

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.

5675

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

5676

References

- Al-Ansari, N. A. and Knutsson, S.: Toward prudent management of water resources in Iraq, *J. Adv. Sci. Eng. Res.*, 1, 53–67, 2011.
- Al-Ansari, N. A., Ali, S. H., and Taqa, A. S.: Sediment discharge of the River Tigris at Baghdad (Iraq), *Proceedings of the Canberra Symposium, IAHS-AISH Publ.*, 128, 399–407, 1979.
- Al-Ansari, N. A., Sayfy, A., Al-Sinawi, G. T., and Ovanessian, A. A.: Evaluation of the water quality for the lower reaches of River Tigris using multivariate analysis, *J. Water Res.*, 5, 173–187, 1986.
- Al-Ansari, N. A., Salman, H. H., and Al-Sinawi, G. T.: Periodicity of selected water quality parameters for the Tigris water at Baghdad, *J. Water Res.*, .6, 11–17, 1987.
- Al-Shahrabaly, Q. M.: *River Discharges for Tigris and Euphrates Gauging Stations*, Ministry of Water Resources, Baghdad, 2008.
- Geohydraulique: Tigris River Training Project within Baghdad City, report submitted to the Ministry of Irrigation-Iraq, Paris, 1977.
- Herza Engineering Company: *Hydrological Survey of Iraq*, report submitted to the Ministry of Agriculture-Iraq, Illinois, 1963.
- Korpak, J.: The influence of river training on mountain channel changes (Polish Carpathian Mountains), *Geomorphology*, 92, 166–181, 2007.
- Lammersen, R., Engel, H., van de Langemheen, W., and Buiteveld, H.: Impact of river training and retention measures on flood peaks along the Rhine, *J. Hydrol.*, 267, 115–124, 2002.
- Marchi, E., Roth, G., and Siccardi, F.: The Po: centuries of river training, *Phys. Chem. Earth*, 20, 475–478, 1996.
- Morris, G. L. and Fan, J.: *Reservoir Sedimentation Handbook*, McGraw Hill Book Co., New York, 2010.
- Nedeco: *Study of the navigation in Tigris River between Baghdad and Mosul*, report submitted to the Ministry of Development, Amsterdam, 1958.
- University of Technology: *Training of Tigris River inside Baghdad City*, report submitted to the Ministry of Agriculture and Irrigation-Iraq, Baghdad, 1992.

5683

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 |

5684

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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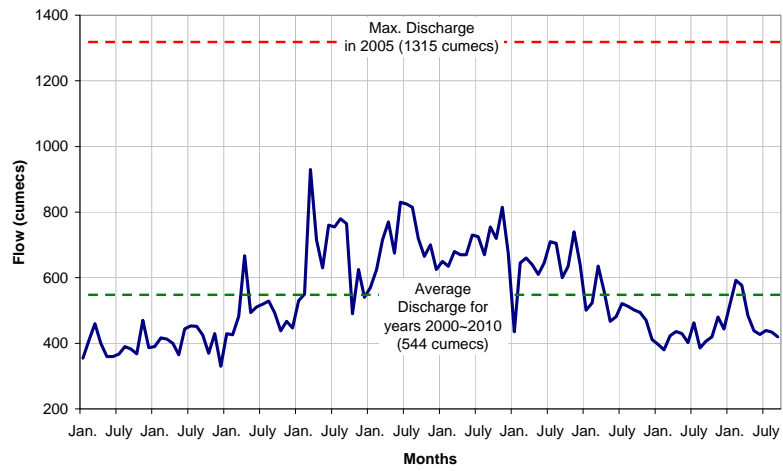


Fig. 2. Recorded Tigris River flow at Sarai Baghdad station for the period 2000–2010. Data source: Shahrabaly (2008).

5687



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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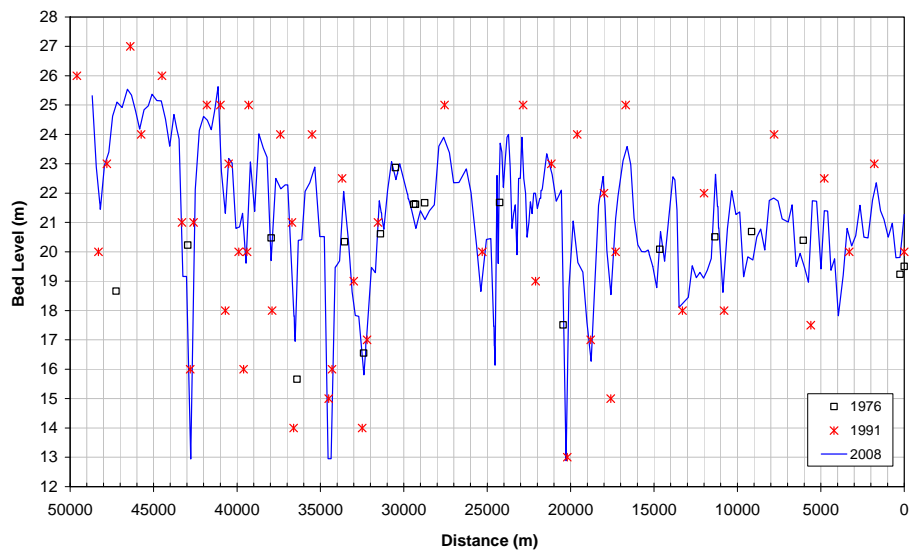


Fig. 5. Tigris River bed elevations during 1976, 1991 and 2008.

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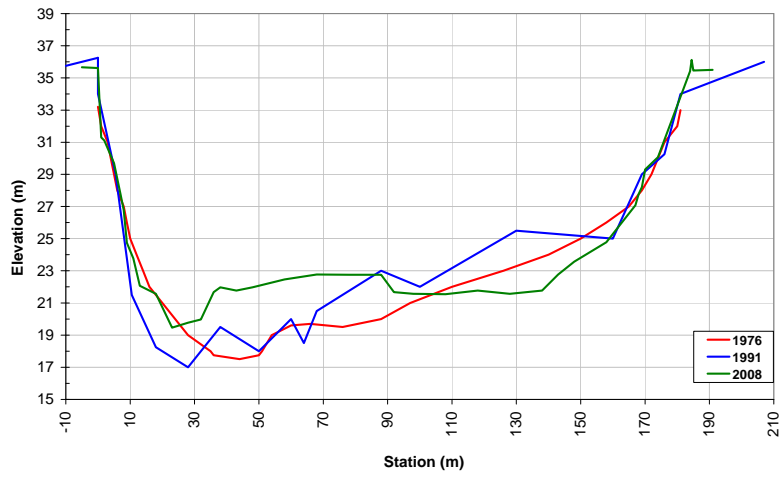


Fig. 6. Changing in geometry shape of Sarai Baghdad gauging station.

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

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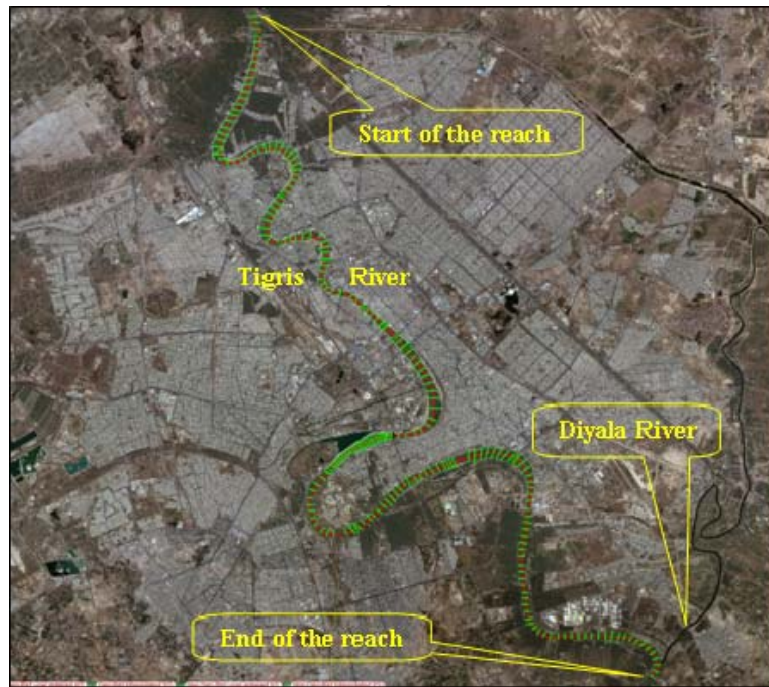


Fig. 8. Cross sections of Tigris River by HEC-RAS.

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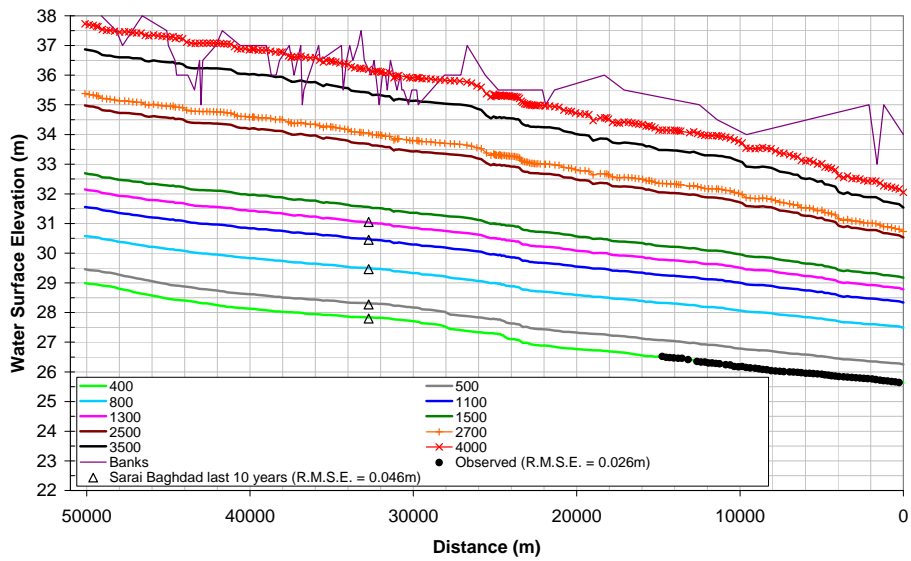


Fig. 9. Computed water surface elevations for different discharge in Tigris and Diyala Rivers with discharge of $5 \text{ m}^3 \text{ s}^{-1}$ with calibration and verification data.

5694

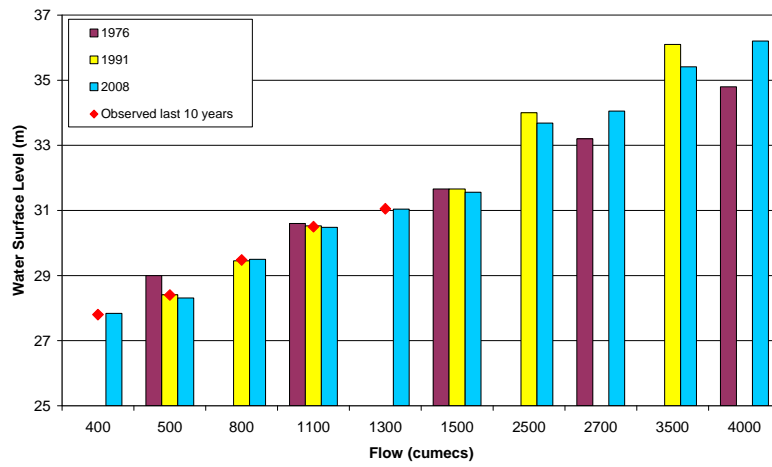


Fig. 10. Comparison for computed water levels at Sarai Baghdad station in 1976, 1991 and 2008.