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Sensitivity of Water Surface Elevation Level in the Tigris River within Baghdad city to the Changes in the Value of Manning's Roughness Coefficient

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Abstract: ***Evaluating the factors affecting the flow properties of the Tigris River is one of the important studies due to the importance of this river to the city of Baghdad. One of the most important factors affecting the properties of the flow is the Manning's roughness coefficient (n). Precise estimation of the value of this parameter for natural rivers is a challenge due to the large number of factors affecting it. This study demonstrates the impact of the changes in the value of this parameter on water surface elevations of Tigris River within Baghdad city. To understand how the changes in this parameter affects the water surface elevations, different scenarios of Manning's n and discharge values were adopted. The range values for Manning coefficient and discharges were (0.025, 0.03, 0.035, 0.04, 0.045) and (500, 1000, 1500, 2000, 2500, 3000 m^3sec^{-1}) respectively. The program HEC-RAS version 4.1 was used in this study and the case of steady –uniform flow was assumed to run it. The results show clearly the effect of changing Manning's n on water surface elevations also It had been seen that the value of n equal to 0.025 and to some degree 0.03 is the most safe and suitable value for Tigris river within Baghdad depending on the adopted flow values in the study.***

Keywords: Tigris river, Manning equation, water surface elevation

1. Introduction

The capital city of Iraq (Baghdad) is divided by Tigris river into two main districts (Al Karkh and Al Rusafa) from the north to the southeast for a distance of 60 km, about 50 km of which are located within the urban areas, and the rest is in rural parts (figure 1). Tigris river reach within Baghdad has compound meanders, single channel and alluvial plain characteristics [1]. River’s banks of the northern part and 49% of the southern part are protected by stones and cement mortar. Numerous bridges (Thirteen) have been installed along the reach [2]. During the last decades, water flow of the river entering Iraq was decreased dramatically due to the huge dams and water project constructed across the river and it’s tributaries in Turkey and Iran [3, 4]; and it is dropped from 927 m^3 sec^{-1} as the average monthly discharge (1960-1999) to about 520 m^3 sec^{-1} (2000-2012) [1]. Nevertheless, a flooding wave of 3000 m^3 sec^{-1} has been registered at the end of 2012. Figure (2) shows the discharge of Tigris river during the years 2000-2010, while figure (3) demonstrates the average monthly discharges recorded at Al-Sarai Baghdad station for the period 1960-2012.

In the last period, three surveys were conducted for Tigris river, the first one had been conducted in 1976 by Geohydraulique [5], the second survey in 1991 by the University of Technology [6], and the third one in 2008 by Iraqi Ministry Of Water Resources [7]. The surveys first and second surveys (1976 and 1991) were focused on the improvement of the river’s flooding capacity and to prevent possible collapses of its banks due to the erosions caused by large flows. As a result, to maintain the cross sections of the river banks during floods a bank protection have been suggested by the former survey andthe later survey recommended the protections details of the banks that were not protected during the first survey [1]. The survey of 2008 showed significant changes in the geometry of Tigris river, as well as significant reduction in it’s flooding capacity. Moreover, the average slope of the bed of the Tigris river within Baghdad became higher (5 cm km^{-1}) in 2008 compared to previous surveys (1.03 cm km^{-1}) and (2.45 cm km^{-1}) conducted in 1976 and 1991 respectively.

The status quo of the Tigris river within Baghdad is characterized by the growing of islands, side and point bars along its path and growing of reed and other types of plants which affects the banks stabilityat some locations due to deep eroding [4].All these obstacles and other problems will affect the hydraulic properties of the river flow because; the changes in the river cross-section,and the changes in the properties of bed and banks will cause changing in the roughness coefficient n that is used in the calculation of flow in natural streams.

The value of n is highly variable and depends on a number of factors including: surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal change; temperature; and suspended material and bedload. When calculating the flow in natural streams, the uniform-flow condition is frequently assumed, and despite this deviation from the real situationthe obtained results are satisfied and provide a suitable solution to many practical problems [8]. Sometimes, natural conditions of the rivers could deviate the assumption of uniform flow significantly from the reality and this needs to be estimated. Therefore, one should not look on a single cross-section, but rather on a stream reach [9].Then an appropriate selection of the value of Manning's n is very significant to the accuracy of the computation. Independently of the flow discharge and/or depth, Manning's n is often assumed to be a constant[10].The difficulty in estimating roughness coefficients have led to the development of several methods, including n-value tables, photographs for comparison, and equations. A direct estimation of Manning's n is a very difficult process when studying natural streams and most

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researchers use calibration when using computer programs to determine Manning's n value through a procedure of trial and error involving comparisons between field measurements and computations of stage and discharge. Typical values of n are 0.025, 0.022 to 0.033 and 0.06 for natural irrigation channels[11], earth channels[10]and for very poor condition streams [12] respectively. Past experience of flow in Iraqi natural rivers indicates that the value of Manning's n may vary between 0.025 and 0.033[13,14].A. A. Ali et. al., 2012[2] in their study on Tigris river within Baghdad, found by model calibration that values of Manning's n of 0.0285 for the main channel and 0.042 for the flood plains are suitable.

An accurate estimation of n value is essential when studying the river capacity and the potential risk of flood during its path within a city like Baghdad.

The aim of this study is to investigate the sensitivity of Tigris's water surface elevation to different values of Manning's roughness coefficient n using one-dimensional hydraulic model for steady flow "HEC-RAS" modeling and field data.

Figure 1 Tigris River within Baghdad city and the bridges locations (Google earth)

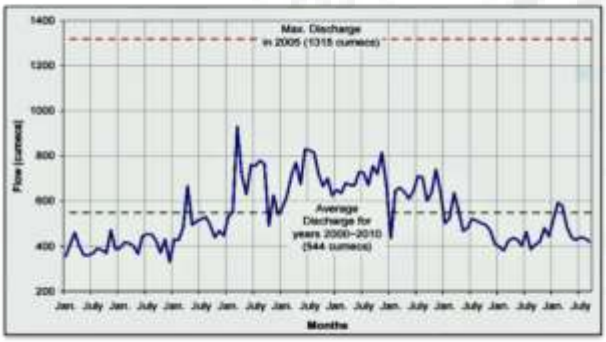

Figure 2: Recorded Tigris River flow at Sarai Baghdad station for the period 2000-2010. Data source: [4][2]

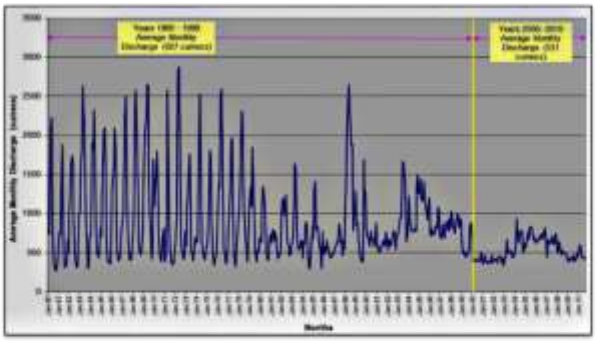

Figure 3: Recorded Tigris River flow at Sarai Baghdad station for the period 1960-2010.Datasource [4]

2. Methodology and Procedure

2.1 HEC-RAS Model

The Hydrologic Engineering Center River Analysis System model (HEC-RAS) was developed by U.S. Army Corp of Engineers in 1995 which is a part of the Institute for Water Resources (IWR). One-dimensional steady and unsteady flow river hydraulics calculations, sediment transport capacity, uniform flow computations, and water temperature analysis can be performed by researcher using this software [15,16]. The latest HEC-RAS version is available free-of-charge under a public domain license from the website of the U.S. Army Corps of Engineers. HEC-RAS requires several input data, the most significant are: channel geometry, past flow events, an estimate of channel roughness left side and right side bank elevation. The channel geometry which includes the profile of the river channel in the study reachis achieved by surveying the river's cross sections. Site specific features such as longitudinal uniformity of cross sectional shape, channel linearity, degree of channel meander, longitudinal slope and uniformity of slope throughout the study reach define the required number of the needed cross sections.

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2.2 Geometrical Data

In this study, the data from the last survey conducted by the Iraqi Ministry of Water Resources was used. The survey of the reach of the Tigris River covered about 49 km of its path, started from Al-Muthana Bridge, at intervals of 250m (totally 194 sections). The details of each section include, bed level, left and right banks levels and proposed Manning's n and other reaches information are the geometrical data which required to run the model. Figure (4) shows Tigris River bed(LOB and ROB) elevations. For the purpose of this study values of Manning's n (0.025, 0.03, 0.035, 0.04, 0.045) were used to observe the changes in water surface elevation level (WSELs) that will occur.

2.3 Boundary Conditions

One-dimensional simulation for a range of steady flows in Tigris River was performed to obtain the effects of the changes in the value of Manning's n and flow regime on the WSEL

Depending on the observations of Iraqi Ministry of Water Resources, the observed lowest discharge was 400 m^3sec^{-1}; on the other hand a flood wave of 3000 m^3sec^{-1} was passed at the end of 2012 through the river inside Baghdad. For the purpose of this study, flows of 500, 1500, 2000, 2500 and 3000 m^3 sec^{-1} were used. A steady and uniform flow were assumed, normal flow type, therefore boundary condition is only necessary at the down- stream end of the river system. To run the model, a range of flow values from 500 to 3000 m^3sec^{-1} were adopted as the upstream boundary and the used normal flow slope was 6.9 cm/km as downstream boundary condition and all of these data were entered to the model through the steady flow data menu.

3. Results

Two scenarios were adopted to run HEC-RAS:

A) Different n values with each specified discharge value
In this scenario the changes that will happen in WSEL due to the change of n values for a certain discharge value was investigated. Six discharge values were used which are 500, 1000,1500,2000,2500 and 3000 m^3sec^{-1}.For each value of these discharges, a range of n values were assumed which are 0.025, 0.03, 0.035, 0.04 and 0.045.The average values of increasing in WSEL (resulted from increasing n values) are shown in table (1), while figures (5) to (10) show the WSEL for Tigris River within Baghdad for each case.

Table 1: The average increasing in WSEL due to the increasing in the adopted n values by amount of 0.05 for each Q value

Discharge (m^3sec^{-1})	Manning's n (from-to)			
	0.025-0.03	0.03-0.035	0.035-0.04	0.04-0.045
500	0.41514	0.38124	0.35195	0.33076
1000	0.5651	0.53164	0.50381	0.48264
1500	0.7189	0.68116	0.64827	0.61989
2000	0.85822	0.80956	0.77082	0.73322
2500	0.97732	0.92213	0.86799	0.83228
3000	1.08346	1.01717	0.96145	0.89776

In this scenario the results show that the differences in WSELfor discharges 500 and 1000 m^3sec^{-1} were small but it shows a significant increase when the value of discharge was increased. Inundation start to take place in the cases when:
a- Discharge equal to 2000 m^3sec^{-1} when ($n \geq 0.04$).
b- Discharge equal to 2500 m^3sec^{-1} when ($n \geq 0.035$).
c- Discharge equal to 3000 m^3sec^{-1} when ($n \geq 0.03$).

For more explanation to the changes in WSELin the cases of scenario A, let's take these two cases:

- When Q=500 m^3sec^{-1}, when n value of 0.025 changed to 0.045 the difference in the average WSEL is 1.48m.
- when Q=3000 m^3sec^{-1}, when n value of 0.025 changed to 0.045 the difference in the average WSEL is about 4m, here the effect of the change in the n value can be seen more evident.

B) Different discharge values with each specified n values
In this scenario the amount of changes in WSEL was calculatedusing specific n value with different discharges (the same values in the first scenario were used but the method of application was reversed). The average values of increasing in WSEL due to the increasing of the adopted Q values by amount 500 m^3sec^{-1} are shown in the table(2) and figures (11) to (15) show the results of different runs for this scenario.

Table 2: The average increase in WSEL when Q value increased by amount 500 m^3sec^{-1} for each adopted n value

Manning's n	Q(m^3sec^{-1}) From-To				
	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
0.025	1.86951	1.43735	1.26517	1.15702	1.07083
0.03	2.01947	1.59115	1.40449	1.27611	1.17698
0.035	2.16987	1.74067	1.53289	1.38868	1.27202
0.04	2.32173	1.88513	1.65544	1.48585	1.36548
0.045	2.47361	2.02237	1.76878	1.58491	1.43096

In this scenario, an important changes in WSELs were observed when discharge values increased by amount of 500 m^3sec^{-1} from 500 m^3sec^{-1}. The results of scenario B show that:

a) In the case of (n=0.025) and for the adopted discharge values there is no inundation will take place.
b) In the case of (n=0.03) and for a flow of 3000 m^3sec^{-1} inundation take place for about 10 km in the northern part of the study area.
c) In the case of (n=0.035) and for a flow value of 2500 m^3sec^{-1} inundation will take place in different places in the northern part of the river, the sum of its length is about 8 km. In addition, for flow value of 3000 m^3sec^{-1} inundation will take place in the reach from section 77(located at the distance 19250 km) and across the reach to the northern part of the study area.
d) In the case of (n=0.04) for flow value of 2500 m^3sec^{-1} inundation will take place in the reach from section 77(located at the distance 19250 km) and across the reach to the northern part of the study area. Moreover, for the flow value of 3000 m^3sec^{-1} inundation will take place along the entire reach of the study area.

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e) In the case of (n=0.045) and for flow values 2500 and 3000 m^3sec^{-1} inundation will take place along the entire reach of the study area. For flow value of 2000 m^3sec^{-1} inundation will take place in some places in the northern part of the river.

For more explanation to the changes in WSEL in this scenario let's take these two examples:

- For the case n=0.025 when Q increased from 500 m^3sec^{-1} to 3000 m^3sec^{-1} the average increase in water surface will be 6.8m.
- For the case n=0.045 when Q increased from 500 m^3sec^{-1} to 3000 m^3sec^{-1} the average increase in water surface will be 9.3m.

The maximum difference in water surface elevation in all cases happened at the section no. 158 which is located at about 1500 m to the north of Al-Aemma Bridge (see figure16 and 17).

Figure (18) illustrates the variation in water surface elevation for the different cases, and from this figure estimation for the average WSEL can be made for any specified n and discharge values. Although this estimation is approximate but it gives good prediction for the results that may caused by any changes in the parameter n with different flow values.

4.2 Conclusion

The results of the two adopted scenarios indicate the following;

1) Based on the adopted flow values in this study, the values of Manning's n equal to 0.025 is the most appropriate in the study area because no inundation state of the river sides noticed .
2) WSEL showed high sensitivity to the increase in n values (which probably may occur due to the bad condition of the river), especially when the flow was 2000 m^3sec^{-1} and more. Also the results showed that the river reach north to Al-Aemma Bridge was the most sensitive and that may be according to the growing islands there.
3) Inundation riskiness is increased when n value increased especially when n≥0.04 and the flow exceed 2000 m^3sec^{-1}.
4) It is noticed that the increase in n values cause decline in the water surface slope and more sedimentation is expected.
5) The appreciate estimation of Manning's n is crucial as a small change in its value can affectthe computed water surface elevation; therefore it needs to be very careful when choosing its value.

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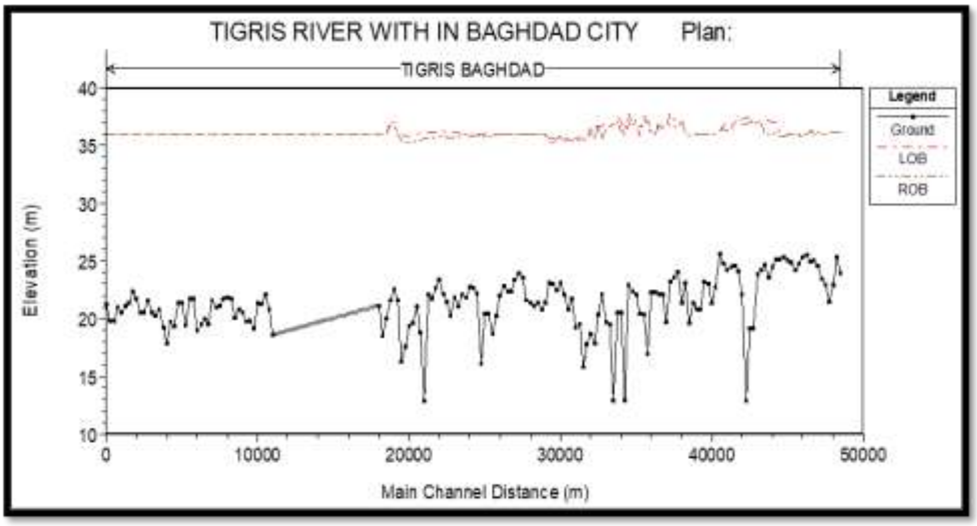

Figure 4: Tigris River bed, LOB and ROB elevations

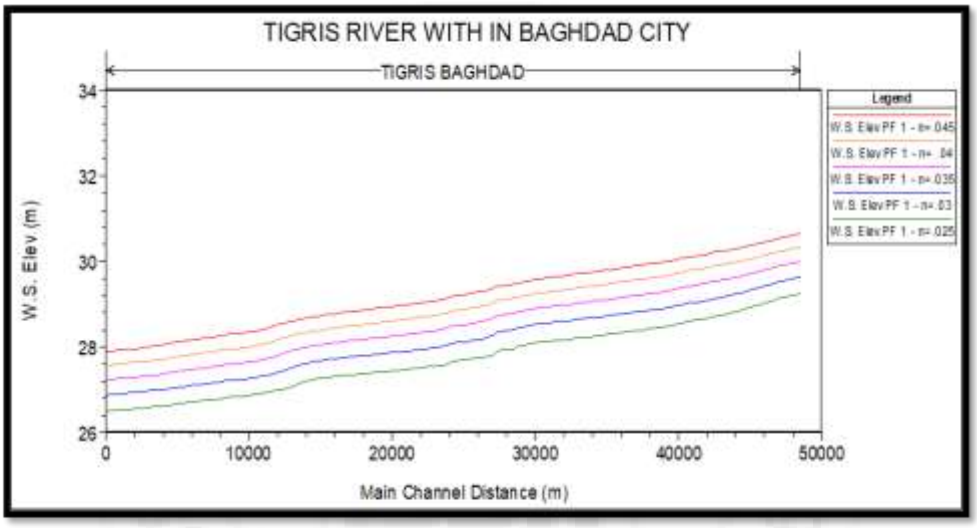

Figure 5: WSEL. For the case Q=500 m^3sec^{-1} with different n values (scenario A)

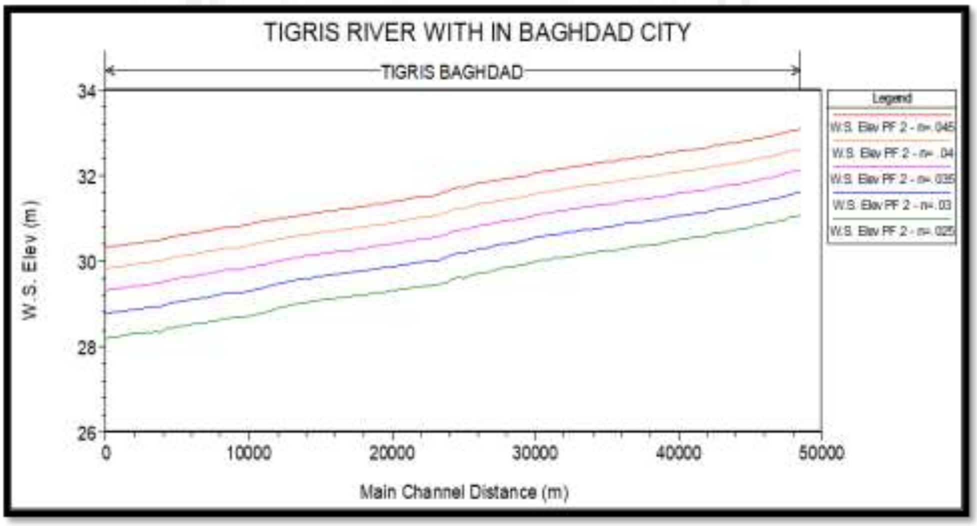

Figure 6: WSEL. For the case Q=1000 m^3sec^{-1} with different n values (scenario A)

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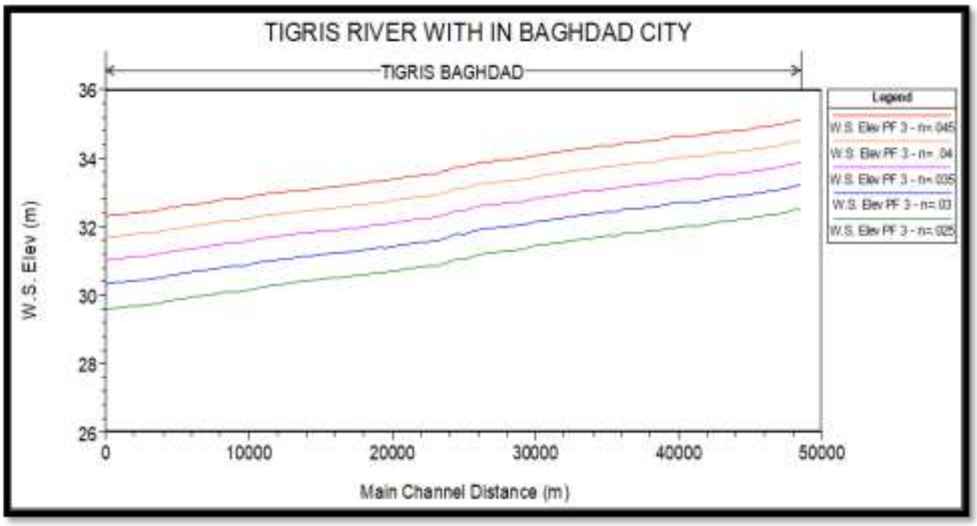

Figure 7: WSEL. For the case Q=1500 m^3sec^{-1} with different n values (scenario A)

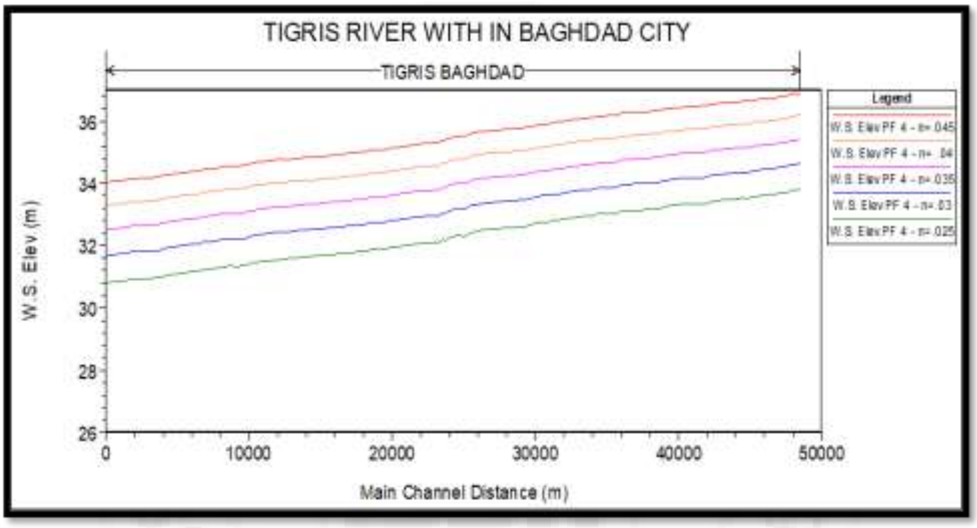

Figure 8: WSEL. For the case Q=2000 m^3sec^{-1} with different n values (scenario A)

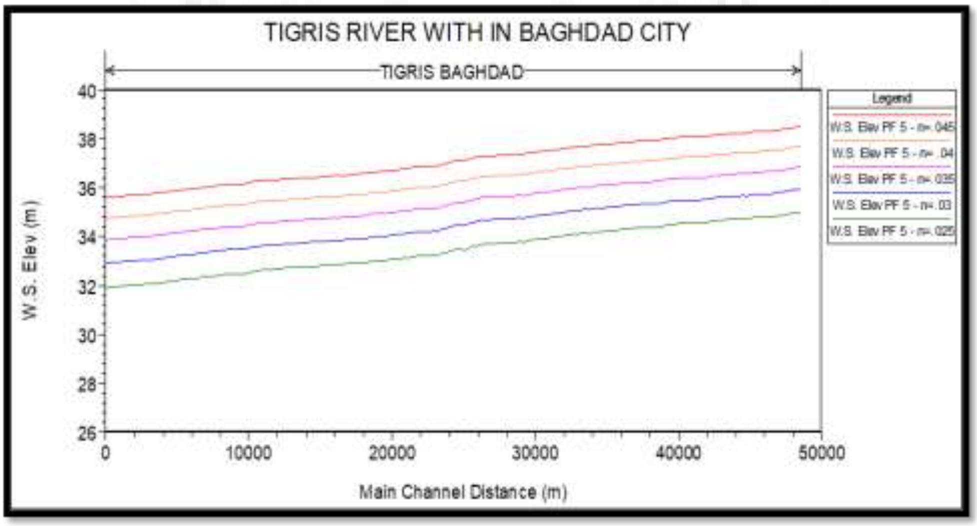

Figure 9: WSEL. For the case Q=2500 m^3sec^{-1} with different n values (scenario A)

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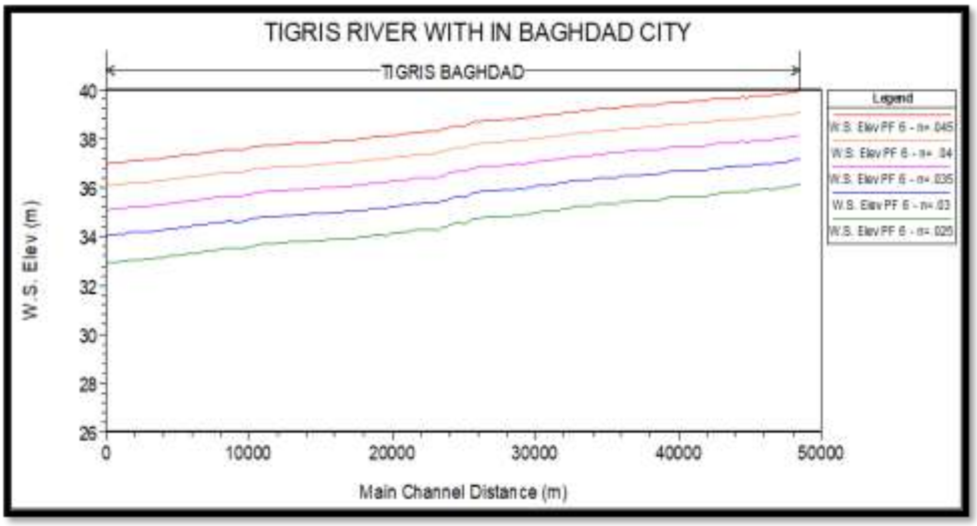

Figure 10: WSEL. For the case Q=3000 m^3sec^{-1} with different n values (scenario A)

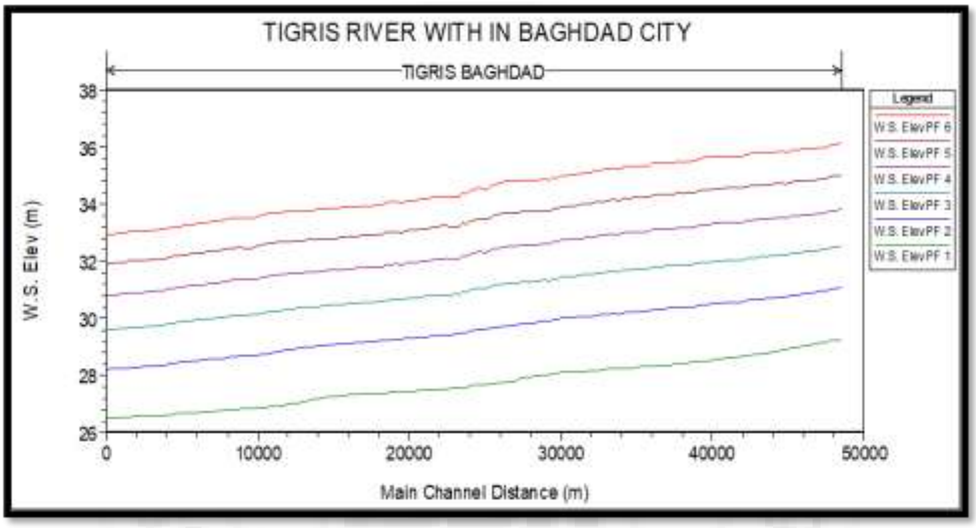

Figure 11: WSEL. For the case n=0.025 with different Q values (scenario B)

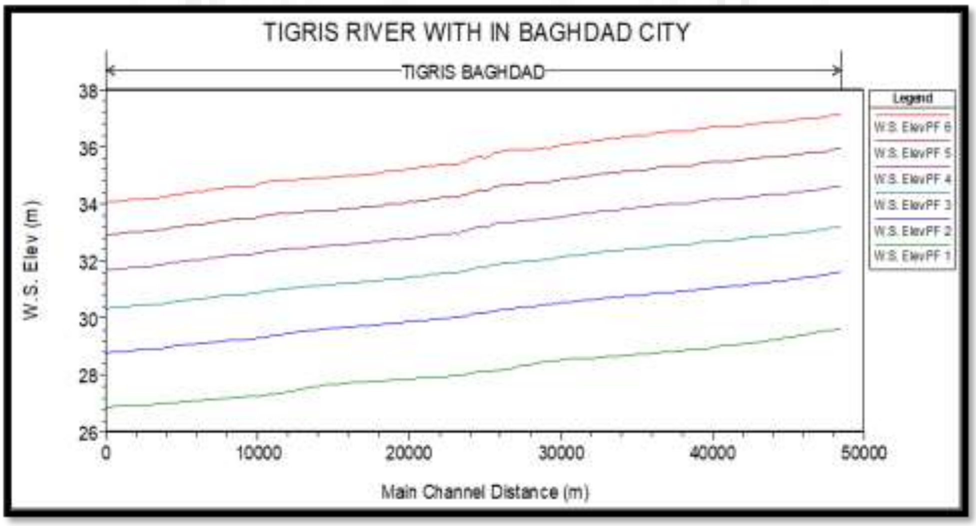

Figure 12: WSEL. For the case n=0.03 with different Q values (scenario B)

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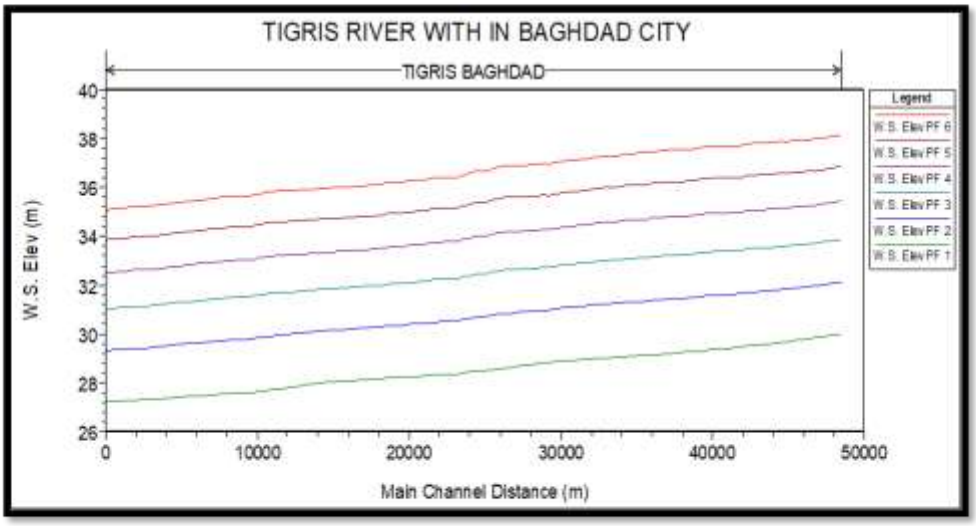

Figure 13: WSEL. For the case n=0.035 with different Q values (scenario B)

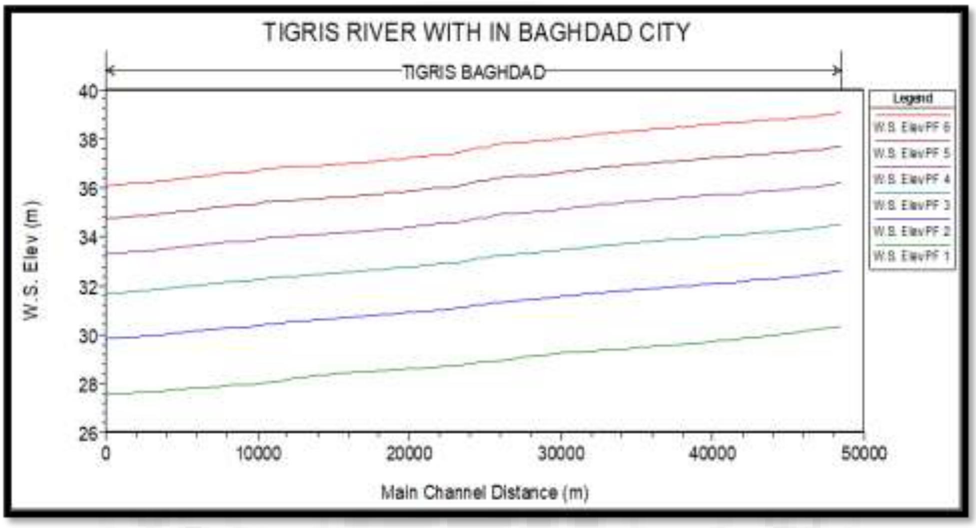

Figure 14: WSEL. For the case n=0.04 with different Q values (scenario B)

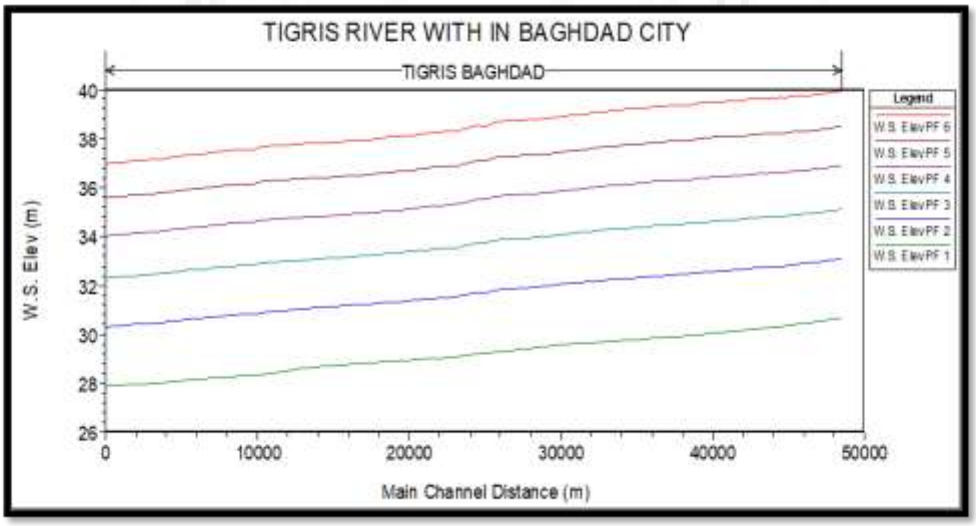

Figure 15: WSEL. For the case n=0.045 with different Q values (scenario B)

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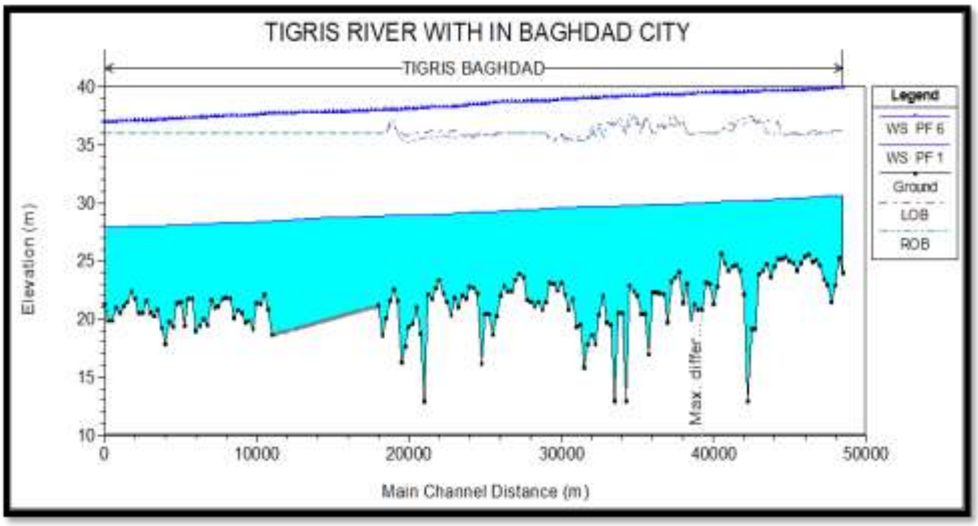

Figure 16: The location of the maximum difference in WSEL section within the river reach

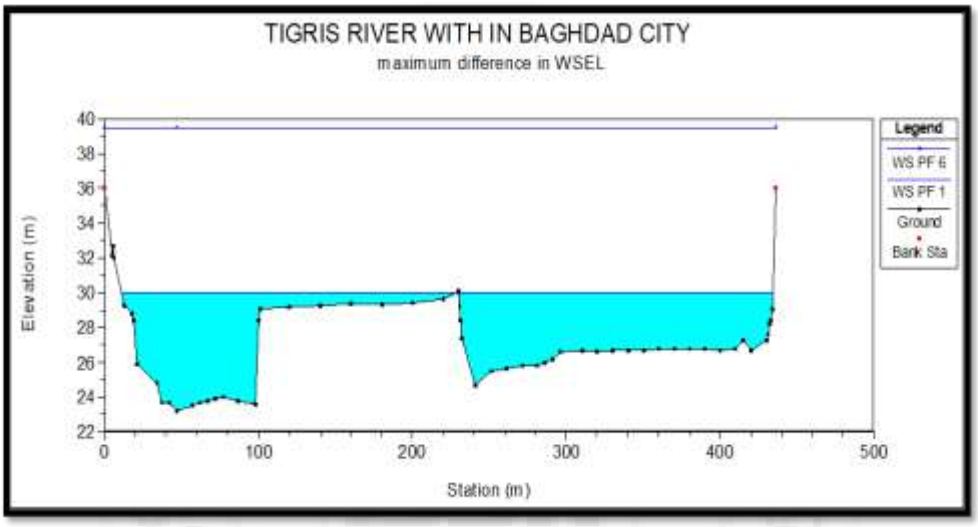

Figure 17: The section (158) where the maximum differences in WSEL occurred

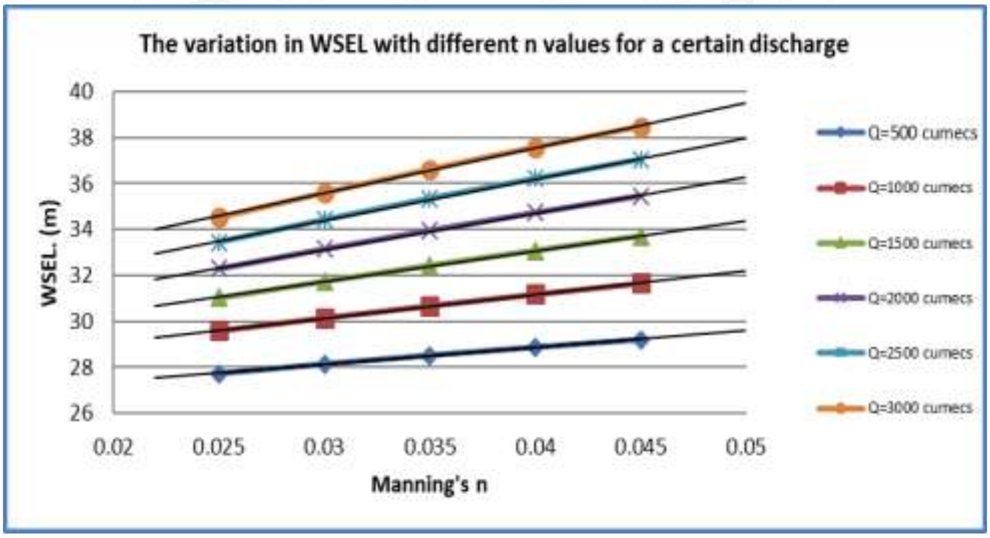

Figure 18: The variation in WSEL with different n values for a certain discharge

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