

Water Resources and Surveying Engineering

Controlling the Salt Wedge Intrusion in Shatt Al-Arab River by a Barrage

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ABSTRACT

Shatt Al-Arab River in Al Basrah, Iraq, has recently recorded massive levels of TDS values (Total Dissolved Solids) in the water as a result of reduced fresh water discharge from sources, causing the river to become salinized due to salt wedge intrusion. Therefore, a block dam in the south reach is required to salt intrusion prevention. The main objective of this research is to simulate the hydraulic impact of a suggested barrage in Ras Al Basha on the Shatt Al-Arab River. The HEC-RAS (5.0.7) model was used to develop a one-dimensional unsteady model to gaining an understanding of the proposed barrage's influence on river behaviour. The daily discharges of the Tigris River provided as the upstream boundary conditions, while the hourly water levels of the Shatt Al-Arab River provided as the downstream boundary conditions. The model was initially run on the basis of daily discharges in Aug 2018 and March 2020 for the model's calibration and verification. Then, a model was run with a proposed barrage, Four cases of discharge were chosen which were the low and moderate discharge that equal to (20-50-100 and 250) m³/s with adopted spring tide cycle. The operation scenarios were examined under the influence of three cases of barrage gates (fully opened, 50% open and programmed opening). The results indicate that the investigated discharges will cause a significant problems in navigation depths, especially in the case of the programming of gates opening where the stages drop range between 2.01-3.3m comparing with the normal case. Furthermore, the velocity indicators show that the significant reduction in velocity upstream the barrage led to more sedimentation in the river reach.

Keywords: HEC-RAS, Seawater intrusion, Block dam, Shatt Al Arab

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السيطرة على الجبهة الملحية في نهر شط العرب باستخدام السدة القاطعة

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الخلاصة

سجل نهر شط العرب في البصرة -العراق مؤخرًا مستويات عالية من إجمالي المواد الصلبة الذائبة (TDS) في المياه نتيجة انخفاض المياه العذبة الواردة اليه من المصادر ، مما تسبب في تتغلغل الملوحة إلى اعالي النهر وعليه يتطلب الامر انشاء سدة قاطعة في الجزء الجنوبي من النهر تحديدا بالقرب من مصب النهر لغرض ايقاف المد الملحي من الخليج العربي. تهدف هذه الدراسة الى محاكاة التأثير الهيدروليكي للسدة المقترحة في منطقة رأس البيشا على شط العرب. تم انشاء نموذج أحادي البعد باستخدام برنامج HEC-RAS (5.0.7) لغرض توضيح التأثير الهيدروليكي للسدة المقترحة على سلوك النهر وتم اعتماد التصاريح اليومية لنهر دجلة كشرط حدودي لمنطقة اعالي النهر ، وكذلك قياسات مستويات مياه لكل ساعة كشرط حدودي لمنطقة المصب. تم تشغيل النموذج مبدئيًا باستخدام بيانات التصاريح اليومية المسجلة في أغسطس 2018 ومارس 2020 لمعايرة النموذج والتحقق منه. بعد ذلك ، تم تشغيل النموذج تحت تأثير السدة المقترحة، وتم اختيار أربع حالات للتصريف التي تمثل التصريف المنخفض والمتوسط الذي يساوي (20 و 50 و 100 و 250) م / 3 ثانية مع دورة المد الربيعي المعتمدة. تم اختبار سيناريوهات التشغيل تحت تأثير ثلاث حالات لبوابات السدة المقترحة وهي حالة الفتح الكلي والنصفي والمبرمج. تشير النتائج إلى أن التصاريح المعتمدة ستسبب مشاكل كبيرة في الاعماق الملاحية ، خاصة في الفتح المبرمج حيث ستخف منسوب المياه بين 2.01-3.3 متر مقارنة بالحالة العادية. علاوة على ذلك ، تُظهر مؤشرات السرعة أن الانخفاض الحاصل في السرعة للحالة المذكورة سيؤدي إلى مزيد من الترسيب في مجرى النهر.

الكلمات الرئيسية: التغلغل الملحي ، السدة القاطعة ، شط العرب

1. INTRODUCTION

The Shatt al-Arab River is one of Iraq's most significant tide rivers, which formed from the Tigris and Euphrates rivers meet in Al Qurna city located about (70 km) North of Al Basrah Governorate south of Iraq as shown in **Fig. 1**. From the point of confluence to its estuary in the Gulf, the river is about 200 kilometers long and its ranges of depth vary between 8 to 17 m, additionally, the river sections width expanding between 250-300 m at Al Qurna to approximately 700 m in Al Basrah and 2km near the river estuary (**Hamdan, et al., 2019**). Two tributaries were joined the river during its course in the left side of the river, these rivers are Al Karun and Al Karkha which were flowing from Iran to Iraq. The tides in the Shatt Al Arab River are mostly semi-diurnal, there are two unequal high and low tides a day, and their effects may felt up to the confluence point northern Al Basrah Governorate (**Hussian, et al., 2009**). Many factors influence the Shatt Al-Arab River's hydrological regime including the released discharge at the upstream river basin and the tidal power that coming from the river mouth (**Salim, 2014**). In recent period, Shatt Al Arab River records a clear reduction of supplied discharge rates according to the policy of the upper basin countries that caused many problems of water use and salinity increasing. Today the main feeder of Shatt al Arab River is the Tigris river, other streams include Al Swaib, Euphrates and Garmat Ali rivers are closed by the Ministry of water resources in Iraq and Al Karun river is blocked by Iran (**Mahmood, et al., 2009**). Several studies were conducted by using mathematical models which involved hydraulic behavior simulation of Shatt al Arab River (**Al-Mahmood, et al., 2011**) (**Al-Fartusi, 2013**) and (**Abbas, 2017**), while other researches concerning the sea water intrusion

topic were implemented for Shatt al Arab river (Hamdan, 2016a) (Abdullah, et al., 2016) and (Hamdan, et al., 2020). The previous researches that related to the impact of barrage set up on the Shatt al Arab river stream were carried out only for the north part of the river reach (MED Ingegneria Report, et al., 2013) and (Hamdan, 2016b). HEC RAS software is a powerful simulation tool was used in rivers and coastal simulation for multiple purposes under different conditions in both one dimension (Al-Zaidy and Al-Thamiry, 2020) (Azzubaidi and Abbas, 2020) (Gharbi, et al., 2016) (Nguyen, et al., 2015) (Kumar, et al., 2017) and (Ahmed, et al., 2016) and tow dimension (Quiroga, et al., 2016) (Tenzin, et al., 2017) and (Papaioannou, et al., 2018). As a result, some researchers advocated for the construction of a dam at the river's mouth to keep salty water from returning from the Arabian Gulf (Lateef, et al., 2020). HEC RAS model one dimension unsteady state was implemented in this study for Shatt Al-Arab River, including its tributaries which is a part of Tigris, Euphrates, Al Karun and Garmat Ali rivers. In general, the area of study within Al Basra Governorate extended from Al Basrah- Maysan border till to Ras Al Besha. The main objective of this research to simulate the impact of proposed barrage and flow characteristics in the south part of the Shatt Al-Arab River (Ras Al Besha region), and to analyze the impact of the suggested barrage under the current conditions on the hydraulic behaviour of Shatt-Al-Arab and its morphology with the adopted tidal condition

2. AREA OF STUDY

Five reaches were included within the area of study with different length, these reaches are the Tigris river extended from Al Kasara region to Al Qurna city which about 52 km, Euphrates river with approximated length 24 km which starts from Al Modaina weir till to confluence point with Shatt al Arab river, Al Karun river is the third reach which about 15 km length, Garmat Ali River was about 5 km length and the main stream of Shatt al Arab River was about 198 km extended from Al Qurna to Ras Al Besha , as shown in Fig. 1.

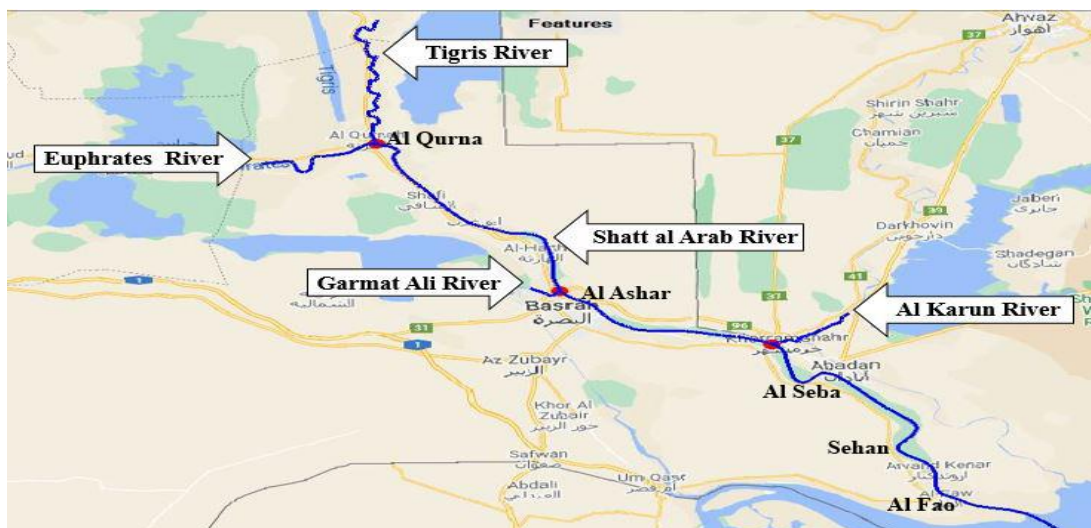


Figure 1. Rivers system site plan within Al Basrah Governorate.



3. NUMERICAL MODELING

The HEC-RAS (5.0.7) software solves the full 1D Saint- Venant equations numerically for unsteady open channel flow. This model developed by the Hydrologic Engineering Centre River Analysis System US Department of Defense (**US Army Corps of Engineers, 2016. Hec-Ras River Analysis System, User Manual, (USACE)**). This application is a professional engineering software package that allows to simulate flow conditions for unsteady open channel by solving the full one dimension Saint- Venant equations numerically by implementing the implicit finite difference scheme technique, **Fig. 2** show the user interface for the model. The data of changing water stages along the river and discharge distribution in various hydraulic conditions were the results of the hydrodynamic model.

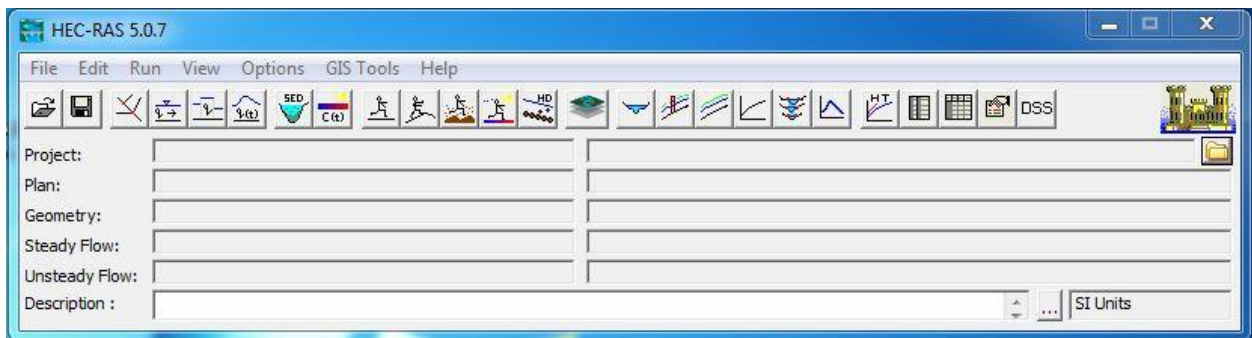


Figure 2. Main Window for HEC RAS.

3.1. Basic Equations Related to One-dimension Unsteady-state Flow

The unsteady state one-dimensional flow is linked to several fundamental equations. The flow characteristics and water level variations are described by the following equations, which are the conservation of mass and momentum integrated vertically ((**USACE) 2016, Hydraulic Reference Manual**).

Continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial Qv}{\partial x} + gA \left(\frac{\partial Z}{\partial X} + s_f \right) = 0 \tag{2}$$

Solving the equations above that represent the equations of “Saint-Venant”;

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \tag{3}$$

$$\frac{\partial v}{\partial t} + \alpha v \frac{\partial v}{\partial x} + g \frac{\partial y}{\partial x} = g(s_0 - s_f) \tag{4}$$

Where the above parameters are: (Q) discharge in m³/s, (q) lateral discharge m²/s, (A) flow cross sectional area in m², (Y) water depth in m, and (α) dimensionless coefficient of velocity.

The dimensionless slope of the bed is (S_0). (S_f) dimensionless friction gradient. (g) gravity of acceleration in m/s^2 , (V) flow velocity in m/s , and (Z) channel elevation in m .

3.2. River System & Geometric Data

Editing the required geometric data is the process of filling the information related to field survey within the area of study, which includes cross section data that represents the stream's geometry, river reach, river station identifiers and main channel bank stations. The model grid consists of five reaches, as shown in **Fig. 3**, the River cross-sections were measured in various locations along the river, about 855 cross sections, with a spacing ranging from 250-1000m between segments, ARC GIS 10.3 was used to create and edit these data (**Ministry of Water Resources MOWR**).

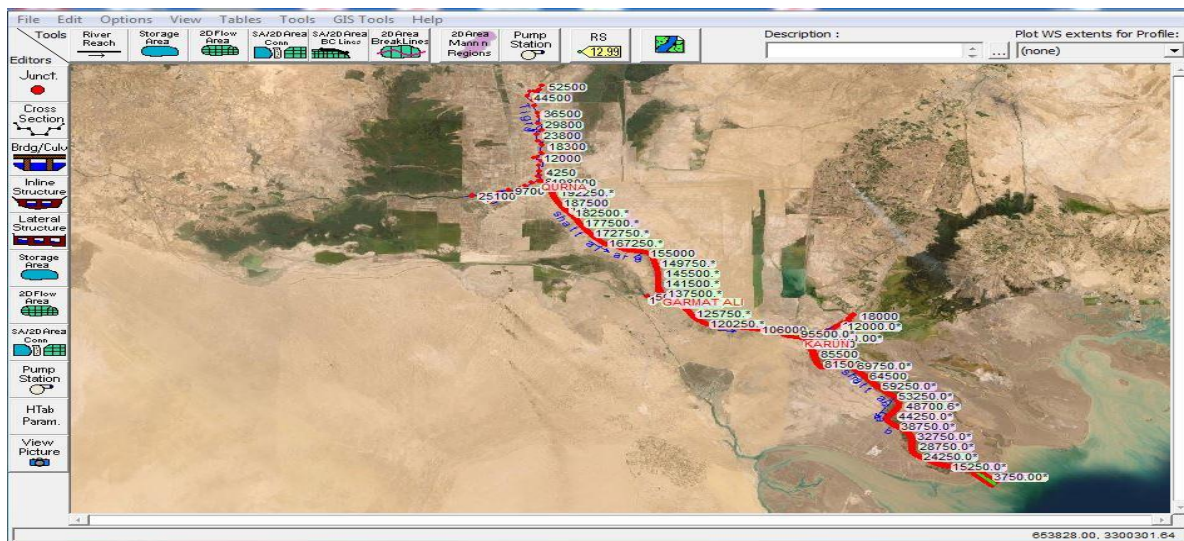


Figure 3. Geometric data editor HEC RAS (5.0.7).

3.3. Design Consideration and Inline Structure Data Editor

Inline structure was suggested in Ras Al Basha location at station 10+600 near the river estuary **Fig. 4**. The design discharge of this proposed structure was based on the estimated flood discharge in this location which expected about $1650 m^3/s$. The mentioned discharge calculated depending on the maximum safe flood discharge probability for (100, 200, and 500) years of the main tributaries for the Shatt Al Arab River, where Euphrates and Tigris rivers were $400 m^3/s$ and $150 m^3/s$ respectively (**Study of Strategy for Water and Land Resources in Iraq, SWLRI, 2014**), additionally, Al Karun and Al Swaib were $800 m^3/s$ and $300 m^3/s$ (**MOWR**). Where it was assumed that the flood occurs simultaneously in all tributaries, which is the worst case in design consecrations. The proposed structure attached with a 33 sluice gates which have a 7m height and 5m width, the invert level was selected as -8m, as shown in **Fig. 5**. It should be mentioned that the inline data were edited after calibration and verification process.



Figure 4. Ras Al Basha inline structure data editor window.

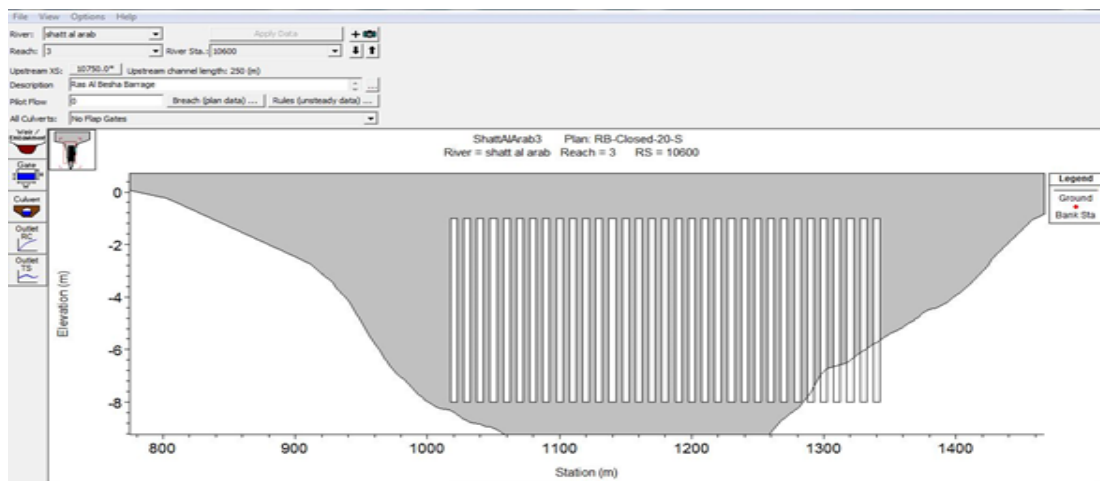


Figure 5. Ras Al Basha inline structure data editor window.

3.4. Upstream and Downstream Boundary Conditions

Previously, the Tigris, Euphrates, Al Karkha, Garmat Ali, and Al Karun Rivers all discharged freshwater into the Shatt Al-Arab River. Dams have recently been built in upstream countries on both the Euphrates and the Karun Rivers for storage purposes, in response to hydrological changes, As a result of these changes, the Tigris River has become the only source of freshwater for the Shatt Al-Arab River (Hamdan, 2016a). The daily discharge released from the Tigris River, which was measured near the Al Basrah border, is considered as the upstream boundary condition, as shown in Fig. 6. The Euphrates, Garmat Ali, and Al Karun rivers were defined as zero discharge, because these rivers were blocked previously. The tidal stages records in the Ras Al Basha region at km (0+000) in the river mouth were used as the downstream boundary condition as shown in Fig. 7. The values of the tide elevations and discharge records in the Shatt Al-Arab River were provided by the Ministry of water resources during the adopted period (MOWR).

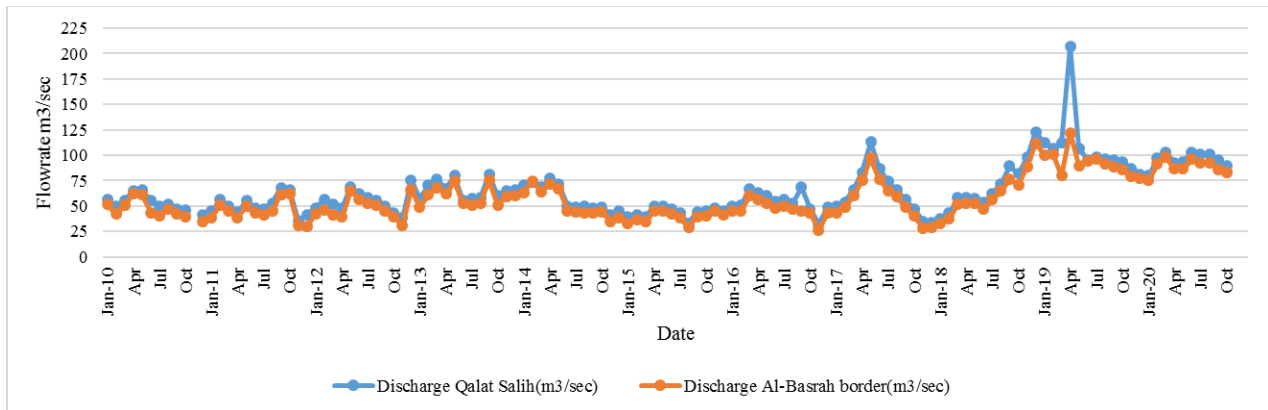


Figure 6. Daily flowrate records of Tigris River for the period 2010-2020, (MoWR).

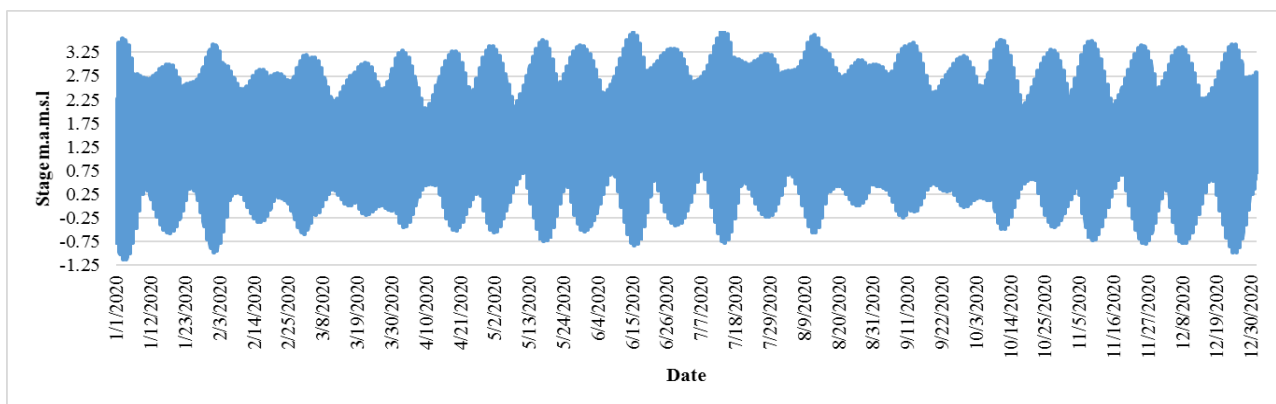


Figure 7. Tidal stage records for the period of 2020, (MoWR).

3.5. Calibration and Verification

Model calibration is an iterative process of changing model parameters and going to compare the model results to the actual system to improve the model until it is judged to be within an acceptable range of accuracy. For the hydraulic models, Manning's roughness coefficient (n) was used as a calibration parameter. Manning's roughness coefficient (n) describes the flow resistance caused by channel roughness caused by bed material and other obstructions. The values of Manning roughness coefficients for tributaries of the Shatt al Arab were seated as 0.028, 0.029 and 0.033 for the Tigris, Euphrates and Garmat Ali main channel respectively and 0.06 for the left and right banks (**Hamdan, et al., 2018**). Manning's n values for the Al Karun river were predicted based on previous studies for similar reach conditions (**Chow, 1959**), As a result, it was estimated that the river banks and main channel used as guides in selecting n values were approximately (0.06 - 0.028).

For the period of 12 Aug 2018, the calibration process was implemented for the main stream of the Shatt Al Arab River with an observed stages set which measured in field (**Al-Galibi, 2018**) [27], Two stations in different sections of the river (Al Ashar at km 125+500 and Al Fao at km 24+000) were chosen as shown in **Fig. 8** to compare the measured and predicted water levels, with the values of (n) ranging between 0.025 to 0.031 for the main channel.. Calibration results show that the value (0.029) give a good agreement and minimum error between simulated and observed water levels as presented in **Table 1**. The results of the water levels hydrographs for the period of 12 Aug 2018 is shown in **Fig. 9**. The model's verification, which is an important and necessary

test for any "simulation model," was accomplished by using a different set of data, following that, the model was tested on another stations (Al Qurna station at km 198+000 and Sehan station at km 41+500) for water level measurements as shown in **Fig. 8** for the period of 6-7 March 2020. **Fig. 10** shows a comparison of observed and simulated water levels. Verification results show a good correlation and minimal error between them, where the correlation coefficients (R2) were 0.91 and 0.95 as shown in **Fig. 11**.



Figure 8. Calibration and verification Stations Site Plane.

Table 1. Root mean square error for the different manning values.

(n) value	RMSE
0.025	0.137
0.026	0.135
0.027	0.133
0.028	0.131
0.029	0.130
0.030	0.131
0.031	0.133

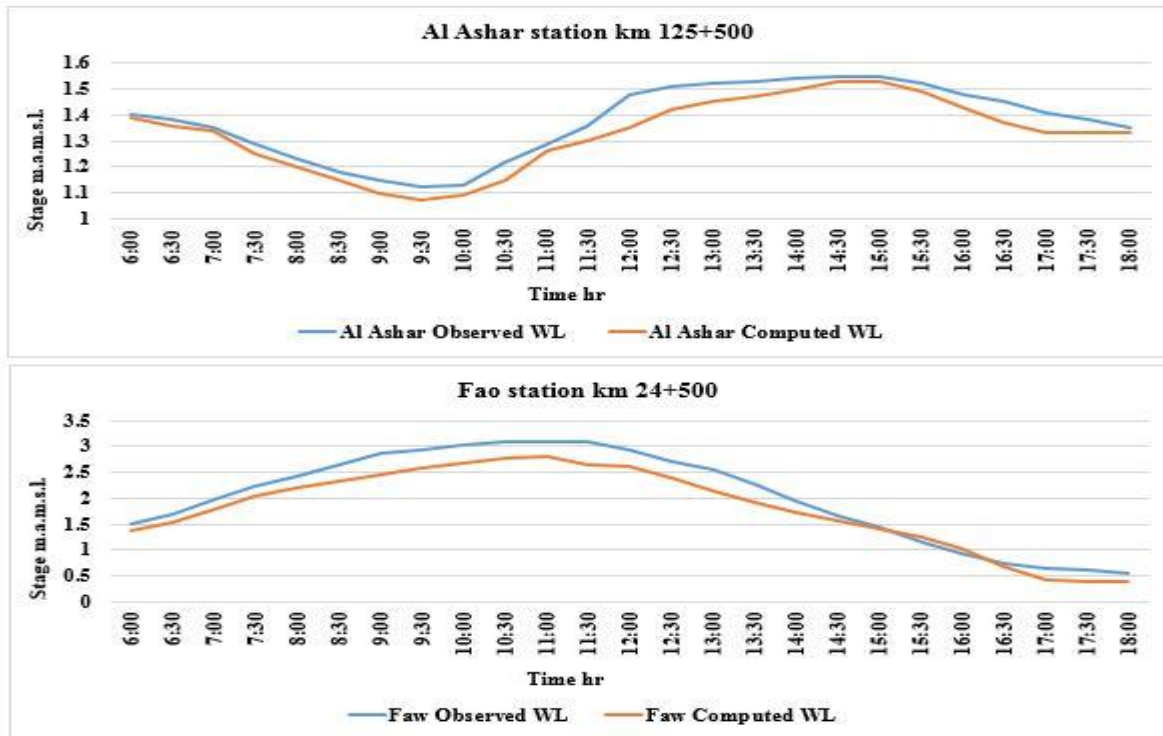


Figure 9. Model calibration comparison between computed and observed stages for Al Ashar and Al Faw stations.

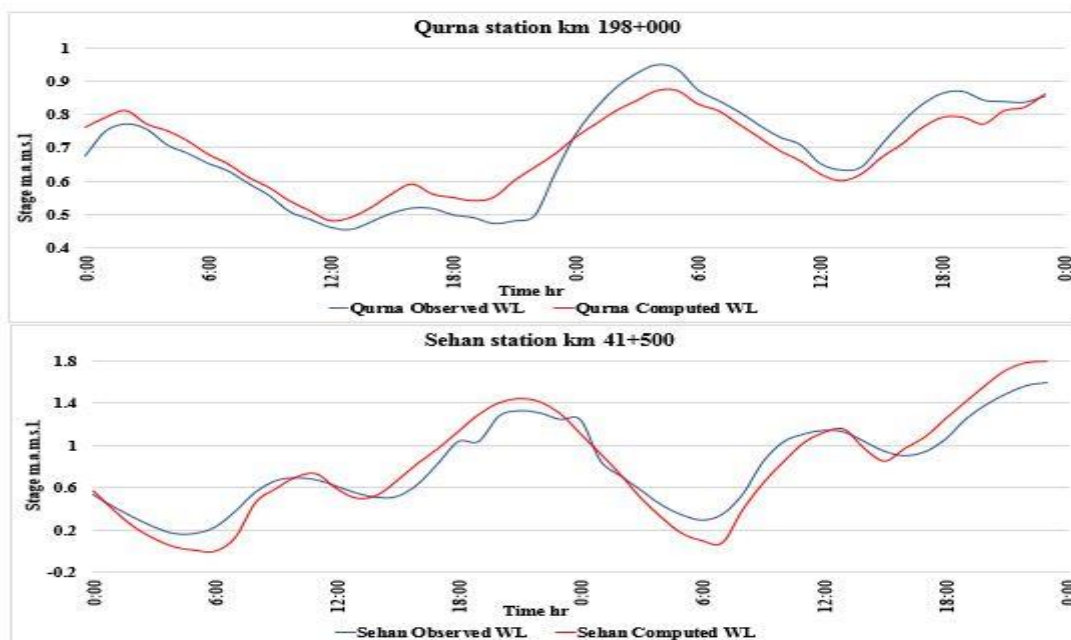


Figure 10. Model verification comparison between computed and observed stages for Al Qurna and Sehan stations.

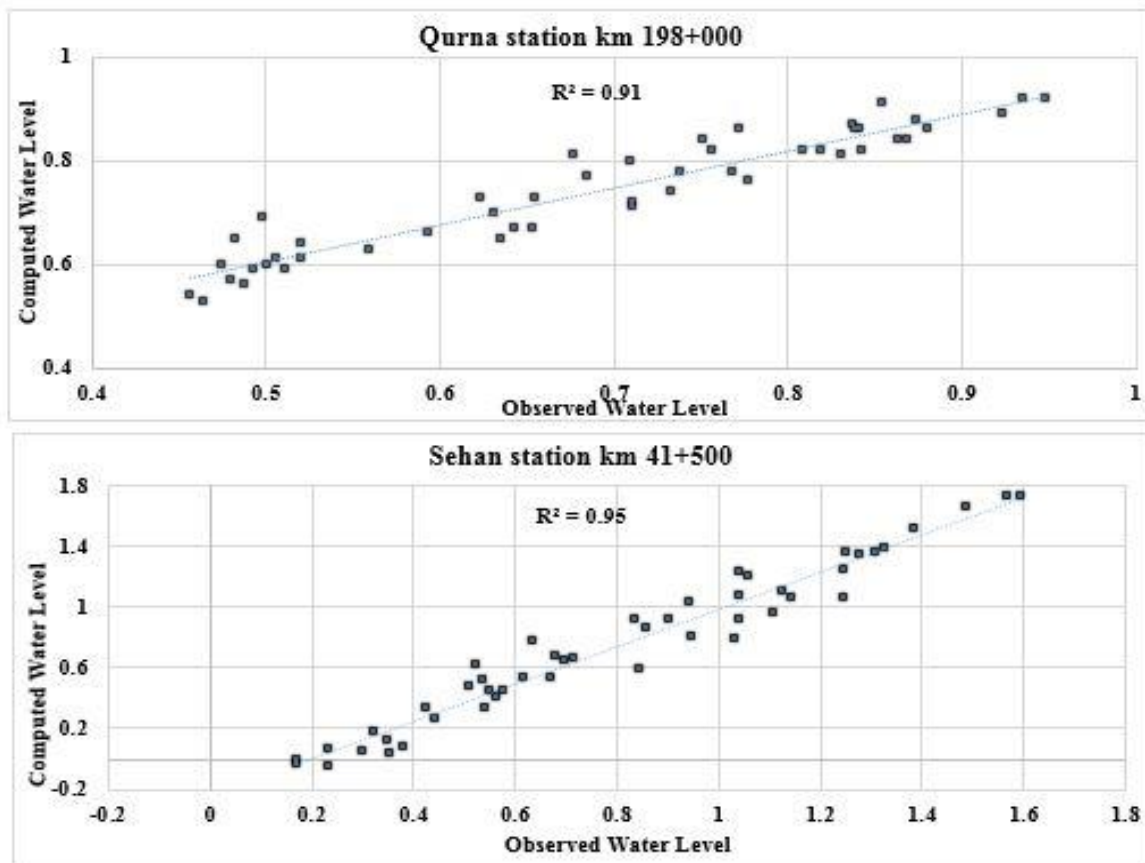


Figure 11. Correlation between computed and observed stages for verification stations.

4. SCENARIOS OF OPERATION

Several simulation sets that take into account a range of discharges (20-50-100-250) m³/sec that represent dry and moderate cases under various regulator gate openings. Two operation scenarios have been examined under different operation cases of the suggested barrage that including Fully opening case (the gate open high is 7 m), 50% opening case (the gate open high is 3.5 m) and Programmed opening case (gates operation with the effect of tides, opened in the case of starting the ebb and closed in the case of starting the flood). The mentioned discharges were taken into consideration, and the model was examined under the influence of adopted spring tide cycle as shown in the **Fig. 12**. Because of the hydrological conditions of the Shatt al-Arab are continuously changing all the time, this principle was used for research and comparison and explain the extreme points of each operating scenario. The operation schema and the scenarios coding for each case are shown in **Fig. 13**, the encoding of the above operation scenarios is as illustrative for example **(RB-20-Full-S)** means Ras Al Besha Proposed Barrage with 20 m³/s discharge, fully opened gates and during Spring tide.

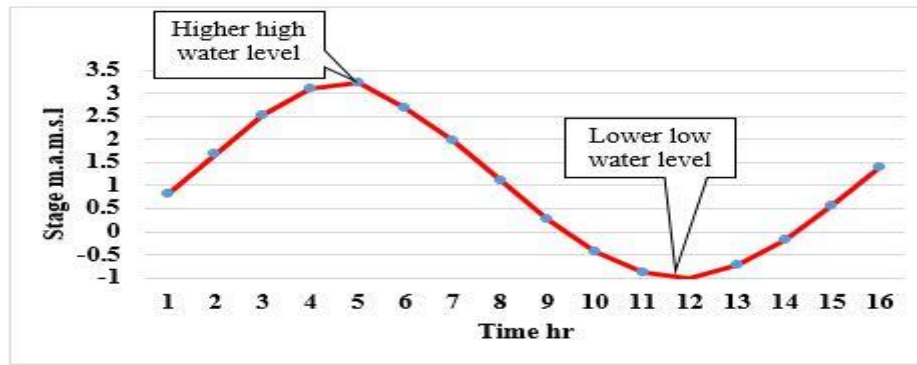


Figure 12. Adopted spring tide cycle.

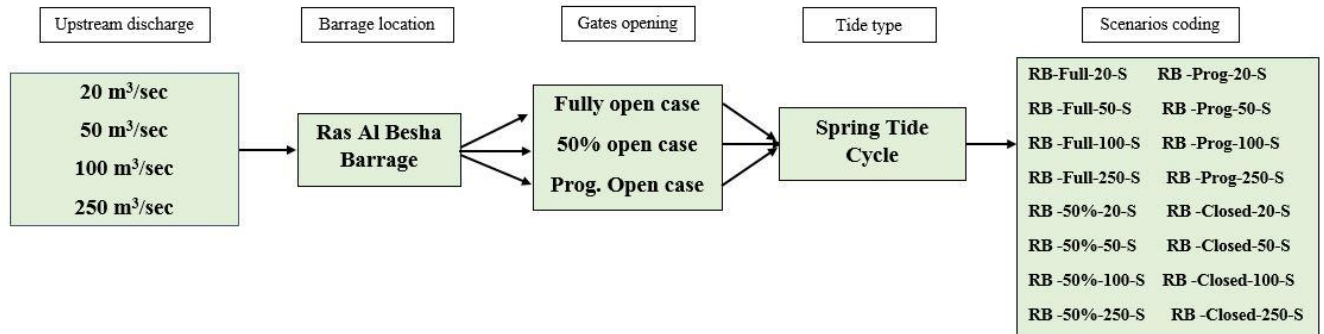


Figure 13. Operation scheme diagram.

5. RESULTS AND ANALYSIS

Once all of the input data and variables have been provided to the model for data processing, the output results in the form of graphs have been obtained. These results includes, maximum water surface elevations profile along the river, and maximum velocity profiles along the river reach. The maximum water surface profile along the study area for the adopted range of flow at the maximum flow was shown below. **Fig.14** for the fully open cases the effect of the tides on water levels upstream and downstream of the barrage appears in this case and the tide's power is dominant. The effect of the incoming discharge on the water levels is clearly visible in the upper river reach, where the stages are relatively affected by the flows entering to the river. The maximum water level for the examined discharges in the upstream side under fully open gates at spring tide are (2.15, 2.15, 2.18 and 2.20) m.a.m.s.l. **Fig.15** for the 50% open cases, the maximum water level in the upstream side at spring tide are (1.71, 1.73, 1.80 and 1.90) m.a.m.s.l. When compared to fully open cases, upstream water levels drop by about 0.26 to 0.50m, but this decrease fades as we get closer to the upper river reach. Downstream water levels increased by 0.18 to 0.28 m compared to fully open cases. **Fig.16** for the prograded open cases, the maximum water level in the upstream side at spring tide are (-1.10, -1.06, -0.80 and 0.17) m.a.m.s.l. There are a



significant drop in upstream water levels ranges from 2.01 to 3.30m compared to the stages in fully open cases, however, this range decreases slightly towards the upper end of the river. The results of the above mentioned cases are detailed in **Table 2**, these results show the maximum water levels for the different stations along the river reach (Al Qurna km 198, Al Ashar km 125, Abu Al Khasib km 109.6, Al Seba km 68.6, Al Fao km 24, Upstream Ras Al Besha km 10.75 and Downstream Ras Al Besha km 10.50). **The above mentioned table shows that the large deterioration in water levels in the upstream side (Navigation channel).**

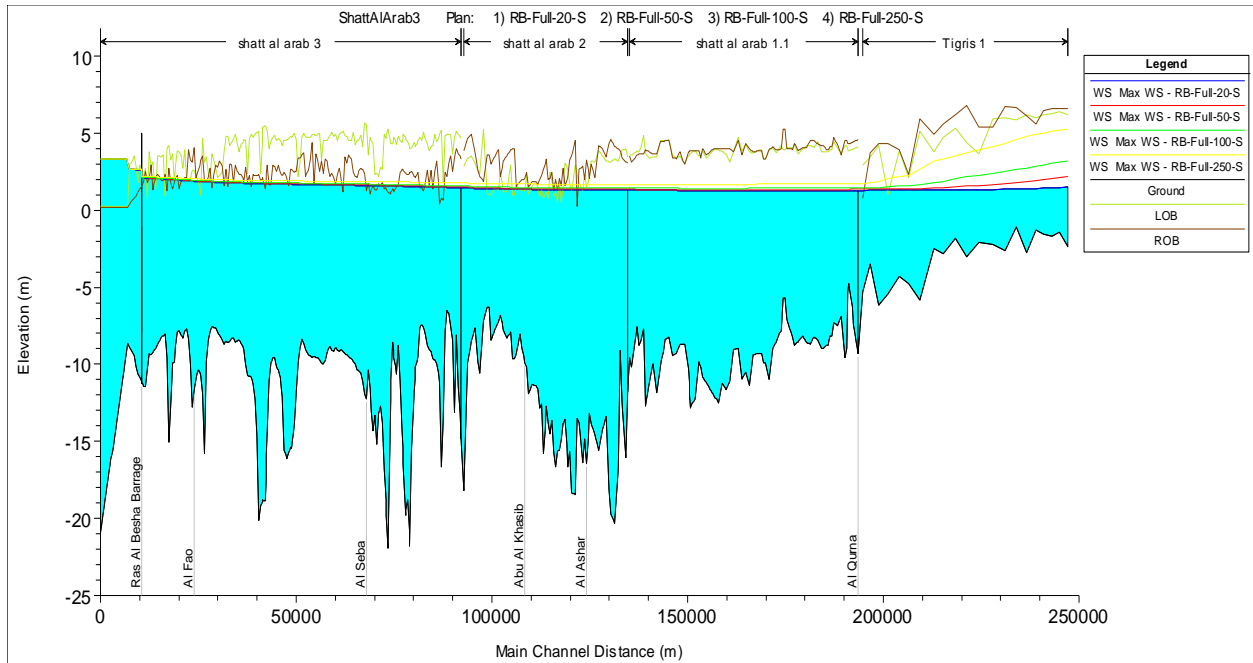


Figure 14. Maximum water level profile along Shatt al Arab River for fully open cases.

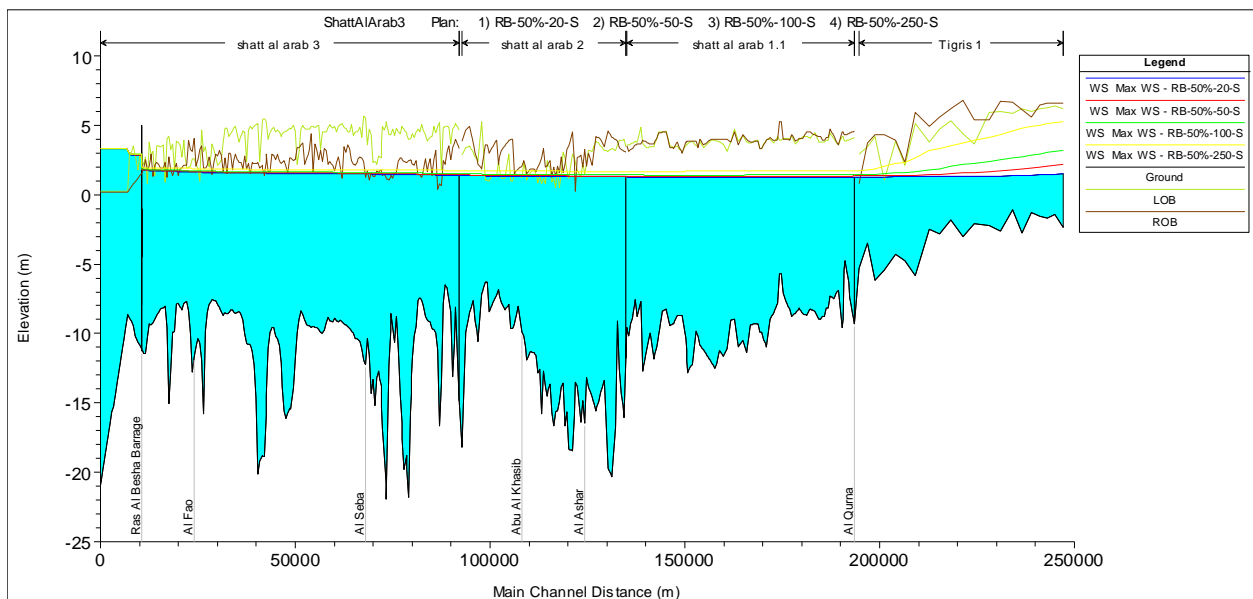


Figure 15. Maximum water level profile along Shatt al Arab River for 50% open cases

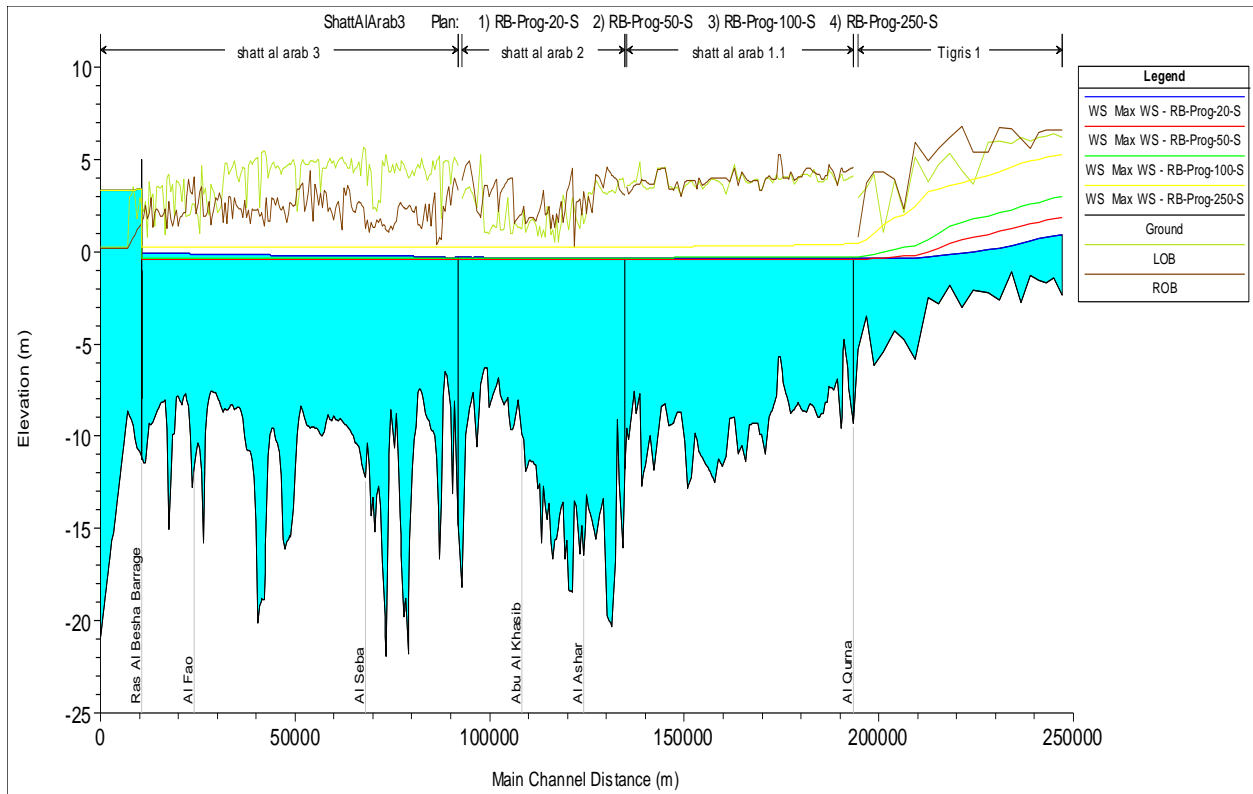


Figure 16. Maximum water level profile along Shatt al Arab River for programmed open cases.

Table 2. Maximum water level along the Shatt Al Arab River.

Case	Km 198	km 125	Km 109.6	Km 68.6	Km 24	Km 10.75	Km 10.5
RB-Full-20-S	1.28	1.33	1.36	1.60	1.90	2.15	2.62
RB-Full-50-S	1.35	1.37	1.40	1.63	1.91	2.15	2.68
RB-Full-100-S	1.46	1.45	1.47	1.69	1.94	2.18	2.69
RB-Full-250-S	1.73	1.67	1.69	1.85	2.05	2.20	2.70
RB-50%-20-S	1.28	1.30	1.32	1.49	1.64	1.71	2.88



RB-50%-50-S	1.35	1.35	1.37	1.53	1.67	1.73	2.88
RB-50%-100-S	1.46	1.43	1.45	1.60	1.72	1.80	2.89
RB-50%-250-S	1.74	1.68	1.69	1.80	1.88	1.92	2.90
RB-prog-20-S	-0.95	-1.09	-1.11	-1.12	-1.11	-1.10	3.27
RB-prog-50-S	-0.86	-1.07	-1.09	-1.09	-1.07	-1.06	3.27
RB-prog-100-S	-0.79	-0.86	-0.87	-0.86	-0.86	-0.80	3.27
RB-prog-250-S	0.19	0.10	0.10	0.13	0.13	0.17	3.27

Fig 17-19 show the maximum velocity distribution profiles for the main reach of the Shatt Al Arab River at the time of a maximum discharge for all mentioned cases as shown below. The negative and positive signs in these graphs represent the ebb and flood velocity directions, respectively.

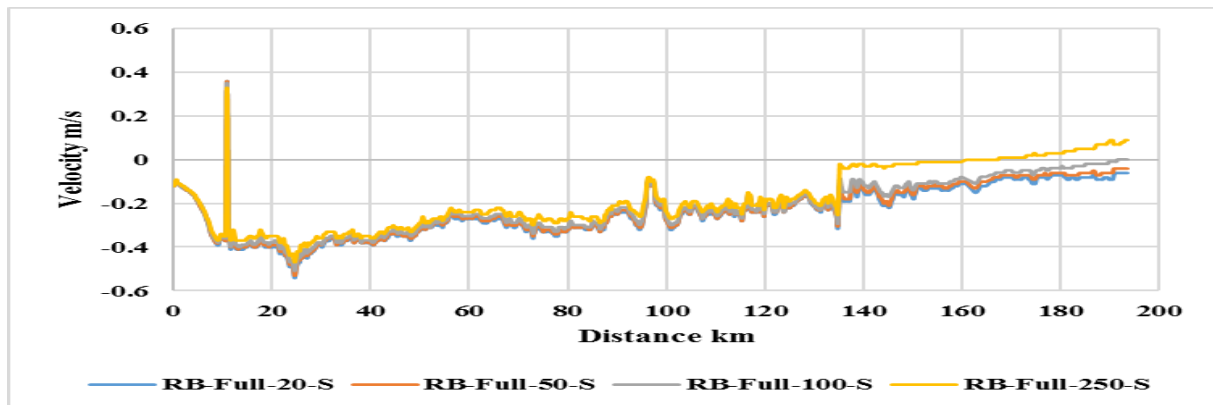


Figure 17. Maximum velocity profile along Shatt al Arab River for fully open cases.

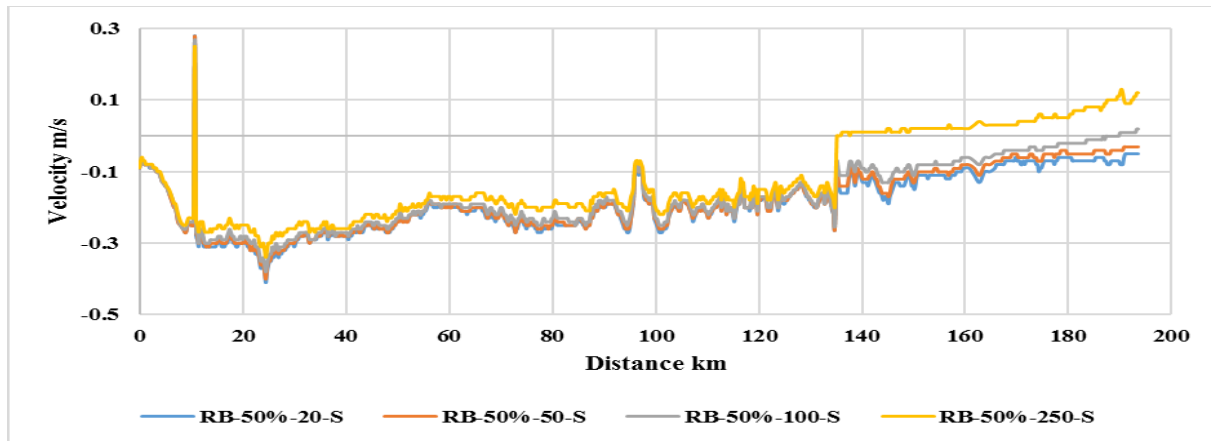


Figure 18. Maximum velocity profile along Shatt al Arab River for 50% open cases.

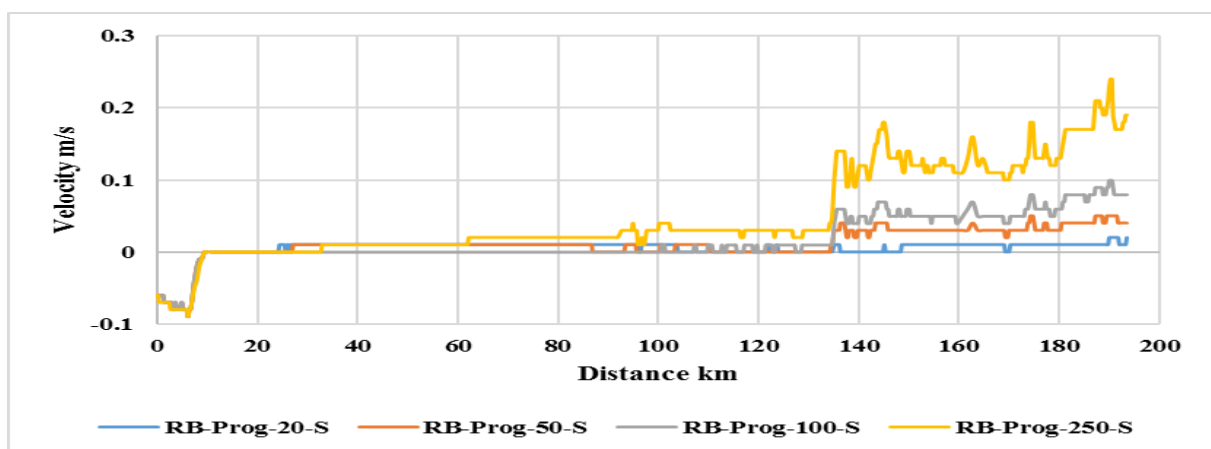


Figure 19. Maximum velocity profile along Shatt al Arab River for programmed open cases.

The following observations can be developed from these graphs:

The irregularity of river geometry, as well as sub-branches connected to the main reach, causes non-uniform velocity distribution during each operation scenario shown in the above figures. Generally, high velocities occur in the upstream region at Al Qurna (confluence point) due to river geometry, where the cross sectional area of the upstream region is smaller than these in downstream reach. Velocities decrease as the river expansions along the river since the cross sections were non uniform in geometry, with wide sections downstream. The power of tide play a big role in velocity distribution, especially in the downstream portion, as we note the velocity range between -0.55 m/s to -0.10 m/s. this variation depends on the gates opening as shown in Fig 17-19.

5. CONCLUSIONS

The following conclusions can be drawn based on the results obtained of this study:

- 1- For the Shatt Al-Arab River the proper value of the Manning roughness coefficient (n) is (0.029). The results revealed that there was a high level of agreement between the predicted and measured levels, with an RMSE of 0.130.
- 2- The results of the analysis show that the proposed location is unsuitable for a multitude of reasons, the most important of which is the lack of guarantee the released flowrates on the



barrage's upstream side. As a result, the required navigational depths upstream of the barrage will be affected especially in the case of programmed opening which cause about (2.01-3.30) m decreasing in water stages. So it is expected to be the suitable location is upstream the present location exactly in the start point of the navigation channel.

- 3- The velocity range is between -0.65 to 0.38 m/sec along the river reach. Additionally, Negative velocity is achieved in the upstream of the barrage in cases of full and 50 % opening, indicating that the salt wedge can be penetrated for a specific distance in these cases.
- 4- High negative velocity was satisfied near the river mouth due to the power of tide that coming from the Arabian Gulf. According to the velocity indicators, the tide's effect can reach up to Al-Qurna city, especially in the drought cases.
- 5- The velocity values at the upstream side of a programmed opening are close to or greater than zero, this indicates that a stagnation scenario has happened and salt wedge intrusion into the upper river has completely stopped. Accordingly, Sedimentation may occur within the river reach more than the normal situation

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