Morphology of Tigris River within Baghdad City

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General Points

The paper by Ali, Al-Ansari and Knutsson is an interesting and temporally appropriate examination of the flooding potential of the River Tigris as it flows through the Iraqi capital city of Baghdad. The authors have used data collected by others, including members of staff of the Iraqi Ministry of Water Resources. They have applied bathymetric information from cross-sections of an exceptionally long reach of the river to a one-dimensional numerical model to estimate the water surface levels to which flood waters of historically measured discharges known to have occurred at Baghdad in the past would reach with the channel changes that have occurred in the last few decades if repeated today. No details of the numerical model are given, but the study represents a highly practical combined application of field and modelling techniques with the ability to point to localities which are potentially vulnerable to flooding today unless steps are taken to raise embankments or introduce other protection measures in the future.

One exceptional feature of the work is the impact of military damage to bridges crossing the river and the resultant debris and reconstruction works stimulating the development of localised shallows and islands. However, the hydraulic responses to river bed changes related to the substantially reduced water discharges resulting from impoundments behind dams in the catchment, and also to the diminished rainfall apparently associated with climatic changes in recent years, may account for the formation of similar bed structures.

In the concluding sections of the paper the predicted surface water level variations through the entire reach during the greatest flood discharges examined ($4000m^3s^{-1}$) are predicted to fall from 38m at the Al-Muthane Bridge in the north to 32m at the confluence with the Diyala River to the south. With the much lower discharge of $1100m^3s^{-1}$ the surface water levels are predicted to fall from 32.5m at the Al-Muthana Bridge to 28.5m at the Diyala confluence. Under the conditions of the high and moderate floods the differences in water surface levels between the input and output gauging stations is predicted to be 6.0m and 4.0m respectively. As a control check for the working of the model the water surface levels for flows of $400m^3s^{-1}$ as observed on the Tigris itself coincided well with the model predictions in the lower third of the reach. No similar actual data are available to give confirmation to the levels predicting conditions from greater flows.

Specific Points

A knowledge of the water discharges at the input and output ends of the reach enabled an estimate to be made of a value for the Manning coefficient of the resistance to flow. A value of 0.45 was needed to enable the numerical model to reproduce the known input and output conditions during low discharges. It would be interesting to know whether this was the best fit value of several tried during the modelling. The use of a single value for the coefficient over such a long reach is inevitably an average figure as the resistance will vary with the meandering morphology, distributiion of reed beds anlong some of the embankments, grain size of material on the bed, and also with any bed forms present.

No discussion of the gross morphology and its impact on the resistance is provided. Similarly, no information is given on the nature of the bed sediments. For coarse sand systems the Manning value quoted may very well be appropriate, but if the sediments contain appreciable quantities of silts and clays, then a lower figure would be more appropriate. The presence of reed beds on the upper banks in several areas would provide much higher resistance to flow and contribute to defining the location of the highest water level during peak flows.

A discussion of the nature of the bed sediments and their bed forms may be significant even if their impact on the study predictions is shown to be minimal. The resistance to flow may be significantly different between dune-bedded sands and relatively flat-bedded mud-dominant sectors. This point serves to draw attention to the absence of any indication of the nature of the river bed between the cross-sections which provide the channel information analysed. A knowledge of such along-channel bathymetric characteristics would permit not only the potentially changing values of resistance to be recognised, but would also draw attention to the problems of comparing data from survey lines traversed at substantial time-intervals.

In the reach of the Tigris examined the bed is likely to be largely of sands which respond to current flows of the lower flow regime by creating migratory dunes. In their simplest geometry these asymmetrical mounds have linear crests orientated at right angles to the direction of the current. Hollows are excavated at the foot of the migratory dunes, and the height difference between crest and hollow floor may often exceed a metre As they mature the dune crests become sinusoidal in plan, with parts of the crest migrating more swiftly than others. Under such conditions any bathymetric survey line run directly across the river will inevitably cross both high and low sectors of the dune field. The question arises as to which depth should a model take, that of the high or low part of the dune field. Even with precise position fixing by DGPS systems on consecutive days of the same flow discharges identical, well controlled, traverses may give appreciable differences in the total and average water depths across that single line. The paper shows abrupt depth changes on traces from the 1991 survey, which may well be of this form. However the much greater regularity of the traces from the 1976 and 2008 surveys appear to lack any such features, suggesting that during those two surveys dune systems may have been absent. These differences may have been inherited from the flows of the river during earlier periods before the surveys were carried out.

The lack of detail on the nature of the bed and any information on river discharges on days preceeding the surveys may well be constrained by the desire to achieve the admirable brevity of the paper. Overall the authors have made a useful initial attempt to predict potential for flooding in the northern sectors of Baghdad. As indicated above much of the information on the bed composition, the grain sizes, the bed forms and their impact on the model remains to be explored.

It would be of historical interest to examine the long record of discharge variation on the Tigris to determine the predicted heights to which the various known floods would have reached with the present bed morphology, and their impact within the city. It is probable that such records exist, probably in old documents and newspapers.

In the early part of their contribution the authors note that during the latter parts of the twentieth century the construction of dams in the headwaters of several of the water systems has led to a decrease in the Tigris flows at Baghdad. Did all three of the surveys examined take place after the effects of these structures was recognised? It would be of interest to know whether the full range of discharges examined in Figure 9 could still be expected to reach the city. There may be a need to reassess the realistic flood peaks expected to reach Baghdad today rather than designing protection systems based on discharge figures from the past.

Technical points

This paper is well worth publishing, but as it stands there are so many, often quite minor, modifications that it will be simpler if I put all my suggested changes into the text. It may take a while for me to retype the work, but I hope that a better product will result. The paper reads adequately as it stands, but I would give it a little polish if I may.

Abstract

In recent years substantial changes have occurred in the morphology of the River Tigris within Baghdad City. Although huge volumes of sediment are being trapped in recently constructed headwater reservoirs, the number of islands in the Tigris at Baghdad is increasing. The debris of bridges destroyed in the wars of 1991 and 2003 and their subsequent reconstruction have enhanced the development of these islands. As a consequenc the ability of the river to carry the peaks of flood waters has been reduced. This has led to potential increas of flooding in parts of the city.

The bed of the River Tigris has been surveyed on three occasions (1976, 1991, and 2008). The most recent, conducted by the Ministry of Water Resoueces, extended 49km from the Al-Muthana Bridge to the confluence with the Diyala River. It yielded cross-section profiles at 250m intervals t The data are used to predict the maximum flood capacity for the river using the one-dimensional hydraulic model for steady flow "HEC-RAS". Calibration of the model was carried out using field measurements for water levels along the last 15 km of the reach and the last 10 years of observatioin at the Sarai Baghdad gauging station.

The model showed a significant predicted reduction in the current river capacity below that which the river had carried during the floods of 1971 and 1988. The three surveys conducted on the same reach of the Tigris indicated that the ability of the river to transport water has decreased,

1. Introduction

The River Tigris is 1850 km in length, rising in the Taunus Mountains of Eastern Turkey. The river flows for about 400 km through Turkey before entering Iraq. The total length of the river in Iraq is 1418 km. It drains an area of 473,103 km^2 which is shared by Turkey, Syria and Iraq, as shown in Figure 1. About 58% of the basin lies in Iraq, and no major tributary joins the Tigris south of Baghdad (Al-Ansari et al ., 1986, 1987), but several 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 the discharge at Baghdad (1140m^{3}s^{-1}) at Kut and Amara, cities to the south.

The average annual flow discharge of the Tigris is 21.2 km^{3}a^{-1} (672 m^{3}s^{-1}) when it enters Iraq. Its main tribuaries contribute a further 24.78km^{3}a^{-1} (786m^{3}s^{-1}) of water and some minor wadies from Iran carry about 7km^{3}a^{-1} (222m^{3}s-^{1}) directly into the southern marsh area (Al-Ansari and Knutsson, 2011).

Several cities have been built on the banks of the Tigris since the dawn of civilization. Among these is Baghdad, the capital city of Iraq. Parts of all of these cities were inundated by the spring floods of the river. To overcome this problem various hydraulic projects have been constructed along the Tigris. The control of the river was most efficient during the twentieth century after huge dams were built to entrap some of the waters (Al-Ansari and Knutsson, 2011). Despite the presence of many hydraulic structures upstream of the city, parts of Baghdad were inundated in 1988. For this reason the Ministry of Water Resources, which had conducted a previous survey of the river in 1976, undertook a second survey in 1991. In 2008 the Ministry od Water Resources made a third survey, extending from the Al-Muthana Bridge to the north of Baghdad to the Tigris-Diyala confluence in the south.

In the last ceentury the nature of the successions of high water and flood conditions and the interactions of the flows with the many control structures have induced erosion and deposition of material on the river bed, and the growth and disappearance of islands, to the extent that is has been classified as an unstable river (Geohydraulique, 1977).

During the last twenty years growing islands have become noticeable features in the Tigris channel within Baghdad City, the numbers of islands increasing with time. In this contribution the iimpact of human activities in dam building, bank lining and dumping of debris within the channel at Baghdad has led to changes in the geometry of the river and its ability to carry flood waters.

2. Discharge of the River Tigris in the period 2000-2010

In recent years the water flows of the Tigris and Euphrates Rivers entering Iraq have decreased dramatically, due to the major water impoundment projects constructed and some remain under construction on these rivers in the neighbouring countries, Turkey, Syria and Iran (Al-Ansari and Knutsson, 2011). In addition the problem has become more severe due to the recent dry climatic period in Iraq. As a result the flow of the Tigris at Baghdad has fallen sharply. The discharge of the Tigris at Baghdad during the years 2000-2010 is shown in Figure 2. The average discharge of 544 m^3s^{-1} is less than half of the mean daily flow of $1140m^3s^{-1}$ prior to 2005 and well below the flood discharges of 4480, 3050 and 1315 m^3s^{-1} recorded in 1971, 1988 and 2005 respectively.

3. Previous studies

In the past several studies have been conducted on the River Tigris. Among these NEDECO (1958) and Hezza (1963) examined the hydraulic conditions controlling flows and the hydrological constraints respectively. Later studies conducted by the Ministry of Irrigation were more related to the present research. The 'Tigris River training project within Baghdad City' in 1977 was conducted with Geohydraulique, and a second study, in 1992, was linked with the University of Technology in Iraq. Suspended sediment samples were collected in both programmes which were designed to improve the river channel by protecting the banks against water erosion in floods and raising the banks in places of expected overflow. The numerical models used in these investigations were for 1-D steady state flow (using a standard step technique) and also a morphological model for the river meanderings.

Similar river training studies have been contucted on many rivers worldwide. Marchi et al (1996) evaluated river training works in the lower Po River of Italy. There training activities had successfully reduced the overflow frequency as a consequence of protection and regulation works on the tributaries and also on the main river. The storage capacity of the river flood bed was reduced due to a reduction of flood expansion areas in the upper and middle parts of the drainage basin.

Lammersen et al (2002) investigated the impact of river training and retention measures on the flood peaks on the River Rhine in Germany. They found that weirs constructed along the upper reaches and other retention measures had successfully influenced the flood conditions along the river. The SYNHP hydrological model was used to describe the flood routing processes in the river by using single linear stores and this was used to evaluate the effects of retention measures in the upper reaches. The 1-D river flow model SOBEK was used to perform flow calculations for the middle and lower reaches, based on the Saint-Vernant equations. The models indicated that the river training activities led to an increase in peak flow.

Korpak (2007) demonstrated the influence of river training on channel erosion in Polish mountain rivers. Using data from 53 years of observations he showed that debris dams and groynes built before 1980 had caused great changes in channel patterns and increased the channel gradient and the rate of river incision. He considered that although the measures to decrease river downcutting in alluvial deposits worked well it had not been eliminated. Korpak noted that river training schemes distort the equilibrium of the channel systems and that most such projects were of limited success in the long term because they rarely considered the entire reaches of the rivers.

4. Control structures upstream of Baghdad City

Four tributaries contribute to the Tigris River flows upstream of Baghdad (Figure 1) A number of dams, barrages and regulators have been constructed on the river during and since the second half of the twentieth century. To link these structures to the Tigris River surveys under examination they can be classified according to three periods of installation. Prior to 1976 the Samara Barrage (1956) and the Dokan dam on the Lesser Zab tributary (1961) were the two main modifications to the river. During the second period, from 1976 to 1981, the Hemrin dam on the Diyala River has operated since 1981, and the Mosul dam on the Tigris began operating in 1986. The only significant major structure constructed since 1991 was the Adhaim dam, opened in 1999. No detail has been given for anticipated discharge of compensation waters from the 10.4 km^3 capacity reservoir to be created by the Ilisu dam, yet to be completed, in Turkey and their potential impact on the water movements in the middle Tigris valley area.

5. Bridges on the River Tigris within Baghdad City

The City of Baghdad is divided into two substantial areas by the River Tigris. These are connected by a number of bridges which disturb the flow of the waters. Prior to 1976 six bridges spanned the river in the north of the city. Six more bridges were constructed during the period 1976 to 1991, four more in the north and two in the southern part of the city. Only one additional bridge has been constructed linking the southern parts of the city since 1991. The geographic distribution of the bridges, with ten towards the north and only three in the south of the city indicates that the resulting disturbance to river flows is greater in the north than in the south.

During the wars of 1991 and 2003 three major bridges (Jumhuriya, Sarafia and the suspension bridge) suffered a high level of damage causing large pieces of concrete and structural steel to fall into the river. Although many of the larger pieces of debris were removed from the river bed, much of the smaller material could not be removed and remains on the river bed.

The reconstruction procedures for the three bridges required the installation of a temporary bridge for the suspension bridge and the formation of an earth structure capped by a roadway to carry heavy machinery in the case of the Al-Sarafia Bridge. The damage to the Al-Sarafia Bridge and the temporary bridges parallel to the suspended bridge are illustrated in Figure 3. The construction and removal of these temporary structures are believed to have enhanced the formation of new islands in the river (Figure 4).

6. Changes in river geometry

Three main islands were recognised in the 1976 survey, namely Suraidat, Um Al-Khanazer and Abu Rumail, and two smaller islands. The first, Kureat, lay in the second meander of the study reach and the second about 9km upstream from the Diyala River confluence.

Between 1976 and 1991 a recreation park was constructed on Suraidat Island and an access connected it to the left bank of the river, creating a small lagoon. Asimilar development at Um Al-Khanazer Island linked it to the right bank, and likewise a lagoon was created beside that bank. The river cross sections of the 1991 survey revealed changes in the bed and banks of the river and there were indications of new islands growing which had not been identified in the 1976 survey, These changes became more noticeable in the 2008 survey.

During the period 1976-1991 most of the banks of the northen part of the river were subjected to artificial protection using rocks and concrete. The same was true in the southern part of the river, but to a lesser extent. By the end of 2002 about 66% of the banks of the reach had been protected to a level of 36-37m above sea level in attempts to canalize the river course within the most populated areas and to avoid bank collapse during floods (Al-Ansari et al., 1979).

The irregularities in the cross sections of the river reflect the variations in flow velocity controling erosion or deposition in new parts of the reach. It is important to note that most of the suspended sediments formerly transported to the reach were now being trapped in the upstream reservoiors, so that the river was attempting to achieve a new stable regime (Morris and Fan, 2010). The recent regional decrease in rainfall, leading to low water levels in the river reaches at Baghdad, and the waters are eroding only below the levels of protection given to the upper banks. It is likely that this will lead to the collapse of parts of the protected banks in the future.

In addition to the variations in bed levels along the reach (Figure 5), changes in elevation on any single cross section between the 1976, 1991 and 2008 surveys reached up to 4m (Figure 6). The 1991 cross section showed the most extreme changes in bed level. This is believed to be due to the survey having been conducted shortly sfter the 1988 major floods. The bed level variation in 2008 was the least and may be attributed to the fact that the survey was conducted 20 years after the high flood of 1988 or alternatively was due to the river having suffered from low flow regime during the past 20 years

The repeated surveys have shown that the average slope of the bed of the Tigris within Baghdad was substantially greater in 2008 (5 cm / km) than in 1976 (1.03 cm / km) .and more than twice that in 1991 (2.45 cm / km). The obstacles presnt in the river during the 2008 survey are listed in Table 1, with details of their location, length and type. Some are islands and others areas of bank accretion . Their positions are indicated in Figure 7.

7. Methodology

7.1 River geometry

The survey conduicted in 2008 by the Iraqi Ministry of Water Resources covered 49km of the river, from the Al-Muthana Bridge in the north to the confluence with the Diyala River in the south. A total of 219 cross sections were surveyed at intervals of 250m, as shown in Figure 8. The findings of this survey have been used in the present investigation to create a 1-D steady flow model, using the HEC-RAS program, with additiional data concerning the locations and dimensions of the bridges.

7.2 Boundary conditions

The average discharge of the river at Baghdad calculated for the previous ten years and additional discharge figures considered in previous studies have been used in the model to define the upstream conditions and a modified rating curve for the river below the Diyala confluence was used to define the downstream boundary for each of the upstream conditions.

7.3 Model calibration

Calibration of the model was achieved by using observed water level variations along the lower 15 km of the studied reach on a single day when the discharge was $400m^3s^{-1}$.

The problems of calibration were extended to an attempt to define suitable values for the Manning coefficients for the main channel and the flood plain. This was achieved by iteration to give coincidence between the computed water surface levels and those observed. The minmum Root Mean Square Errors (RSME) of 0.026m were obtained for the coefficient values of 0.0285 for the main channel and 0.042 for the flood plains. No precise data for the water consumption through the reach were available and an estimate of the lateral inflow /outflow was included within the average inflow from the Diyala River of 5m^3s^{-1}.

7.4 Model verification and application

A range of different scenarios were examined by increasing the discharge, starting from the average flow for the previous ten years, in order to determine the critical discharge that can cause inundation, For some of these discharges (from 500 t0 1300 m^3s^{-1}) water surface levels had been recorded at the Sarai Baghdad station during that ten year period. A new RSME was computed for these observations giving good coincidence (RSME = 0.046m) as shown in Figure 9.

8. Results and discussion

The procedure of increasing upstream discharge was continued so that areas that had been inundated could be detected. The discharges that were considered in this work started at 500m^3s^{-1} and increased in the same step intervals as those considered in previous studies. Each of these discharges was repeated in the model for four scenarios. The difference in each scenario was the lateral inflow represented by the Diyala river. Thee lateral inflow for the initial (base) scenario was 5m^3s^{-1}, which is the known average inflow observed in the Diyala, and it was also used for calibration purposes. The three other lateral inflows examined were 25, 50 and 100m^3s^{-1}. The effect of the backwater curve associated with each lateral inflow was also checked. The avaerage differences in water surface elevation for each scenario compared with the base condition are shown in Table 2. These difference indicate that the lateral inflow exerted no significant influence during periods of higher discharges.

The water surface elevations computed at gthe Sarai Baghdad station from the present study are plotted against those from previous studies (1976 and 1991) in Figure 10. The more recent water level predictions are lower than those of the 1976 study for low discharges but higher than those for high discharge. They are always lower than the levels recorded in 1991.

The plots in Figure 9 indicate that discharges that are higher than 2700 m^3s^{-1} could cause partial inundation in some areas in the northern tpart of the reach. The critical water surface elevation for inundation in the reach is 35 m at station 43,000m.. For discharges greater than 3500m^3s^{-1} the inundation could take place along approximately 9 km of the reach. Fopr the southern part of the reach under examination the inundation is not expected to occur below a discharge of 35000 m^3s^{-1}.

The water surface slopes for the base condition varied from 6.03 to 6.84 cm / km for discharges between 400 and 1500m^3s^{-1} respectively. For discharges of 2500 and 2700 m^3s^{-1} respectively the slopes were 8.59 and 8.96 cm / km, but reached 10 cm / km for discharges of 3500 and 4000m^3s-^{1}.

The rating curve used to define the downstream boundary condition needs modification for the high water stages to give more reliable estimates of the new geometry conditions in the river.

9 Conclusions

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

9.1 Recent stortages in the flow have kept the water levels low on all of the river cross sections so that the protected banks have had little value for flood protection, however, they have helped the river to reach a new stable regime.
9.2 Since the water is now eeroding below the protected bank levels this will lead to the collapse of parts of these banks in the future.
9.3 The variations in the level of the river bedwere less in the 2008 survey than during the surveys of 1976 and 1991.
9.4 The average slope of the river bed was steeper in 2008 than during the earlier surveys
9.5 The bed obstacles during the 2008 survey were greater in number and occupied the most complicated locations than during the two earlier surveys.
9.6 The output from the model showed very good coincidence with the observed water surface levels at the Sarai Baghdad ststion and also along the lower 15 km of the reach examined.
9.7 The computed water surface slopes varied from 6.03 to 6.84 cm / km during low flow conditions.
9.8 Inundation could take place along approximately 9 km of the reach surveyed with discharges greater than 3500m^3s^{-1}.

Acknowledgements

It is their paper not mine. All I have done is to hopefully improve the English and clarify some of the science. There is still no detail from any survey lines alonmg to river rather than across it, and no mention is made of the bed sediments. I would have expected Iraqi personnel to have made some reference to the potential impact of the Ilisu dam in Turkey, which will surely reduce the normal flows in the Tigris and certainly reduce the flood peak discharges when it comes into action in the next few years. With the survey data and the model used here there will be information to demonstrate what the impact actually is.

References

I would not seek to modify the listed items except to note that the work of Al-Shahrabaly (2008) does not appear to be referred to in the text. Perhaps it should be near the start, rather than being hidden in reference to the Minisry of Water Resources.