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Water Flow Simulation of Tigris River Between Samara and Baghdad Based on HEC-RAS Model

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HIGHLIGHTS

- Model has been operated to steady state based on the recorded discharge.
- Model has been operated to unsteady state based on the recorded discharge (2012-2017) years.
- HEC-RAS can use successfully for modelling the ecosystem behaviour of Tigris River within a steady area.

ARTICLE INFO

ABSTRACT

This work aims to use the digital elevation model (DEM) or 3-Dimensional surface to model and analyze the water flow in the Tigris River. The first stage of this study is based on filed data acquisition survey at 38 stations. These stations were adopted to implement the one-dimensional steady and unsteady numerical flow models. The HEC-RAS software was used to implement these models. The most important results of the steady-state model were that the maximum discharge and velocity and minimum flow area were 638.17 m^3/sec, 2.12 m/sec and 301.42 m^2 respectively. These values occurred at station 66+700. While, the minimum discharge and velocity and maximum flow area were 504.5 m^3/sec, 0.13m/sec and 4758.13 m^2 respectively. The results of unsteady state were analyzed based on the recorded discharge in the year 2018. The maximum and minimum discharge (flow velocity) were 638.12 m^3/sec (2.42 m/sec) at the stations 94+666+7 and 635.57 m^3/sec(0.14 m/sec) at station 00+00, respectively. The maximum and minimum Froude number were 0.52 and 0.02 at stations 94+666+7 and 04+800, respectively. These results help to identify the flow choking areas that cause defects. In addition, it can be the base for determining the critical sedimentation stations in which the bed level rises and aggravate the flow choking problem within the considered reach of the Tigris River.

1. Introduction

Water is one of the primary natural sources for consumption, fish breeding, entertainment, etc. Therefore, traditionally, humans have always been utilizing water resources [1]. Surface water, especially across large cities, is exposed to discharge of numerous contamination sources. These contaminants can alter the balance of the ecosystems [2]. Due to rapid development and urbanization, water scarcity and pollution have significantly affected the availability and quality of water resources. The simulation model of river are the latest techniques by which the behavior of rivers and water characteristics can be studies in a precise and clear manner. These models can provide us the characteristics of water within the river such as velocity, flow, and level. It also gives accurate result for the geometric characteristics of the shape of river, such as longitudinal profile and cross sections, their specifications and areas of strength and weakness. Recently, the use of simulation models, such as HEC-RAS, DEM and 3-Dimensional surface programs have become valuable alternative in most studies. Al-Khafaji [3] evaluated the hydraulic performance of Almsharah River, in the South of Iraq, via using the HEC-RAS software with aid of filed measurements. Nama [4] used HEC-RAS to estimate the sediment transport capacity of Tigris River within the Mosul City. Furthermore, Nama and Abdulhusain [5] utilized HEC-RAS to estimate the riverbed scour due to accumulation of floating debris on Almsharah Bridge piers. Also, Nama [6] determined the distribution of shear stress in the meandering of Tigris River within Baghdad City via using the HEC-RAS and GIS. (Abdelbasset et al.) [7] built hydraulic style by using program HEC-RAS and GIS, where they managed to calculate water flow currents through the Al-Wahada Dam. The result showed that the HEC-RAS and GIS model can be used successfully in Simulation results based on constructed model profile and cross section of water elevation and moping of flooded area. (Dang and Kumar) [8] studied the techniques of remote sensing using GIS to generate a hydrological model to calculate the hazard of flooding on the marshy of the Meakong Delta in Chai Minha City. The result showed that the GIS model can be used successfully in simulation based on constructed model to generate a hydrological model to calculate the hazard of flooding in the urban area. Sharma and Mujumdar [9] used one-dimensional

model HEC-RAS and two-dimensional model CCHE2D to simulate the flood zoning in the Sungai Maka district in Kelantan state, Malaysia . The results of these two models in most sections approximately Similar but the differences were in the shape of the river. Traore et al. [10]used GIS to build DEM for study river basin in Kayanga , Senegal. It is located between the Kounkane threshold and Niandouba Dam. The result showed that the GIS model can be used successfully in Simulation results based on constructed model. Onea and Bagatur [11] have predicted flood frequency factor for Gumbel distribution with regression and GEP models. Bagatu and Onen [12] have presented the development of a predictive model for flood routing using genetic expression programming. Romali et al. [13] presented application of HEC-RAS and ARC GIS for floodplain mapping in Segamat town, Malaysia. Khalfallah and Saidi [14] have presented spatiotemporal floodplain mapping and prediction using HEC-RAS-GIS tools in the Mejerda River, Tunisia. The main objective of this study is to demonstrate the ability of simulation model to recognize behavior of rivers and water characteristics can be studied in a precise and clear manner. Alwan, Samueel, and Abdullah , [14] studied the accuracy of different elevation model; The area of study is located East of the Amarah city (Maysan governorate) in the South of Iraq which is outlying the capital (Baghdad), The results showed that the ALOS V1.1 model is the most accurate of the open-source models followed by the SRTM V3 model and then followed by ASTER V2. The results obtained from a pair by Pleiades high resolution (PHR) 1B satellites show a higher accuracy than the results obtained from the open-source models.

Maatooq and Hameed ,[15]studied a series of experiments runs were carried out through combining different geometric and hydraulic parameters to produce different experiment conditions. These parameters are flow rate, bed slope, and different initial incised and wide channels for both rectangular and trapezoidal sections. Karim and Sahib ,[16]in this study the EPANET software was used for automatically solving problems of the network. The main objective of this study is to analyze the irrigation network of the proposed Taq-Taq Dam using hydraulic simulation software, the results concluded that the simulated model seems to be reasonably close to those of an actual network system. The study area was selected based on its importance in terms of the amount of inflow water, representing a good example of the ecological system. Simulation models need to define the characteristics of the study areas in a precise way to provide way to need to define the characteristics of the study area in a precise way to provide accurate results, in particular the definition of the geometric characteristics of the rivers of study area, which were represented in this study by the main rivers branch of the Tigris river in the Salah Al-Din Governorate. Using HEC-RAS mathematic model is a method to determining water level and hydraulic specifications of flow. Therefore, the parameter of water surface profile, within time of maximum discharge, for steady and unsteady flow condition, have calculated. This calculation, determine the hydraulic specification of flow, such as, flow depth, critical depth, flow energy and other hydraulic parameters of zone [17]. In this paper, four corrected satellite images for the year 2015 were used to produce the path of these river and their banks from both sides.

2. Materials And Methods

2.1 Study Area and data collection

The Tigris River is one of the largest rivers in the Middle East, stretching for over 1900 km, of which 1415 km are within Iraq, the catchment area reaches to 235,000 km^2. Tigris River sharing with Euphrates River are the main source for man's use, especially for drinking water since they pass the major cities in the country [16]. In this paper, it begins the study area of the Tigris River from Samarra barrage-to Baghdad city-Resafa station show as the Figure (1). The data collection in this study data are important and spatial of two categories: spatial data and attribute data. Spatial data illustrate the river location with geographical characteristics, whereas attribute data describe and represent spatial data as number or phrases. The plan data, geometric, flow data, and hydraulic design data are used for modeling with HEC-RAS model. The basic input data requirements to run one-dimension include river location coordinates, river cross sections, and initial water surface.

Figure 1: Tigris River in the Samarra barrage-to Baghdad city-Resafa station
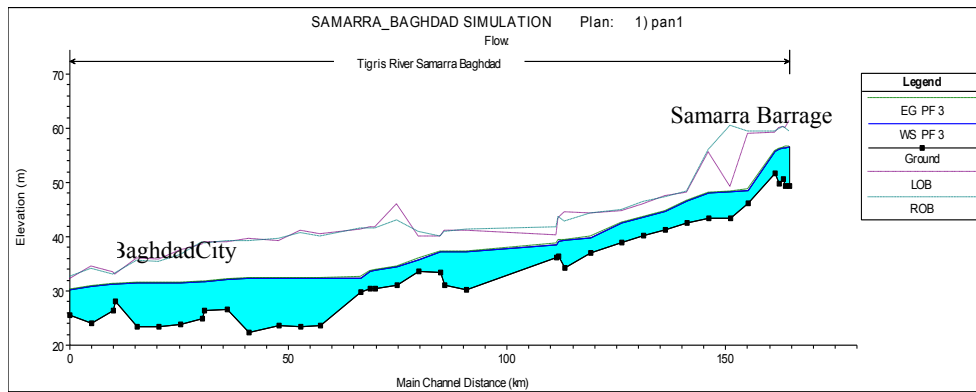
Figure 1 continued
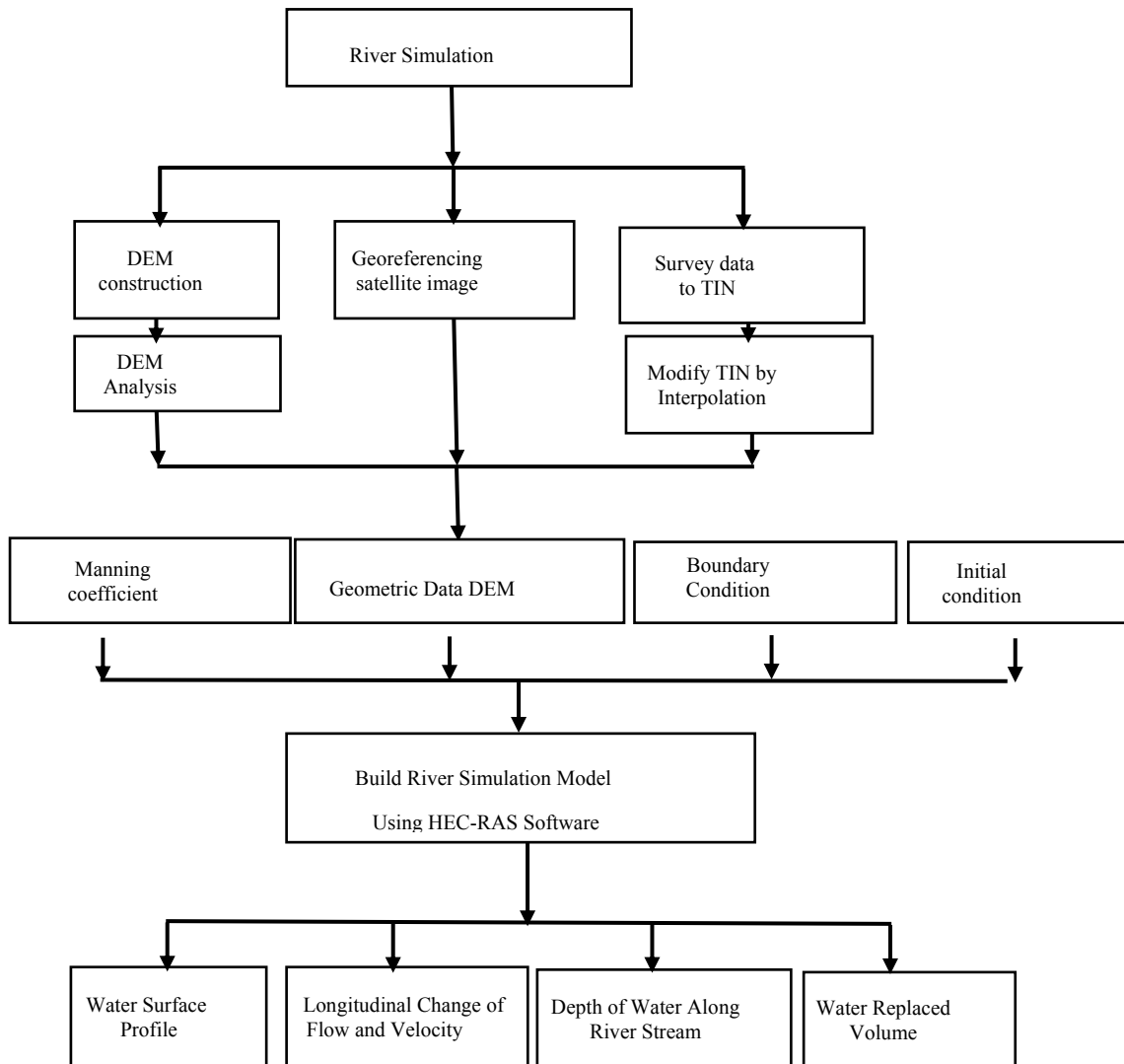
Figure 2: Methodology of Simulation

2.2 Methodology

The method used in this study is to obtain discharge and hydrological data from previous years. Hydraulic structures in the working route were determined (cross section areas, gradient between sections, hydraulic radius, manning coefficient). Then, HEC-RAS software was used to build simulates model the hydrodynamic flow and water flow within the river as shown at Figure (2). To obtain results that explain the reasons for the transformation of the Tigris River a swamp that collects pollutants and sediments that impede the movement of water.

2.3 HEC-RAS Software

HEC-RAS program is one of the 1D dynamic models developed by U.S. Army Corps. Hydrology makes calculations in semi unsteady, unsteady flows with one- and two-dimensional unsteady river flow calculations with one-dimensional steady

hydraulic flow. The first version of HEC-RAS was released in July 1995.Since then many upgrades have been released from 1.1 to 5.07. In this study version 4.0 was used. In this program, subcritical, supercritical, and mixed flow solution options are provided for the determination of water surface profiles under stable current conditions. In this program, one-dimensional energy equation is used for the solutions made under steady flow conditions.

The physical laws in unsteady flow which govern the flow of water in a stream are:

(1) The principle of conservation of mass (continuity).

(2) The principle of conservation of momentum.

These laws are expressed mathematically in the form of partial differential equation, which will hereafter be referred to as continuity and momentum equations. The data required to run the program includes three groups that are entered in succession, as follows (19):

- Geometric Data:
- Initial Conditions
- Boundary Conditions

2.4 Coefficient of determination R^2

It is square of the correlation (r) between observed and simulated values. R^2 Ranges from 0 to 1 mathematically, coefficient of determination (R^2) is presented as :

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_i^{obs}-Q_{ave}^{obs})(Q_i^{sim}-Q_{ave}^{sim})}{[\sum_{i=1}^{n}(Q_i^{obs}-Q_{ave}^{obs})^2\sum_{i=1}^{n}(Q_i^{sim}-Q_{ave}^{sim})^2]^{0.5}}\right]^2 \qquad (1)$$

Where Q_i^{obs} is observed value (m^3/s), Q_{ave}^{obs} is the average observed value of n value, Q_i^{sim} is simulated value (m^3/s), Q_{ave}^{sim} is the average simulated value of n value and is the number of observation.

3. Results

Hydraulic analysis of the study was carried out using the HEC-RAS package program version of 4.0, Figure 3 (a, b). The data obtained because of the observations and measurement discharge, velocity, area, cross section, and Froude number of the state of flow in the Tigris River between the Samarra Dam and the city of Baghdad. The two scenarios (steady and unsteady).

(a)

Figure 3: (a) Some forms of cross section of the Samara-Baghdad for the different station of the Tigris River section (1). (b) Some forms of cross section of the Samara-Baghdad for the different station of the Tigris River section (38)

Figure 3 continued (b)

1. First scenarios (steady): model has been operated to steady state based on the recorded discharge. The model operated for three possibilities (Max discharge, average discharge, and min discharge). The above results were checked where it was found that Max discharge reached 638.17m^3/sec at the section and reached the highest value of the flow velocity was within limits 2.12 m/sec as for the highest area reached at 301.42 m^2 at the section 15 show the Table (1) and Figure (4). When passing average discharge reached 557.86 m^3/sec and the value of the flow velocity was limits 2.21m/sec as for the average area reached at 252.86 m^{2v}at the section 15 shows the Table (2) and Figure (5). When passing min discharge reached 504.5 m^3/sec at the section and reached the min value of the flow velocity was within limit 0.13m/sec as for the min area reached at 4758.13m^2 at the section11, shown in Table (3) and Figure (6). The steady state successfully in Simulation results the velocity not more 2.5 m/sec and Froude number not more 1.5.

2. The second scenarios (unsteady): model has been operated to unsteady state based on the recorded discharge (2012-2017) years. The Max discharge reached 638.12 m^3/sec at the section 34, The Min discharge reached 635.57 m^3/sec at section (1). The Max velocity passing through the river reached 2.42m/sec, the Min velocity passing through the river reached 0.14 m/sec. The Max Froude number reached 0.52 at section 34, the Min Froude number reached 0.02 at section 12, as shown in Table (4).

Table 1:   Monthly discharge of the city of Baghdad Sarai for the years 2012-2017 from (MOWR).

Year	2012	2013	2014	2015	2016	2017
Jan	507	490	490	474	444	461
Feb	480	608	509	437	694	467
Mar	490	708	581	463	611	506
Apr	495	500	524	453	482	562
May	458	433	465	438	499	601
Jun	450	498	439	448	528	530
Jul	510	507	470	400	519	483
Aug	471	560	455	431	518	463
Sep	454	510	410	456	490	444
Oct	480	466	475	466	468	485
Nov	500	717	543	477	473	532
Dec	503	560	507	534	417	521

Table 2:   Monthly discharge of the city of Baghdad Sarai.

Calculate 2017	Observed 2017
467.4	416
465.57	467
524.19	506
561.67	562
604.55	601
546.64	530
480.98	483
465.05	463
415.13	444
478.43	485
506.07	532

3.1 Calibration

HEC-RAS has the capabilities to process automated calibration to minimize a specific objective function, such as sum of the absolute error, sum of the squared error. Therefore, automated calibration in conjunction with manual calibration was used to determine a practical range of the parameter values preserving the hydrograph shape and minimum error in volumes. Flow calibration was carried out over the period 2012-2017 and model validation was carried out over the period of the same years in Baghdad Sarai as shown in Table (5). The coefficient of determination (R^2) during calibration were found to be 0.906. The model performance is reasonably good in simulating flows for periods of the calibration period. The simulated results achieved a success with an accuracy of R^2 0.906, compared with the monthly discharge of the city of Baghdad Sarai for the years 2012-2017 from The Ministry of Water Resources (MOWR) [14]shown in the Table (5), Table(6) and Figure (4).

4. Conclution

There are several findings and outcomes that outlined from the investigation and analysis of this research, which can be summarized as follow:

1.   The performance of the model was found to be rather good agreement with R^2 (0.9068) during the calibration periods.

2.   The HEC-RAS can use successfully for modelling the ecosystem behaviour of Tigris River within a steady area.

3.   From the data result for steady- state model (maximum discharge, velocity, and minimum flow area) was 638.17 m^3/sec, 2.12 m/sec and 301.42 m^2 respectively. It showed the weakness in the Tigris River (Samarra barrage-to Baghdad city-Resafa station) these values occurred at station 66+700. While, the minimum discharge, velocity and maximum flow area were 504.5 m^3/sec, 0.13 m/sec and 4758.13 m^2 respectively. The results of unsteady state were analyzed based on the recorded discharge in the year 2018. The maximum and minimum discharge (flow velocity) were 638.12 m^3/sec (2.42 m/sec) at the stations 94+666+7 and 635.57 m^3/sec (0.14 m/sec) at station 00+00, respectively. The maximum and minimum Froude number were 0.52 and 0.02 at stations 94+666+7 and 04+800, respectively.
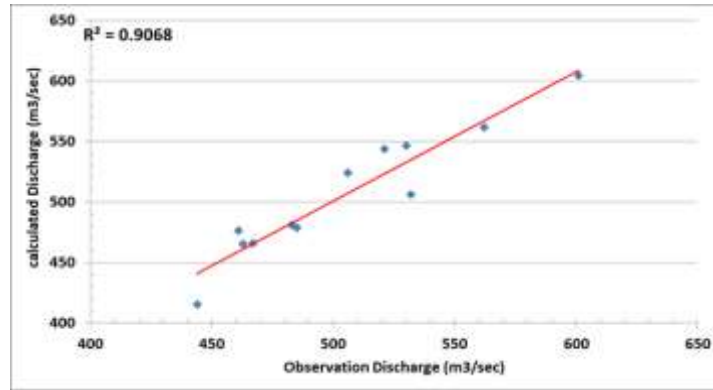

Figure 4: Scatter plot of calculated and observation discharge.

Figure 5: Reach   in   steady   state   with   Mix   discharge (Q=638.17m3/sec).**Appendix**

Table 3: Output of the Tigris River of the steady stat Max discharge (Q=638.17m3/sec)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(m^3/s)	(m)	(m)	(m)	(m/m)	(m/s)	(m^2)	(m)	
Samarra Baghdad	1	638.2	25.56	30.68	30.71	0.000142	0.78	814.5	326.09	0.16
Samarra Baghdad	2	638.2	24.12	31.3	31.32	0.000106	0.65	984.05	419.1	0.14
Samarra Baghdad	3	638.2	26.28	31.67	31.68	0.000054	0.43	1470.27	691.79	0.1
Samarra Baghdad	4	638.2	28	31.7	31.71	0.000077	0.44	1446.36	861.51	0.11
Samarra Baghdad	5	638.2	23.43	31.84	31.84	0.000012	0.24	2661.99	1009.14	0.05
Samarra Baghdad	6	638.2	23.37	31.89	31.9	0.00001	0.23	2819.08	984.31	0.04
Samarra Baghdad	7	638.2	23.84	31.96	31.97	0.000023	0.39	1640.22	477.66	0.07
Samarra Baghdad	8	638.2	24.79	32.06	32.07	0.000016	0.37	1747.59	427.8	0.06
Samarra Baghdad	9	638.2	26.28	32.07	32.08	0.000079	0.56	1133.94	481.08	0.12
Samarra Baghdad	10	638.2	26.54	32.63	32.67	0.000186	0.92	692.68	266.12	0.18
Samarra Baghdad	11	638.2	22.34	32.7	32.7	0.000002	0.13	4758.13	912.17	0.02

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
Samarra Baghdad	12	638.2	23.54	32.72	32.72	0.000003	0.16	4033.48	963.2	0.02
Samarra Baghdad	13	638.2	23.45	32.73	32.73	0.000002	0.15	4279.19	755.72	0.02
Samarra Baghdad	14	638.2	23.66	32.74	32.74	0.000007	0.36	1762.23	239.43	0.04
Samarra Baghdad	15	638.2	29.85	32.82	33.05	0.001586	2.12	301.42	165.75	0.5
Samarra Baghdad	16	638.2	30.46	34	34.04	0.000206	0.9	711.34	306.56	0.19
Samarra Baghdad	17	638.2	30.46	34.19	34.23	0.00016	0.83	768.87	308.03	0.17
Samarra Baghdad	18	638.2	31.14	34.88	34.9	0.000116	0.71	901.44	359.32	0.14
Samarra Baghdad	19	638.2	33.54	36.09	36.21	0.00095	1.48	430.72	275.43	0.38
Samarra Baghdad	20	638.2	33.34	37.58	37.61	0.000132	0.8	802.15	294.19	0.15
Samarra Baghdad	21	638.2	31.12	37.65	37.66	0.000025	0.48	1335.51	295.43	0.07
Samarra Baghdad	22	638.2	30.12	37.76	37.77	0.000019	0.35	1831.98	544.11	0.06
Samarra Baghdad	23	638.2	36.26	38.89	39.06	0.001384	1.85	351.27	224.43	0.46
Samarra Baghdad	24	638.2	36.36	39.5	39.61	0.000856	1.46	438.12	265.86	0.36
Samarra Baghdad	25	638.2	34.23	39.74	39.75	0.00003	0.45	1430.07	416.09	0.08
Samarra Baghdad	26	638.2	37.11	40.18	40.26	0.00063	1.27	501.85	296.95	0.31
Samarra Baghdad	27	638.2	39	43.02	43.06	0.000275	0.85	746.92	430.59	0.21
Samarra Baghdad	28	638.2	40.22	44.16	44.18	0.000185	0.58	1097.07	838.21	0.16
Samarra Baghdad	29	638.2	41.37	45.14	45.17	0.000212	0.76	842.91	479.8	0.18
Samarra Baghdad	30	638.2	42.45	46.78	46.82	0.000577	0.86	741.69	737.83	0.27
Samarra Baghdad	31	638.2	43.3	48.32	48.36	0.000191	0.81	790.92	374.61	0.18
Samarra Baghdad	32	638.2	43.3	48.61	48.61	0.000023	0.33	1956.81	738.25	0.06
Samarra Baghdad	33	638.2	46.1	48.79	48.95	0.001919	1.8	355.4	288.93	0.52
Samarra Baghdad	34	638.2	51.7	55.91	56.09	0.000808	1.9	336.42	131.18	0.38
Samarra Baghdad	35	638.2	49.8	56.51	56.61	0.000344	1.41	453.6	145.56	0.25
Samarra Baghdad	36	638.2	50.6	56.8	56.85	0.000177	1.05	609.68	184.56	0.18
Samarra Baghdad	37	638.2	49.4	56.88	56.93	0.000148	1	639.68	182.56	0.17
Samarra Baghdad	38	638.2	49.4	56.97	56.98	0.000022	0.44	1462.55	341.24	0.07

Table 4: Output of the Tigris River of the steady stat for Average Discharge (Q=557.86m3/sec)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(m3/s)	*(m)*	*(m)*	*(m)*	*(m/m)*	*(m/s)*	*(m2)*	*(m)*	
Samarra Baghdad	1	557.86	25.56	30.41	30.44	0.000142	0.76	729.86	303.19	0.16
Samarra Baghdad	2	557.86	24.12	31.04	31.06	0.00011	0.64	878.21	395.27	0.14
Samarra Baghdad	3	557.86	26.28	31.44	31.44	0.000059	0.43	1308.59	672.31	0.1
Samarra Baghdad	4	557.86	28	31.47	31.48	0.000093	0.45	1247.6	845.25	0.12
Samarra Baghdad	5	557.86	23.43	31.61	31.62	0.000013	0.23	2437.05	999.32	0.05
Samarra Baghdad	6	557.86	23.37	31.67	31.67	0.00001	0.21	2599.33	979.02	0.04
Samarra Baghdad	7	557.86	23.84	31.74	31.74	0.000021	0.36	1533.79	464.42	0.06

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Samarra Baghdad	8	557.86	24.79	31.82	31.83	0.000014	0.34	1648.58	414.09	0.05
Samarra Baghdad	9	557.86	26.28	31.83	31.85	0.000078	0.54	1023.96	449.14	0.12
Samarra Baghdad	10	557.86	26.54	32.38	32.42	0.000178	0.89	628.11	246.99	0.18
Samarra Baghdad	11	557.86	22.34	32.44	32.44	0.000001	0.12	4523.91	907.41	0.02
Samarra Baghdad	12	557.86	23.54	32.46	32.46	0.000003	0.15	3784.68	960.6	0.02
Samarra Baghdad	13	557.86	23.45	32.47	32.47	0.000002	0.14	4083.55	751.33	0.02
Samarra Baghdad	14	557.86	23.66	32.48	32.48	0.000006	0.33	1699.96	238.38	0.04
Samarra Baghdad	15	557.86	29.85	32.51	32.76	0.001948	2.21	252.86	152.53	0.55
Samarra Baghdad	16	557.86	30.46	33.8	33.84	0.000212	0.86	649.12	304.97	0.19
Samarra Baghdad	17	557.86	30.46	33.99	34.02	0.00016	0.79	707.21	306.46	0.17
Samarra Baghdad	18	557.86	31.14	34.67	34.7	0.000115	0.67	828.14	353.15	0.14
Samarra Baghdad	19	557.86	33.54	35.91	36.02	0.001054	1.46	381.42	269.1	0.39
Samarra Baghdad	20	557.86	33.34	37.35	37.38	0.000121	0.76	736.92	273.74	0.15
Samarra Baghdad	21	557.86	31.12	37.42	37.43	0.000023	0.44	1267	294.56	0.07
Samarra Baghdad	22	557.86	30.12	37.53	37.53	0.000019	0.33	1701.6	544.09	0.06
Samarra Baghdad	23	557.86	36.26	38.65	38.83	0.001759	1.91	296.99	217.5	0.51
Samarra Baghdad	24	557.86	36.36	39.35	39.45	0.00089	1.4	397.66	262.86	0.36
Samarra Baghdad	25	557.86	34.23	39.57	39.57	0.000027	0.41	1359.26	412.15	0.07
Samarra Baghdad	26	557.86	37.11	39.97	40.05	0.000682	1.26	441.62	280.04	0.32
Samarra Baghdad	27	557.86	39	42.78	42.82	0.000257	0.85	653.25	357.77	0.2
Samarra Baghdad	28	557.86	40.22	43.87	43.89	0.000183	0.63	888.11	598.45	0.16
Samarra Baghdad	29	557.86	41.37	44.89	44.92	0.000233	0.77	729.1	437.81	0.19
Samarra Baghdad	30	557.86	42.45	46.67	46.71	0.000609	0.84	661.93	707.45	0.28
Samarra Baghdad	31	557.86	43.3	48.19	48.22	0.000181	0.75	741.34	374.6	0.17
Samarra Baghdad	32	557.86	43.3	48.45	48.46	0.000021	0.3	1843.73	735.16	0.06
Samarra Baghdad	33	557.86	46.1	48.62	48.79	0.002259	1.82	306.22	275.36	0.55
Samarra Baghdad	34	557.86	51.7	55.77	55.92	0.000733	1.76	317.55	129.06	0.36
Samarra Baghdad	35	557.86	49.8	56.31	56.4	0.000321	1.31	424.87	143.57	0.24
Samarra Baghdad	36	557.86	50.6	56.57	56.62	0.000163	0.98	569.14	178.86	0.18
Samarra Baghdad	37	557.86	49.4	56.65	56.7	0.000136	0.93	598.32	176.87	0.16
Samarra Baghdad	38	557.86	49.4	56.73	56.74	0.000019	0.4	1381.54	333.53	0.06
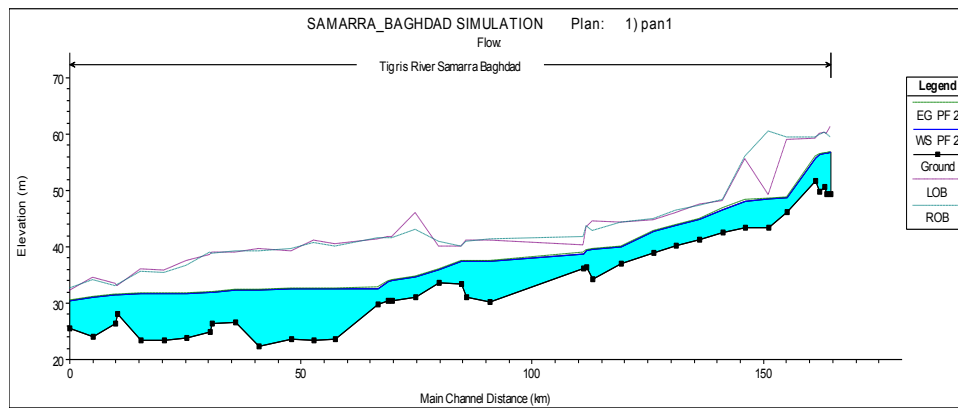
Figure 6: Reach in steady state with average discharge (Q=557.86m3/sec)

Table 5: Output of the Tigris River of the steady stat for Min Discharge (Q=504.5m3/sec)

Reach	River Sta	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
Samarra Baghdad	38	638.17	49.4	56.97	56.98	2.20E-05	0.44	1462.55	341.24	0.07
Samarra Baghdad	1	638.17	25.56	30.68	30.71	0.00014	0.78	814.5	326.09	0.16
Samarra Baghdad	2	638.17	24.12	31.3	31.32	0.00011	0.65	984.05	419.1	0.14
Samarra Baghdad	3	638.17	26.28	31.67	31.68	5.40E-05	0.43	1470.27	691.79	0.1
Samarra Baghdad	4	638.17	28	31.7	31.71	7.70E-05	0.44	1446.36	861.51	0.11
Samarra Baghdad	5	638.17	23.43	31.84	31.84	1.20E-05	0.24	2661.99	1009.14	0.05
Samarra Baghdad	6	638.17	23.37	31.89	31.9	0.00001	0.23	2819.08	984.31	0.04
Samarra Baghdad	7	638.17	23.84	31.96	31.97	2.30E-05	0.39	1640.22	477.66	0.07
Samarra Baghdad	8	638.17	24.79	32.06	32.07	1.60E-05	0.37	1747.59	427.8	0.06
Samarra Baghdad	9	638.17	26.28	32.07	32.08	7.90E-05	0.56	1133.94	481.08	0.12
Samarra Baghdad	10	638.17	26.54	32.63	32.67	0.00019	0.92	692.68	266.12	0.18
Samarra Baghdad	11	638.17	22.34	32.7	32.7	2.00E-06	0.13	4758.13	912.17	0.02
Samarra Baghdad	12	638.17	23.54	32.72	32.72	3.00E-06	0.16	4033.48	963.2	0.02
Samarra Baghdad	13	638.17	23.45	32.73	32.73	2.00E-06	0.15	4279.19	755.72	0.02
Samarra Baghdad	14	638.17	23.66	32.74	32.74	7.00E-06	0.36	1762.23	239.43	0.04
Samarra Baghdad	15	638.17	29.85	32.82	33.05	0.00159	2.12	301.42	165.75	0.5
Samarra Baghdad	16	638.17	30.46	34	34.04	0.00021	0.9	711.34	306.56	0.19
Samarra Baghdad	17	638.17	30.46	34.19	34.23	0.00016	0.83	768.87	308.03	0.17
Samarra Baghdad	18	638.17	31.14	34.88	34.9	0.00012	0.71	901.44	359.32	0.14
Samarra Baghdad	19	638.17	33.54	36.09	36.21	0.00095	1.48	430.72	275.43	0.38
Samarra Baghdad	20	638.17	33.34	37.58	37.61	0.00013	0.8	802.15	294.19	0.15
Samarra Baghdad	21	638.17	31.12	37.65	37.66	2.50E-05	0.48	1335.51	295.43	0.07
Samarra Baghdad	22	638.17	30.12	37.76	37.77	1.90E-05	0.35	1831.98	544.11	0.06
Samarra Baghdad	23	638.17	36.26	38.89	39.06	0.00138	1.85	351.27	224.43	0.46
Samarra Baghdad	24	638.17	36.36	39.5	39.61	0.00086	1.46	438.12	265.86	0.36

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Samarra Baghdad	25	638.17	34.23	39.74	39.75	0.00003	0.45	1430.07	416.09	0.08
Samarra Baghdad	26	638.17	37.11	40.18	40.26	0.00063	1.27	501.85	296.95	0.31
Samarra Baghdad	27	638.17	39	43.02	43.06	0.00028	0.85	746.92	430.59	0.21
Samarra Baghdad	28	638.17	40.22	44.16	44.18	0.00019	0.58	1097.07	838.21	0.16
Samarra Baghdad	29	638.17	41.37	45.14	45.17	0.00021	0.76	842.91	479.8	0.18
Samarra Baghdad	30	638.17	42.45	46.78	46.82	0.00058	0.86	741.69	737.83	0.27
Samarra Baghdad	31	638.17	43.3	48.32	48.36	0.00019	0.81	790.92	374.61	0.18
Samarra Baghdad	32	638.17	43.3	48.61	48.61	2.30E-05	0.33	1956.81	738.25	0.06
Samarra Baghdad	33	638.17	46.1	48.79	48.95	0.00192	1.8	355.4	288.93	0.52
Samarra Baghdad	34	638.17	51.7	55.91	56.09	0.00081	1.9	336.42	131.18	0.38
Samarra Baghdad	35	638.17	49.8	56.51	56.61	0.00034	1.41	453.6	145.56	0.25
Samarra Baghdad	36	638.17	50.6	56.8	56.85	0.00018	1.05	609.68	184.56	0.18
Samarra Baghdad	37	638.17	49.4	56.88	56.93	0.00015	1	639.68	182.56	0.17
	38	Max WS	638.17	49.4	57.01	57.02	0.000021	0.43	1475.47	342.35
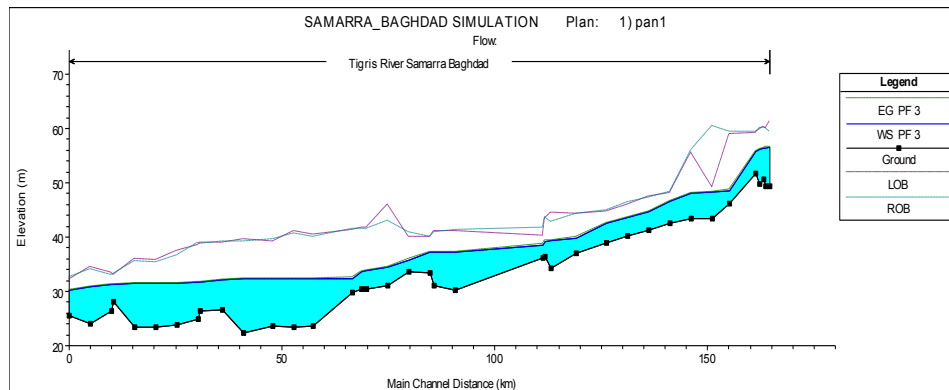
Figure 7: Reach in steady state with Min discharge (Q=504.5 m/sec)

Table 6: Output of the Tigris River Unsteady State

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m³/s)	(m)	(m)	(m)	(m/m)	(m/s)	(m²)	(m)	
Samarra Baghdad	1	Max WS	635.57	25.56	30.67	30.7	0.000142	0.78	811.75	325.22	0.16
Samarra Baghdad	2	Max WS	635.61	24.12	31.3	31.32	0.000106	0.65	983.38	419.06	0.13
Samarra Baghdad	3	Max WS	635.67	26.28	31.69	31.7	0.000052	0.43	1484.98	693.53	0.09
Samarra Baghdad	4	Max WS	635.68	28	31.73	31.73	0.000073	0.43	1464.13	862.95	0.11
Samarra Baghdad	5	Max WS	635.76	23.43	31.94	31.94	0.000011	0.23	2765.45	1013.62	0.04
Samarra Baghdad	6	Max WS	635.83	23.37	31.99	31.99	0.000009	0.22	2914.1	986.59	0.04
Samarra Baghdad	7	Max WS	635.89	23.84	32.06	32.07	0.000021	0.38	1687.32	483.41	0.06
Samarra Baghdad	8	Max WS	635.92	24.79	32.15	32.16	0.000015	0.36	1787.64	433.22	0.06
Samarra Baghdad	9	Max WS	635.92	26.28	32.17	32.18	0.000071	0.54	1181.75	494.33	0.11
Samarra Baghdad	10	Max WS	635.95	26.54	32.74	32.78	0.000168	0.88	722.3	274.79	0.17
Samarra Baghdad	11	Max WS	635.97	22.34	33.18	33.18	0.000001	0.12	5193.76	920.97	0.02

Samarra Baghdad	12	Max WS	636.02	23.54	33.19	33.19	0.000002	0.14	4489.14	967.94	0.02
Samarra Baghdad	13	Max WS	636.05	23.45	33.2	33.2	0.000001	0.14	4635.67	763.66	0.02
Samarra Baghdad	14	Max WS	636.07	23.66	33.21	33.21	0.000006	0.34	1875.57	241.33	0.04
Samarra Baghdad	15	Max WS	636.71	29.85	34.32	34.38	0.000244	1.07	593.71	222.79	0.21
Samarra Baghdad	16	Max WS	636.72	30.46	34.71	34.74	0.000086	0.68	931.31	312.12	0.13
Samarra Baghdad	17	Max WS	636.73	30.46	34.8	34.82	0.000078	0.67	957.22	312.77	0.12
Samarra Baghdad	18	Max WS	636.78	31.14	35.2	35.22	0.00008	0.63	1016.81	368.81	0.12
Samarra Baghdad	19	Max WS	636.81	33.54	36.49	36.56	0.000459	1.18	541.05	282.97	0.27
Samarra Baghdad	20	Max WS	636.83	33.34	37.9	37.93	0.000092	0.71	897.88	299.62	0.13
Samarra Baghdad	21	Max WS	636.83	31.12	37.97	37.98	0.00002	0.45	1430.76	296.64	0.06
Samarra Baghdad	22	Max WS	636.84	30.12	38.06	38.07	0.000014	0.32	1993.86	544.14	0.05
Samarra Baghdad	23	Max WS	636.89	36.26	40.3	40.34	0.000209	0.83	769.23	375.08	0.19
Samarra Baghdad	24	Max WS	636.89	36.36	40.4	40.44	0.000211	0.93	687.41	287.95	0.19
Samarra Baghdad	25	Max WS	637	34.23	40.6	40.6	0.000017	0.35	1806.03	493.31	0.06
Samarra Baghdad	26	Max WS	637.13	37.11	41.09	41.13	0.000157	0.8	793.45	329.95	0.17
Samarra Baghdad	27	Max WS	637.28	39	42.78	42.82	0.000336	0.98	652.08	356.9	0.23
Samarra Baghdad	28	Max WS	637.47	40.22	44.09	44.11	0.000212	0.61	1041.29	815.43	0.17
Samarra Baghdad	29	Max WS	637.67	41.37	45.11	45.14	0.000223	0.77	825.94	473.78	0.19
Samarra Baghdad	30	Max WS	637.8	42.45	46.85	46.88	0.000479	0.81	791.48	755.97	0.25
Samarra Baghdad	31	Max WS	637.89	43.3	48.44	48.47	0.00016	0.77	833.31	374.61	0.16
Samarra Baghdad	32	Max WS	637.98	43.3	48.9	48.9	0.000016	0.29	2172.78	744.11	0.05
Samarra Baghdad	33	Max WS	638.06	46.1	49.62	49.68	0.000364	1.05	606.13	315.45	0.24
Samarra Baghdad	34	Max WS	638.12	51.7	55.34	55.64	0.001621	2.42	264.01	120.68	0.52
Samarra Baghdad	35	Max WS	638.13	49.8	56.5	56.6	0.000346	1.41	452.71	145.5	0.26
Samarra Baghdad	36	Max WS	638.14	50.6	56.81	56.86	0.000175	1.04	611.43	184.82	0.18
Samarra Baghdad	37	Max WS	638.15	49.4	56.89	56.94	0.000147	1	641.34	182.78	0.17
Samarra Baghdad	38	Max WS	638.17	49.4	57.01	57.02	0.000021	0.43	1475.47	342.35	0.07

Acknowledgment

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