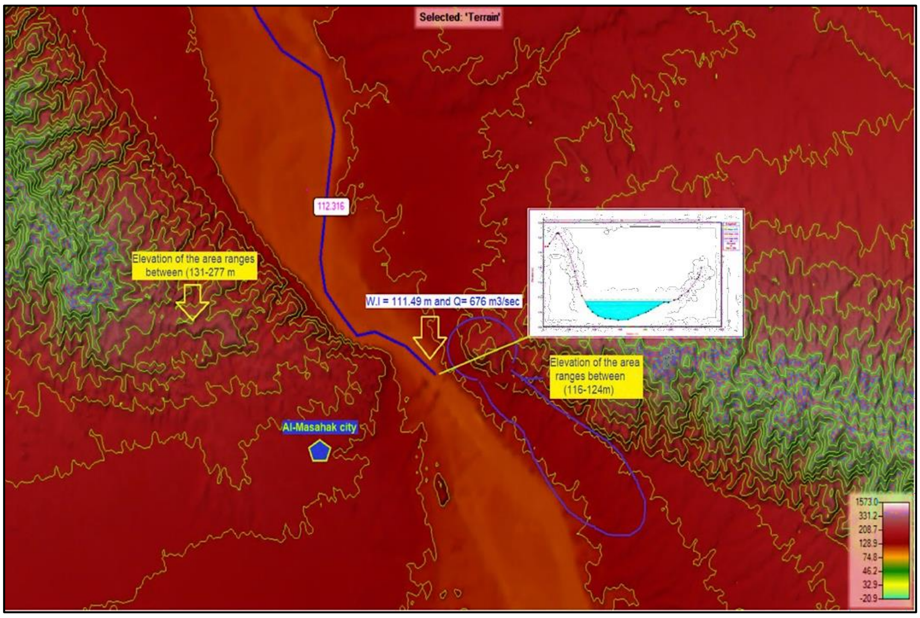

Figure 18. Select a location of dam between Makhoul and Al-Fatha.

Conclusions

The HEC-RAS software V.5.0.7 provides the water profile for the case of unsteady flow. This profile will facilitate adopting the appropriate control to ensure a reasonable level of water regarding the discharge that comes behind the Mosul dam upstream of the river. Water surface modelling using HEC-RAS 5.0.7 is an effective tool for hydraulic study and handling of river water management. The final Manning's roughness coefficients (n) of the main channels for the Mosul and Tikrit sites were 0.036 and 0.026 respectively. Through many trial runs of the HEC-RAS simulation model, it was found that the differences between observed and computed water surface profiles of Tigris River can be decreased if the reach of the river is separated into multi parts having different values of Manning's 'n' coefficient, for this reason, Tigris River was separate for four main sites. The Root Mean Square Error RMSE, MAE, and Nash-Sutcliffe Efficiency Criteria NSE, tests were used for calibrating the unsteady state flow model where it served as a comparison of calculated water levels by the model for each of the Manning index values 'n' with the observed water levels as a function. The simulation of the present study can be used in the future to study the effect of constructing a dam in the Tikrit region. The simulation under study can be used in the future to study the TDS, transportation of sediment loads, or pollution along the river.

Acknowledgements

The authors would like to thank Directorate of National centre of water resources management in Baghdad for their support and providing the data of the discharge (m^3\sec) and water level (m.a.s.l) of the Tigris River.

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