2D-Unsteady Flow within a Reach in Tigris River

Thair Sh. Kayyun, Dheyaa H. Dagher

Abstract— The use of mathematical models to solve the problems of the flow in natural channels needs to understand many characteristics of hydraulic flow as well as the design and evaluation of engineering projects and to predict the dangers of natural accidents so that it is possible to give warnings in advance .The length of reach study was (19.5 Km) lies in Northern of Tigris River between Al-Muthana Bridge and Sarai gauging station in Baghdad city in Iraq**.** An unsteady two-dimensional mathematical model for simulating the flow of the studied reach was implemented and run by using the HEC-RAS (Version (5.03) software, and making use of recorded field measurements for running and carrying out the calibration and verification processes , In this study presented a new model for 2D unsteady flow and calculating (velocity and water surface elevation) for the flooding scenarios of flow rate (3050 m^3/sec). the maximum and minimum velocities which are equal from 1.84 to 4 m/s .The maximum and minimum water surface elevations were recorded (37 and 35 m.a.s.l) ,respectively.

Keywords — mathematical models, Tigris River, HEC-RAS (Version (5.03), 2D unsteady flow.

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1 INTRODUCTION

The increasing need for limited water resources and the urgent need to maintain the quality of water suitable for other human uses necessitate the use of advanced technical methods to predict them. These methods are essential in the planning, design and management of water resources. The intense human interest in water flow control in rivers results of the urgent need to protect human life and physical resources and economic establishments from the dangers of natural flood accidents and the investment of energy resulting from these resources in the fields of agriculture, navigation and others, [8].The Tigris River is one of the most important rivers in the Middle East. It rises from the Taurus Mountain range in the south-eastern part of Turkey and flows towards the southeast for 1580 km, passing through Turkish-Syrian borders and entering Iraq. In Iraq, it flows towards the south until it combines with the Euphrates River at Qurnah, forming the Shatt Al-Arab River. This river discharges its water into the Arabian Gulf. Within Baghdad City, the capital of Iraq, the Tigris River bisects Baghdad into two parts for a distance of about 50 km within the urban zone starting. The first reach of the Tigris river (19.5 Km length) lies at Northern reach of Tigris river between Al- Muthana Bridge and Sarai gauging station .The second part ending at the confluence with the Diyala River to the south, [1].

2 STUDY AREA

The selected reach of the Tigris river (19.5 Km length) lies at Northern reach of Tigris river between Al- Muthana bridge and Sarai gauging station in Baghdad city in Iraq Figure 1: A and B) . This area was selected because it has no tributaries and the other reason there are a few structures that intersects with the selected reach.

2 THEORITICAL BASIS

3.1 Equations of 2D-Unstedy Flow Model

HEC-RAS will combine continuity and the Diffusion-Wave form of the momentum equation to compute the water surface elevation at a point in time, i.e. WSEL. The unsteady differential form of the Mass Conservation (Continuity) equation is:

$$\frac{\partial H}{\partial t}+\frac{\partial (uh)}{\partial x}+\frac{\partial (vh)}{\partial y}+q=0 \qquad (1)$$

Where t is time, H is a water surface elevation, h is the water depth, q is a source or sink term, and u and v are the velocity components in the X and Y direction. In vector form,

$$\frac{\partial H}{\partial t}+\nabla.hV+\frac{\partial (vh)}{\partial y}+q=0 \qquad (2)$$

Where V= (u, v) is the velocity and (∇) is the vector of the partial derivative given by

$$\nabla=(\frac{\partial}{\partial x},\frac{\partial}{\partial y})$$

The Diffusion-Wave form of the Momentum Equation can jest regarded the barotropic pressure gradient and bottom friction.

$$-g\nabla H=C_f V \qquad (3)$$

Where g is gravity acceleration and C_f is the bottom friction. HEC-RAS use Manning's formula, the Diffusion-Wave Equation results:

$$-g\nabla H=\left(\frac{n^2\, g|V|}{R^{\frac{4}{3}}}\right)V \qquad (4)$$

Where n is the Manning's Roughness Coefficient and R is Hydraulic Radius. The velocity will have determined by a balance between barotropic pressure gradient and bottom friction.

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$$V = -\frac{(R(H))^{\frac{2}{3}}}{n}\,\frac{\nabla H}{(\nabla H)^{\frac{1}{2}}} \qquad (5)$$

Now, the Diffusion Wave can be direct substitution in the Mass Conservation, [2].

$$\frac{\partial H}{\partial t} - \nabla\left(\frac{(R(H))^{\frac{2}{3}}}{n(\nabla H)^{\frac{1}{2}}}\right)\nabla H + q = 0 \quad (6)$$

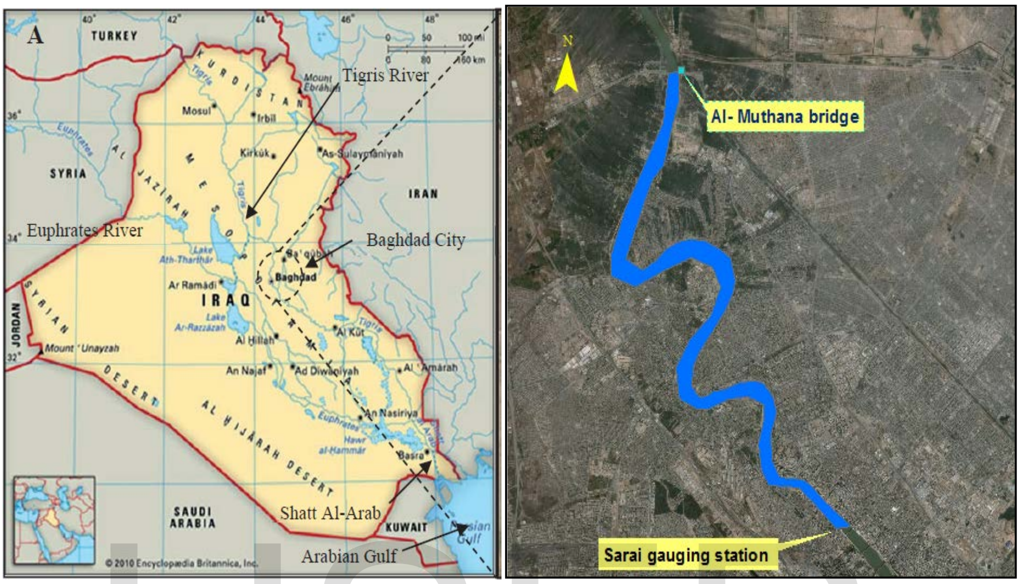

Fig. 1. (A) Map of Iraq (B) Satellite imagery showes The Tigris River between Al- Muthana bridge and Sarai gauging station at Baghdad city,(Google earth program,2017)

3.2 Evaluation of HEC-RAS model Performance

Three statistical criteria were used to assess the performance of the HEC-RAS model ie

1-Coefficient of determination (R^2): describes the proportion of the variance in measured data explained by the model. R2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable [9].

$$R^2 = \frac{\sum_{i=1}^{n}(X_{obs} - \bar{X}_{obs})(X_{obs} - \bar{X}_{sim})^2}{\sum_{i=1}^{n}(X_{obs} - \bar{X}_{obs})^2 \sum_{i=1}^{n}(X_{obs} - \bar{X}_{sim})^2} \quad (7)$$

2-Nash-Sutcliffe efficiency (NSE): The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance [8]. NSE indicates NSE ranges between $-\infty$and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. How well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation (8):

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(X_{obs} - X_{sim})^2}{\sum_{i=1}^{n}(X_{obs} - \bar{X}_{obs})^2} \qquad (8)$$

3-RMSE- the root mean standard error: RMSE is one of the commonly used error index statistics [3]. published a guideline to qualify what is considered a low RMSE based on the observations standard deviation. Based on the recommendation by [10] a model evaluation statistic, named the RMSE-observations standard deviation ratio (RSR), was developed. RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information recommended by [7]. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation (3):

$$\text{RSR} = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs} - X_{sim})^2}{\sum_{i=1}^{n}(X_{obs} - \bar{X}_{obs})^2}} \quad (9)$$

Where X_{obs}=the observed value variable.

X_{sim}=the simulated value variable.

$\bar{X}_{obs}$ = mean of the simulated values variable.

4 METHODOLOGY AND DATA REQUIREMENT

HEC has added the ability to perform two-dimensional (2D) hydrodynamic routing within the unsteady flow analysis portion of HEC-RAS 2D flow modeling is accomplished by adding 2D flow area elements into the model in the same manner as adding a storage area. A 2D flow area is added by drawing a 2D flow area polygon; developing the 2D computational mesh; then linking the 2D flow areas to 1D model elements and/or directly connecting boundary conditions to the 2D areas. The digital elevation model must be converted to Terrain layer by the Arc GIS program, where the digital elevation model can be loaded from the site (www.eorc. JAXA .ip) with cell size (12.5*12.5) and pixel depth (16 bit). The Figure 3 shows the digital elevation model in Arc GIS program Then the Figure 4 shows Terrain layer within HEC-RAS model.The HEC-RAS terminology for describing the computational mesh for 2D modeling begins with the 2D flow area. The 2D flow area defines the boundary for which 2D computations will occur. A computational mesh (or computational grid) is created within the 2D flow area. In this study that selected boundaries located at the distance are ranging between (3000 - 4000) m from the left and right bank of the Tigris river. Figure 5 shows the boundaries of 2D flow. The mesh of the reach contains 86951 cells, the area of maximum cell is equal 2327.47m^2, area of minimum cell is 726 (m^2), and average cell area is (903.04 m^2). Additionally, One of the important boundary condition for upstream for developing the unsteady flow that be needed for generating the 2D flow modeling is the flow hydrograph , Since the two-dimensional model is a model for the flood that occurs to the rivers, so the maximum flood case was taken by the Tigris River in 26/4/1988, which is 3050 and water surface elevation 35 (m.a.s.l) so will use this flow rate as a peak discharge. , minimum discharge is 461 m3/sec and then the program can be interpolated the other values of the hydrograph , the base time of the hydrograph were taken as 24 hours , Figure 6 shows the flow hydrograph as a boundary condition for the upstream the Tigris Rive reach which is used in two-dimensional unsteady flow model .

5 RESULTS AND DISCUSSION

5.1 Calibration of HEC-RAS model for n Manning Roughness Coefficient

The effect of the increase in the flow rate effected on the roughness coefficient highlights by drawing the rating curve. For the natural river is curved distinct and increasing rapidly to the top in low discharges and be less steeper in the medium and high discharges and hence the development reduces the speed and increases attributed to the same discharge shall be in favor of river navigation, but in the same time is not in favor of high pass discharges for example a cross section for sarai station the water level in the drought 1930 equal 27.95 rose in flooding of May 1950 to 35.72 where the difference 7.79 m, The Calibration process was achieved by using the recorded data during the period from 1976 to 1980 at Sarai station, Table 1 shows the measured water surface elevation relative to flow rate conducted by [6] where used in The Calibration process for a range of river discharges started from 250 to 1815m3/s , with increment interval of 200 m3/s. A comparison between the measured by [6] and model predicted rating curves showed that the roughness coefficient where equal (0.02, 0.0225, 0.027 and 0.03) for the main channel and 0.038 to 0.042 for the left and right banks is shown in Figure 7. Obviously, the Figure 7 shows that the value (0.027) closest to the measured rating curve of the Tigris River.Table 2 shows the values of (R2), NSE and RSR .The roughness coefficient where equal(0.027) for the main channel and 0.041 for the left and right banks which record a good accuracy ,therefore can be used this value in the HEC-RAS model.

5.2 Results of the 2-D Unsteady Flow Model

The verification of 2-D unsteady flow can be used any records of flooding wave for Tigris river during the period (1930- 2004), [4]. Therefore, Figure 8 shows the hydrograph of flooding in for the period from 23/2/ 1977 to 31/3/ 1977, where the peak flow was 1625 m3/sec, and the base time of the hydrograph equal 900 hours. The benefit from this hydrograph is to verify the results of the 2-D unsteady flow model. Model verification is an important part of understanding the accuracy and uncertainty of the model. The 2-D unsteady flow model will be verify by comparison the results calculated by the HEC-RAS program with respect to observed water surface elevation as shown in the Figure 8 .The determination coefficient (R2) is equal to 0.928, and the NSE and RSR values are equal to 0.63 and 0.29, respectively.After a successful HEC-RAS model run, there will be three results layers called velocity, and water surface elevation. These layers can be used to visualize the model results in an inundation mapping form (e.g. two-dimensional map of the geometry, with water and other layers on top of it. Figures 9 and 10 show the results of the 2D model of velocity and water surface elevation for a peak flow (Q = 3050 m^3/sec) for Tigris River reach, respectively. The two maps of 2D model in which can be exported to Arc-Gis (10.4.1) program to increase the degree of resolution of this map like the colour of the legend for the model. Additionally, 2D model results in the form of a longitudinal profile plots and tables are available. For each 2D Flow Area “Mesh”, longitudinal profile plots are available for water surface elevation and Velocity. In Figure 9 shows the maximum and minimum velocities which are equal to (1.84 to 4 m/s), Figure 10 shows maximum and minimum water surface elevations were recorded (37 and 35 m.a.s.l) ,respectively .The predicted water surface elevation for Sarai gauging station which is equal 35 (m.a.s.l) in which is acceptable with the measured water surface elevation which is equal to 35.05(m.a.s.l) for peak flow at year 1988 . The average velocities is equal to 2.4 m/s, this value is acceptable with The measurements of the velocity that were conducted by **[6]** at the Sarai gauging station which was ranging between 1.2 to 2.4 m/s for flow rate (2500) m^3/sec .The water surface elevation is dropped rapidly approach near the downstream because the high energy slope which is equal 10 cm /km .

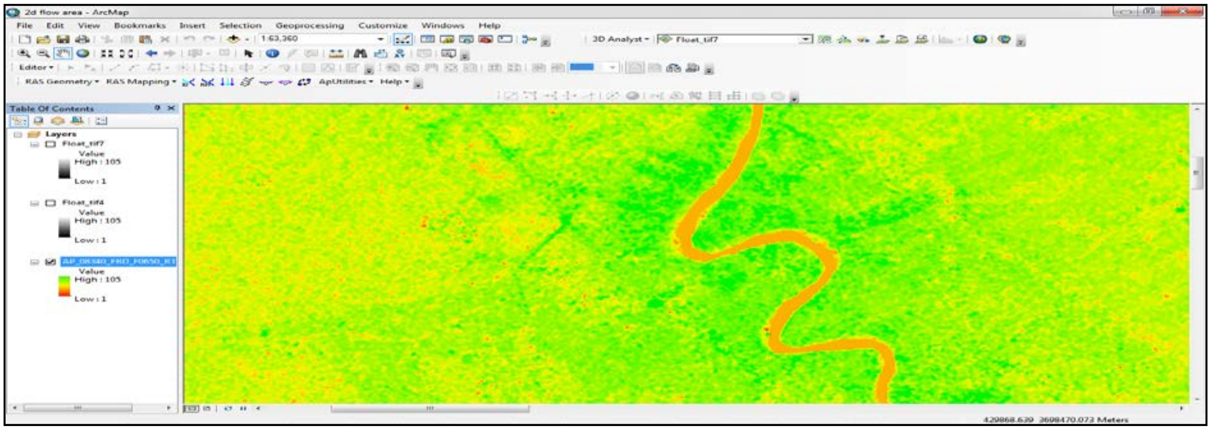

Fig. 2. The digital elevation model in Arc GIS program

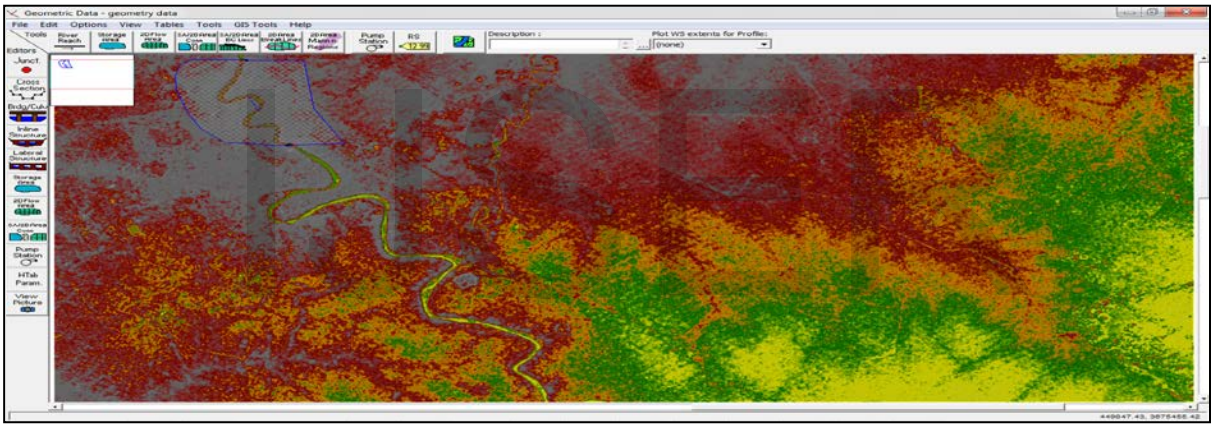

Fig 4: RAS Mapper with a Terrain Data Layer added

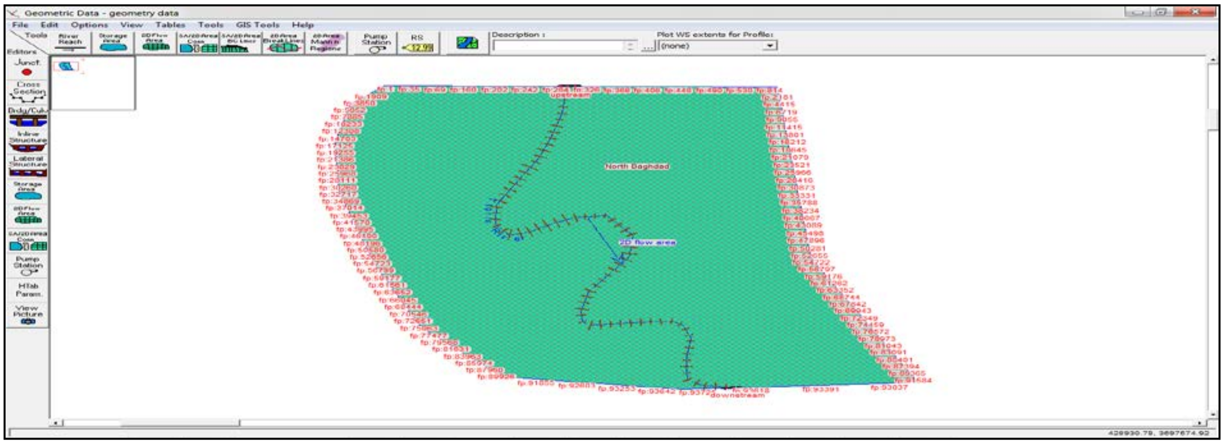

Fig 5: 2D flow area boundaries locate between (3000 -4000) m from the left and right bank of the Tigris River.

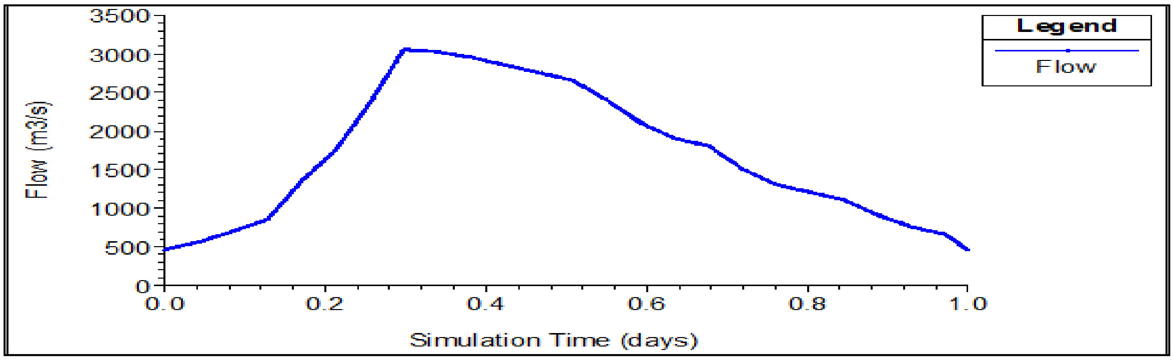

Fig 6: The flow hydrograph of the unsteady for peak flow rate 3050 m^3/sec (HEC-RAS Model)

Table 1: The measured stage relative to flow rate conducted by (Geohydraulique, 1980)

NO.	Discharge m^3/s	Stage (m.a.s.l)
1	250	27.00
2	425	28.00
3	625	29.00
4	925	30.00
5	1225	31.00
6	1500	32.00
7	1825	33.00

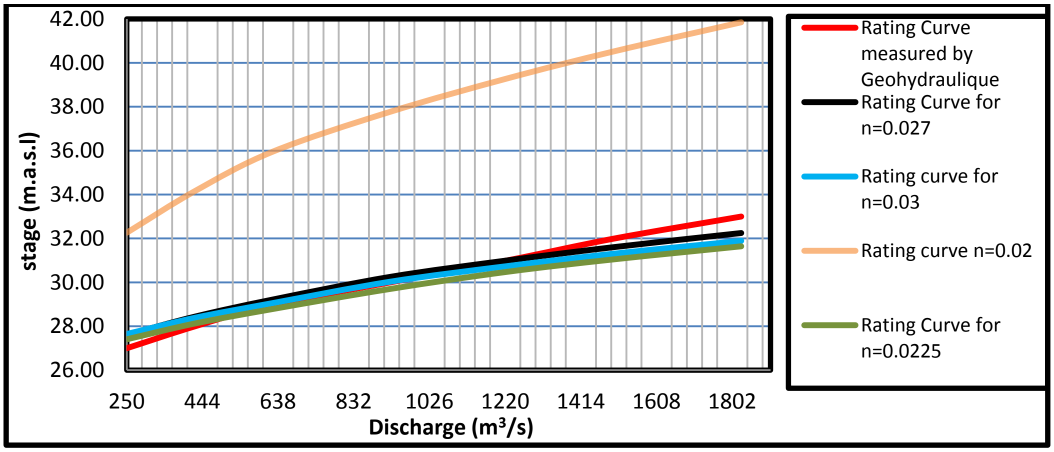

Fig 7: Calibration process for n values by HEC-RAS model

Table 2: The values of (R^2), NSE, and RSR for The roughness coefficient

	n=0.02	n=0.0225	n=0.027	n=0.03
R^2	0.9932	0.9939	0.9942	0.994
NSE	13	0.72	0.95	0.92
RSR	0.375	0.052	0.2	0.29

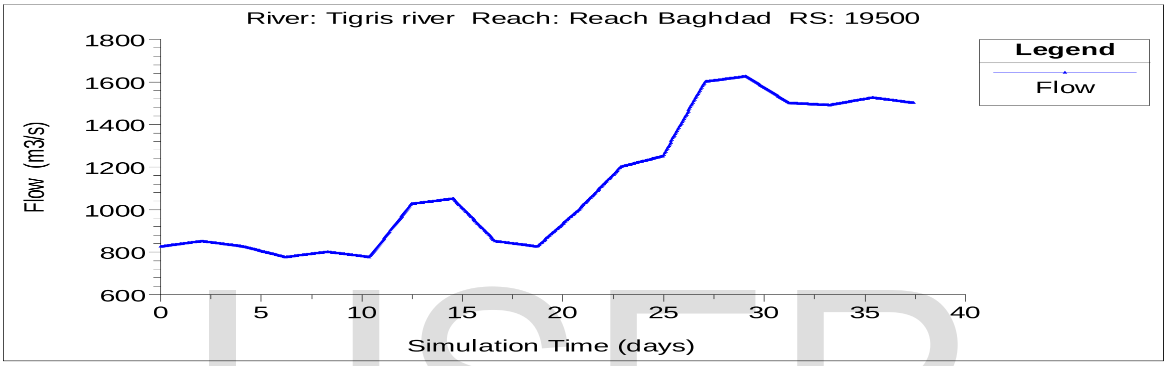

Fig 8: The hydrograph of flooding for the period from 23/2/ 1977 to 31/3/ 1977.

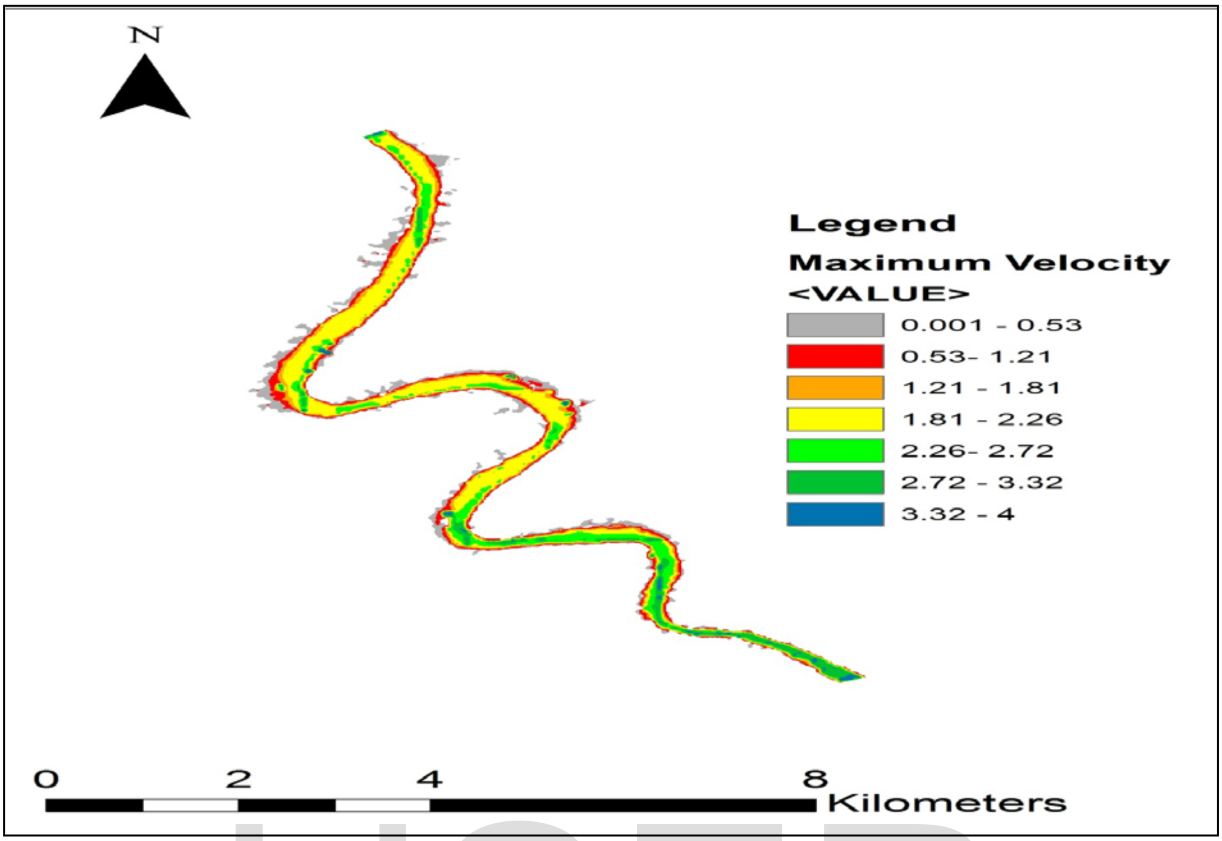

Fig 9: 2D model of velocity for peak flow (Q = 3050 m^3/sec) in Tigris River reach

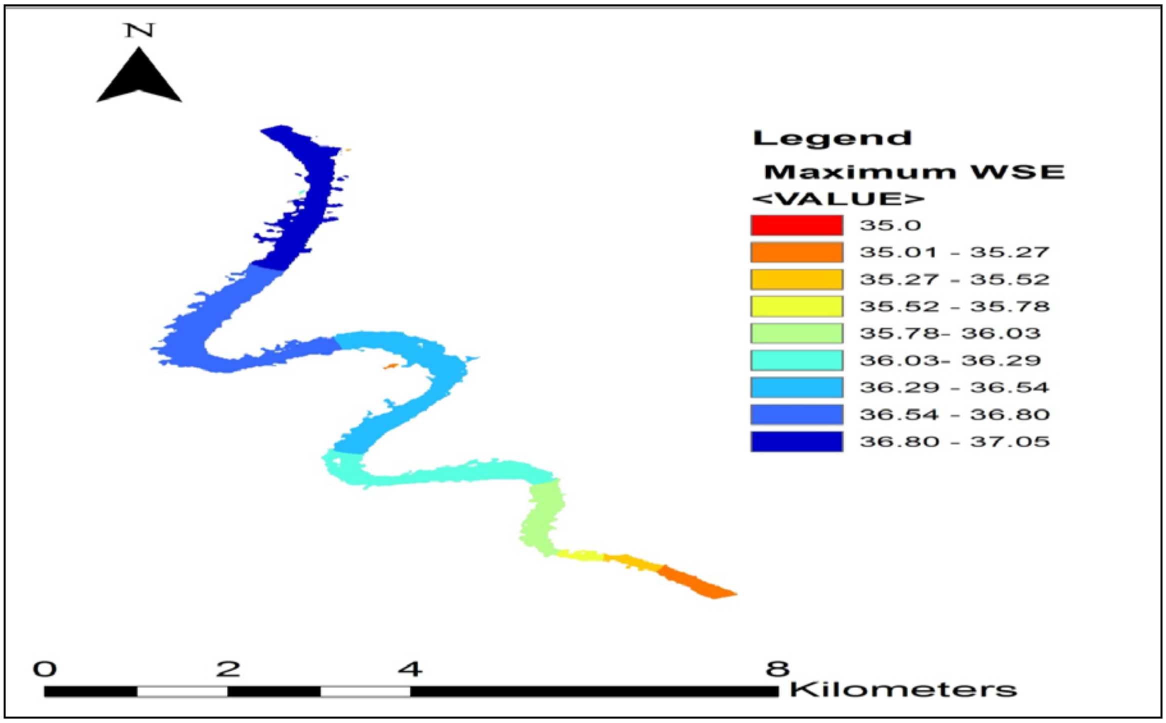

Fig 10: 2D- model of water surface elevation for peak flow (Q = 3050 m^3/sec) in Tigris River reach

5 CONCLUSIONS

The results of analysis of the 2-D Unsteady Flow Model of the Tigris River led to following conclusions:
1-In this study presented a new model for 2D unsteady flow and calculating (velocity and water surface elevation) corresponding to flooding scenario for peak flow rate is equal (3050 m3/s). Maximum and minimum water surface elevations were recorded (37 and 35 m.a.s.l), respectively.
2- The predicted water surface elevation for Sarai gauging station which is equal 35 (m.a.s.l) in which is acceptable with the measured water surface elevation which is equal to 35.05(m.a.s.l) for peak flow at year 1988.
3-The average velocities is equal to 2.4 m/s, this value is acceptable with The measurements of the velocity that were conducted by [6] at the Sarai gauging station which was ranging between 1.2 to 2.4 m/s for flow rate (2500) m3/sec .

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