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Morphology of Tigris River within Baghdad City

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Abstract

Changes in the morphology of the River Tigris within Baghdad City are very noticeable in recent years. The number of islands is increasing with time despite the fact that huge amount of sediments are trapped in reservoirs upstream Baghdad City. The debris of destroyed bridges in the wars of 1991 and 2003 had enhanced the development of these islands. As a consequence the ability of the river had been reduced to pass flood waves. This fact caused partial flooding of parts of Baghdad City.

Cross sections of the River Tigris were surveyed in three occasions (1976, 1991 and 2008). The last survey conducted in 2008 by Ministry of Water Resources covered 49 km of the river from Al-Muthana Bridge to its confluence with Diyala River at 250 m intervals. The data was used to predict the maximum flood capacity for the river using one-dimensional hydraulic model for steady flow “HEC-RAS”. Calibration was carried out for the model using field measurements for water levels along the last 15 km from its reach and the last 10 yr observations at Sarai Baghdad station.

The average discharge of the river in Baghdad had been calculated for the past ten years. This value was introduced in the model. Then different scenarios were applied by increasing the discharge in order to find out the critical discharge that can cause inundation. The procedure continued to detect the areas that had been inundated and the water level was recorded.

The model showed a significant reduction in the current river capacity in comparison with what the river had used to hold during floods of 1971 and 1988. The three surveys conducted on the same reach of the River Tigris indicated that the capacity of the river to pass water had been decreased. In addition the changes in the morphology of the river cross sections were very clear.

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1 Introduction

The Tigris River is 1850 km long, rising in the Taurus Mountains Eastern Turkey. The river flows about 400 km through Turkey and then it enters Iraq. The total length of the river in Iraq is 1418 km. It drains an area of area of 473 103 km^2 which is shared by Turkey, Syria and Iraq as shown in Fig. 1. About 58 % of the basin lies in Iraq. No major tributary joins River Tigris south of Baghdad (Al-Ansari et al., 1986, 1987). Few canals draw water from the Tigris in this region for irrigation purposes. For this reason the mean annual daily flow of the river falls below its value at Baghdad (1140 m^3 s^{-1}) in Kut and Amara cities at the south.

The average annual flow of the Tigris River is 21.2 km^3 yr^{-1} (672 m^3 s^{-1}) when it enters Iraq. Its tributaries contribute with 24.78 km^3 yr^{-1} (786 m^3 s^{-1}) of water and there are about 7 km^3 yr^{-1} (222 m^3 s^{-1}) of water brought by small wadies from Iran which drains directly toward the marsh area in the south (Al-Ansari and Knutsson, 2011).

Several cities were built on the banks of the Tigris since the dawn of civilization. Among these is Baghdad the capital of Iraq. Parts or all of these cities were inundated during the spring flood of the Tigris. To overcome this problem, hydraulic projects were constructed along the Tigris River. The control of the river was more efficient during the twentieth century where huge dams were built on the River Tigris (Al-Ansari and Knutsson, 2011). Despite all the hydraulic structures upstream Baghdad City, parts of the city was inundated in 1988. For this reason the Ministry of Irrigation conducted a new survey on the Tigris River in 1991 following the last survey which was executed in 1976. Later in 2008, the Ministry of Water Resources conducted a survey that extends from Al-Muthana Bridge in the north of Baghdad to Tigris – Diyala Rivers confluence in the south.

During the last 20 yr, growing islands became noticeable phenomena in the channel of River Tigris within Baghdad City and the numbers of islands are increasing with time. This research highlights the interactions with human activities on the River Tigris by building dams, bank lining and the debris dumped in the river channel within Baghdad.

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In view of these acts, changes in the geometry of Tigris River within Baghdad City and it's effectiveness on the flooding capacity of the river are examined.

2 Discharge of the River Tigris for the period 2000–2010

In recent years, water flow of the Tigris and Euphrates Rivers entering Iraq decreased dramatically, due to the huge water projects constructed on these rivers in the neighboring countries (Turkey, Syria and Iran) (Al-Ansari and Knutsson, 2011). In addition, the problem became more severe due to the recent dry climatic period in Iraq. In view of these factors the flow of the Tigris River dropped tremendously at Baghdad City. Figure 2 shows the discharge of the Tigris River during the years 2000–2010. The average discharge was 544 $m^3 s^{-1}$. This value is far away from the mean daily flow prior to 2005 (1140 $m^3 s^{-1}$) and flood discharges for the years 1971, 1988 and even 2005 where the flows were 4480, 3050 and 1315 $m^3 s^{-1}$, respectively.

3 Previous studies

There are number of studies conducted on the River Tigris. Among these are studies Herza (1963) which dealt with hydrological conditions of flow and Nedeco (1958) concerning the hydraulic conditions of flow. Further studies conducted by the Ministry of Irrigation are more related to this research work. The first was conducted in 1977 in cooperation with Geohydraulique which was entitled (Tigris River training project within Baghdad City) and the second with the University of Technology-Iraq in 1992 under the same title. In both studies, the geometry of the river was surveyed within Baghdad City in 1976 and 1991. Furthermore, suspended sediment samples were collected in these investigations also. These investigations were conducted to improve the river channel by protecting the banks against water erosion in floods and raising the banks in places of expected overflow during floods. The mathematical models used in these

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investigations were 1-D steady flow (using standard step technique) and morphological model for meanderings.

Similar river training studies were conducted on various rivers all around the world. Marchi et al. (1996) conduct evaluation for river training works in the lower Po River (in Italy). These training activities had reduced the overflow frequency as a consequence of protection and regulation works on the tributaries and on the main river. It reduced the storage capacity of the river flood bed due to a reduction of flood expansion areas in the upper and middle basin.

Lammersen et al. (2002) investigated the impact of river training and retention measures applied to Rhine River (in Germany) on the flood peaks along the river. They found that the weirs, which have been constructed along the upper reaches, and retention measures, which have been taken during the last years, have influenced the flood conditions along the river. SYNHP hydrological model was used to describe the flood routing processes in the river by using single linear stores and it was applied to evaluate the effects of retention measures along the upper reaches. One-dimensional river flow model "SOBEK" was used to carry-out flow calculations for the middle and lower reaches based on the Saint-Vernant equations. The results of the models showed that the effects of the river training activities led to a rise of the peak flow with the consideration of retention measures.

Korpak (2007) explained the influence of river training on erosion channels changes for rivers in mountains (in Poland) over 53 yr. Debris dams and groynes where built before 1980 caused great changes in channel pattern and increasing of channel gradient and magnitude of river incision. The measures that considered to decrease the river downcutting (mostly involved drop structures) worked considerably well, but the river continued incising toward the bedrock. The researcher mentioned that river training schemes distort the equilibrium of channel systems and most of them were ineffective in the long term because they did not consider the whole stretch of the river.

4 Control structures upstream Baghdad City

Four tributaries contribute to the Tigris River flow upstream Baghdad City and one tributary at its southern part (Fig. 1). Number of dams and, barrages and regulators were constructed on the river since the second half of the twentieth century. To link these structures with the surveys conducted on the Tigris River, they can be classified in three periods. The first period is prior 1976. During this period the first structure established was Samara barrage in 1956 and in 1961 Dokan dam on the Lesser Zab tributary was in operation in 1961. The second period starts after 1976 and ends in 1991. Two main dams were constructed in this period. They are Hemrin dam (operated in 1981) on Diyala River and Mosul dam (operated in 1986) on Tigris River. During the third period (after 1991), only Adhaim dam (operated in 1999) on Adhaim River was constructed.

The sequence of floods and high water periods of the Tigris Rive and the interaction of the control structures with these events in the last century, the river was subjected to erosion and deposition processes in such away that it is classified as unstable river (Geohydraulique, 1977). This instability reflected by appearance and disappearance of islands, banks erosion, etc.

5 Bridges on Tigris River within Baghdad City

Tigris River runs through Baghdad City dividing it in two parts. Number of bridges was constructed on the River Tigris to connect both parts of the city. These bridges disturbed the flow of the river. Prior to 1976, six bridges were constructed on the river in the northern part of Baghdad. During 1976–1991, six more bridges were constructed on the river; four of them on the northern part while other two were on the southern part of the city. After 1991, only one bridge was constructed on the southern part of Baghdad. This makes the total number of bridges in north part of Baghdad 10. This

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implies that the disturbance of flow is relatively higher in the northern part of the Tigris River within Baghdad City.

During wars in 1991 and 2003, three major bridges (Jumhuriya, suspended and Sarafia bridges) on Tigris River were subjected to high level of damage and large pieces of concrete and steel fall down in the river. Large debris was removed from the river while relatively small parts remained on the bed of the river.

Reconstruction procedure required installing temporary bridge as in case of suspended bridge or dumping an area from the river bed to make earth road for the heavy machinery as in case of Al-Sarafia Bridge. Figure 3 shows the damage happened to Al-Sarafia Bridge and the temporary bridges parallel to the suspended bridge. All these practices, added more obstacles to the flow within the river. The debris left on the bed of the river enhanced the formation of new islands (Fig. 4).

6 Changes in river geometry

Islands development in the River Tigris changed tremendously during the past 40 yr. There were only three main islands noticed in the 1976 survey. They are Suraidat, Um Al-Khanazer and Abu Rumail islands. Two more small islands were not mentioned in that survey. The first located at the second meandering within the study reach (Kureat) and the second about 9 km upstream Diyala River confluence.

During 1976–1991, a recreation park was constructed on Suraidat Island. To connect the island with the bank of the river, the left arm of the river was converted to a lagoon. By this, the island was connected to the bank of the river. The same was done with Um Al-Khanazer Island. In this case the right arm of the river was converted to a lagoon.

River cross section of 1991 survey revealed that there were indications of new islands growing which were not noticed in the 1976 survey. In addition, changes in the bed and the banks of the river took place. These changes varied from increase of the depositions on the inner side of meanders, to the increase of the bed levels. These changes became more noticeable in the 2008 survey.

During the period 1976–1991, most of the banks of the northern part of the river were protected by stones and cement. The same is true for the southern part of the river but to a lesser extent. At the end of 2002, about 66 % of the banks of the river reach were protected to the level 36–37 m a.s.l. The objectives were to canalize the river course within the most popular urban areas and to avoid river banks collapse during flood (Al-Ansari et al., 1979).

The irregularity of Tigris River cross sections was reflected on the variation in flow velocity along its reach and consequently, flow velocity was capable of eroding the bed in some sections of the river. This caused erosion and deposition in new segments of the reach. It is noteworthy to mention that most of the suspended sediments were trapped in the upstream reservoirs which enhanced the river to reach a new stable regime (Morris and Fan, 2010).

Recent water shortages in the flow kept the water level low in the river cross section. In such a case the protected banks have no value. In view of this new condition, the water is eroding below the protected banks now. This will lead to the collapse of parts of these protecting banks in future.

The comparison the river bed levels in 1976, 1991 and 2008 showed that in addition to the fluctuation in bed elevations along the reach (Fig. 5), considerable changes in elevations took place with time for the same section (Fig. 6). It is clear that the bed level fluctuation in 1991 was relatively the maximum. This can be due to the fact that this survey was conducted shortly after the 1988 flood. The variation in 2008 was the minimum which can be attributed to some factors. One of these is the fact that the survey was conducted 20 yr after the high flood of 1988. Secondly, the river suffered from low flow regime during the past 20 yr.

Generally, the average slope of the bed of the Tigris River within Baghdad became higher in 2008 (5 cm km^{-1}) compared to previous surveys conducted in 1976 (1.03 cm km^{-1}) and 1991 (2.45 cm km^{-1}).

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The current obstacles in river were summarized in Table 1. The location, type and length of each obstacle are described. Some of these obstacles are islands and others are bank depositions. Figure 7 shows the locations and shapes of these obstacles.

7 Methodology

7.1 River geometry

The last survey conducted on Tigris River in Baghdad was in 2008 by the Iraqi Ministry of Water Resources. The survey covered 49 km of the river reach staring from Al-Muthana Bridge at the north of Baghdad City till the confluence with Diyala River south of the city. 219 cross sections were surveyed at intervals of 250 m.

This survey was used in current work. A 1-D steady flow model was build from these cross sections using HEC-RAS program. The model was supplied with additional data concerning the locations and dimensions of bridges were supplied to the model. The locations of the cross sections used of the river reach are shown in Fig. 8.

7.2 Boundary conditions

The average discharge of the river in Baghdad had been calculated for the past ten years. This value of flow and other values (the flow values considered in previous studies) were used in the model as upstream boundary conditions.

The modified rating curve for the river to the downstream of Diyala confluence was used as downstream boundary for all upstream conditions.

7.3 Model calibration

Calibration was done for the model by using observed water levels along last 15 km of the reach. These observations were recorded in short periods at the same day for discharge of 400 $m^3 s^{-1}$.

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Calibration process included the modification of Manning's *n* for the main channel and the floodplain to achieve coincidences between computed water surfaces and observed one. The minimum Root Mean Square Errors (RMSE) (RMSE = 0.026 m) were obtained for Manning's n as 0.0285 for the main channel and 0.042 for floodplains. Precise data about water consumption along the reach were not available; therefore, the lateral inflow/outflow values were included with average flow of Diyala River where it was 5 $m^3 s^{-1}$.

7.4 Model verification and application

Different scenarios were applied by increasing the discharge, starting from the average flow for the past ten years, in order to find out the critical discharge that can cause inundation. For some of these discharges, observed water surface were recorded in Sarai Baghdad station during the past ten years. These observations covered the discharges from 500 to 1300 $m^3 s^{-1}$. New RMSE was computed for these observations and it gave good coincidence (RMSE = 0.046 m) as shown in Fig. 9.

8 Results and discussion

The procedure of increasing upstream discharge continued so that areas that had been inundated can be detected. The discharges that were considered in this work started at 500 $m^3 s^{-1}$ and increased in the same steps as that were considered in previous studies. All these discharges were repeated in the model for 4 scenarios. The different in each scenario was the lateral inflow that represented by Diyala River flow. The lateral inflow for the first (base) scenario was 5 $m^3 s^{-1}$. This represents the average observed flow in Diyala River and it was also used for calibration purposes. Three more lateral inflow values (25, 50 and 100 $m^3 s^{-1}$) were also considered. The effect of back water curve that associated with each lateral inflow was checked. Table 2 shows the average differences in water elevation for each scenario with respect to the water elevations in

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the base scenario. These differences indicate that the effect of lateral inflow had not significance in higher discharges.

Comparing with the previous studies, the water surface elevations computed at Sarai Baghdad station from current work were drawn with those from previous studies (1976 and 1991) in Fig. 10. The current water levels were lower than those of 1976 study for low discharges and became higher for high discharge. While they stayed always lower than those water levels recorded in 1991.

Figure 9 shows that the discharges that are higher than 2700 $m^3 s^{-1}$ could cause partial inundation in some areas in the northern part of the reach. The critical elevation for inundation along the reach is 35 m at station 43 000 m. For discharges greater than 3500 $m^3 s^{-1}$, the inundation could take place along approximately 9 km reach. For the southern part of the reach, the inundation is not expected to happen up to 3500 $m^3 s^{-1}$ discharge.

The surface water slopes for the base scenario varied from 6.03 to 6.84 $cm\,km^{-1}$ for discharges 400 to 1500 $m^3 s^{-1}$, respectively. For discharges 2500 and 2700 $m^3 s^{-1}$, the slopes were 8.59 and 8.96 $cm\,km^{-1}$, respectively. While it reached 10 $cm\,km^{-1}$ for discharges 3500 and 4000 $m^3 s^{-1}$.

The rating curve used as downstream boundary condition needs more modification in high water stages to be more reliable for the new geometry conditions for the river.

9 Conclusions

The results of the three surveys and the operation of the model on the channel of the River Tigris indicate the following consequences on the river channel:

1. Recent water shortages in the flow kept the water level low in the river cross section and the protected banks have no value and enhanced the river to reach a new stable regime.

2. Since the water is eroding below the protected banks levels now, this will lead to the collapse of parts of these protecting banks in future.

3. The bed levels fluctuation was the minimum according to the 2008 survey relative to those of 1976 and 1991.

4. The average slope of the river bed became higher in 2008 compared with previous surveys.

5. The current observed obstacles in 2008 survey are the highest in number in the most complicated in location compared to the two surveys in 1976 and 1991.

6. The results of the model showed very good coincidence with the observed water levels in Sarai Baghdad station and along the last 15 km of the reach.

7. The computed surface water slopes varied from 6.03 to 6.84 $cm\,km^{-1}$ for low flows.

8. The inundation could take place along approximately 9 km reach for discharges greater than 3500 $m^3\,s^{-1}$.

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Table 1. Main observed obstacles in Tigris River within Baghdad City in 2008.

Location	Type	Length (km)	Symbol (Fig. 7)
Kura'at	Bank deposition	1.4	A
Kadhmiyah	Bank deposition	0.6	B
Kadhmiyah	Island	1.0	C
Kadhmiyah	Bank deposition	1.2	D
Adhmiyah	Bank deposition	0.6	E
Adhmiyah	Bank deposition	0.8	F
Etiafiyah	Bank deposition	0.7	G
Sinak-Jumhuriyah	Small islands	–	H
Abu Nuwas1	Island	0.6	I
Abu Nuwas2	Island	0.3	
Abu Nuwas	Bank deposition	1.0	J
Jadriyah	Island	0.4	K
Dura	Bank deposition	1.5	L
Dura	Island	0.4	M
Dura	Island	1.0	N
Dura	Island	1.1	O

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Table 2. Average differences in water elevation (m) for each scenario with respect to base scenario.

Tigris Flow	Lat. Flow 25	Lat. Flow 50	Lat. Flow 100
400	0.040	0.102	0.209
500	0.038	0.087	0.186
800	0.030	0.067	0.142
1100	0.023	0.052	0.110
1300	0.019	0.044	0.095
1500	0.017	0.039	0.083
2500	0.010	0.023	0.049
2700	0.009	0.021	0.047
3500	0.008	0.020	0.045
4000	0.007	0.019	0.043

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Fig. 1. Map of Iraq showing the Tigris and Euphrates Rivers.

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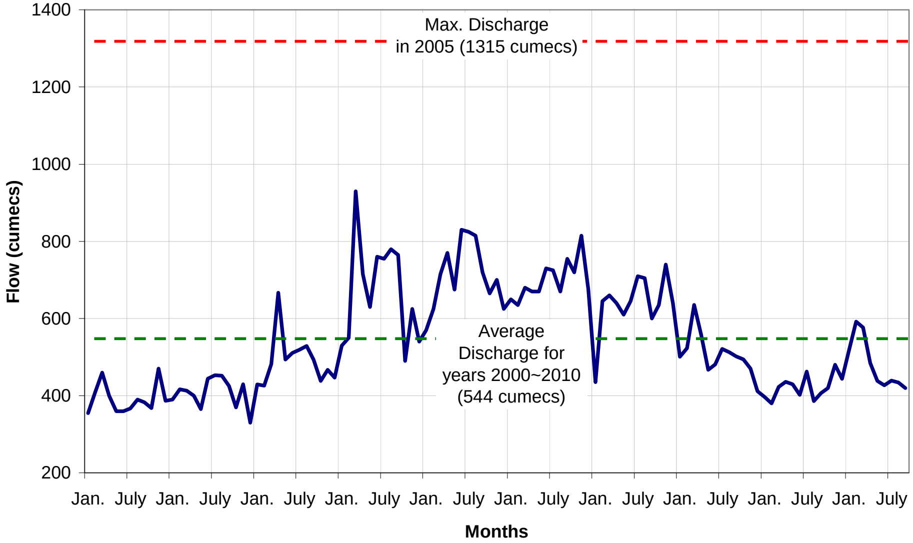

Fig. 2. Recorded Tigris River flow at Sarai Baghdad station for the period 2000–2010. Data source: Shahrabaly (2008).

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(a) (b)

Fig. 3. (a) Destroyed parts from Al-Sarafia Bridge have fallen in the river (from http://www.wikipedia.org). **(b)** Temporary bridges parallel to the suspended bridge.

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Fig. 4. Small growing islands at Jumhuriyah Bridge location.

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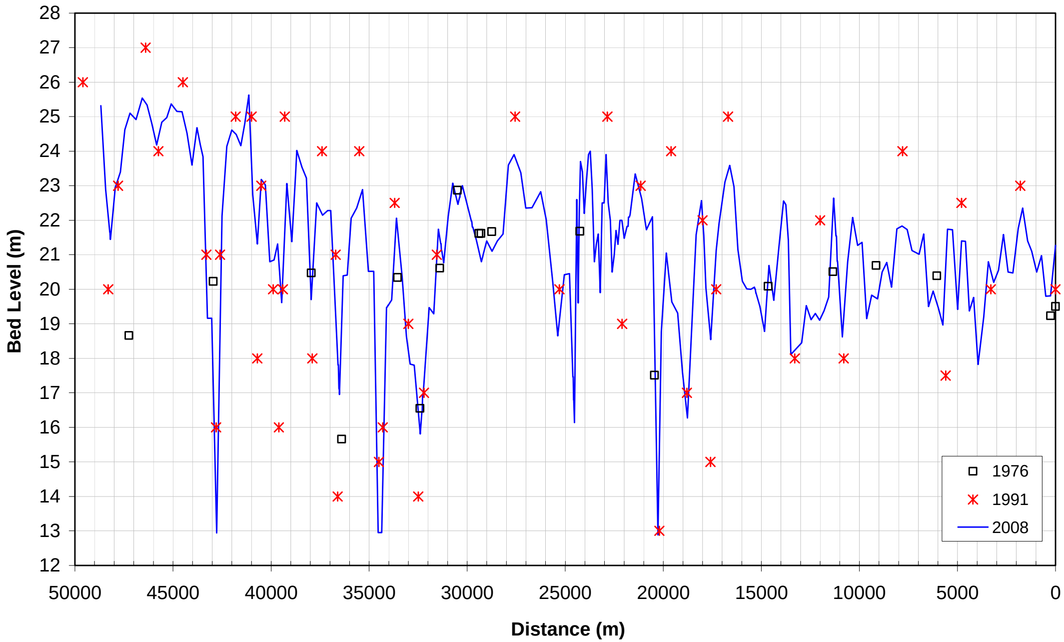

Fig. 5. Tigris River bed elevations during 1976, 1991 and 2008.

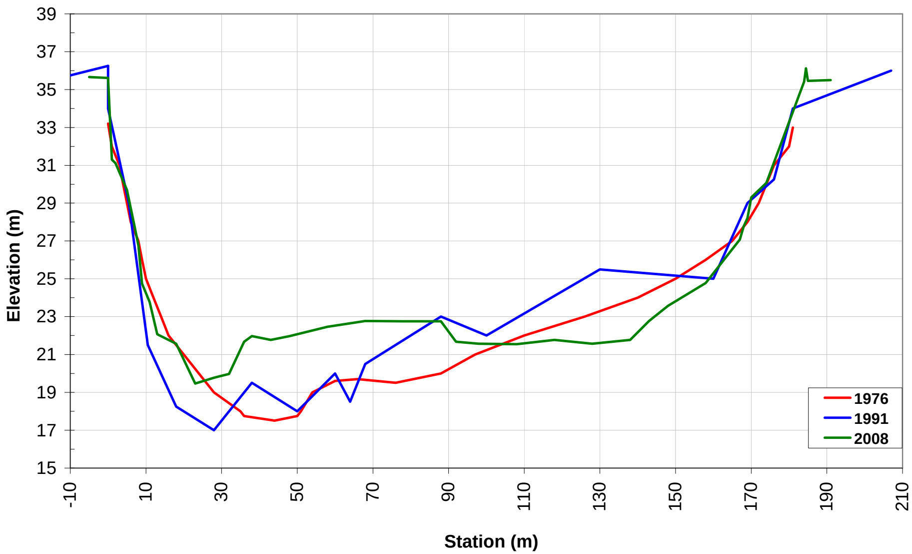

Fig. 6. Changing in geometry shape of Sarai Baghdad gauging station.

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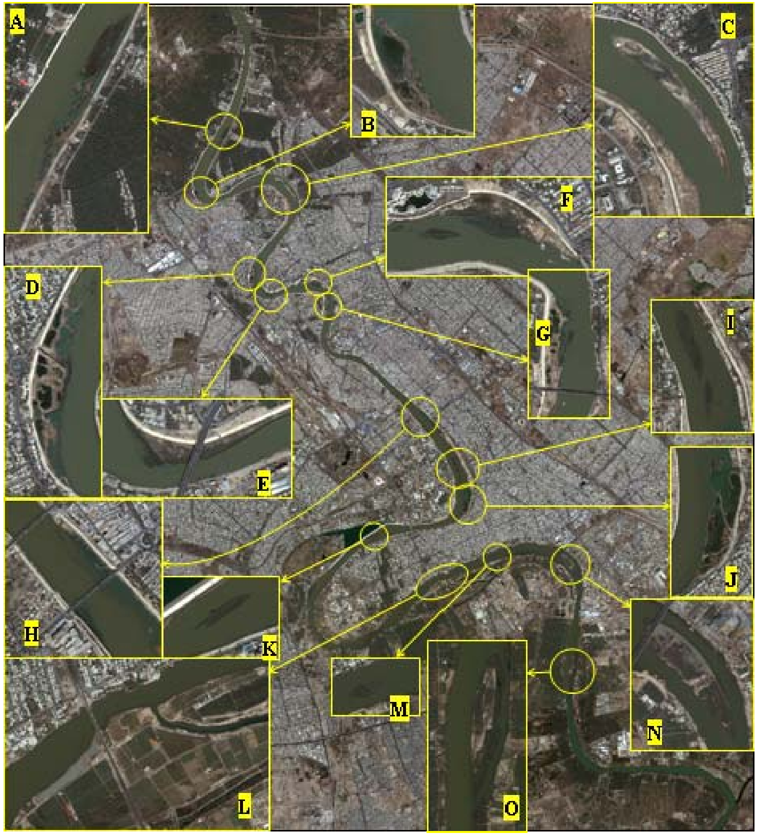

Fig. 7. Observed obstacles in Tigris River in 2008.

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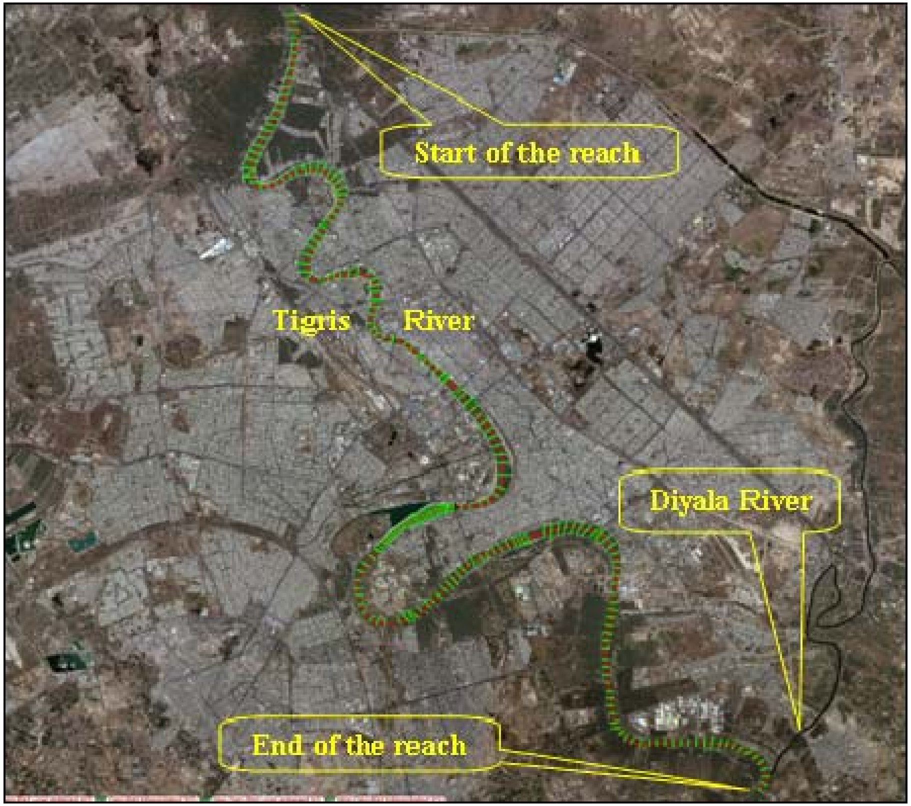

Fig. 8. Cross sections of Tigris River by HEC-RAS.

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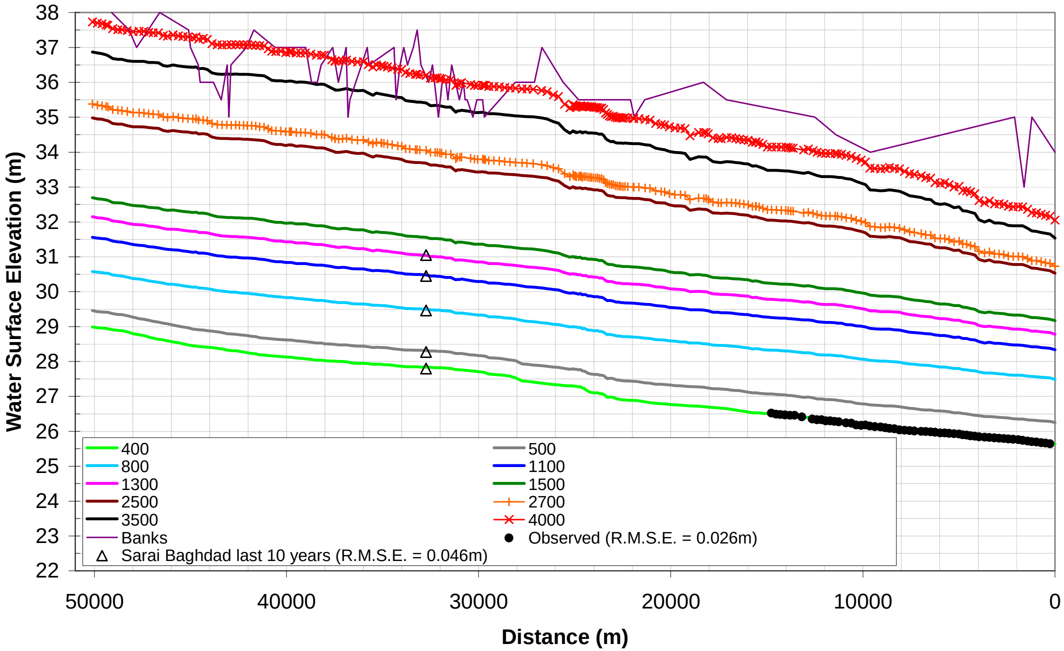

Fig. 9. Computed water surface elevations for different discharge in Tigris and Diyala Rivers with discharge of 5 $m^3 s^{-1}$ with calibration and verification data.

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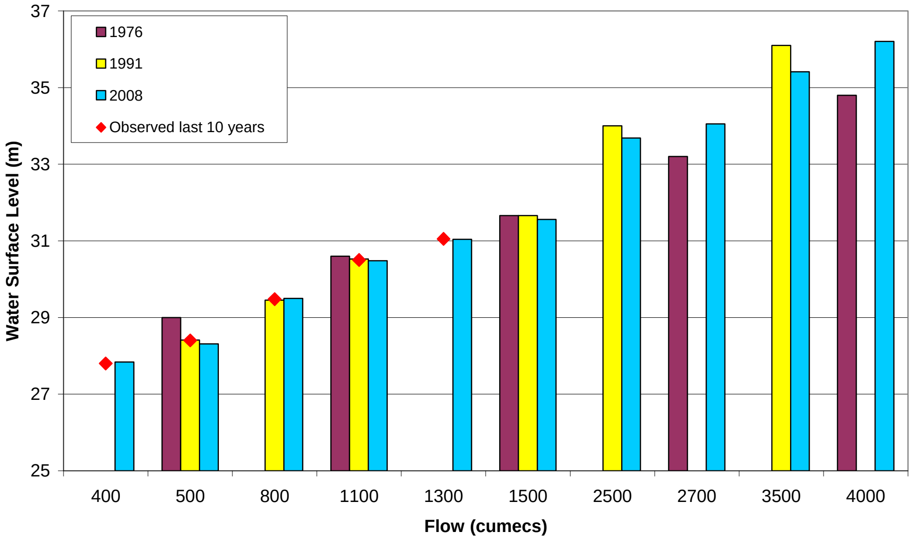

Fig. 10. Comparison for computed water levels at Sarai Baghdad station in 1976, 1991 and 2008.

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