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Hydraulic Simulation of Suggested Barrage on Shatt Al Arab River to Prevent the Salt Intrusion (Al Seeba as a Case Study)

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Abstract - The Tide River of Iraq, The Shatt al-Arab River is generated by the confluence of the Tigris and Euphrates rivers at the city of Qurna, which is located northern of the Al-Basra Governorate due to climate change and excessive consumption, the flow of the two rivers decreased which resulted in a high percentage of dissolved solids in the river, which caused the river to become salinized as a result of salt wedge intrusion. This study's primary goal is to model the Shatt Al-Arab River's hydraulic response to a proposed barrage in Al Seba to reduce the salinity. In this study, to evaluate the effect of the suggested block dam, a one-dimensional unsteady model was created using HEC-RAS 5.0.7. Four discharge instances, with low and moderate discharges of (20-50-100 and 250 m3/s) and the selected spring tide cycle, were selected. There are four barrage gate cases. (totally open, 50% open, programmed opening, and fully closed) were used in the operation scenarios. The research shows that the examined discharges will significantly affect navigation depths, particularly when gates are programmed to open with stages dropping approximately (0.6 - 1.2) m in comparison to the normal situation. Also, according to the velocity indicators, the barrage's large velocity reduction upstream increased the amount of silt within the river's stream. As a result, a Suggested Barrage is needed on the south reach to avoid salt intrusion.

النمذجة الهيدروليكية للسدة التنظيمية المقترحة على شط العرب لمنع التوغل الملحي (موقع السيبة)

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المستخلص - يعتبر شط العرب أحد الانهار ذات النظام المدي في العراق، ويتكون عند التقاء نهري دجلة والفرات شمال محافظة البصرة في جنوب العراق. يؤدي انخفاض تصاريف المياه العذبة من المصادر إلى زيادة الملوحة في مجرى النهر نتيجة تغلغل اللسان الملحي. نتيجة لذلك، ظهرت الحاجة الى سدة تنظيمية قاطعة على مجرى النهر. الهدف الأساسي لهذه الدراسة هو نمذجة السلوك الهيدروليكية للنهر بوجود السدة المقترحة في منطقة السيبة. تم إنشاء نموذج جريان غير مستقر أحادي البعد باستخدام HEC-RAS (5.0.7) كشرط حدودي للمقتربات السفلى للنهر. تم اعتماد مدى من التصاريف تمثل حالات الندره والمتوسطة والوفره (20 – 50 – 100 – 250 م^3 / ثانية) مع اعتماد دورة المد الربيعي. تم اعتماد عدة حالات تشغيلية للسدة المقترحة (الفتح الكلي، الفتح النصفي، الفتح المبرمج والغلق الكامل). بينت النتائج أن التصاريف المقترحة ستؤثر بشكل ملحوظ على الاعماق الملاحية للنهر وبالأخص في حالات الفتح المبرمج حيث ستنخفض المناسيب بحدود (0.6 – 1.2) متر مقارنة بالوضع الطبيعي. أيضا، وفقا لمؤشرات السرعة اظهرت النتائج انخفاض بالسرع في مقدم السدة المقترحة عن المعدلات الاعتيادية الامر الذي يؤدي الى زيادة كمية الطمي في مجرى النهر.
الكلمات المفتاحية: HEC-RAS ، اللسان الملحي ، السدة القاطعة ، شط العرب ، السيبة.

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Introduction

In the city of Al Qurna, about 70 kilometers north of the Al Basrah Governorate in southern Iraq, the Tigris and Euphrates Rivers confluence to form the Shatt al-Arab River, which is one of Iraq most important tide rivers in Iraq. It marks the final stage of the Tigris and Euphrates river system as shown in Fig. 1. The river is about 200 kilometers long from confluence point to its estuary in the Gulf, the final 95 kilometers of the Shatt Al-Arab river stream, which forms an international borderline, run through Iraq and Iran, with depths between eight and seventeen meters. The width of the river fluctuates, ranging from around two kilometers close to the river's estuary to 700 meters in Al Basrah and 250–300 meters in Al Qurna (Hamdan *et al.,* 2019). The tides in the Arabian Gulf and the Tigris River's discharge have recently had a significant impact on the river's hydrological system (Moyel, 2014). The tide patterns in the Arabian Gulf are mostly semidiurnal, and their effects can be felt as far north as Al-Qurna in the governorate of Basra (Al-Mahdi *et al.,* 2009). In recent years, there has been a shortage of fresh water reaching the Shatt Al-Arab River each year, resulting in increased salinity in the river (Hamdan and Dawood, 2016). The Tigris River is now the main feeder of the Shatt al-Arab River; Iraqi Ministry of Water Resources has blocked access to several streams, including the Euphrates, Garmat Ali, and Al Swaib Rivers, and Iran has blocked the Al Karun River. Several studies involving simulation of hydraulic dynamics of the Shatt al-Arab River were conducted using mathematical models (Ahmad *et al.,* 2016; Abbas, 2017; Hamdan, 2016; Al-Fartusi, 2018), while other various aspects of the seawater intrusion process's impacts and the recognition of the best strategies for dealing with this problem were executed for the Shatt al-Arab river (Hamdan, 2016; Hamdan *et al.,* 2020). The Shatt Al-Arab River is confronted with a variety of natural and anthropogenic challenges, resulting in a noticeable decline in the quality and quantity of its water(Abdullah et al., 2016). HEC RAS software is a powerful modeling system that has been used in simulations of rivers and coastlines for a variety of purposes and under various conditions; one-dimensional as well as two-dimensional (Ali and Al Thamiry 2023; Azzubaidi, 2020; Quirogaa *et al.,* 2016; Farooq *et al.,* 2019).

The one-dimensional unsteady state model for the River Shatt Al-Arab and its tributaries, HEC RAS (5.0.7), was utilized in this research. The model includes a portion of the Al Karun, Garmat Ali, Euphrates, and Tigris Rivers within the Al Basra Governorate, which stretches from the boundary between Al Basrah and Maysan to Ras Al Besha.

The main aim of this work was to model and provide a detailed analysis of the hydraulic characteristics in the Shatt Al-Arab River under the impact of the proposed barrage in the Al Seba site in various conditions. The study examined The major Shatt Al-Arab reach, excluding any branches or intakes that followed the river's course. Additionally ignoring the impact of wind on the model's hydraulic characteristics and the effects of marine sinking in the river reach since the appropriate authorities have not provided enough information about it.

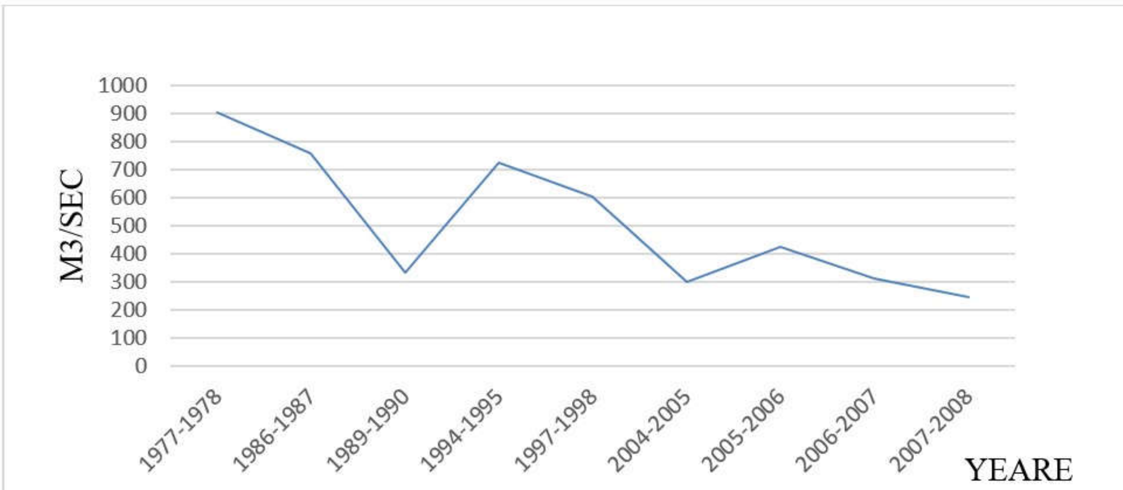
Description of the River Stream and Climatic Conditions

The Shatt al-Arab River basin is one of the transboundary basins as it is shared by six countries (Turkey - Iran - Syria - Saudi Arabia - Jordan - as well as Iraq) (Al-Galibi, 2020) The total area of the river's water recharge basin is about 938305 km2, this large area on which the river basin extends made it the largest river basin in Southwest Asia (Al-Asadi, 2017). The Shatt al-Arab River basin in Iraq occupies an area of 498,800 km2 to represent the largest country with an area extension of the river basin, representing 53.16% of the total area of the basin. The estimated total amount of water that can be produced by the river basin is estimated at 106.02

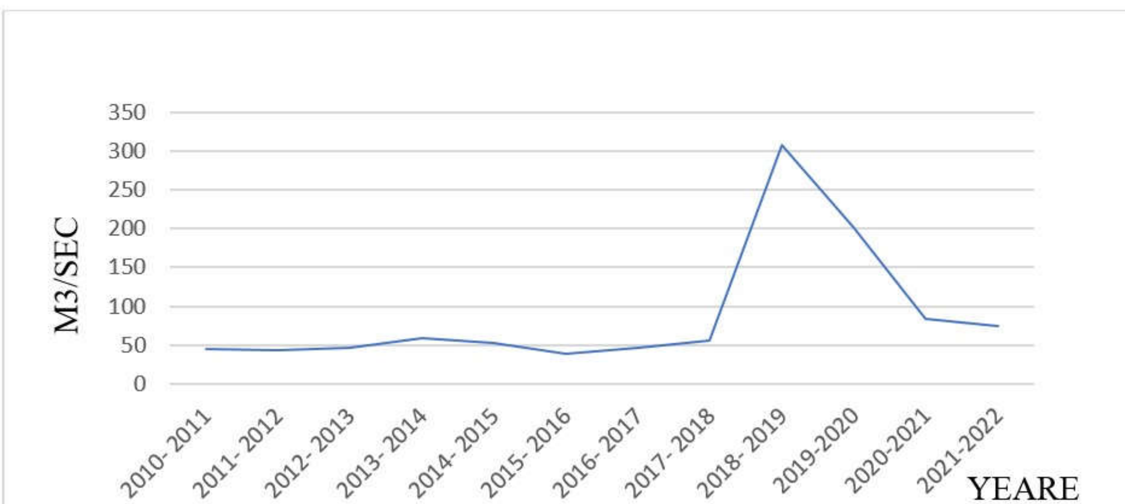
km^3/year, and although Iraq owns 53.16% of the total area of the river basin, it contributes about 16.77 km3/year to supplying the basin with water, representing 15.81% of the total amount of water available in the basin (Al-Galibi, 2020). Climatic conditions are the most important factor that controls the volume of water flow and the nature of runoff in river basins, as there is a strong relationship between atmospheric elements and the hydrological cycle (Bates *et al.,* 2008). In recent decades, the world has witnessed clear changes in climate elements (IPCC, 2007). The flow of water in the tributaries of the Shatt al-Arab River basin is mainly dependent on winter rains and melting spring snow in the Turkish and Iranian mountains (Al-Asadi, 2017). The annual average of total atmospheric precipitation throughout the river basin varies from 100 to 1000 mm/year (Issa *et al.,* 2013), while the average atmospheric precipitation in the upstream region (Turkey-Iran) was 643 mm/year for the period 1941-2007 (Republic of Turkey, 2009). Atmospheric precipitation affects the volume of water discharge temporally and spatially in the river basin, as we see a variation in discharge between year and year season, and even from day to day, and the reason for this is due to the variation in the amount of rain and snow falling from year to year and season to season (Al-Dulaimi, 2006). Climate change in the region will cause increased drought and water scarcity, with rainfall at the regional level falling to 25% of the overall average of total air precipitation, while rainfall at the local level will increase to 40% (UNWWAP, 2009).

The river basin region is expected to suffer from a significant rise in temperatures and be exposed to severe heat waves, which causes more droughts in the region, as temperatures in the river basin region rise during the end of this century by 3-5 degrees Celsius (Elasha, 2010). Recorded temperatures indicate an increase in average temperatures of 0.64°C per 100 years (Republic of Turkey, 2009). The evaporation factor is also added to other climatic variables that cause increased water scarcity and drought within the Shatt al-Arab basin. The total annual volume of surface evaporation in the Shatt al-Arab basin is about 11.68 km3/year, and it is natural that the rates gradually decrease towards the north, so evaporation rates decrease upstream, reaching about 1.73 km3/year in Turkey (Beaumont, 1998; Ohara *et al.,* 2011). The increase in the volume of evaporation from surface water in the Shatt al-Arab basin due to global climate change (Aqrawi, 1995) has caused significant losses in water potential within the river basin (Milly *et al.,* 2005; UNWWAP, 2009; Republic of Turkey, 2009; Terink *et al.,* 2013; Bozkurt and Sen, 2013), with a 10–30% reduction in runoff annually from major upstream areas by 2050 (Milly *et al.,* 2005). Iraq will lose about 22% of the water from the Tigris and Euphrates river basin due to climate change in general (Issa *et al.,* 2013), not to mention other human factors that contributed to the scarcity of water within the basin, including rapid population growth, consumption of large amounts of water in agriculture, as well as dams and reservoirs built in the upper upstream countries (Turkey-Iran-Syria) (Al-Galibi, 2020). The hydrological system of the Shatt Al-Arab River was subjected to a comprehensive change after 2009 due to the cutting and diversion of most of the main tributaries of the river, as the Euphrates River was cut before its confluence with the Tigris River by the Iraqi government in 2010, and the Karkheh and Karoun rivers were diverted to Iranian territory before their mouth in the Shatt al-Arab. As full control of the drainage of the Tigris River before it reaches the Shatt al-Arab River through the Qal'at Saleh regulator in Maysan Governorate. These works have affected a lot on the hydrological system, so the year 2009-2010 can be counted as a pivotal year in the hydrological history of the Shatt al-Arab River, and therefore the researchers believe that it is necessary to divide the annual discharges of fresh water into two stages, the first of which is all the water years monitored before 2009, while the second phase included the years of monitoring after 2010.

The general rate of discharge of the Shatt al-Arab River reached 512 m^3/s during the period (1977-2008) (Fig. 1), while the general rate of discharge of the Shatt al-Arab River was 88 m3/s during the period (2010-2022) (Fig. 2), which means that the water discharge decreased by 424 m3/s from the rate of discharge during the period (1977-2008), while the rate of water discharge south of the Shatt al-Arab near the mouth of Karun rises to 1189 m3/s and 815 m^3/s during the period (1948-1960) (1994-1995) respectively (Al-Asadi, 2017).



(Figure 1) Freshwater discharge in the Shatt Al-Arab River (m3/s) in Basra city for the period 1977-2008 (MOWR, 2020)



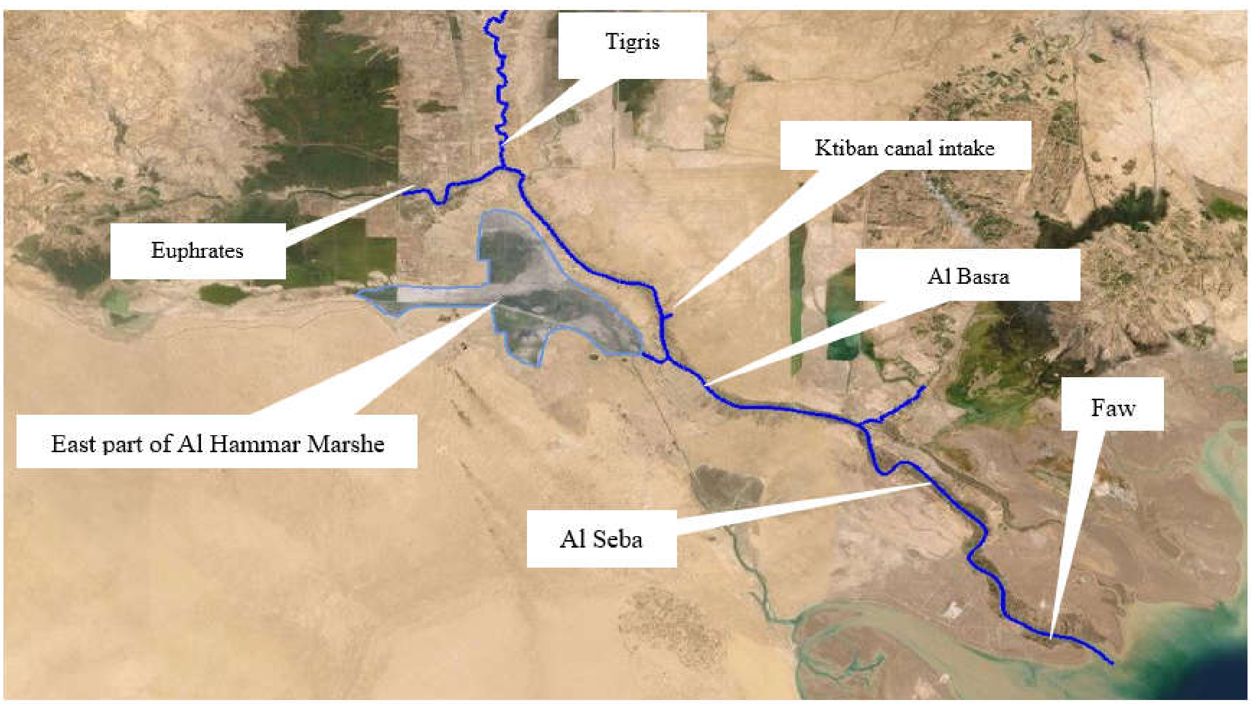
(Figure 2) Freshwater discharge in the Shatt Al-Arab River (m3/s) in Basra city for the period 2010-2022. (MOWR 2020)

The rates of water discharge in the Shatt al-Arab River witnessed annual variations during the period (1977-2008) and (2010-2022), as the rate increased to 903 m^3/s and 308 m3/s for the water year (1977-1978) and (2018-2019) respectively, and the rate of water discharge in the water year (2007-2008) and (2015-2016) decreased to 246 m3/s and 39 m3/s respectively (Figs. 1 and 2).

The general average monthly discharge in the city of Basra for the period (1977-2008) and (2010-2022) recorded its highest increase during April and May, reaching 693 m3/s and 165 m3/s respectively (Fig. 1 and 2). The reason for the decrease in water discharges in the river can be attributed to the growth of water projects in the countries of the upper basin (Turkey, Syria, Iran), the prevalence of drought in the basin area since the nineties, the decrease in water surplus and runoff (Brekke *et al*., 2009: 6-11) and if the water years (2018-2020) are excluded from being exceptional years due to the state of bad flooding in the basin countries, all monthly and annual discharges were much less than the actual need for the Shatt al-Arab River.

Research Area and Hydrological Regime

Iraqi marine waters include the Shatt AL-Arab estuary and several open coastal waters such as Khor Al-Amaya, and Khor Abdullah, which are located in the northwestern part of the Arabian Gulf (Al-Mahdi *et al.,* 2009). The study area in this research starts from the Shatt Al Arab estuary (outer bar region) up to Al Basrah Missan borders. Within the mentioned area there are five reaches of varying lengths were included. Tigris River stretches 52 kilometers from Al Kasara to Al Qurna. The Euphrates River is a 24 km long. It extends from the Al Modaina weir to the Shatt al-Arab river's confluence. The third reach is the Al Karun River, with a length of about 15 kilometers. The Shatt al-Arab River's mainstream, which reaches Ras Al Besha from Al Qurna, is about 198 km long and Garmat Ali River with 5 km length, as shown in (Fig. 3). In the last decades the Shatt Al-Arab River had freshwater along its path due to the high freshwater inflow from these rivers, with no salinity intrusion from the Arabian Gulf. Several dams have been built in Turkey, Syria, and Iran in the last few decades as a result of water resource development in both the Tigris and Euphrates basins, and the Shatt Al-Arab River flow regime has been influenced by dams built along the Karun river in Iran, resulting in a significant reduction in freshwater inflow to the river.

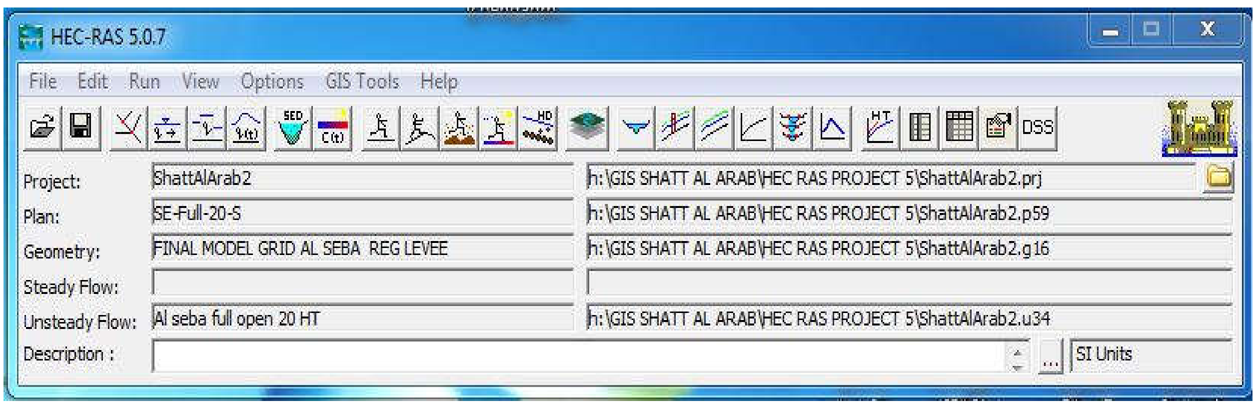


(Figure 3) General site plan of Shatt Al-Arab within the study area, by (ArcGIS 10.3, ESRI 2021)

Additionally, following the construction of an embankment on the Euphrates River by Iraqi Ministry of Water Resources in 2009, the problem became even worse. Furthermore. Currently, in the Shatt Al-Arab River, the Tigris River is the only source of fresh water. The inflow varies seasonally and is reduced in some periods to the point where water consumption in the Basra province exceeds the inflow, causing saltwater from the Arabian Gulf to enter the upper reaches of the river, causing the Shatt Al-Arab to suffer (Abdullah, 2017). The Shatt Al-Arab tidal regime has a mixed semi-diurnal tide with two high and two low water levels, which defines it., as well as diurnal inequality (Ali and Al Thamiry 2021; Abdullah 2002 ; Lafta *et al*., 2020)**.**

Materials and Methods

Regarding open channel unsteady flow, the 1D Saint- Venant equations are fully solved numerically by the HEC-RAS (5.0.7) tool. This model was created by the US Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System. This software is an advanced engineering application hat implements the implicit finite difference scheme technique to model the flow characteristics of unsteady open channels. The user interface for the mentioned model is shown in Fig. 4. The hydrodynamic model generated information on the distribution of discharge under different hydraulic conditions and fluctuating water levels along the river.



(Figure 4) Main Window for HEC RAS

One-Dimension Unsteady-State Flow Basic Equations

Several basic equations are linked to the unsteady state of one-dimensional flow. The subsequent formulas represent the vertically integrated conservation of mass and momentum, and describe the flow characteristics and water level variations (USACE, 2016).

Continuity equation:

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

Momentum equation:

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

solving the mentioned equations, which stand in for the "Saint-Venant" equations;

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

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

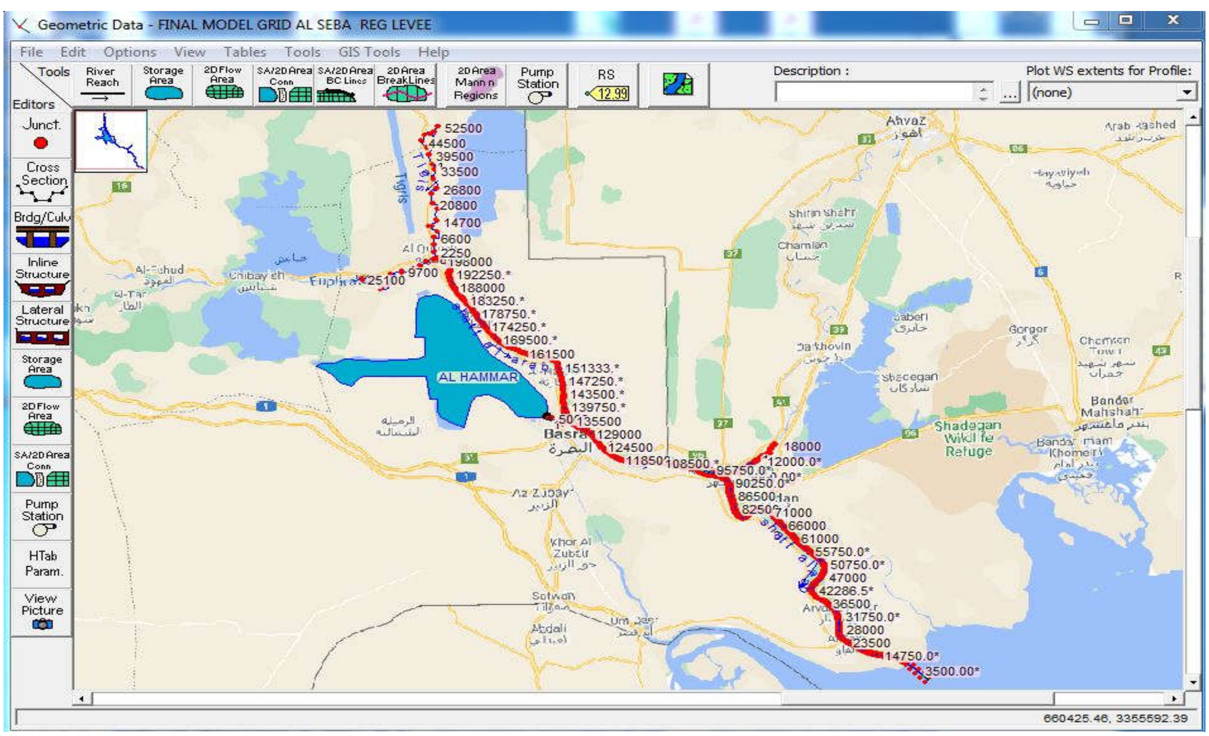
where Q is the discharge (m^3/s), q is the lateral discharge (m^2/s), A is the cross-sectional area of flow (m^2), y is the depth of the water (m), and α is the coefficient of velocity without dimensions. The bed's dimensionless slop is S_0. S_f is the friction gradient's dimensionless. g is the gravity of acceleration (m/s^2), V is the velocity of flow m/s, and Z is the level of the channel in m.

Geometric Data and River Network

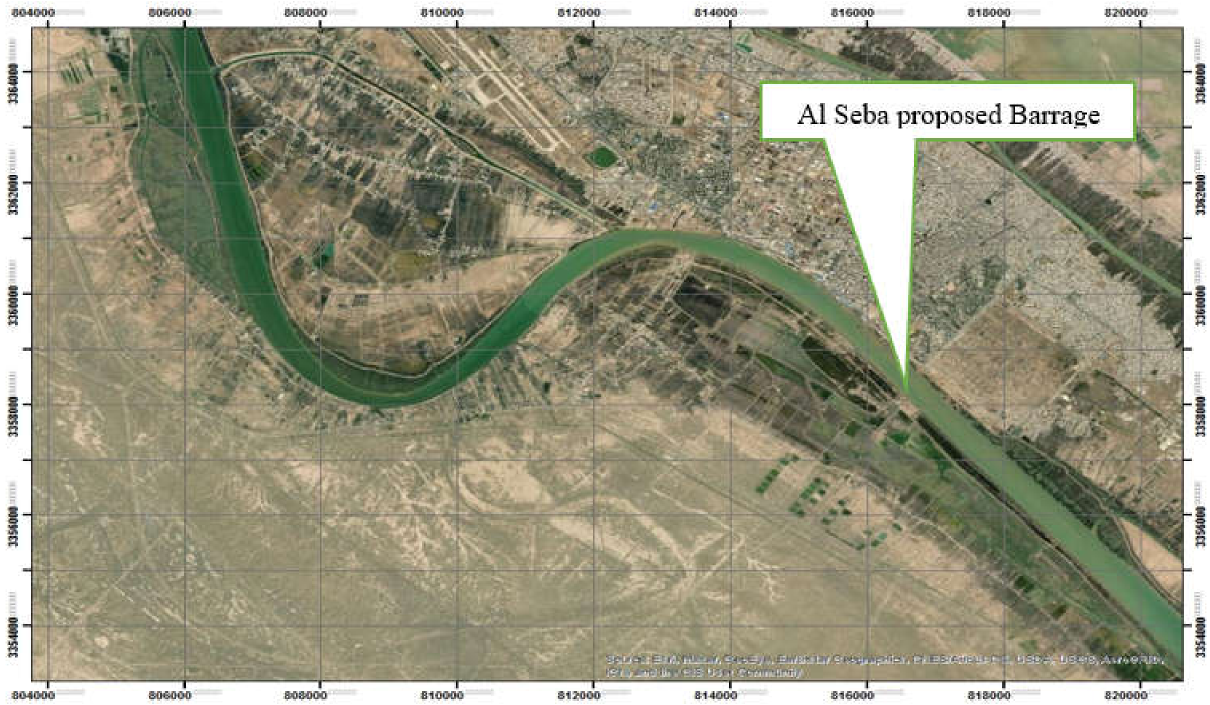
The process of completing the information linked to field surveys within the region of research contains data on cross-sections that show the shape of the stream river station identification and river reach, and major channel bank stations, is known as editing the required geometric data. As shown in Fig. 5, the model grid consists of five reaches. At different locations along the river, cross-sections of the river were measured; Approximately 855 cross-sections in all, spaced 250–1000 meters apart between parts. These data were created and edited using ARC GIS 10.3.

Considering Design Aspects and the Inline Structure Data Editor

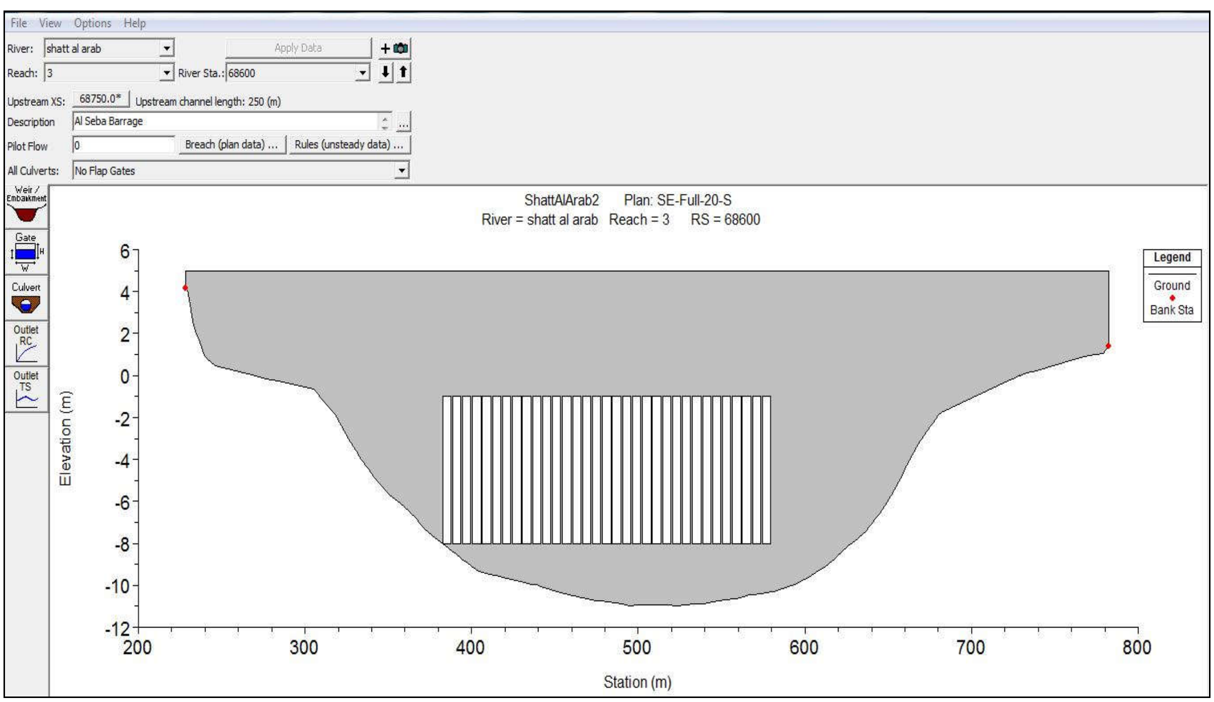
In Al Seba, the inline structure was proposed which is located at km 67+600 (816537 m Easting and 3358456 m Northing) as shown in Figs. 6 and 7. The suggested barrage in Al Seba location has an estimated design discharge of about 1650 m^3/sec with vertical sluice gates (5m width * 7m height). The total number of gates is 33 gates; these gates' invert level is (-8 m.a.m.s.l). The worst-case scenario for design considerations was that the flood would occur simultaneously in every tributary.



(Figure 5) Editor window of Geometric data (HEC RAS 5.0.7 - 2021)



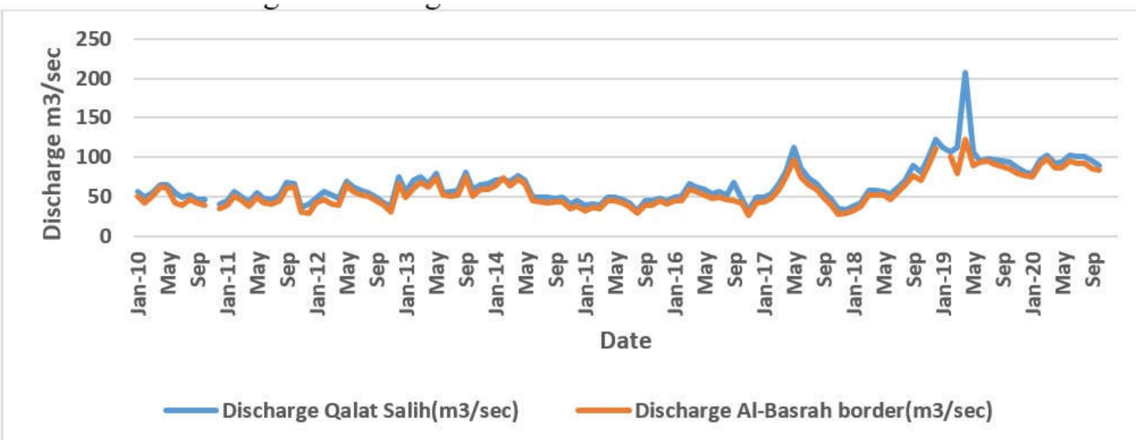
(Figure 6) Suggested location for a proposed barrage, (ArcGIS 10.3, ESRI 2021)



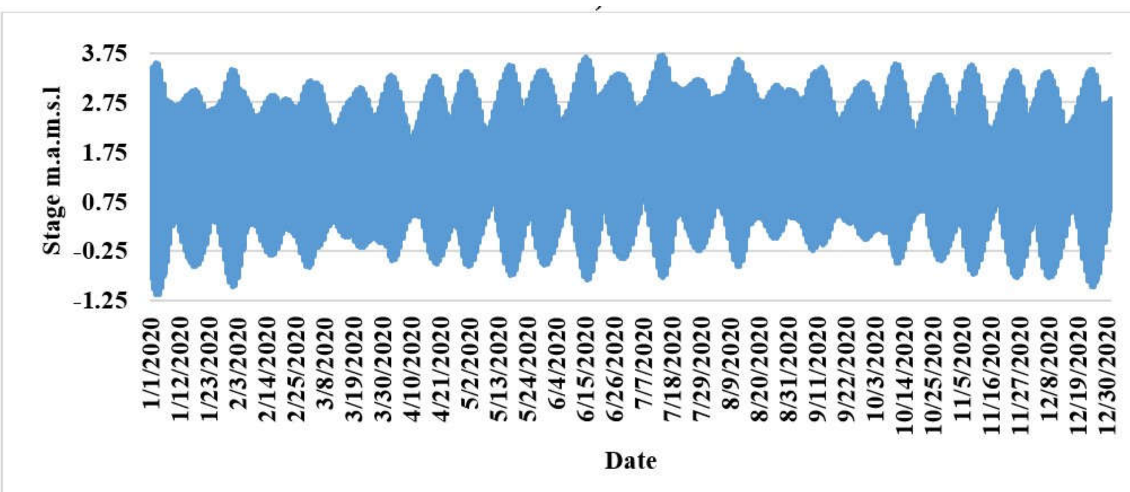
(Figure 7) Al Seeba Barrage cross section (HEC RAS 5.0.7, 2021)

Boundary Conditions for Upper and Lower Approaches

A boundary condition explains how a function behaves at the edge (border) of its defined region. Previously, the Shatt Al-Arab River received freshwater discharge from the rivers Tigris, Euphrates, Garmat Ali, Al Karun, and Al Karkha. In response to climate changes, The main freshwater source of the Shatt Al-Arab River is now the Tigris River (Hamdan, 2016a). The upstream boundary condition is represented in Fig. 8 as the Tigris River's daily discharge, which was measured close to the Al Basrah border. Because these rivers were previously blocked, there was a designation of zero discharge for the rivers Garmat Ali, Al Karun, and the Euphrates. As can be seen in Fig. 9, the downstream boundary condition was determined using the tide stage records for the Ras Al Besha area at the river mouth.



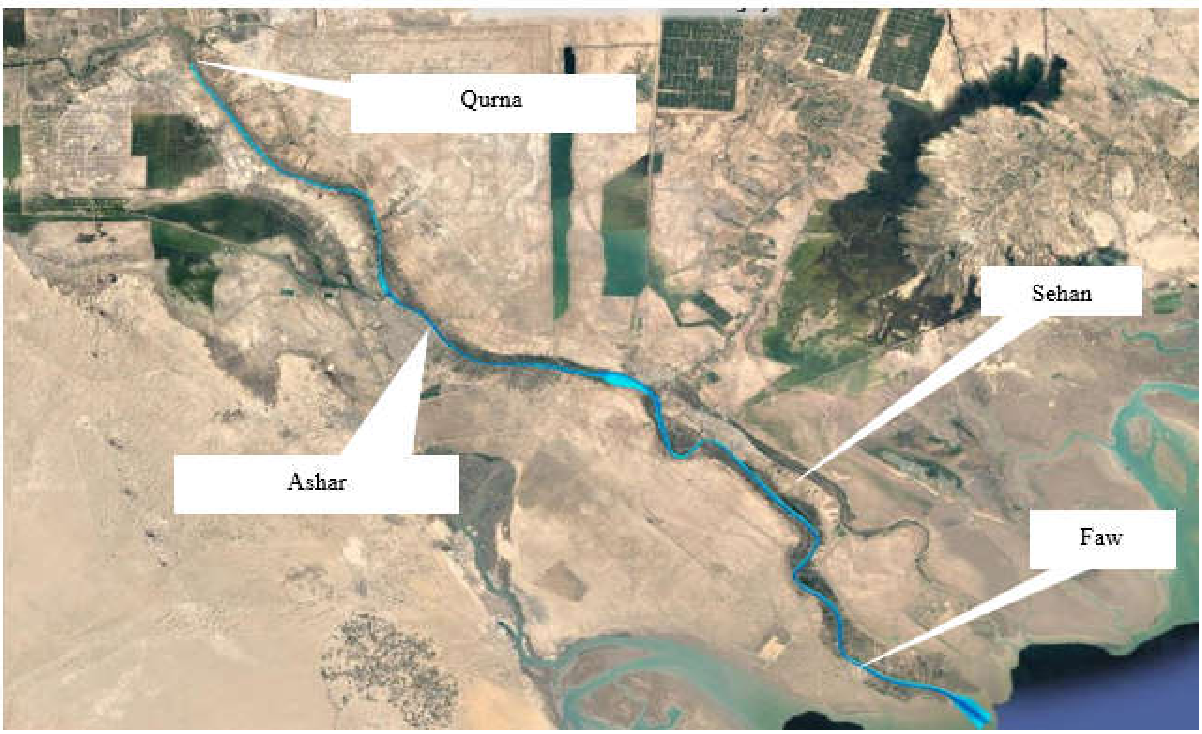
(Figure 8) Tigris River daily flow rates from 2010 to 2020 (Ali and Al Thamiry, 2021)



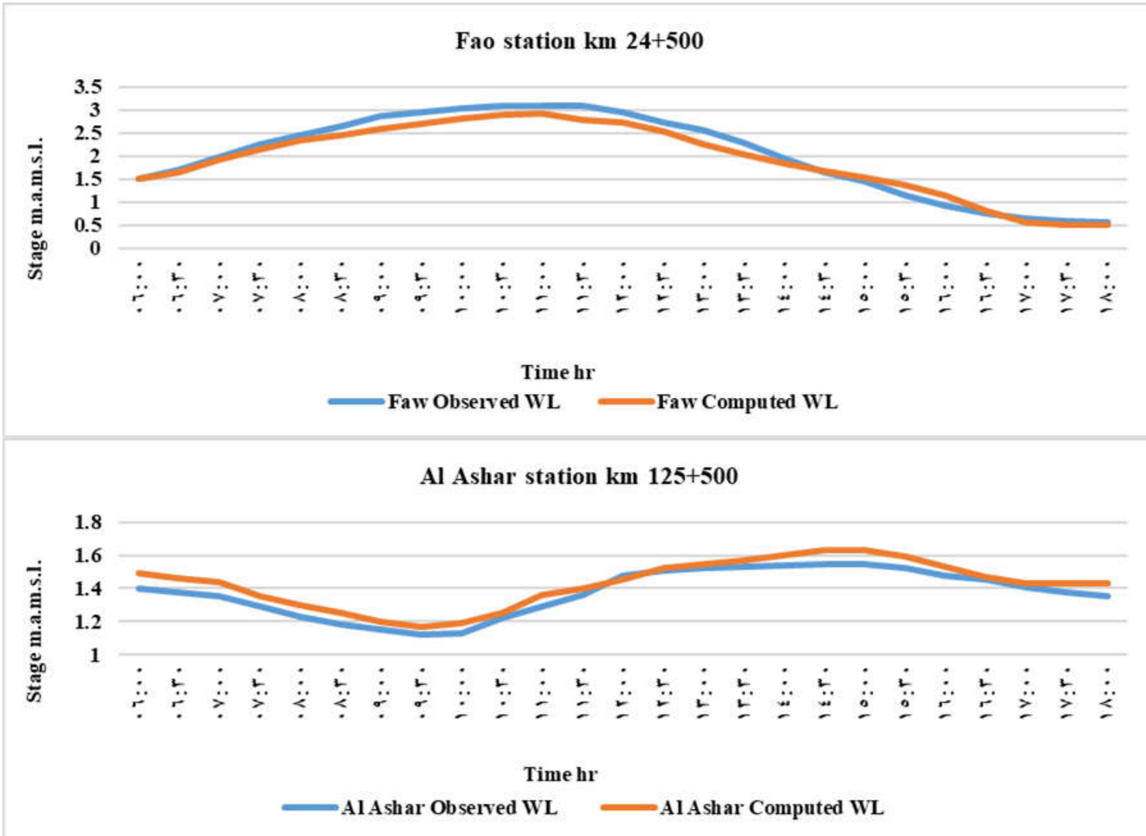
(Figure 9) Records for tidal stages during the year 2020 (Ali and Al Thamiry, 2021).

Calibration and Verification

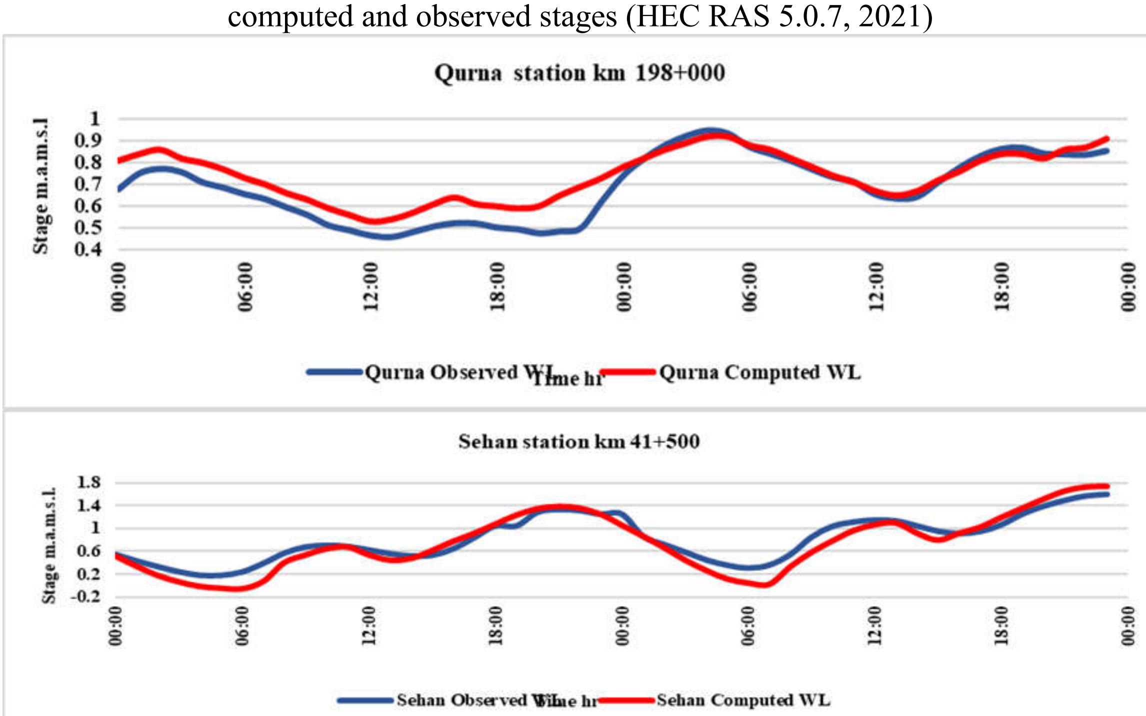
Model calibration is an iterative test that involves altering the model's parameters and matching the outcomes with the real system to enhance the model until it is deemed to have an acceptable accuracy range. Manning's roughness coefficient (n) explains the flow resistance generated on by the roughness of the bed and other obstacles in the channel, was employed as a calibration parameter. For the period of 12 Aug 2018, an observed stages set that was measured in the field was used to conduct the calibration process for the Shatt Al Arab River's main stream (Al–Galibi, 2020). As seen in(Fig. 10 and 11), there are two stations along the river: At km 125+500, Al Ashar, and at km 24+000, Al Fao.



(Figure 10) Calibration and verification Stations Site Plane (ArcGIS 10.3, ESRI, 2021)



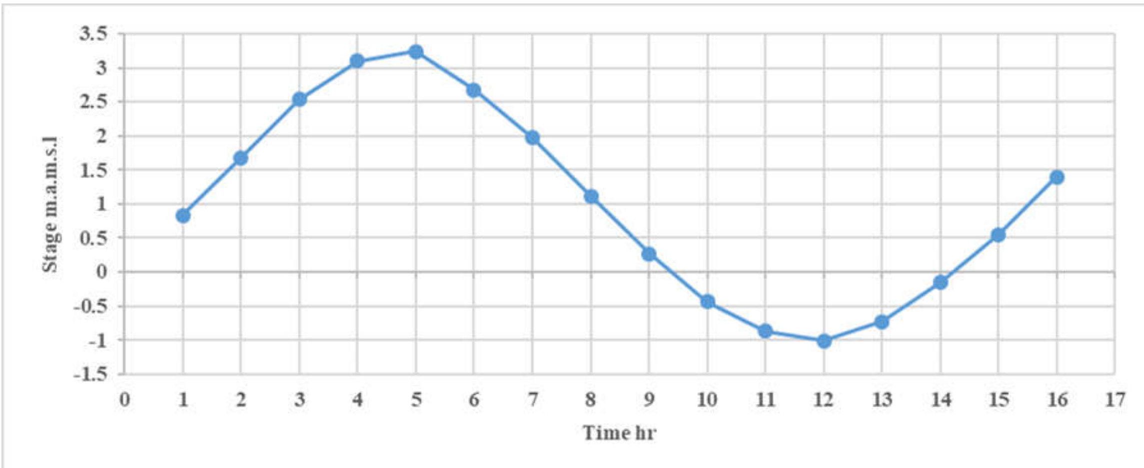
(Figure 11) Evaluation of the model calibration for Al Ashar and Al Fao stations comparing the computed and observed stages (HEC RAS 5.0.7, 2021)



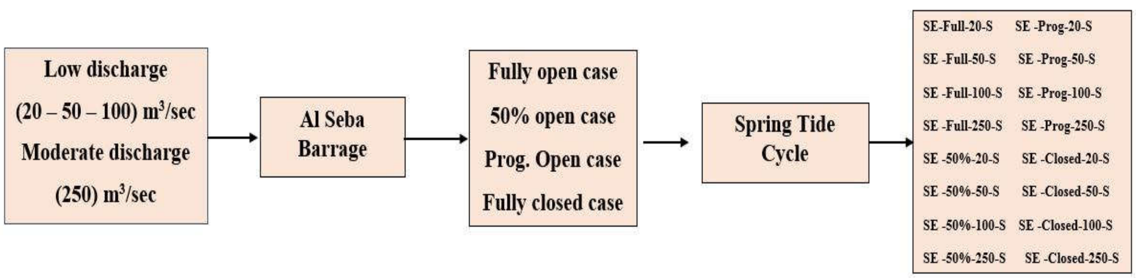
(Figure 12) Comparison of the calculated and Al Qurna and Sehan's recorded stages stations during the model verification (HEC RAS 5.0.7- 2021)

Scenarios of Operation

Several simulation sets accounting for a range of 20–50–100–250 m3/sec discharges were employed in this study. That simulate dry and mild conditions with various regulator gate openings under the adopted spring tide cycle. Figs. 13 and 14



(Figure 13) Adopted spring tide cycle (HEC RAS 5.0.7, 2021)



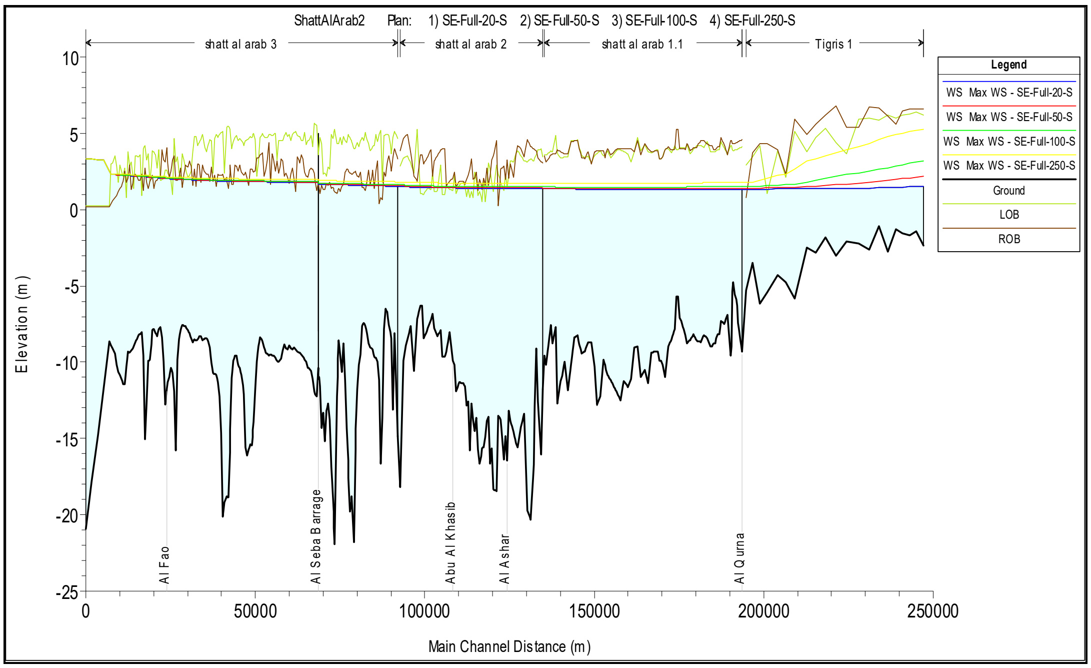
(Figure 14) Scenarios of Operation Scheme

Results and Analysis

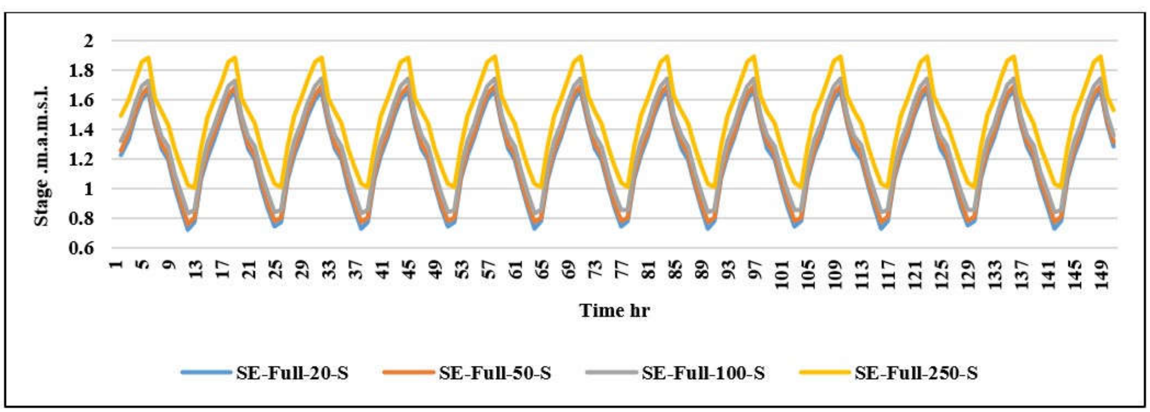
After sending the model with all of the input data and variables for analysis, graphs displaying the outcome results have been generated. These outcomes contain maximum and minimum levels of the surface of the water presented in Fig. 15 to Fig.26 along the river reach. For the fully open cases, Figs. 15 to 17, the increase in discharge has a substantial impact on the upper river's water levels. However, this influence lessens as one moves downriver to the barrage location.

The degree of change in water levels caused by discharge is relatively minimal at the downstream portion, and this effect vanishes toward the river's mouth as a result of the tidal phenomena. Nearly all of these occurrences involve minor fluctuations in water levels that are roughly similar to the river's normal condition. Under fully open gates at spring tide, the high water stage for the investigated flow in the upper and downstream sides, respectively, is (1.62, 1.68, 1.73, 1.89) and (1.71, 1.75, 1.80, 1.95) m. a.m .s .l. Regarding the specific cases of 50% open, Figs. 18 to 20 the upstream stages are lower than the stages in full open cases by 0.06 m and greater than the fully open cases by 0.1 to 0.15 m in the downstream portion. Comparing program opening cases to fully open situations, the influence of programming gates opening on the variance of water stages is apparent as shown in Figs. 21 to 23. In comparison to fully open cases, the water levels on the upstream side dropped by 0.6 to 1.20m, increasing levels in the downstream part range from 0.25 to 0.35m.

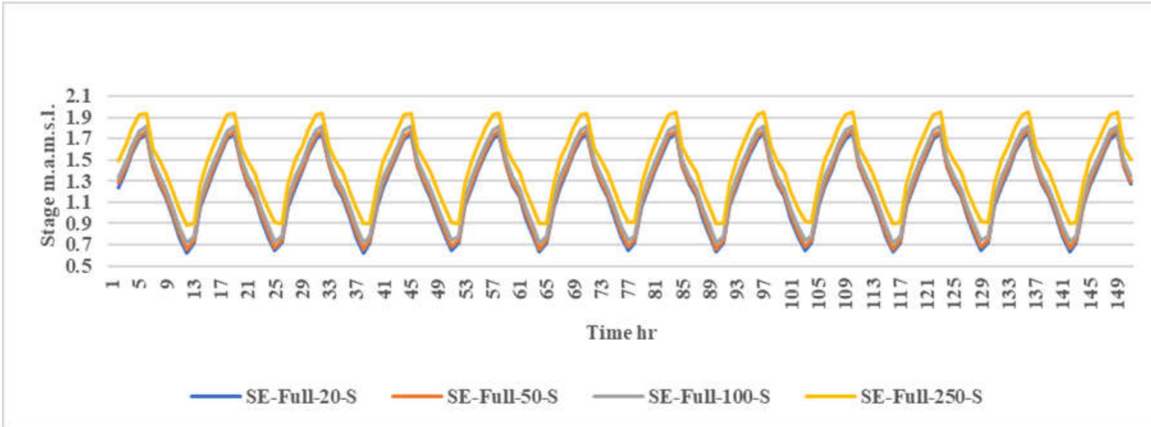
For the fully closed cases Figs. 24 to 26, the maximum water level should not exceed 2.5 meters in Al Basrah city to prevent a flood from occurring. The upstream water level is based on the upstream discharge and the time of gate operation. in this research, the operation period was 20 days and the maximum stage level has not exceeded 2.3 m as shown in Fig. 25. In comparison to fully open cases, the water levels in the downstream portion increased between 0.10 and 0.30 meters; this increase progressively drops down as you approach the river's estuary.



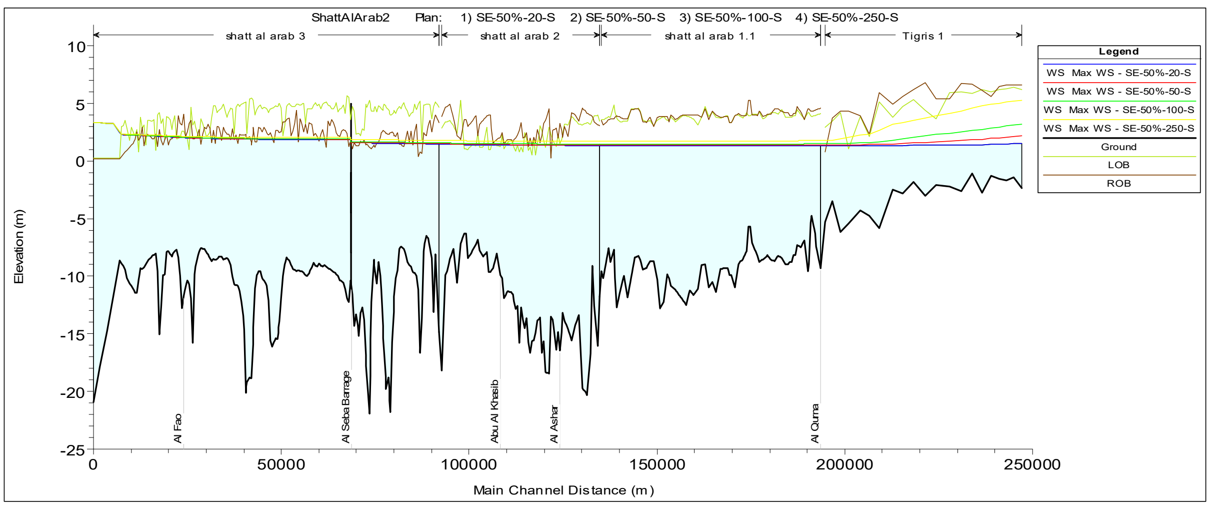
(Figure 15) Shatt Al-Arab's maximum water level profile with suggested barrage in Al Seba for fully open cases spring tide. (HEC RAS 5.0.7, 2021)



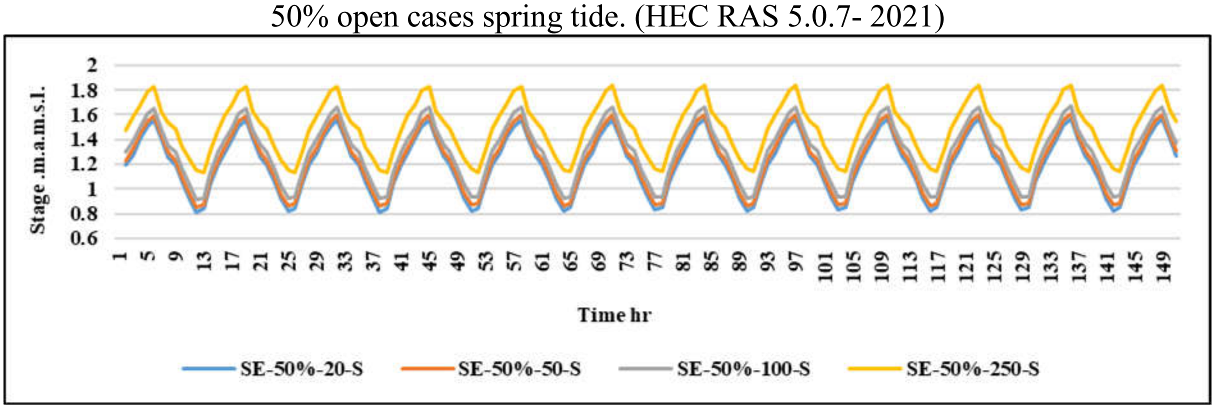
(Figure 16) Stage hydrograph at section 68+750 at full open cases during spring. (HEC RAS 5.0.7- 2021)



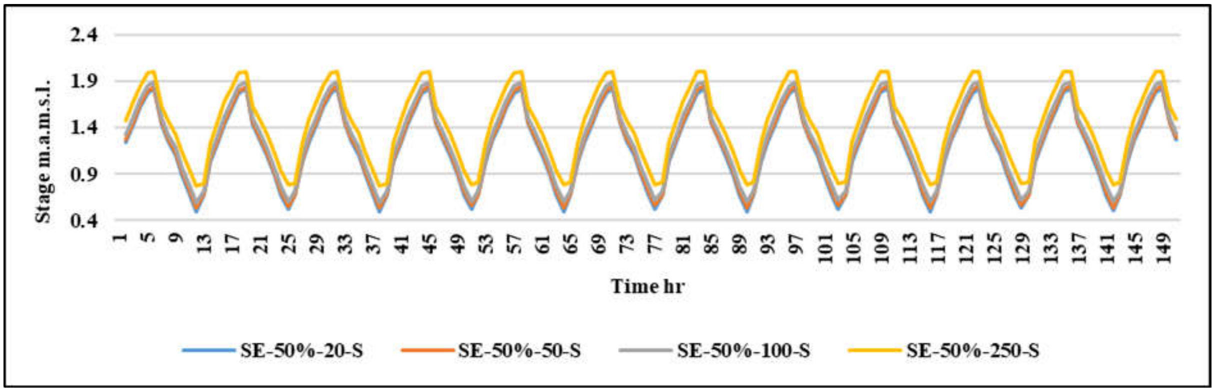
(Figure 17) Stage hydrograph at section 68+500 at full open cases during spring. (HEC RAS 5.0.7- 2021)



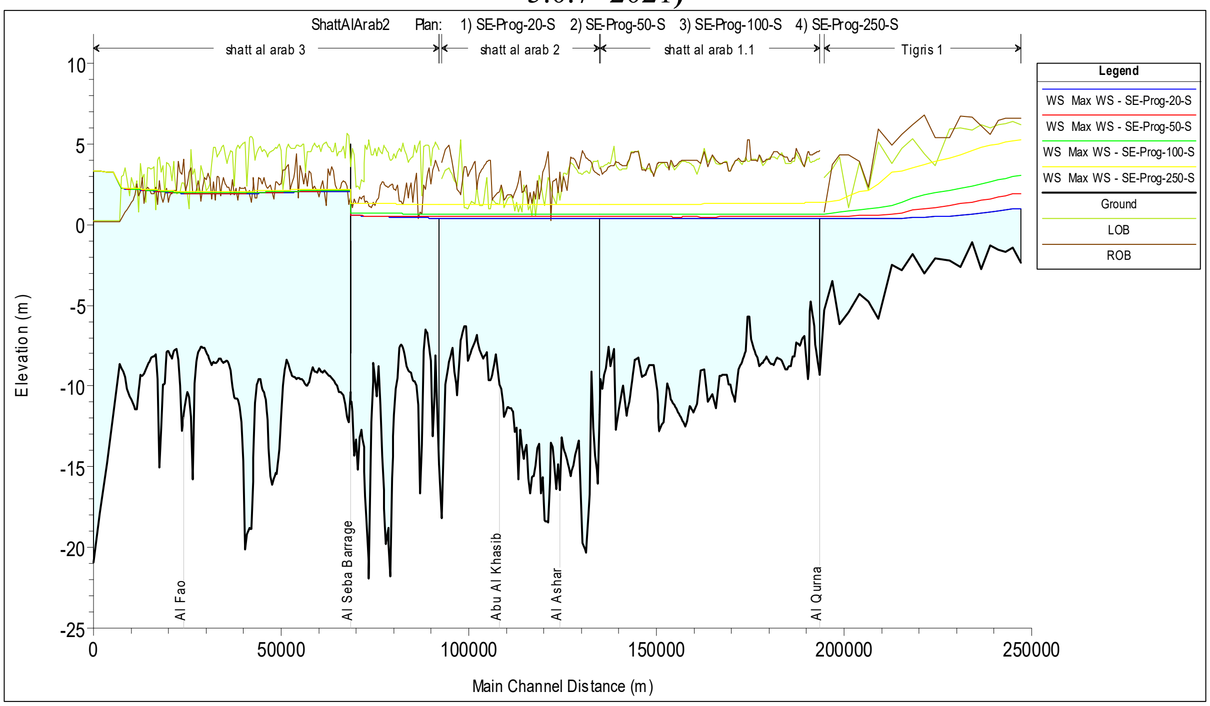
(Figure 18) Shatt Al-Arab's maximum water level profile with a suggested barrage in Al Seba for 50% open cases spring tide. (HEC RAS 5.0.7- 2021)



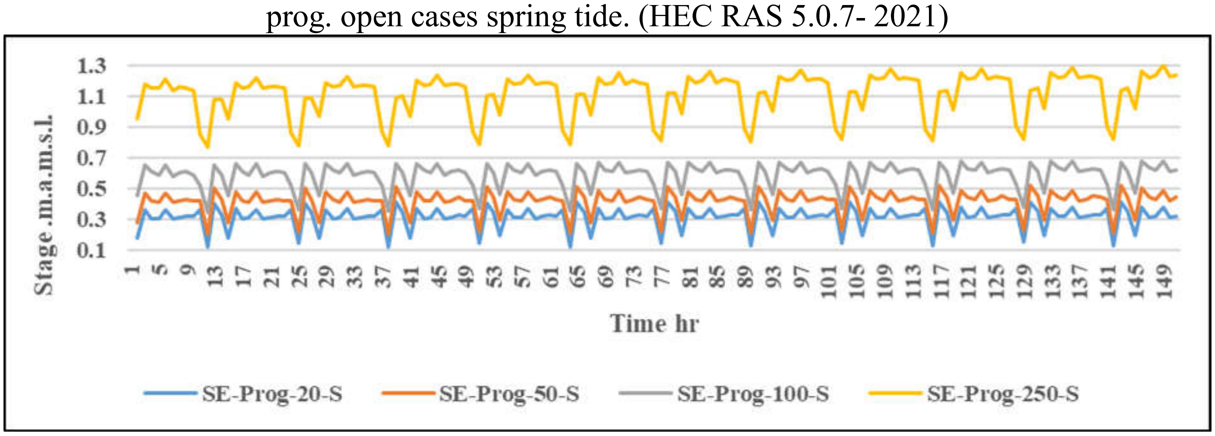
(Figure 19) Stage hydrograph at section 68+750 at 50% open cases during spring. (HEC RAS 5.0.7- 2021)



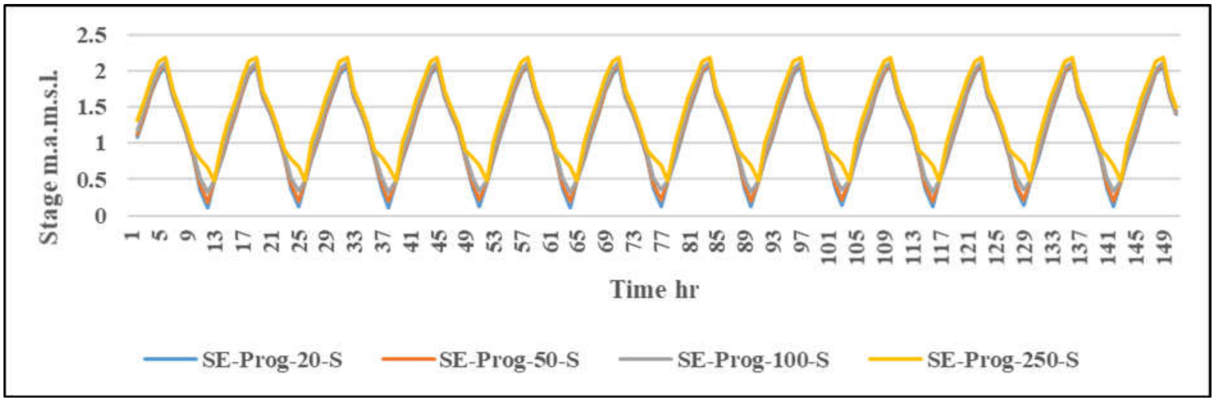
(Figure 20) Stage hydrograph at section 68+500 at 50% open cases during spring. (HEC RAS 5.0.7- 2021)



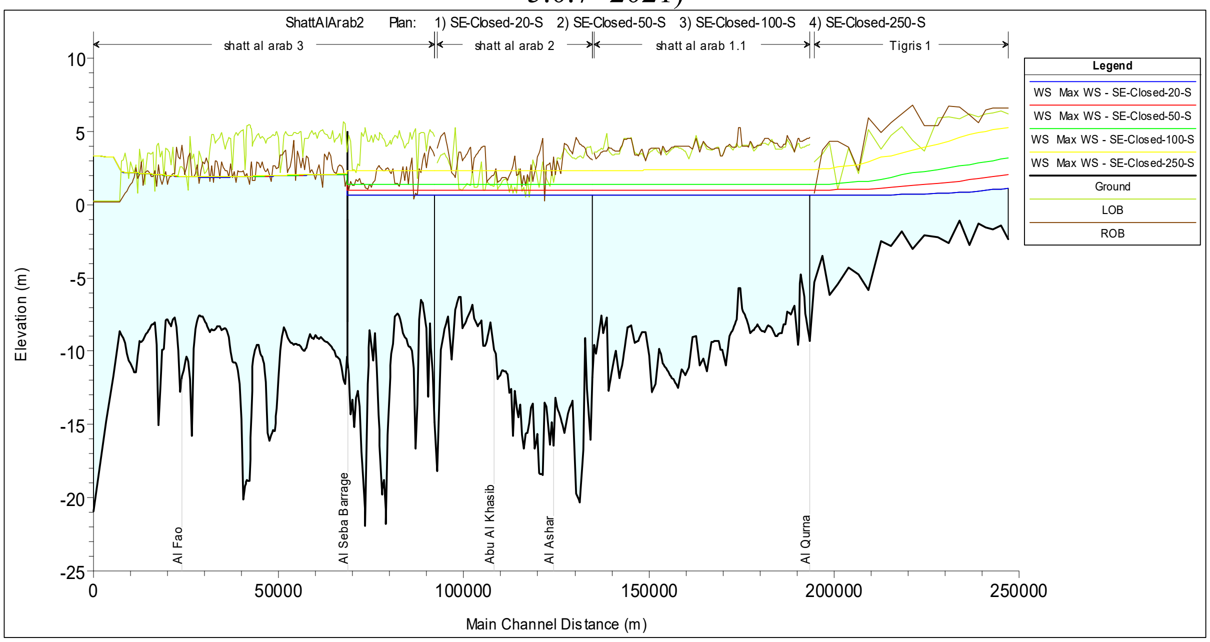
(Figure 21) Shatt Al-Arab's maximum water level profile with suggested barrage in Al Seba for prog. open cases spring tide. (HEC RAS 5.0.7- 2021)



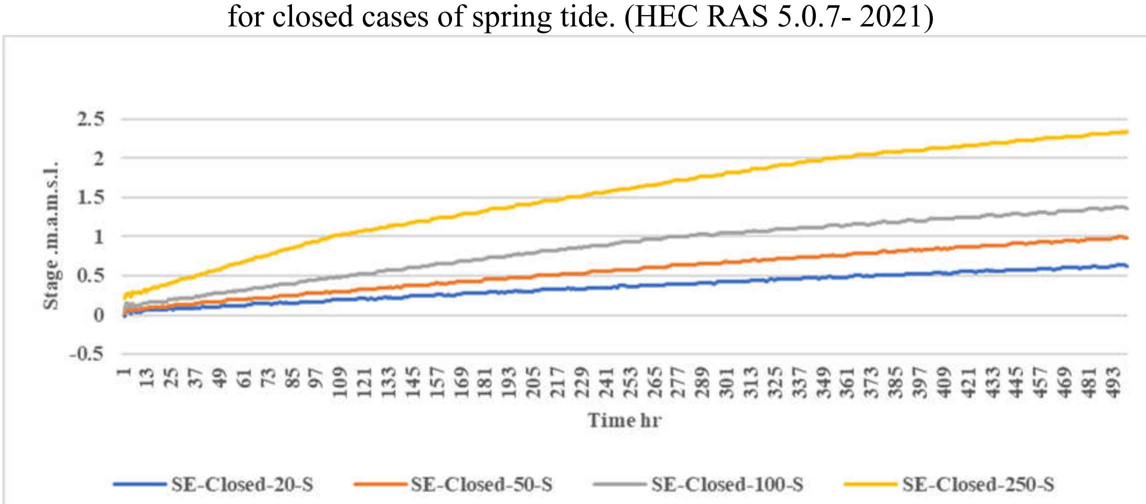
(Figure 22) Stage hydrograph at section 68+750 at Prog open cases during spring. (HEC RAS 5.0.7- 2021)



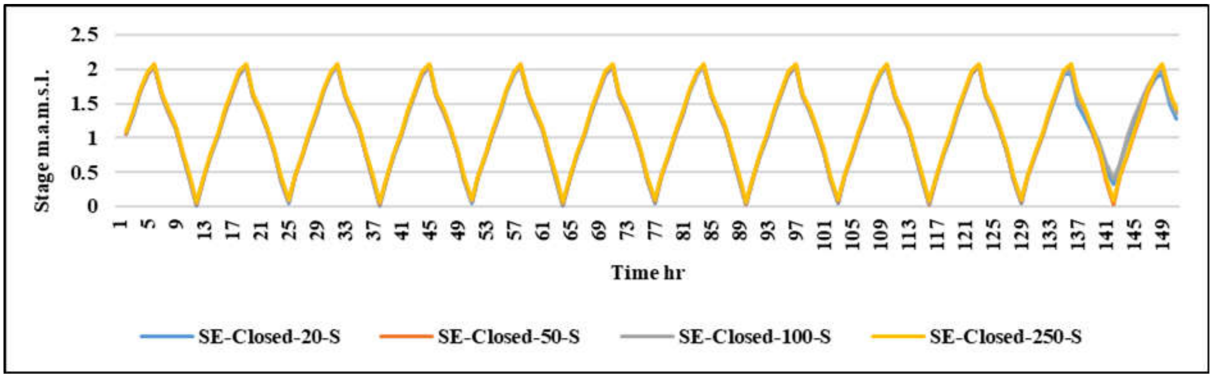
(Figure 23) Stage hydrograph at section 68+500 at Prog. open cases during spring (HEC RAS 5.0.7- 2021)



(Figure 24) Shatt Al-Arab's maximum water level profile with a suggested barrage in Al Seeba for closed cases of spring tide. (HEC RAS 5.0.7- 2021)

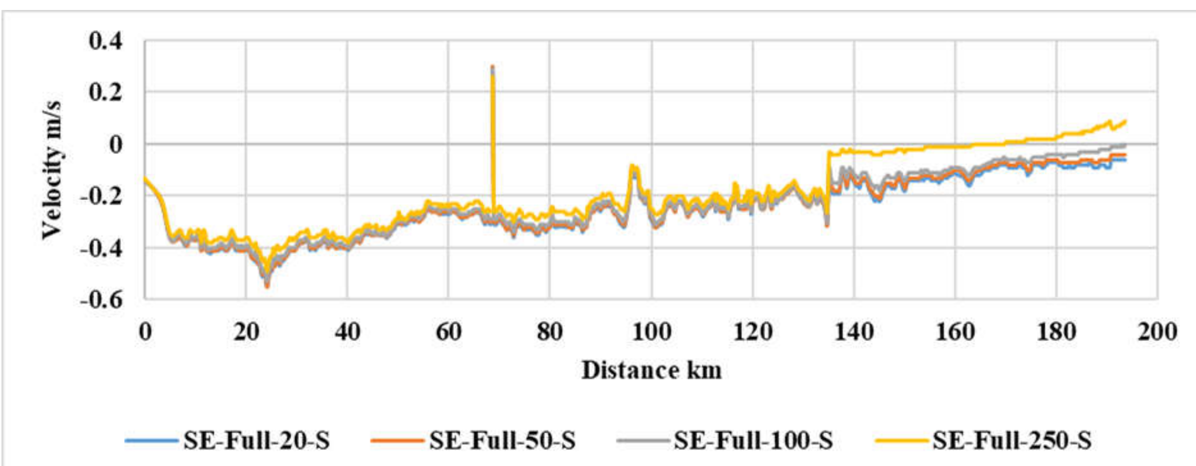


(Figure 25) Stage hydrograph at section 68+750 (upstream side) at closed cases during spring tide. (HEC RAS 5.0.7- 2021)

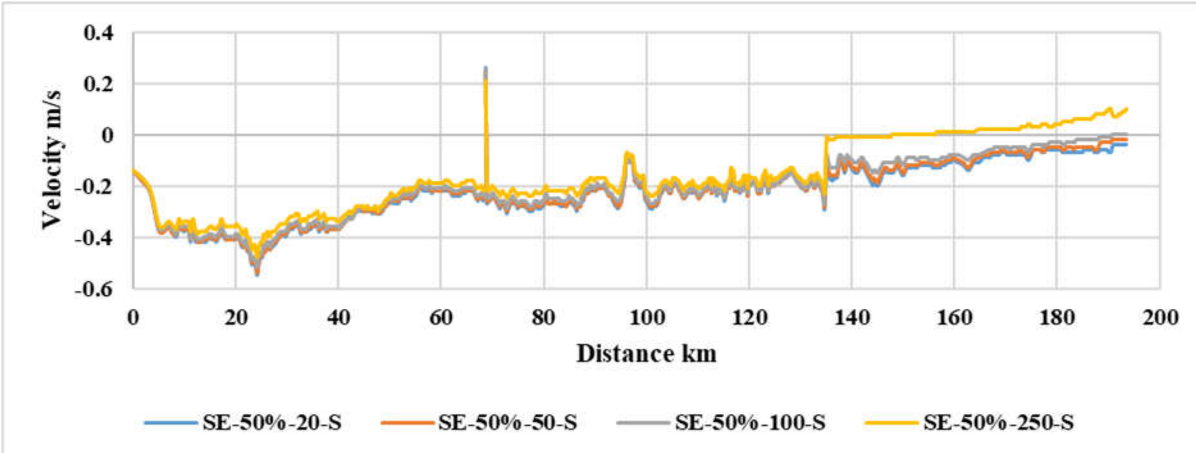


(Figure 26) Stage hydrograph at section 68+500 at closed cases during spring tide (HEC RAS 5.0.7- 2021)

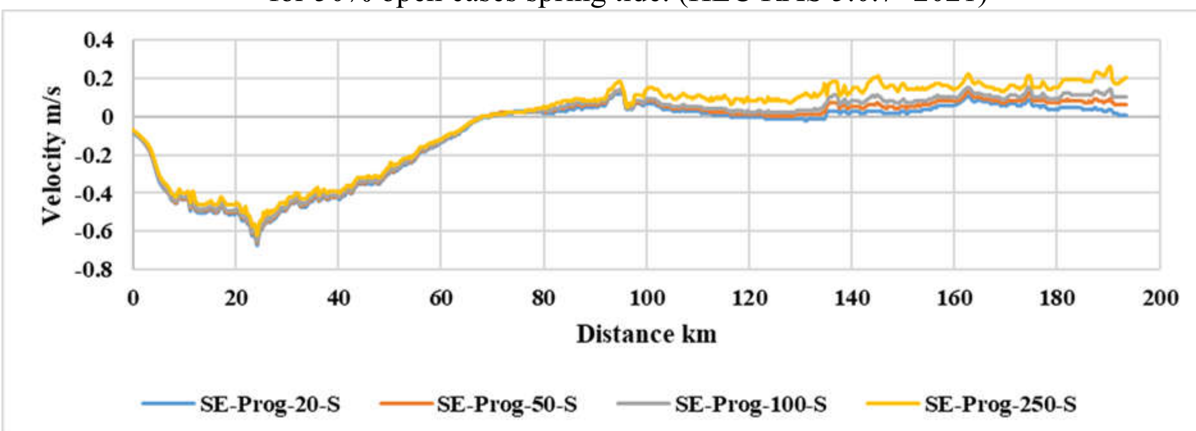
Each operation scenario presented in the above figures has a non-uniform velocity distribution Figs. 27 to 30 due to the variable river geometry and sub-branches connecting to the mean reach. In general, there are significant velocities in the upstream reach Within Al Qur'an according to the Area in cross-section and river morphology. As the geometry of the cross sections is not regular, as the river grows wider, the velocities reduce. As we can see from the above figures, for the downstream reach, the variation of velocity fluctuates around -0.55 m/s and -0.10 m/s, the power of the tide has a significant impact on the distribution of velocity, specifically in the downstream portion.



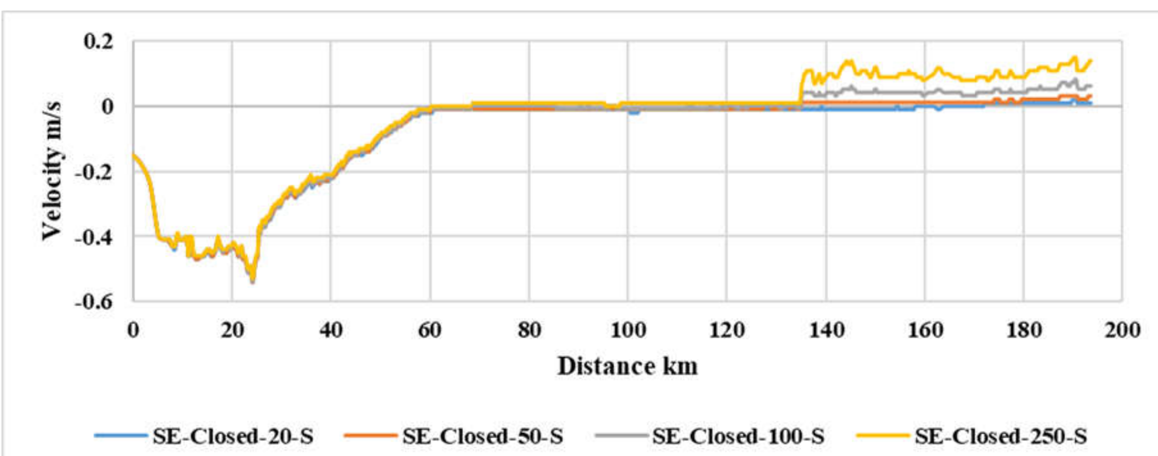
(Figure 27) Maximum velocity profile along Shatt Al-Arab with a suggested barrage in Al Seba for fully open cases spring tide. (HEC RAS 5.0.7- 2021)



(Figure 28) Maximum velocity profile along Shatt Al-Arab with a suggested barrage in Al Seba for 50% open cases spring tide. (HEC RAS 5.0.7- 2021)



(Figure 29) Maximum velocity profile along Shatt Al-Arab with a suggested barrage in Al Seba for prog. open cases spring tide (HEC RAS 5.0.7- 2021)



(Figure 30) Maximum velocity profile along Shatt Al-Arab with a suggested barrage in Al Seba for closed cases spring tide. (HEC RAS 5.0.7- 2021)

Conclusions

In this study, the possibility of stopping the entry of the saltwater in the Shatt Al Arab River was investigated via the proposed crossing structure in Al Seba location, exposed to a range of discharge (20, 50, and 100) m3/s, considering the impact of spring and neap tides on the river estuary. Furthermore, the gate operation of the proposed structure (fully open, 50% open, program open, and fully closed) was tested based on each case. Based on the results of this research, the following conclusions can be made:

1- The results of analysis explain that the suggested site is inappropriate for many reasons, the most significant of which is that the flow rates that will be discharged on the upstream side of the barrage are not guaranteed. This will affect the necessary depths for navigation upstream of the barrage, especially when the event of a scheduled opening that causes a reduction in water stages of approximately (0.6-1.2) m. Therefore, it is predicted that the ideal location will be accurately upstream of the current location in the navigation channel's starting point.
2- Along the river reach, the variation of velocity is between -0.50 to 0.30 m/sec (the negative sign indicates that the velocity direction is from the river estuary to the upper river) . In conditions of full and 50% opening, negative velocity is also reached upstream of the barrage, showing that the salt intrusion can be breached for a defined distance in these circumstances.
3- In the proposed site, the operation of the barrage is jointly carried out by the Iraqi and Iranian sides, because the structure is located within the common lands. Furthermore, the difficulty of construction is due to the river section.
4- It is necessary to establish a navigation lock to secure the movement of ships and boats in both directions.
5- No flood occurs.
6- As a result of the Arabian Gulf's tide's power, a high negative velocity was attained close to the river estuary. The tide can have an impact up to Al-Qurna city, per the velocity indicators, particularly in drought conditions.
7- The velocity measurements upstream of a programmed opening are nearly zero or larger. This reflects a stagnation scenario has occurred and the entrance of salt wedges into the upper river has stopped. Hence, more salting than usual may take place inside the river reach.

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