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Distribution of Shear Stress in the Meanders of Tigris River Within Baghdad City

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Abstract

Distribution of bed and banks shear stress was studied considering the effect of bends on this distribution within the main three meanders, Al-Kadimiyah, Al-Atafiyah and Al-Jadiriyah in Tigris River within Baghdad City. A steady flow hydraulic model, using the HEC-RAS software, was used to simulate the flow in Tigris River within Baghdad City in order to obtain the flow characteristics in ten slices across the considered cross section along the river reach for the cases of 400, 800 and 1300 m^3/s which represent the minimum, average and maximum discharge of the river flow during the period from 2000 to 2010.

The calibration and verification process was carried out using two sets of discharge and stage measurements. These processes showed that the Manning's n values were between 0.025 to 0.028 for the main channel and 0.038 to 0.042 for the left and right banks and the water surface slope was 7 cm/km.

Application of the hydraulic model for the three cases of discharge (400, 800 and 1300 m^3/s) shows that the maximum and minimum flow velocity were (0.39, 1.11), (0.53, 1.13) and (0.57 and 1.37m/sec), respectively. While the water surface slopes varied from 6.5 to 8.5 cm/km for discharges between 400 and 1300 m^3/s, respectively. These slopes increased at the bridges to about 9 cm/km.

Results of applying the hydraulic model were used to compute the shear stress in each slice across all the considered cross sections for the three meanders using the reach-averaged boundary shear stress equation and the Federal Highway Administration guidance was used to estimate the shear stress within the high shear stress locations. The Arc-GIS software was used to process the data by making use of the available interference facilities between the HEC-RAS and Arc-GIS softwares.

The estimated maximum shear stresses in the three bends for the discharges 400, 800 and 1300 m^3/s showed that the meandering effect increase the maximum shear stress in Al-Kadimiyah, Al-Atafiyah and Al-Jadiriyah bends by about 16%, 22% and 31%, respectively.

The locations and distribution of shear stress in the case of considering the meanders effect at the upstream and downstream of the bends does not affect. While it is changed in the bend and become coincident with the characteristics of flow and river geometry. The influence of disparity in the values of shear stress appears through upgrowth of the islands within the river at the locations of low shear stress with continuous changes in the geometry of the river to be coincident with the distribution of shear stress.

Keyword: Shear stress, Meander, Tigris River.

Eastern Turkey and flows for about 400 km through Turkey before entering Syria and then Iraq. The total length of the river in Iraq is 1418 km, Rasheed (2011). Several cities have been built on the banks of Tigris River since the dawn of civilization. Among these is Baghdad, the capital city of Iraq. The city of Baghdad is located on the conjunction of the Tigris and Diyala rivers. The length of the river in Baghdad City from Al-Muthana Bridge to the confluence with the Diyala River is 49 km. there are thirteen bridges located on Tigris River within Baghdad City: Al-Muthanah, Al-Aameh, Al-Adamiyah, Al-Sarafiah, Bab-Almuoadam, Al-Shuhada, Al-Ahrar, Al-Sinak, Al-Jumhuriyah, Al-Moalak, Al-Jadiriyah, Al-Hasaniyn and Al-Rasheed.

The bed of Tigris River at Baghdad is mainly composed of fine sand less than 1 mm in diameter, whilst the channel banks are mainly composed of silt and clay. The width of the river varies between 190 and 500 m. This part of the river is characterized by meanders and islands, Nadhir (1979).

Tigris River meanders in Baghdad in several areas. Al-Kadimiyah, Al-Atafiyah and Al-Jadiriyah are the most important meander that meanders sharp and distinctive with sinuosity reach 4.1, 2 and 1.5 respectively, **Figure 1**.

Several studies have been conducted on the River Tigris. Some of these are more related to this research.

There are two studies conducted by the Ministry of Irrigation. 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.

G. Al-Mashidani (1980). Compared some commonly used statistical distributions to find their applicability for describing minimum flows of the Tigris River at Baghdad gauging station. Drought flows with given return period have, thereafter, been predicted by these techniques. The mean of the estimated flows by the various distributions has been calculated to represent a design drought; upper and lower values estimated have been used to give an idea of variation in drought flow estimation. The suggested methodology can avoid the dilemma as to which distribution to select for drought flow estimation.

Ammar A. Ali (2012). Studied the impact of growing islands on the flood capacity of Tigris River in Baghdad City using HEC-RAS software through performing a study one-dimensional hydraulic model. The average discharge of the river in Baghdad had been calculated for the past ten years. Different scenarios were applied by increasing the discharge in order to find out the critical discharge. The primary runs for 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 and indicate 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.

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 impact 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.

Shear stress is used as an indicator in fluvial studies to predict locations of erosion or deposition. Erosion is particularly important for meandering channels where infrastructure and riparian zones are susceptible to changes in planform geometry. Extensive research has previously been conducted to assist in the prediction and prevention of changes in planform geometry by examining shear stress distributions in bends with variations in geometric and flow parameters.

Bends in meandering streams have been examined by researchers for decades to understand the distribution of velocity and shear stress and its effect on bend migration. Complex nature of flow in bends is influenced by channel geometry characteristics, flow characteristics, and fluid and sediment properties. Shear stresses are directly affected by local accelerating, decelerating, and secondary flows (Ippen et al., 1960). By isolating variables, researchers have developed relationships between boundary shear stress and geometric characteristics.

This research aims to study the distribution of bed and banks shear stress and to considered the effect of bends on this distribution within three meanders, Al-Kadimiyah, Al Adhamiyah and Al-Jadiriyah in Tigris River within Baghdad City.

Shear Stress Distribution In Bends

A characteristic spiral flow in bends results from centripetal acceleration directed to the outer bank. Near the bed, centripetal acceleration is influenced by a boundary causing a differential to the acceleration near the free surface.

Maximum shear stress is generally present just downstream of the bend apex where secondary circulation is strongest as seen in **Figure 2**. As flow exits a bend, secondary circulation begins to decrease and is eventually dissipated near or in the second bend as opposing centripetal acceleration establishes secondary flows. While the general flow pattern is known, it is noted that shear stress is not temporally or spatially constant as it varies with discharge, bend tightness, and cross-sectional form (Knighton, 1998).

Determining shear stress in bends is difficult due to the presence of secondary circulation and resulting complex flow fields. Some of the more common methods for determining shear stress may not be applicable in bends due to assumptions made in derivation.

Reach-averaged boundary shear stress estimates are common for open-channel flow studies. Programs such as the Hydrologic Engineering Center‟s River System Analysis (HEC-RAS), commonly used in practice (Gordon *et al*., 2004), calculates reach-averaged boundary shear stress estimates (USACE, 2008). Henderson (1966), as well as other textbooks, provide derivations of shear stress based on momentum principles resulting in Equation (1):

$$\tau_0 = \gamma R_h S_f \qquad \text{..... (1)}$$

where: τ_0 = boundary shear stress, (F/L^2);
γ = specific weight of the fluid, (F/L^3);
Rh = hydraulic radius, (L); and
Sf = friction slope, (L/L).

If further assuming steady uniform flow, the friction slope (Sf) can be assumed equal to the water-surface slope (Sw) as well as the bed slope (So) (Henderson, 1966; Julien, 1998).

HEC-RAS uses a standard step backwater calculation procedure for steady flow simulations to determine cross-sectional averaged properties of flow. Friction slopes are computed at each cross section by the following equation (USACE, 2008):

$$S_f = \left(\frac{Q}{K}\right)^2 \quad \text{….. (2)}$$

where: Sf = friction slope or slope of the energy grade line (L/L);

Q = total flow rate (L^3/T); and

K = total conveyance of cross section (unit less).

A summary of assumptions in the derivation of Equation (2) follows (Henderson, 1966):

- one-dimensional flow;
- steady flow;
- bed and bank shear are equal;
- velocity coefficients are constant over the reach;
- shear along the water surface is negligible; and
- small channel slope (tanθ≈sinθ).

Nezu and Nakagawa (1993) note that the accuracy of this method is dependent on the amount of cross-sectional data available so that small deflections in the bed and water surface can be determined.

The (FHWA), Federal Highway Administration, (2005) gives guidance for a shear stress multiplier around a bend in the *Hydraulic Engineering Circular No. 15* (*HEC-15*). It is stated that shear stress is affected by secondary currents and that maximums are found near the inside entrance of a bend and on the outside of the bend toward the bend exit where it persists further downstream as seen in **Figure 3,** Nouh and Townsend (1979). The FHWA (2005) provides Equation (3) for utilizing the shear stress multiplier:

$$\tau_b = K_b \tau_d \quad \text{…………. (3)}$$

where: τ_b = side shear stress on the channel;

Kb = ratio of channel bend to bottom shear stress; and

τ_d= shear stress in channel at maximum depth.

K_b is developed by Young *et al.* (1996) based on Lane (1955) as:

$$K_b = 2.00 \quad \text{if} \quad \left(\frac{R_c}{T_w}\right) \le 2$$

$$K_b = 2.38\text{-}0.206\left(\frac{R_c}{T_w}\right) + 0.0073\left(\frac{R_c}{T_w}\right)^2 \quad \text{if} \quad 2 < \left(\frac{R_c}{T_w}\right) < 10$$

$$K_b = 1.05 \quad \text{if} \quad 10 \le \left(\frac{R_c}{T_w}\right) \quad \text{…………….. (4)}$$

where: Kb = ratio of channel bend to bottom shear stress;

Rc = radius of curvature; and

Tw = top width of the channel.

Flow Routing Hydraulic Models

A steady two dimensional flow hydraulic model is required to simulate the flow in Tigris Rive within Baghdad City in order to obtain the water surface elevation, flow depth, hydraulic radius, flow velocity, slope of the energy grade line and top width across each considered cross section along the river under a set of steady flow conditions.

The HEC-RAS software (Version 4.0), USACE (2010), was used to accomplish this target. This software provides the possibility of computing the flow characteristics in forty-five vertical slices in each cross section.

Geometric Data

A topographical survey for 219 cross-sections with interval of 250m along 49 km (some cross sections were conducted at lesser intervals especially at meanders) started from Al-Muthanah Bridge in the north was conducted by Ministry of Water Resources, MoWR, (MoWR, 2008), 2007-2008, **Figure 4**. The results of this survey and the geometric data of the thirteen bridges that located on Tigris River within Baghdad City (Al-Muthanah, Al-Aameh, Al-Adamiyah, Al-Sarafiah, Bab-Almuoadam, Al-Shuhada, Al-Ahrar, Al-Sinak, Al-Jumhuriyah, Suspension, Al-Jadiriyah, Al-Hasaniyn and Al-Rasheed), Ministry of Construction and Housing (2012), were used to represent the geometry of the river.

Flow Regime

Water flows of the Tigris and Euphrates Rivers entering Iraq have decreased annually in a dramatic way for the past two decades, **Figure 5**, MoWR (2011), due to the major water impoundment projects constructed; some remain under construction on these rivers in the neighboring 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 (about 19% the trend of fall line according to the discharge values mentioned by Al-Shahrabaly, (2008)). Twenty years average discharge ($671 m^3/s$) decreased to ($531 m^3/s$) during 2000–2010, MoWR (2011), and it is less than half of the mean daily discharge of ($1140\ m^3/s$) prior to 2005 and well below the flood discharges of 4480, 3050 and $1315 m^3/s$ recorded in 1971, 1988 and 2005, respectively.

Boundary and Initial Conditions

The HEC-RAS model deals with the boundary conditions depending on the flow regime. In a sub critical flow regime, which is the flow regime in the river under consideration, boundary conditions are only necessary at the downstream ends of the river system and deals with its data in a separated window. Since there is no records for the water surface elevations at the end of this river reach, therefore the normal depth type of boundary condition was selected to be the downstream boundary condition in this model. According to the flow conditions and river geometry the initial water surface slope along this reach was within arrange of 6.0 to 9 cm/km. This slope should be checked during the calibration and verification processes.

Model Calibration

A calibration process was carried out using stage measurements at 49 stations along the river within Baghdad. These measurements were conducted during July 2008 by Ministry of Water Resources, MoWR (2008), **Figure 6**. The average discharge of the river during this month was 480m^3/s. This discharge was adopted in the calibration process.

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 and to check the used value of the downstream boundary condition which was the normal depth (0.69 cm/km). This was achieved by iteration to give coincidence between the estimated water surface elevation (WS) and those observed (OWS), as shown in **Figure 6**. Finally, with a Root Mean Square Errors (RSME) of 0.024m, the calibrated Manning's n values were between 0.025 to 0.028 for the main channel and 0.038 to 0.042 for the left and right banks with normal depth of (0.7 cm/km).

Model Verification

The verification process was achieved by using the recorded data during the period from 2000 to 2010 at Sarai station, Ministry of Water Resources(2010), and the estimated rating curve using the hydraulic model for a range of river discharges started from (400m^3/s) to maximum (1300m^3/s), corresponding to the recorded minimum and maximum discharges at Sarai station during the period from 2000 to 2010, with increment interval of 100 m^3/s. A comparison between the measured and model predicted rating curve was as shown in **Figure 7**, which shows an acceptable agreement.

Computation of Shear Stress in the Bends

The implemented flow routing model was used to compute the shear stress within three meanders, Al-Kadimiyah, Al-Atafiyah and Al-Jadiriyah in Tigris River. This model was used to estimate the water surface elevation, flow depth, hydraulic radius, flow velocity, slope of the energy grade line and top width in ten slices across each cross section of the three meanders, **Figure 8,** for the flow cases of 400, 800 and 1300 m^3/s which represent the minimum, average and maximum discharge of the river, respectively, during the period from 2000 to 2010.

These estimated data were used to compute the shear stress in each slice using equation (1). The Arc-GIS software (Version 10) was used to process the data by making use of the available interference facilities between the HEC-RAS software (Version 4.0) and Arc-GIS software (Version 10).

The estimated shear stress in the three meanders for the considered three river flow cases was as shown in **Figure 9**.

To consider the effect of bend on the shear stress for the three meanders, the FHWA guidance, equations (3 and 4), were used to estimate the shear stress within the high shear stress locations according to **Figures 2 and 3.** These computations were performed using the spatial analysis tools within the Arc-GIS software. The estimated shear stresses within the three meanders considering the bend effect were as shown in **Figure 10**.

Results Analysis and Discussion

Results of calibration and verification processes showed that the Manning's n values were between 0.025 to 0.028 for the main channel and 0.038 to 0.042 for the left and right banks which coincident with the main channel of clear, straight, full, no rifts or deep pools (0.025 to 0.033) and flood plains of pasture no brush with high crass (0.03 to 0.05) according to Chow (1959). The water surface slopes varied from 6.5 to 8.5 cm/km for discharges of 400 and 1300 m^3/s, respectively. These slopes increased at the bridges to about 9.0 cm/km.

The estimated maximum shear stresses in the three bends for the 400, 800 and 1300 m^3/s flow rates without considering the effect of bend and with considering this effect were as listed in **Table 1.** These values show that the meandering effect increasing the maximum shear stress in Al-Kadimiyah, Al-Atafiyah and Al-Jadiriyah bend by about 16%, 22% and 31%, respectively.

The locations of the high shear stress in the case of ignoring the bends effects coincident with the characteristics of the flow and river geometry at the upstream and downstream of the bends and the maximum shear stresses occurred at these locations. While in the bends, the distribution of the shear stress was not coincident with the characteristics of the flow and river geometry in most of the considered cases.

In the case of considering the bends effects on the shear stress distribution, this distribution was not affected at the upstream and downstream of the bends. While the shear stress distribution in the bends was changed and became coincident with the characteristics of the flow and river geometry.

The influence of disparity in the values of shear stress appears through upgrowth of the islands within the river at the locations of the low shear stress with a continuous change in the geometry of the river cross-section to be coincident with the distribution of the shear stress values. **Figures 11, 12 and 13** show the upgrowth of the island in the bends within the low shear stress zones and bed scour within the high shear stress zones and the change in cross-section of the river at these zones.

Conclusions

Results of operating the hydraulic model and shear stress estimation considering the meandering effects in Tigris River within Baghdad City indicates the followings:

1- Manning's n values for the studied reach ranged between 0.025 to 0.028 for the main channel and 0.038 to 0.042 for the left and right banks.

2- The water surface slope varied from 6.5 to 8.5 cm/km for the discharges range between 400 to 1300m^3/sec, respectively. While it increase to about 9 cm/km at the bridges.

3- The estimated maximum shear stress in Al-Kadimiyah, Al-Atafiyah and Al-Jadriyah Bends for the discharge of 400, 800 and 1300 m^3/sec increased about 16%, 22% and 31%, respectively, when considering the meanders effect.

4- The locations and distribution of shear stress in the case of ignoring the meanders effect was not coincident with the river geometry in most of the considered cases.

5- In the case of considering the meanders effect, the shear stress distribution at the upstream and downstream of the bends does not affect. While it is changed in the bend and become coincident with the characteristics of flow and river geometry.

6- The influence of disparity in the values of shear stress appears through upgrowth of the islands within the river at the locations of low shear stress with continuous changes in the geometry of the river to be coincident with the distribution of shear stress.

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Table 1: Estimated maximum shear stresses

Bend	Discharge, m^3/s.	Shear stress, N/m^2.	
		Without bend effect	With bend effect
Bend 1 (Al-Kadimiyah)	400	6.7	7.8
	800	7.3	8.2
	1300	7.4	8.5
Bend 2 (Al-Atafiyah)	400	6.4	7.3
	800	6.5	8.5
	1300	6.6	9.9
Bend 3 (Al-Jadiriyah)	400	1.6	1.9
	800	3.0	3.7
	1300	4.3	5.5

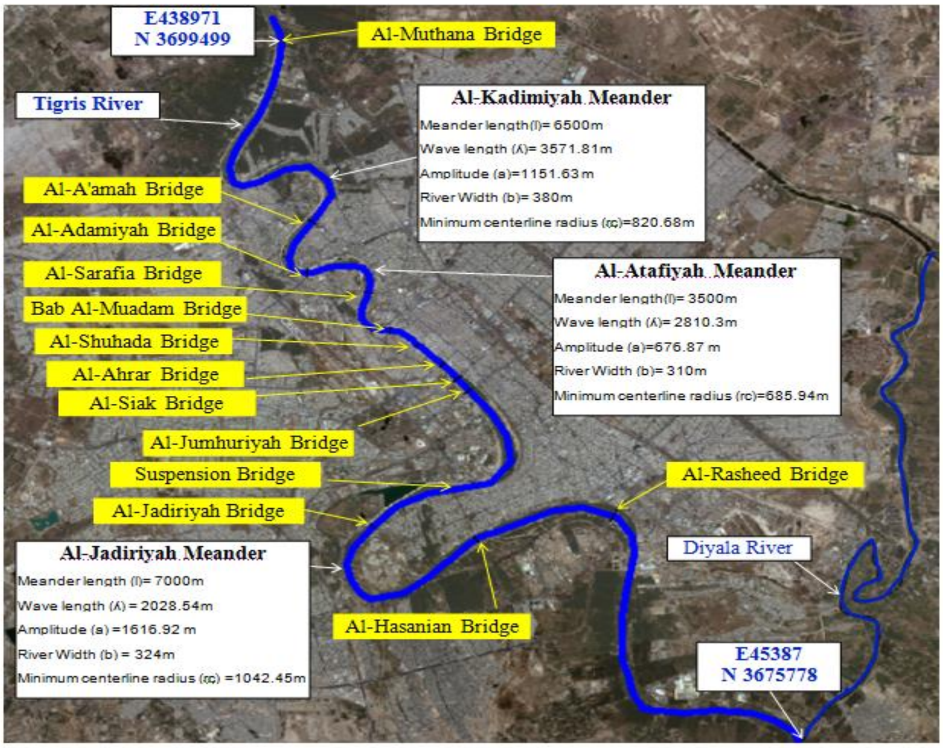

Figure 1: Scheme of Tigris River within Baghdad City

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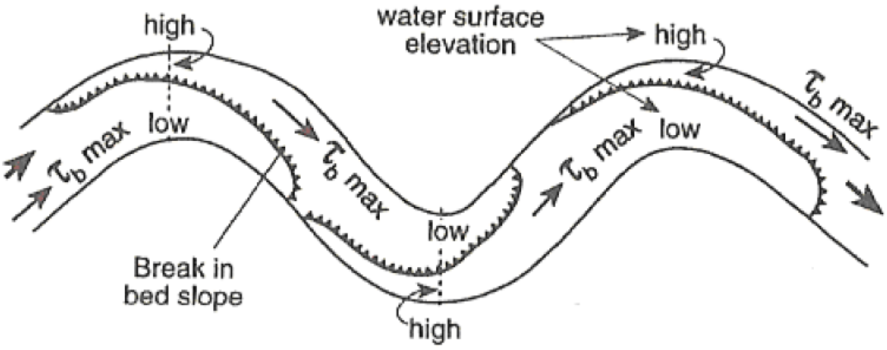

Figure 2: Generalized shear stress distribution in meandering channels (Knighton (1998) after Dietrich (1987)).

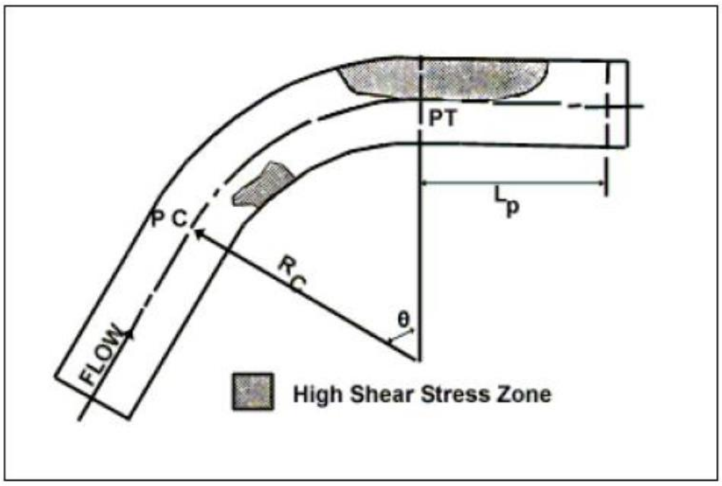

Figure 3: Locations of high shear stress, *[Nouh and Townsend, 1979]*.

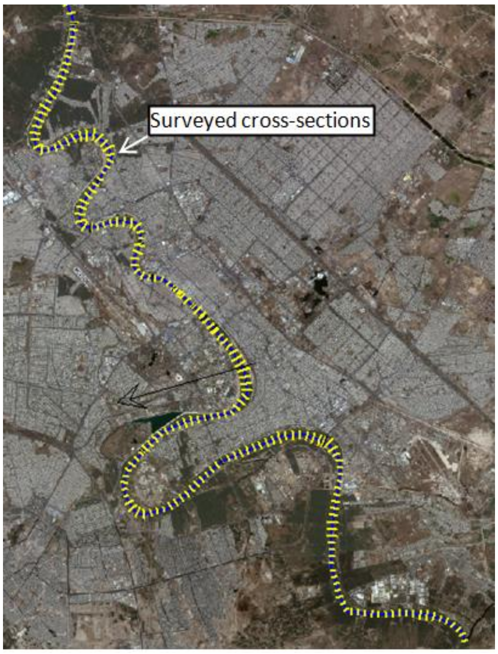

Figure 4: Surveyed cross-sections *[MoWR (2008)]*.

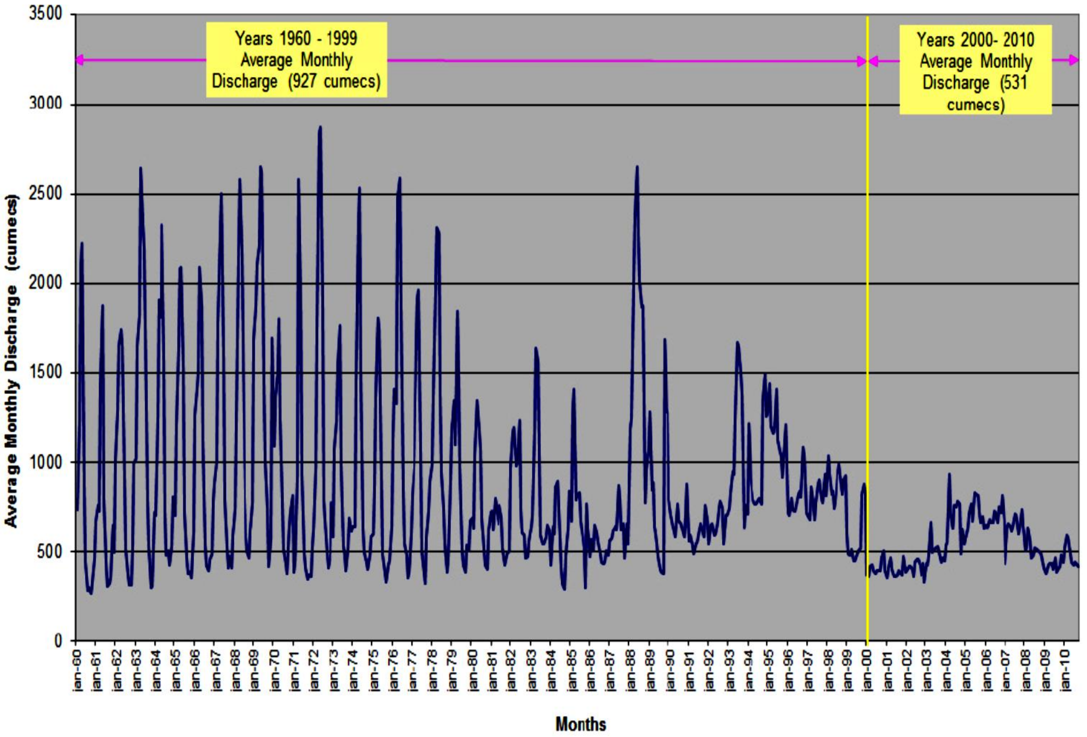

Figure 5: Recorded Tigris River flow at Sarai Baghdad station for the period 1960–2010, [Ministry of Water Resources (2011)].

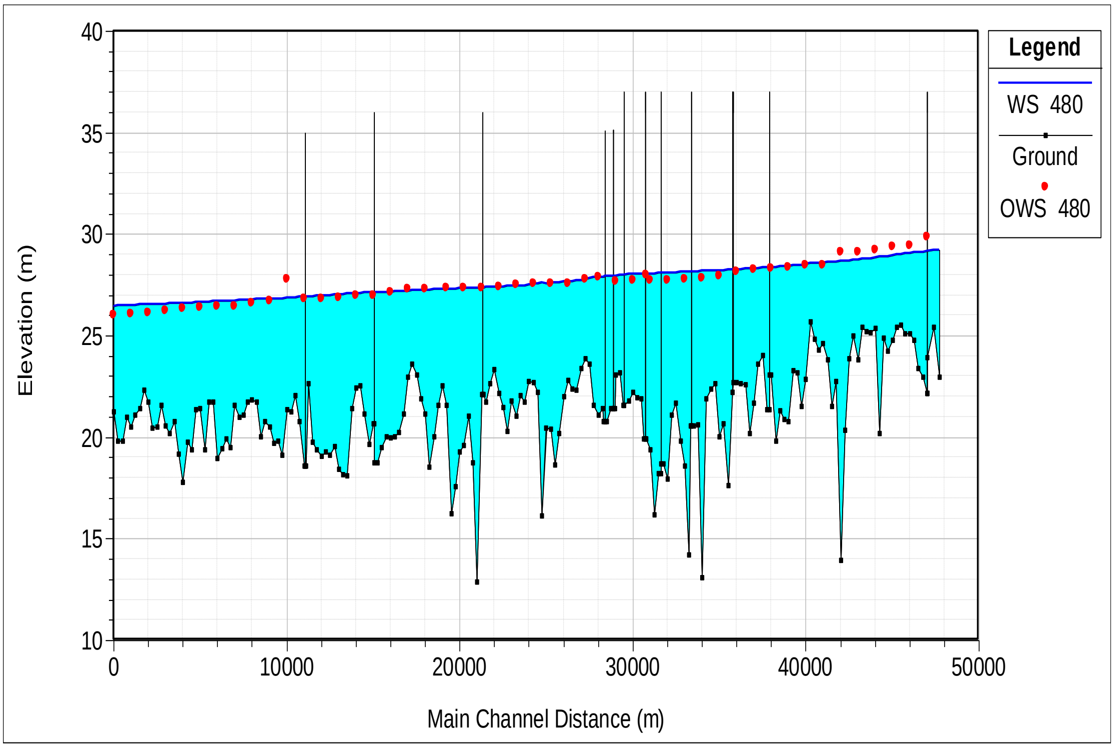

Figure 6: Comparison between the estimated stage using the calibrated data and the measured stage along the studied reach.

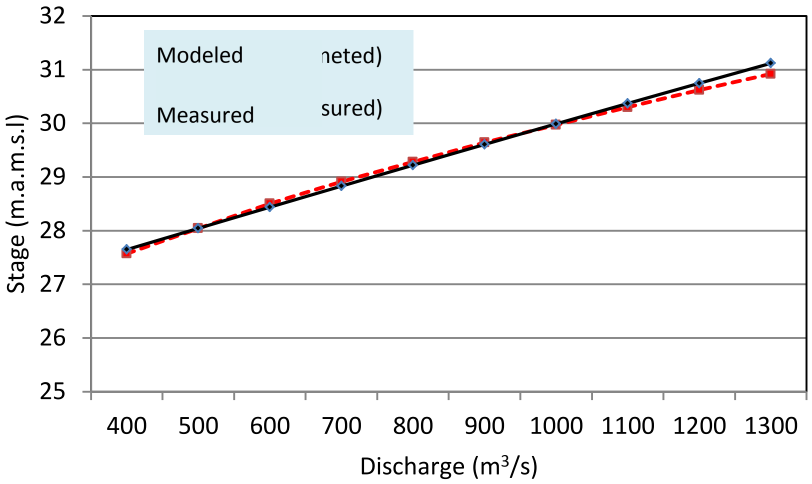

Figure 7: Comparison between the measured and the model predicted rating curve

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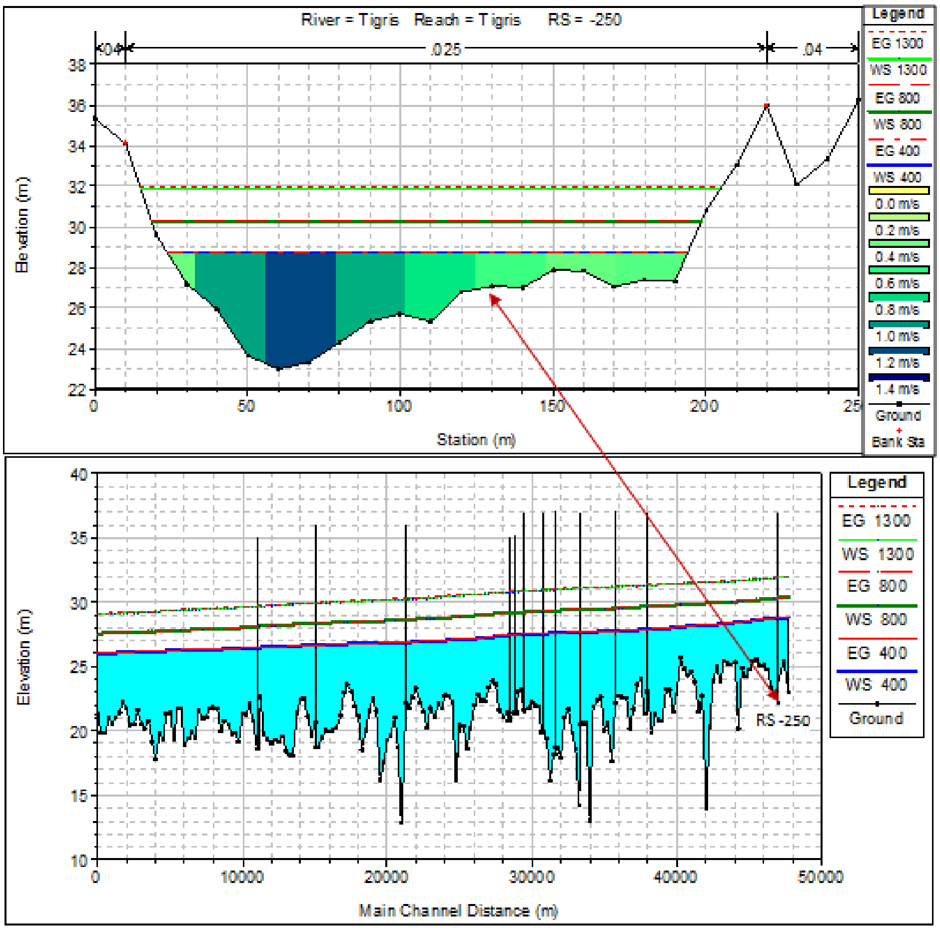

Figure 8: Estimation of river flow data using the hydraulic model

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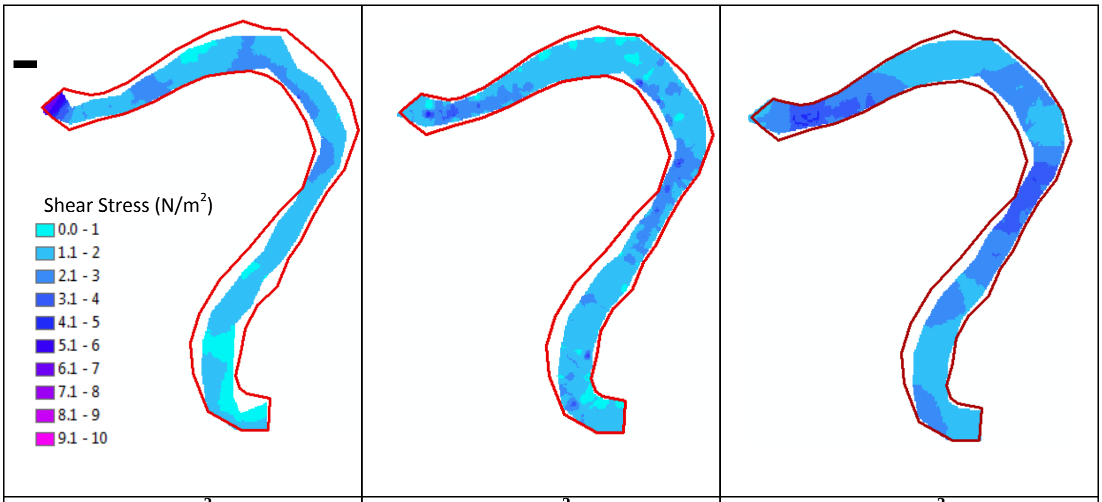
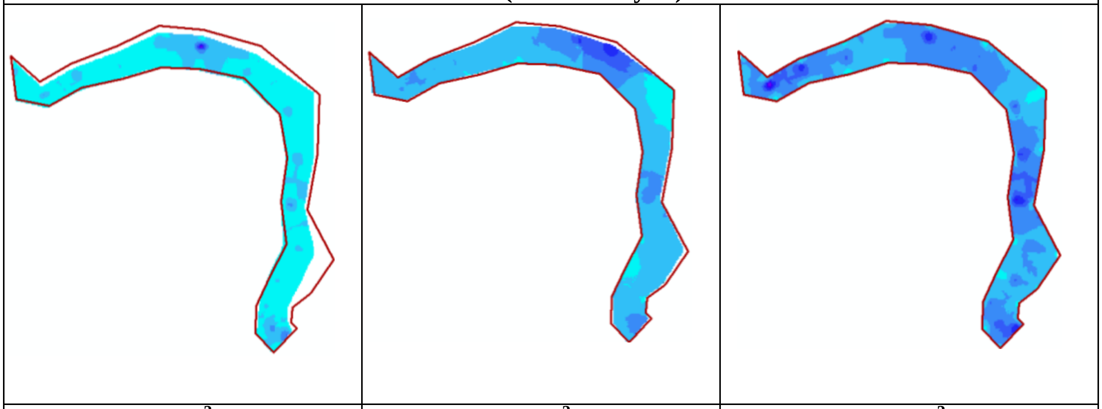


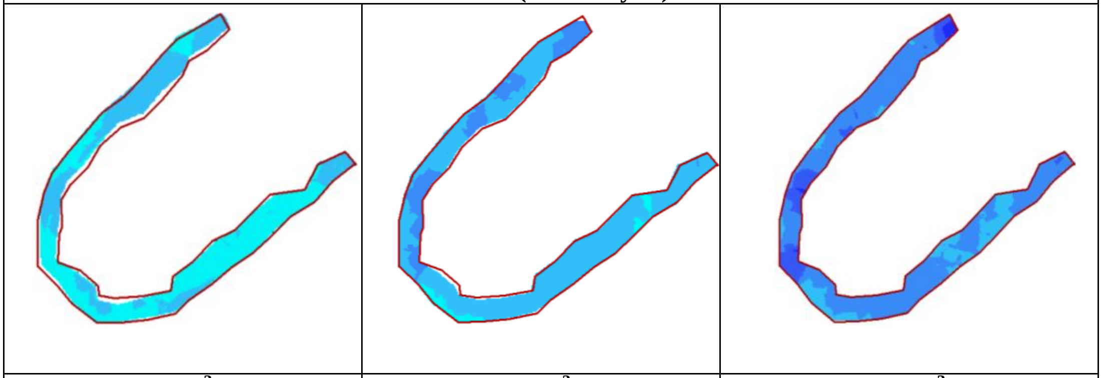
400 m^3/s 800 m^3/s 1300 m^3/s

Bend 1 (Al-Kadimiyah)



400 m^3/s 800 m^3/s 1300 m^3/s

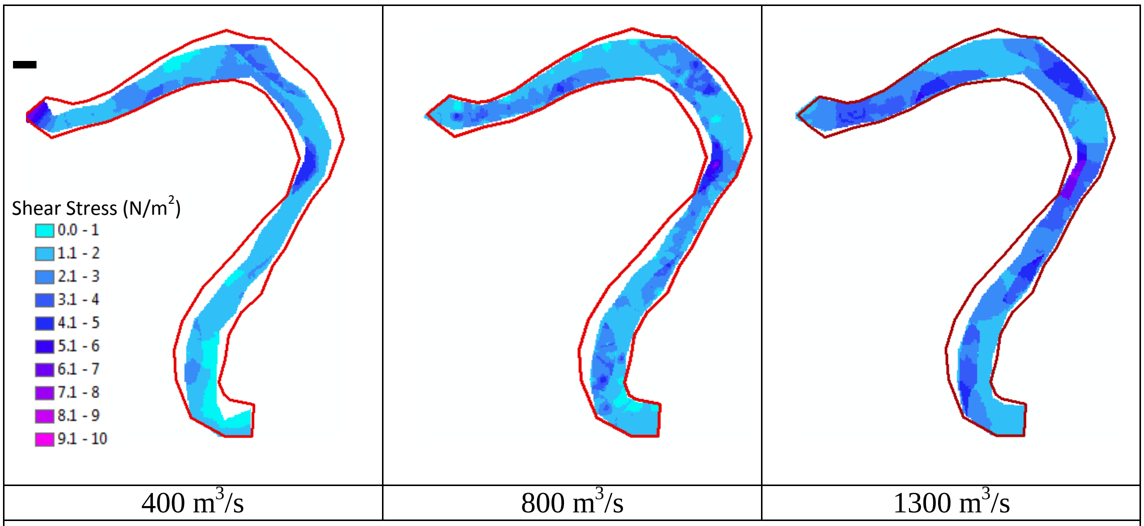
Bend 2 (Al-Atafiyah)



400 m^3/s 800 m^3/s 1300 m^3/s

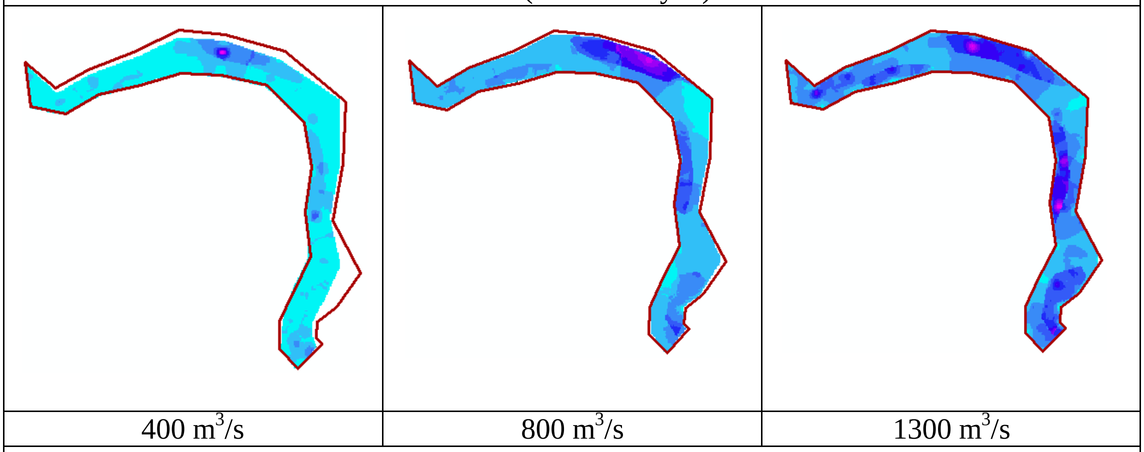
Bend 3 (Al-Jadiriyah)

Figure 9: The estimated shear stress.



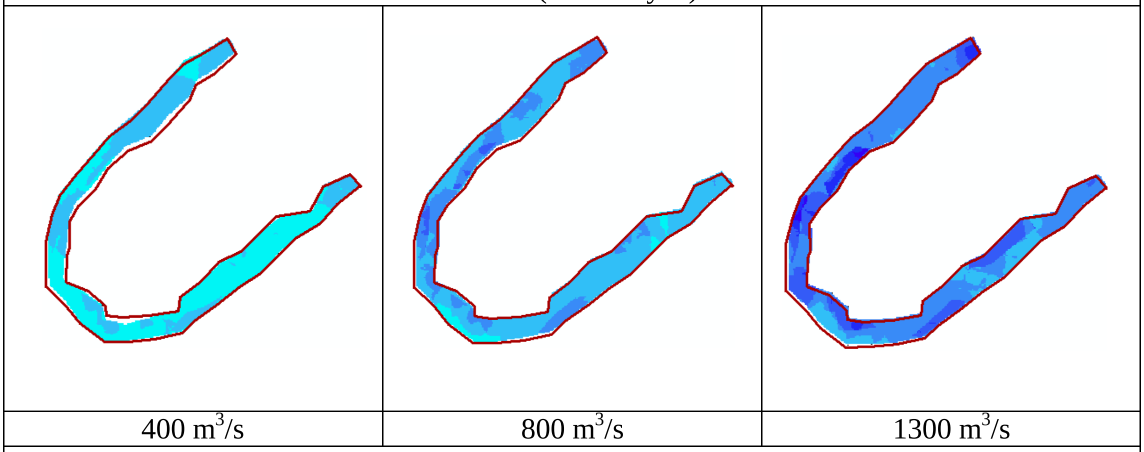
400 m^3/s 800 m^3/s 1300 m^3/s

Bend 1 (Al-Kadimiyah)



400 m^3/s 800 m^3/s 1300 m^3/s

Bend 2 (Al-Atafiyah)



400 m^3/s 800 m^3/s 1300 m^3/s

Bend 3 (Al-Jadiriyah)

Figure 10: The estimated shear stresses considering the bend effect.

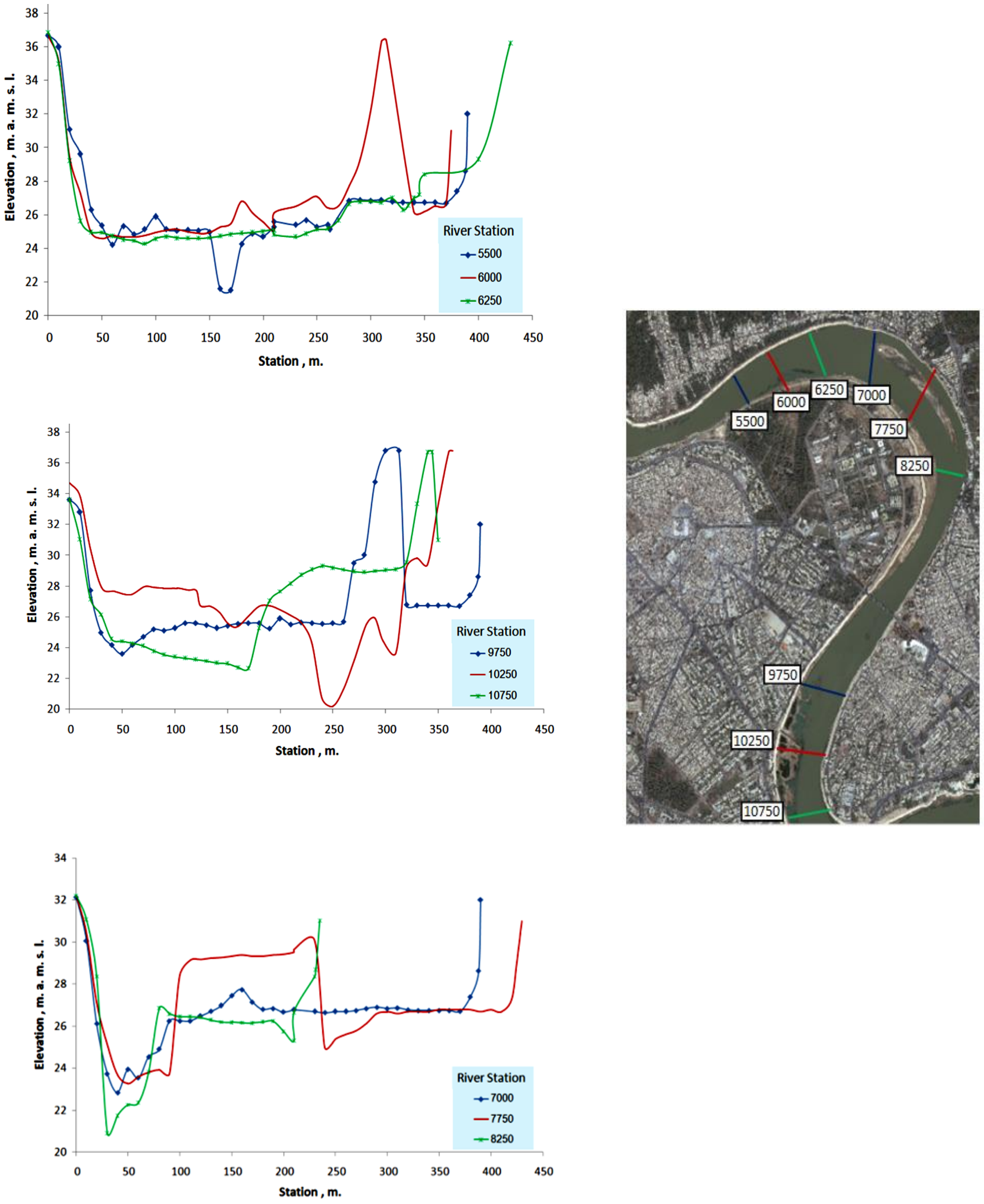


Figure 11: Upgrowth of islands and bed changes in some cross-sections of Bend 1 (Al-Kadimiyah).

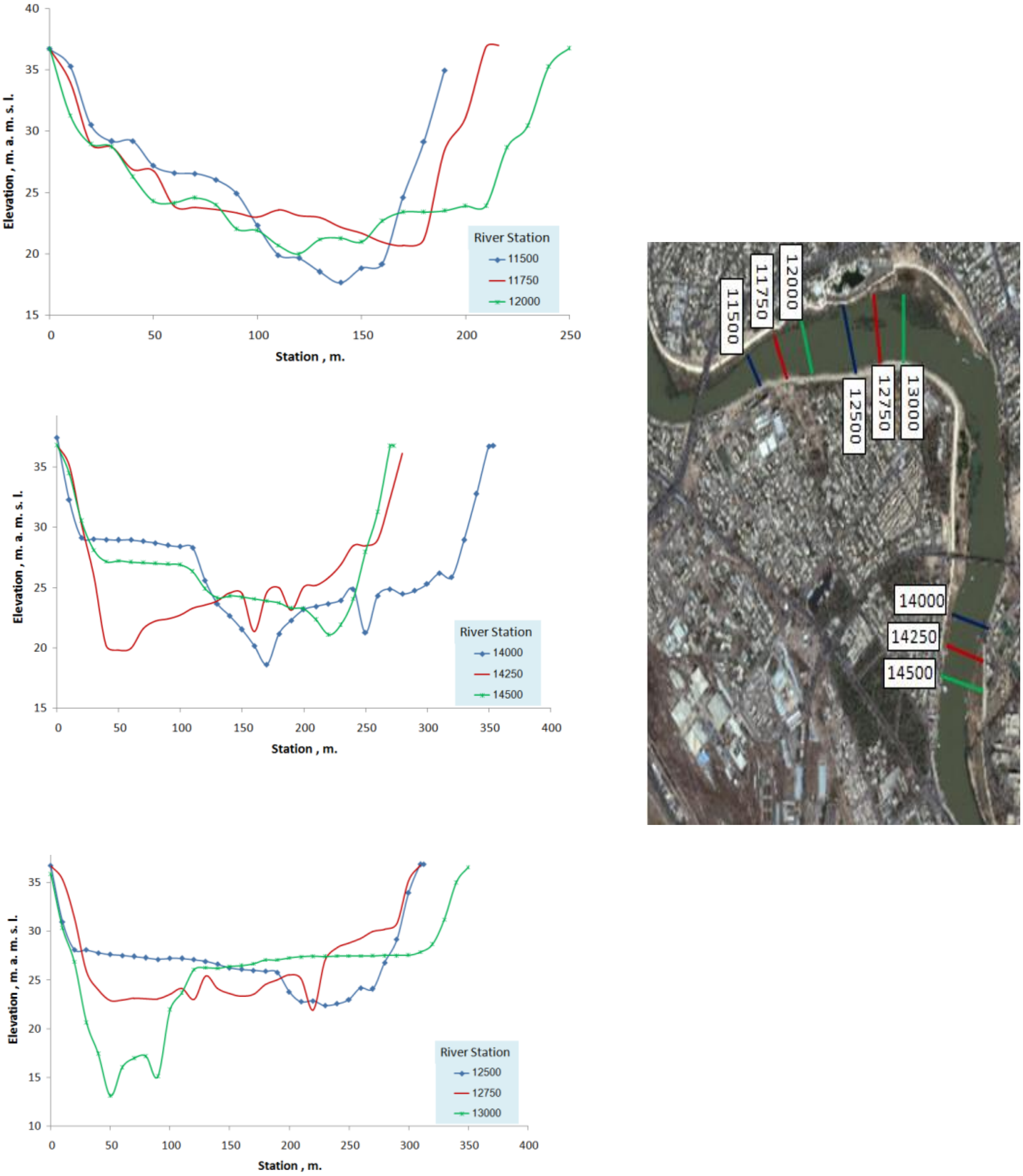


Figure 12: Upgrowth of islands and bed changes in some cross-sections of Bend 2 (Al-Atafiyah).

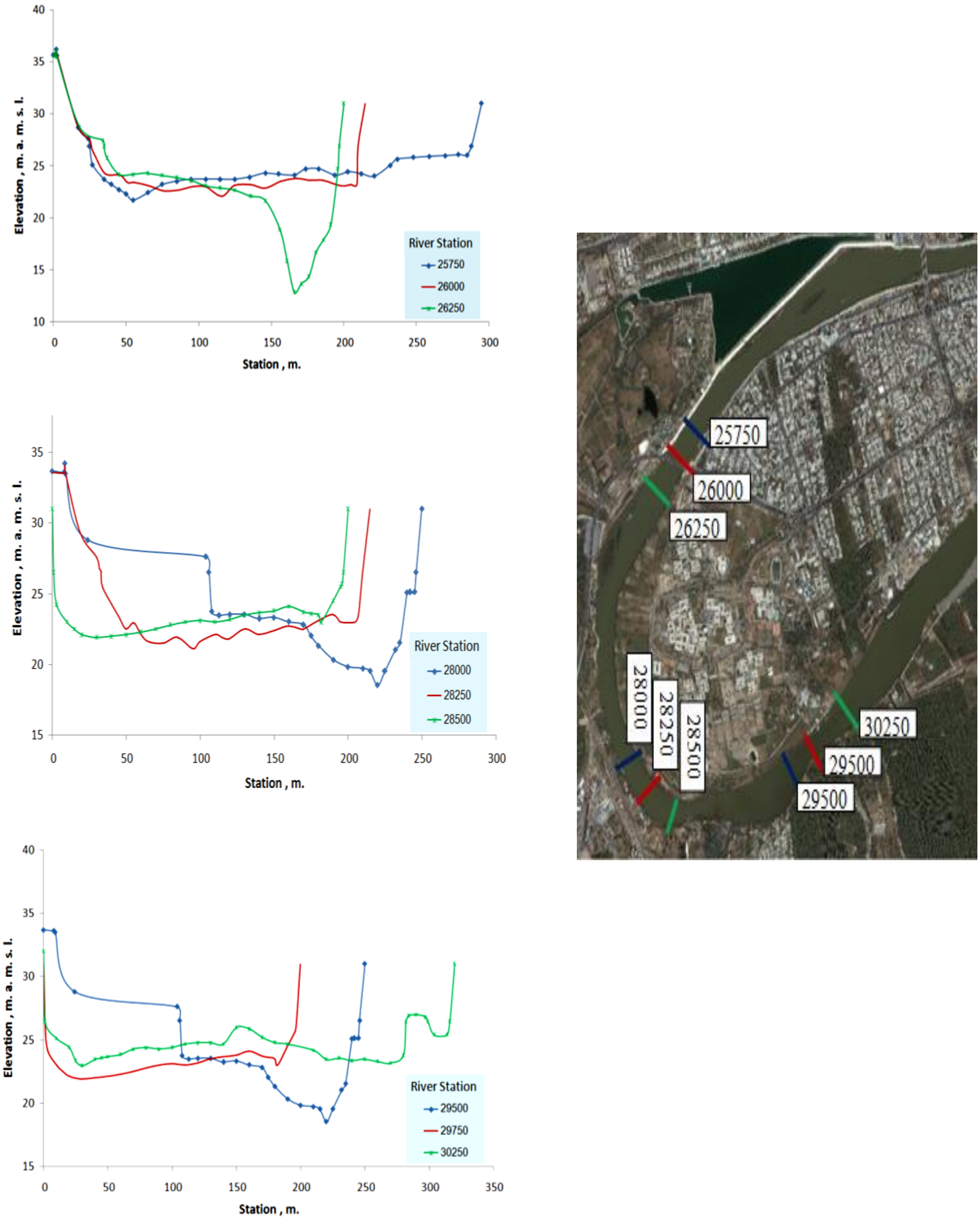


Figure 13: Upgrowth of islands and bed changes in some cross-sections of Bend 3 (Al-Jadiriyah).

توزيع اجهاد القص في تعرجات نهر دجلة في بغداد

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الخلاصة

تم دراسة توزيع قيم اجهاد القص في قاع وضفاف النهر اخذين بنظر الاعتبار تاثير الانحناءات على هذا التوزيع في التعرجات الثلاثة الرئيسية الكاظمية والعطيفية والجادرية في نهر دجلة ضمن مدينة بغداد.

استخدم نموذج هيدروليكي للجريان الثابت باستخدام برنامج ال HEC-RAS لمحاكات الجريان في نهر دجلة ضمن مدينة بغداد لإيجاد خصائص الجريان في عشرة شرائح عمودية على عرض مقاطع النهر على طول مقطع النهر لحالات الجريان 400 و 800 و 1300م^{3}/ثا والتي تمثل اقل ومعدل واعلى تصريف للنهر خلال الفترة من 2000 الى 2010م.

تم اجراء عملية المعايرة والتحقق باستخدام مجموعتين من التصاريف والمناسيب المقاسة. بينت هاتين العمليتين ان قيم معاملماننك تراوحت بين 0.025 و 0.028 للقناة الرئيسية و 0.038 الى 0.042 للضفاف الفيضانية وميل سطح الماء 7سم/كم.

بينت نتائج تطبيق النموذج الهيدروليكي لحالات التصريف الثلاثة (400 و 800 و 1300م^{3}/ثا) ان اعلى واقل سرعة جريان كانت (0.39 و 1.11) و (0.53 و 1.13) و (0.57 و 1.37م/ثا), على التوالي. بينما ميل سطح الماء تراوح بين 6.5 الى 8.5سم/كم للتصاريف 400 و 1300م^{3}/ثا. هذهِ الميول تزداد عند الجسور لتصل الى حوالي 9 سم/كم.

استخدمت نتائج تطبيق النموذج الهيدروليكي في حساب اجهاد القص في كل الشرائح ضمن القطع العرضي لكل المقاطع العرضية للتعرجات الثلاثية باستخدام معادلة متوسط إجهادِ قصٍّ الحد المتاخم لمقطع القناة وتم اعتماد دليل الادارة الاتحادية للطرق السريعة في حساب اجهاد القص في مواقع اجهاد القص العالية. وتم استخدام الحقيبة البرمجية Arc-GIS في اجراء العمليات الحسابية وعرض وتحليل النتايج بالاستفادة من ميزات وامكانيات تبادل وتحليل البيانات المتوفرة في برنامج ال HEC-RAS و الحقيبة البرمجية Arc-GIS.

ان اعلى قيم اجهاد القص التي حسبت في الانبعاجات الثلاثة للتصاريف 400 و800 و 1300م^{3}/ثا بينت ان تأثير التعرج يزيد قيم اجهاد القص القصوى في تعرج الجادرية والعطيفية والجادرية بنسب تصل الى حوالي 16% و 22% و 31%, على التوالي.

ان موقع وتوزيع اجهاد القص في حالة اخذ تأثير التعرج بنظر الاعتبار لاتتأثر في مقدم ومؤخر الانحناء. بينما تتغير هذهِ القيم والتوزيع في الانحناء وتصبح متوافقة مع خصائص الجريان وشكل النهر.ان تأثير التفاوت في قيم اجهاد القص تظهر من خلال نمو الجزرات في النهر عند مواقع اجهاد القص الواطىء مع استمرار تغير شكل النهر حتى تصبح متطابقة مع توزيع اجهاد القص.