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INVESTIGATION OF THE IMPACT OF EXTREME FLOOD FLOW ON THE SHATT AL-ARAB RIVER AND MARSH SYSTEM

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ABSTRACT

The Shatt Al-Arab River is one of the main sources of surface water in the Basrah Governorate, which is important for domestic, industrial, and agricultural purposes. It is a tidal river affected by the tidal and ebb of the Arabian Gulf. This study focused on the effect of extreme flood flow in the Shatt Al-Arab River that leads to riverbank overflow, floodplain inundation, and rise in water level in the adjacent Al-Hammar Marsh. The flood inundation map is produced using the 2D HEC-RAS model (Version 6.4.1). The results offer a way to predict the flood extent and show the impact of the extreme flood flow, it showed that Basrah city is the most dangerous location exposed to flood on the right bank of the Shatt Al Arab River. Suitable management is needed to address the risk. This study highlighted the importance of flood control and operation of the Shatt Al-Arab River in the wet seasons and the need for an emergency plan so that the impact of the potential losses during the peak flood can be mitigated and at the same time, the benefit is optimized through water storage in the marsh system.

Keywords: al-sweeb river, HEC-RAS 2D, basrah, shatt al-arab, inundation map.

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INTRODUCTION

The Shatt Al-Arab River is located in southern Iraq. It extends from Al-Qurna City which is located at the confluence of the Tigris and the Euphrates Rivers north of Al-Basrah governorate (Ali, and Al-Thamiry, 2021). The river then flows for about 190 km to the Arabian Gulf (Al-Mahmoud *et al.,* 2015). The lower part of the river is part of the Iraqi-Iranians borders and is used as a marine canal for ships that sail to the Iraqi and Iranian ports. Some of the major tributaries that feed the Shatt al-Arab include the Al-Sweeb and the Al-Karun Rivers (Figure-1). The estuarine-deltaic area of the Shatt al-Arab is characterized by river sediment that seeps into the shallow, narrow part of the Arabian Gulf (UN-ESCWA, 2013).

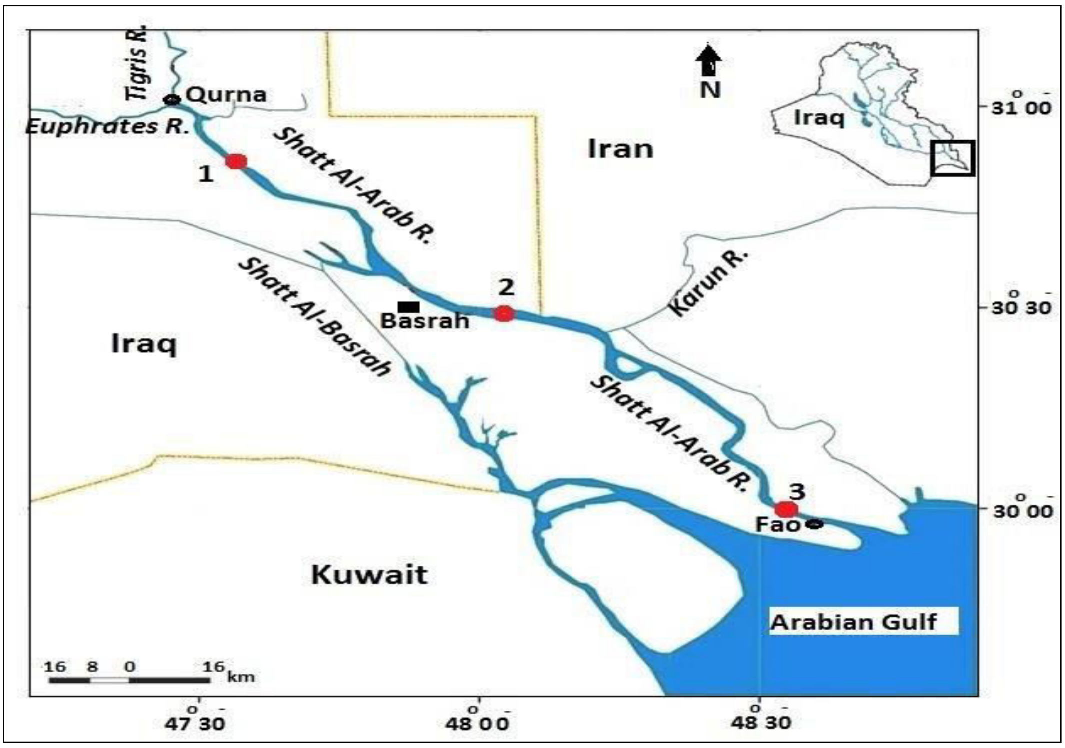

Figure-1. Shat Al-Arab River.

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The annual rainfall of the Basrah catchment area for 2019 was 168.75 mm. Rainfall-runoff in the Shatt Al-Arab River plays an important part in the basin water source (Jaleel, and Farawn, 2013). When there is a deficit in freshwater supply to the Shatt Al-Arab River, there is a rise in the salinity intrusion (Hamdan, 2016) (Al-Asadi, *et al*., 2022). On the other hand, during high flow conditions, Shatt Al-Arab is prone to overflow. The increased runoff replenishes the Al-Hammar Marsh located on its west (Dawood, *et al*., 2018), causing the wetted area of the marsh to vary significantly between the wet and dry seasons, with a significant impact on the local water resource. The excess water may also cause floods along its coast, especially in Basrah City.

Basrah governorate is an area of more than 4 million people. It is the second-largest district entity in Iraq serves as the focal point of economy and sports activities (Al-Asadi, and Alhello, 2019), and is famously known for its important oil production. Due to the importance of the livelihood and economy of the region, several studies have been conducted to investigate the hydraulic conditions of the Shatt Al-Arab, especially its impact during extreme floods.

Al-Mahmoud *et al*., 2011 used a Mike 11 hydrodynamic model to study the hydraulic behavior of Shatt Al-Arab. The model covered the part of Shatt Al-Arab from Qurna to Al-Maaqal Port. The study investigated the salient hydraulic parameters of the river which can be considered for the design of hydraulic structures along the river.

Abbas, 2016 implemented a one-dimensional hydrodynamic model for the Shatt Al-Arab River using HEC-RAS software to analyze its flow conditions and estimate the TDS of the river reach. The study area covered the part of the Tigris River from Qalat Saleh to the Qurna, part of the Euphrates River from Medainah to Qurna, and the reach of Shatt Al-Arab from Qurna to Abu Al Khaseeb. Hamdan *et al*., 2018 carried out a study of the flow in the part of the Al-Arab River from the confluence of Tigris and Euphrates in Qurna to the Abu Flus port. The hydraulic model was also based on the HEC-RAS software and covered part of the Tigris and Euphrates Rivers. They showed that the maximum velocity in the Shatt Al-Arab is below 0.8 m/s from the Qurna confluence and decreased in the downstream direction due to an increase in the river width, and the Manning's roughness coefficient for Shatt Al- Arab is about 0.033.

Ali and Al-Thamiry, 2023 carried out a one-dimensional hydraulic HEC-RAS model to evaluate the capacity of the Shatt Al-Arab River to control flood discharge. They showed that the banks in the southern part of the Shatt Al-Arab River between Garmat Ali to Ras Al-Bisha are vulnerable to flood, especially during spring tide. The river capacity was estimated at 850 m^3/s.

The literature review showed a lack of study using a two-dimensional model for the Shatt Al-Arab. For a wide river that is tidal-dominant, a fully 2D model is expected to capture the river flow hydrodynamic more accurately (HEC-RAS Hydraulic Reference Manual, 2023). This study aims to investigate the bank overflow condition of the Shatt Al-Arab River under extreme flood flow that leads to inundation of the surrounding area.

THE STUDY REACHES

The study area covered the main rivers in Basrah Governorate, which includes the Tigris and the Euphrates rivers, where the confluence in Al-Qurna city is the beginning of the Shatt Al-Arab River. Figure 2 shows the schematic of the study area.

The upstream boundary of the Tigris River was set at the Qalaat Saleh Regulator which is approximately 90 km upstream of Al-Qurna City. Qalaat Saleh Regulator is one of the main hydraulic structures along the Tigris River and is used to control the water level upstream of the regulator for irrigation and water supply purposes. Also included in the study is the inflow from the Al-Kassarah River into the Tigris.

The Euphrates River was simulated starting from the Al-Chybaish closing weir, which is located about 27.6 km upstream of the confluence. This weir prevents water from passing across it to the downstream reach. The Al-Ezz River which flows into the Euphrates was also considered.

The entire 190-km length of the Shatt Al-Arab River from the confluence to its estuary in the Arabian Gulf was simulated in the model. The Al-Sweeb and the Al-Karun Rivers were simulated in the model as the feeders of the Shatt Al-Arab. The Al-Sweeb is a major inflow with high runoff from the Hawizeh marsh at the Iraq-Iran border. Meanwhile, the Al-Karun is also from the Iranian side.

The Shatt Al-Arab River branches out into the Al-Hammar Marsh upstream of Basrah City via the 15-km long Garmat Ali River. (Dawood, *et al*., 2018) The Al-Hammar Marsh measures approximately 123 km long with an average width of 26 to 35 km. It consists of shallow marshes and seasonal wetlands ranging from 1.8 to 2.7 m in depth.

The Shatt Al-Arab River has a very low surface gradient (Khalifa, 2019). The mean hydraulic slope is about 1 to 1.5 cm/km. The width of the river varies between 275 m and can be up to 2 km at some locations as it approaches the estuary and its depth ranges between 8 to 17 m (Hamdan, 2016). The Arabian Gulf is a shallow water body with an average depth of approximately 50m. The tides in the Gulf are predominantly semidiurnal (Hamdan, *et al*., 2019).

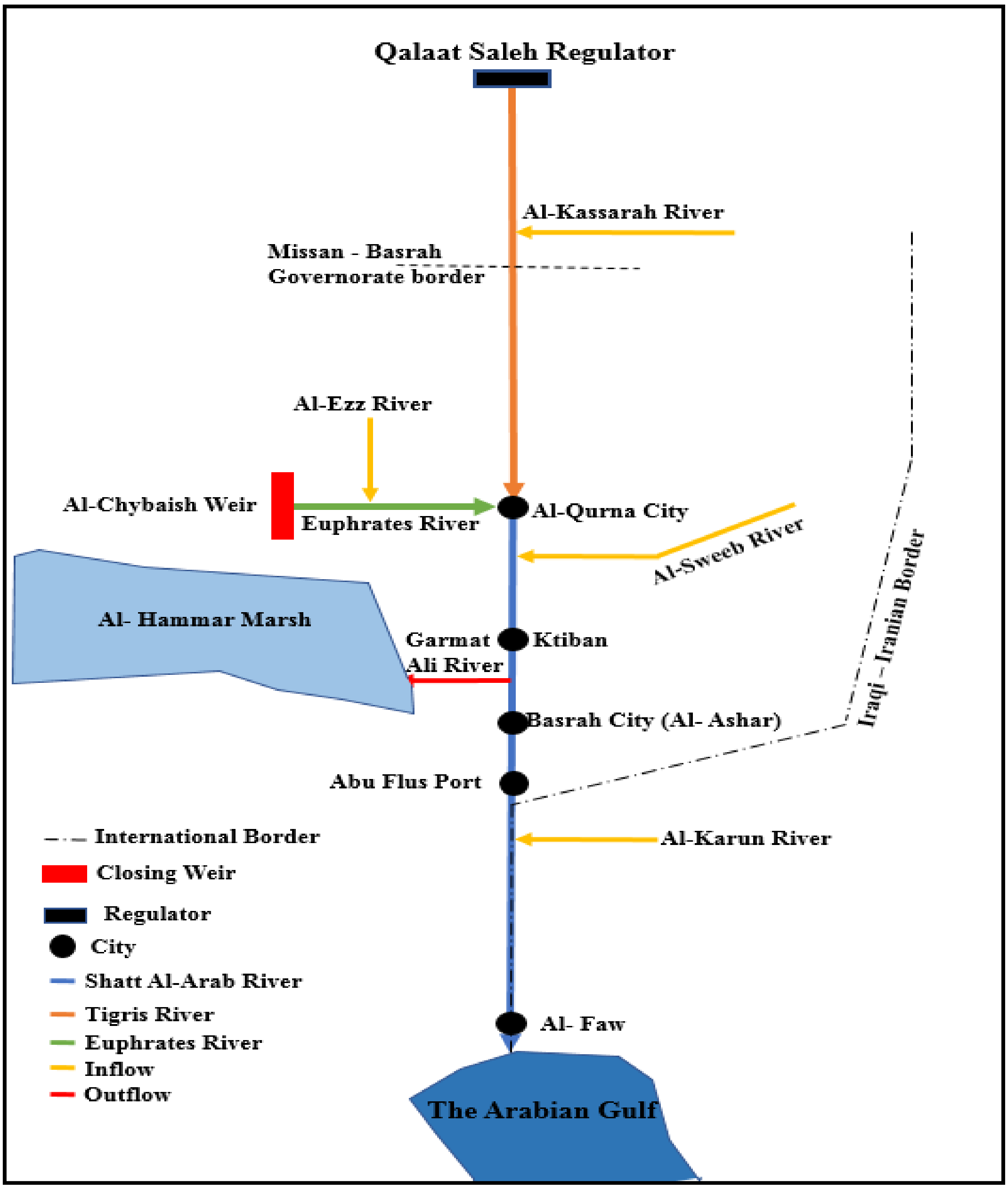

Figure-2. Schematic diagram of the Shatt Al-Arab River system.

THE HYDRAULIC MODEL

The Hydraulic modeling of this study was conducted using the Hydrologic Engineering Centre's River Analysis System, HEC-RAS v6.4.1, developed by the United States Army Corps of Engineers (USACE). The software has been extensively used in hydraulic modeling of flow in rivers and channels, sediment transport, water quality analysis, floodplain determination, and scouring around bridge piers. The software is capable of obtaining the water surface profile for steady and unsteady flow. The computation process of water surface profile for one dimensional, steady, gradually varied flow is based on solving the energy equation in an iterative procedure based on the standard step method. For the one-dimensional, unsteady flow simulation, the computations are based on solving the continuity and momentum equations by the implicit finite differences method. The model is available for 1D and 2D modeling. In this study, a 2D HEC-RAS model was used (HEC-RAS Hydraulic Reference Manual, 2023).

Model Geometry

The model geometry of the study area was constructed based on the surveyed river cross-section for the study reaches as shown in Figure-3 (a, b). These are integrated with the Digital Elevation Model (DEM) data of the surrounding area including the Al-Hammar marsh. The terrain model was then created using RAS Mapper for Finite Volume Method (FVM) implementation in the HEC-RAS model (Najm, 2018). The resulting model has a total of 402,070 elements with a mesh grid size of 55 m. This provides adequate resolution for the narrowest width

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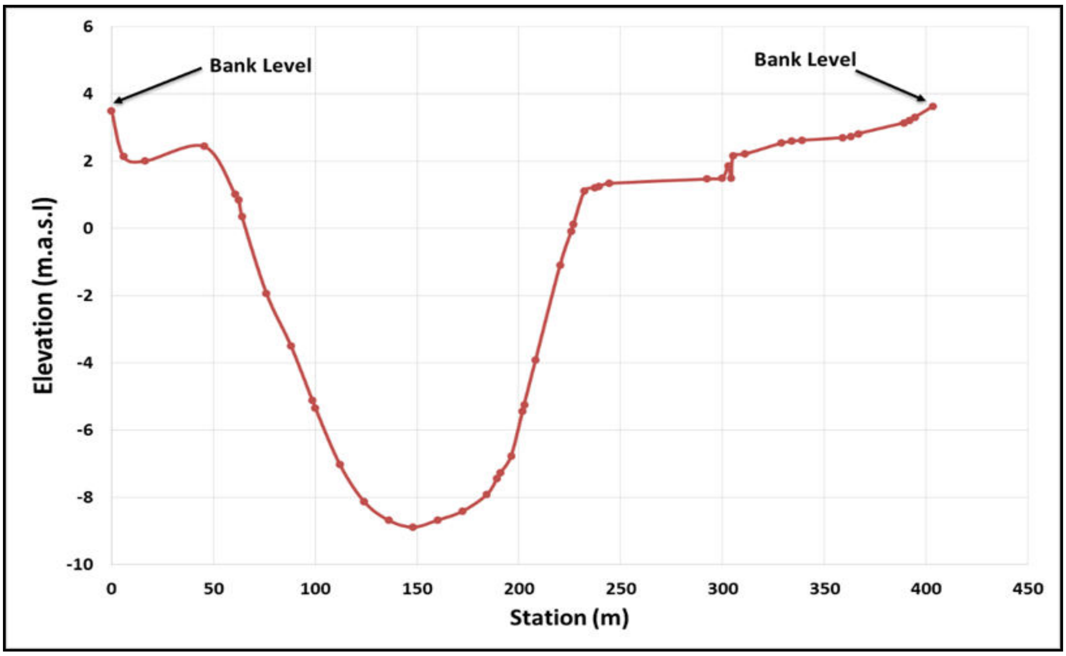
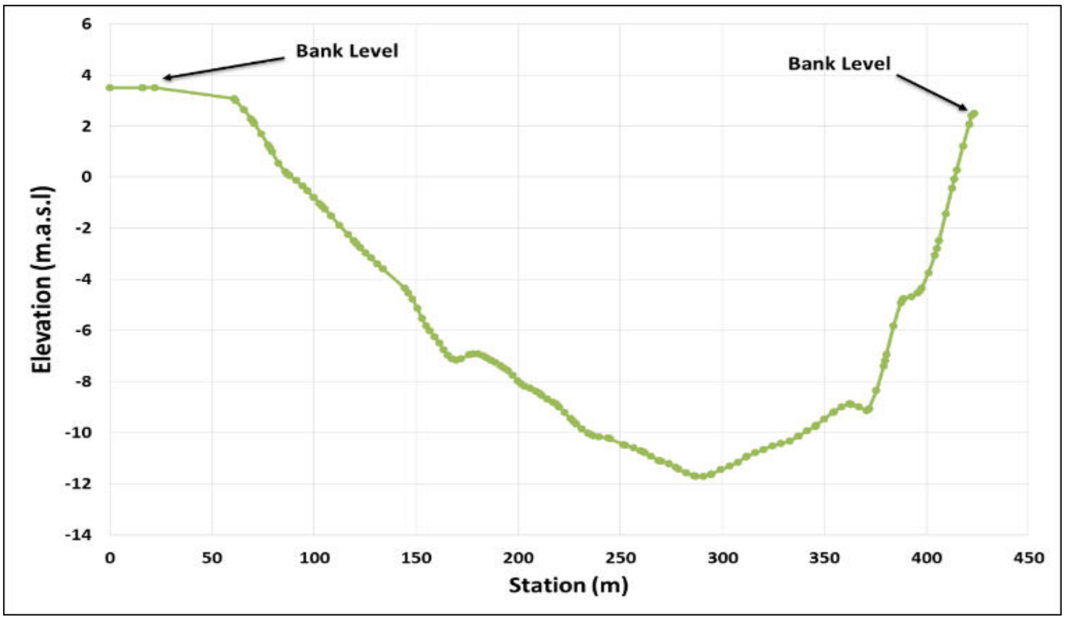
of the Shatt Al-Arab River at Al Qurna which is 275 m (Hamdan, 2016). The generated mesh is shown in Figure-4.

The survey data showed that the Shatt Al-Arab right bank (looking in the downstream direction) starts with a level of more than 4.5 m in Al-Qurna city (190 km from the mouth), and descends gradually to 2.7 m as the river approaches the mouth. The minimum bank level on the right bank extends from Basrah Silo to Abu Flus port (98 km from the mouth) at 2.5 m. Meanwhile, the level of the left bank of the Shatt Al-Arab River starts at nearly 4.5 m in Al-Qurna City and maintains at 3.5 m towards the estuary, which is much higher than the right bank. Table-1 summarises the level of the banks at selected locations along the Shatt Al-Arab River.



a) Shatt Al-Arab River cross-section at Ktiban location.



b) Shatt Al-Arab River cross-section at Basrah Silo location.

Figure-3. Typical cross-section of the Shatt Al-Arab River at (a) Ktiban, and (b) Basrah Silo.

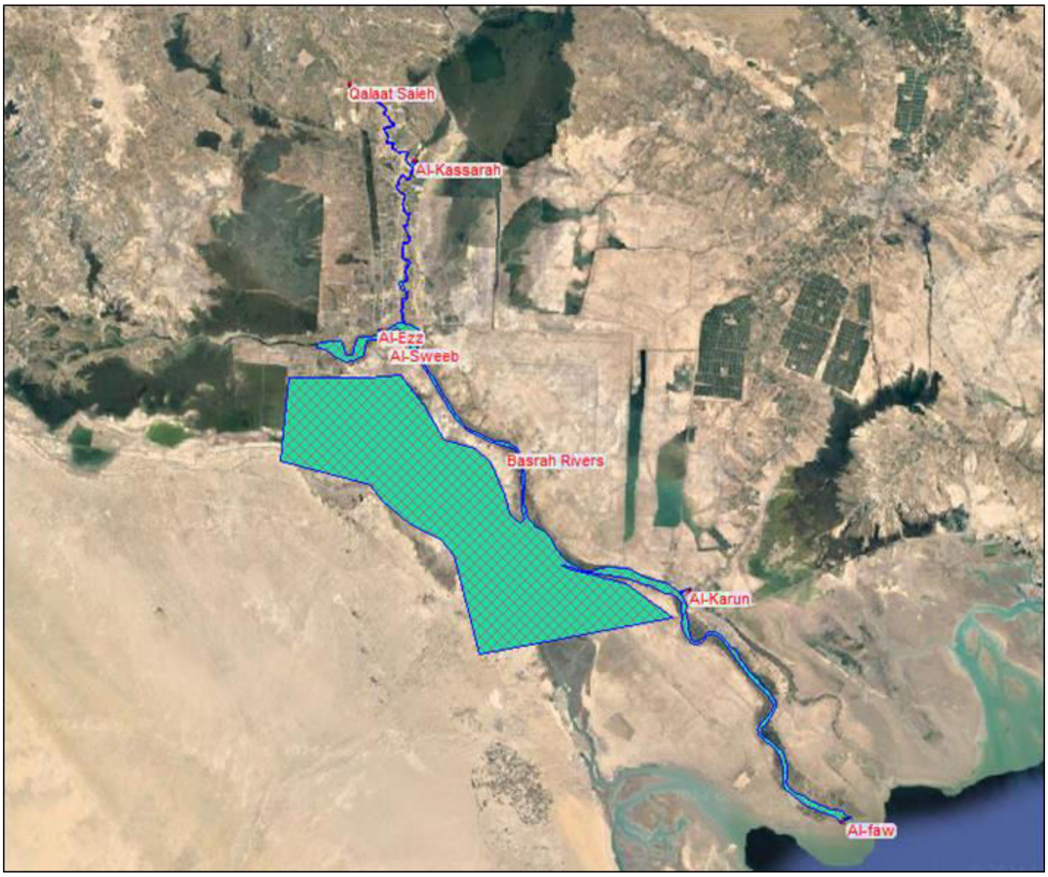


Figure-4. Model mesh generation for Shat Al-Arab River and Al-Hammar Marsh and Basrah City.

Table-1. The bank levels along the Shatt Al-Arab River.

Location	Distance from the river mouth (km)	Longitude	Latitude	Right Bank level (m)	Left Bank level (m)
Al-Qurna	190	47° 26.984'E	31° 20.785'N	4.5	4.5
Ktiban	136	47º 45′ 40.44" E	30º 39′ 56.32″ N	3.5	3.5
Sindibad Island	125	47°46'39.23"E	30°34'31.52"N	3	3.5
Basrah Silo	120	47°49'17.05"E	30°32'41.84"N	2.5	3.5
Al-Ashar	117	47º 50′ 38.26" E	30º 31′ 9.00″ N	2.5	3.5
Al-Faw	15	48°27'45.00" E	29°59'22.45" N	2.7	3.5

Boundary Conditions

A set of streamflow hydrographs and tidal water level data for the 2 months from 1 April to 30 May in the year 2019 was used in the model (Iraqi Ministry of Water Resources, 2020). These include the inflow at the Qalaat Saleh Regulator, Al-Kassarah, Al-Ezz River, Al-Karun, and the Al-Sweeb River (Figure-5). The downstream boundary condition was the hourly tidal stage at Al-Faw city as shown in Figure6. The tidal range is in the order of 2 to 2.5 m during spring tide conditions.

During this period, the flood was dominated by a large amount of flow from Al-Karun (up to 700 m^3/s) and Al-Sweeb (up to 800 m^3/s). Note that the Al-Sweeb River represents the outflow of Hawizeh Marsh which is fed mainly by the Karkheh River as shown in Figure-7. A previous hydrological study states that the maximum observed flow from Karkheh Dam, located approximately 300 km upstream of Hawizeh Marsh, reached 2,500 m^3/s. Furthermore, the hydrological model predicted that the maximum outflow from Karkheh Dam may reach up to 6,000 m^3/s (Fooladi, 2023).

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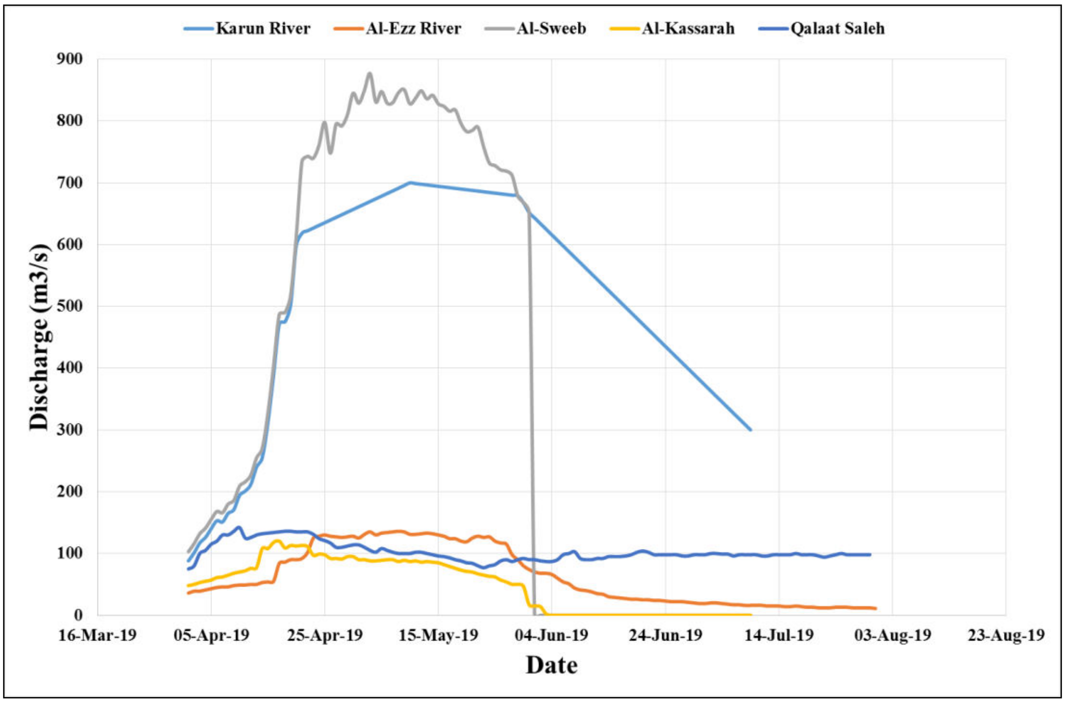

Figure-5. The inflow hydrograph is used as upstream boundary conditions.

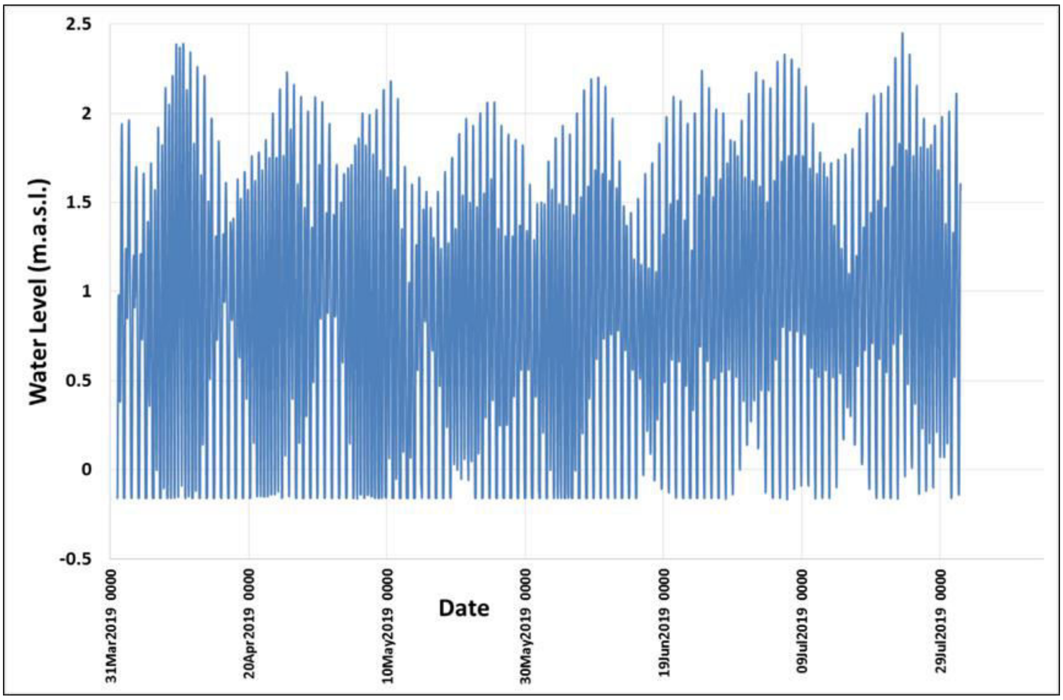

Figure-6. The tidal water level at Al-Faw City.

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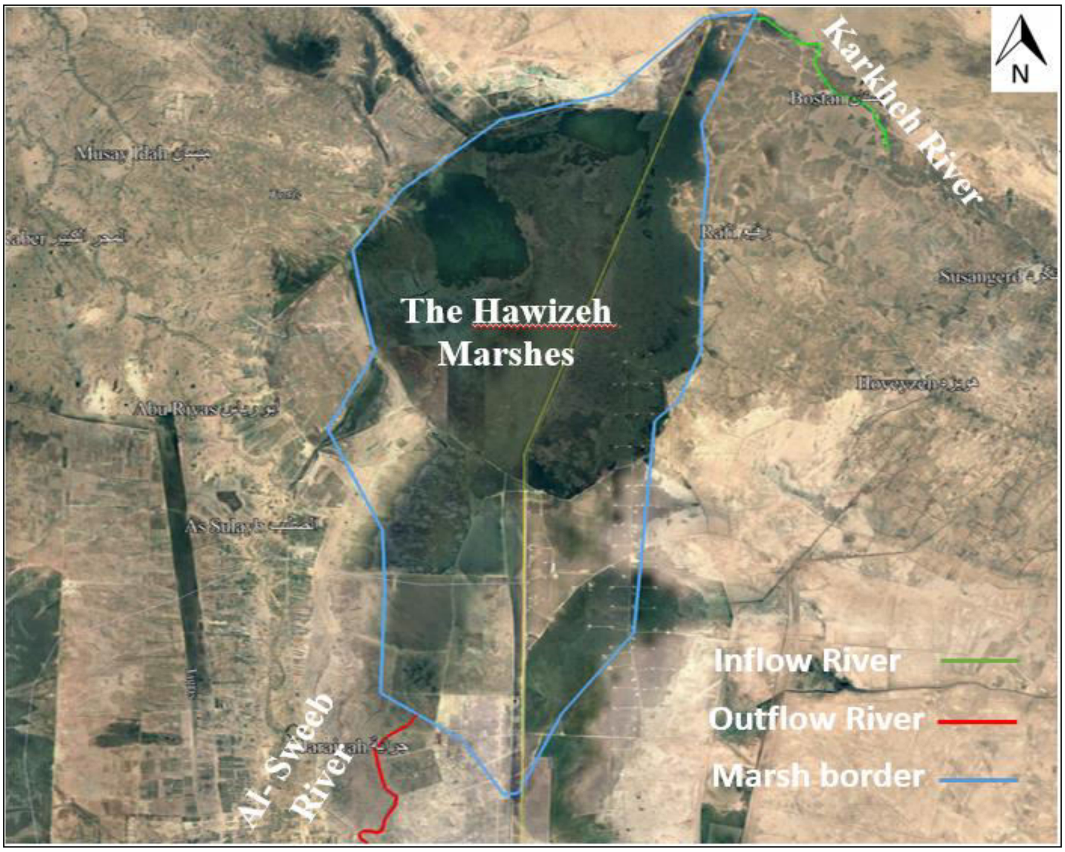

Figure-7. Hawizeh Marsh, showing the inflow from Karhheh River and outflow to Al-Sweeb River.

Considering the above extreme historical event, and assuming that the Hawizeh Marsh is filled and provides minimal attenuation effect, 3 peak flow scenarios from the Al-Sweeb, 1,750 m^3/s, 2,000 m^3/s and 2,250 m^3/s (Figure-8), are considered to simulate the extreme flood condition to investigate flood inundation of the surrounding area of Shatt Al-Arab River.

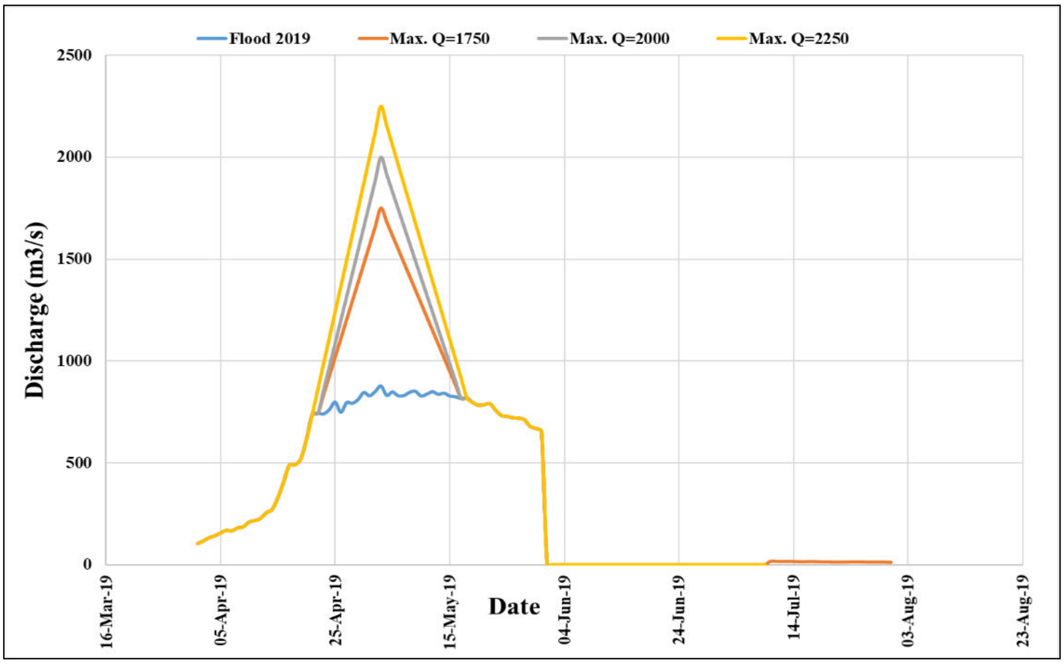

Figure-8. Synthetic extreme inflow hydrograph of the Al-Sweeb River.

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RESULTS AND DISCUSSIONS

Simulated Riverbank Overflow

Table-2 summarizes the maximum flow rate and maximum water level for Scenarios 1 to 3. Based on the maximum water level obtained, there is no bank overflow for Scenario 1 when the peak discharge from the Al-Sweeb is 1,750 m^3/s. However, river bank overflow occurs under Scenario 2 and 3.

Table-2. Simulated maximum flow rate and maximum water at selected locations.

Location	Scenario 1: 1,750 m^3/s		Scenario 2: 2,000 m^3/s		Scenario 3: 2,250 m^3/s	
	Max. flowrate (m^3/s)	Max. Water Level (m)	Max. flowrate (m^3/s)	Max. Water Level (m)	Max. flowrate (m^3/s)	Max. Water Level (m)
Al-Qurna	394	3.6	400	3.91	408	4.2
Ktiban	2077	2.63	2,300	2.8	2517	2.98
Basrah Silo	1761	2.4	1,900	2.51	2031	2.64
Abu Flus Port	1932	2.24	2,070	2.3	2204	2.37

For Scenario 2, the maximum water level recorded in Al-Qurna city is just below 4 m with a maximum discharge of 400 m^3/s. The river stage remained below the bank level and thus did not lead to riverbank overflow. At Ktiban station, a maximum discharge of 2, 300 m^3/s is recorded with a maximum water level of 2.8 m. Similarly, the river stage stays below the left and right banks in this location which measures 3.5 m. Meanwhile, Basrah Silo recorded a maximum flow rate of 1, 900 m^3/s with a water level of 2.51 m, which is above the right bank level of the river, hence causing bank overflow. The left bank, which is about 3.5 m above sea level, is still safe. Figures 9 and 10 show the stage hydrograph of Al-Qurna, Ktiban, and Basrah silo for scenarios 2 and 3.

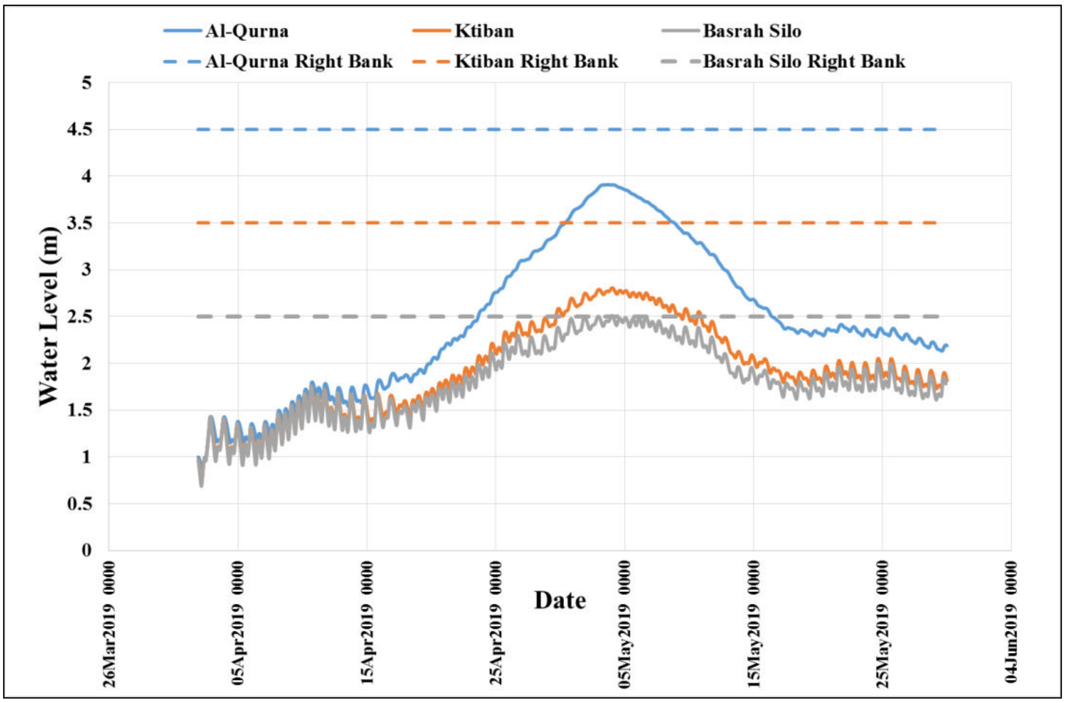

Figure-9. The stage hydrograph of Al-Qurna, Ktiban, and Basrah Silo under Scenario 2, showing bank overflow at Basrah Silo.

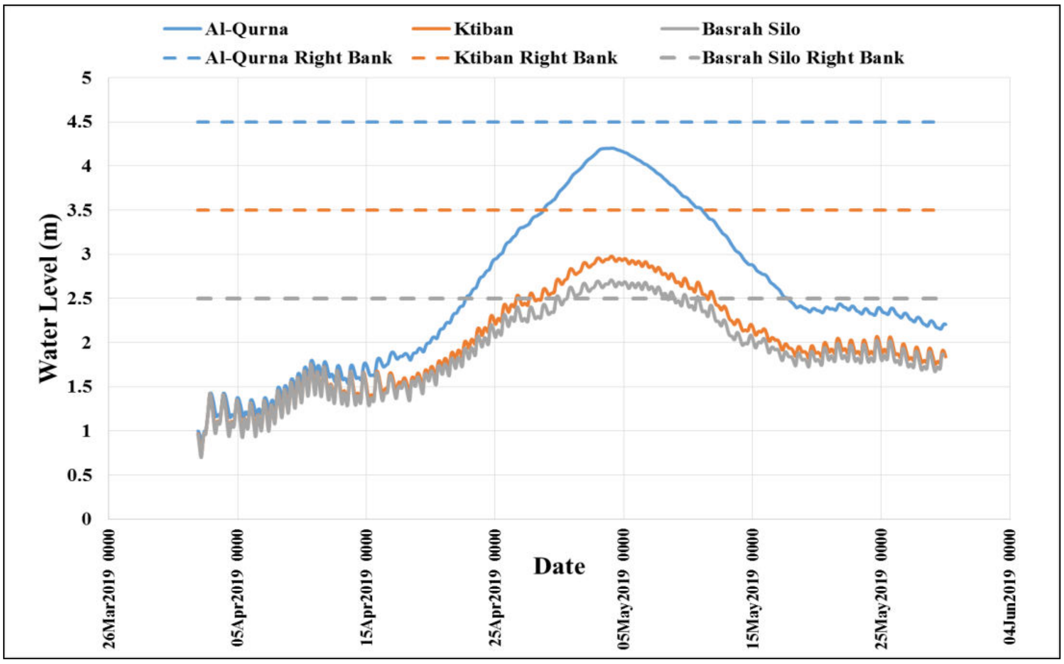

Figure-10. The stage hydrograph of Al-Qurna, Ktiban, and Basrah Silo under Scenario 3, showing bank overflow at Basrah Silo.

The results of the model indicate that the maximum flood wave in Scenario 2 reaches Basrah City 24 hours (1 day) after the time of flood peak at the Al-Sweeb and the bank overflow lasts for 2 hours (Table-3). In Scenario 3, the flood wave arrives at Basrah City within 12 hours after the flow records in Al-Sweeb with 1900 m^3/s, and the water level will be drawdown for 15 hours, and this level will rise again over 2.5m after 4 hours from the flood at Al-Sweeb records 2000 m^3/s and causes bank overflow up to 14 hours. In the latter case, which is closer to the historical event, there is very limited lead time for actions and the impact on the community along the river floodplain lasts more than half a day. Hence, an appropriate mitigation or emergency plan will be required to prevent the potential damage of similar flood events.

Table-3. Simulated riverbank overflow.

Location	Scenario 1: 1,750 m^3/s		Scenario 2: 2,000 m^3/s		Scenario 3: 2,250 m^3/s	
	Timebank overflow begins (h)	Duration of bank overflow (h)	Timebank overflow begins (h)	Duration of bank overflow (h)	Timebank overflow begins (h)	Duration of bank overflow (h)
Al-Qurna	-	-	-	-	-	-
Ktiban	-	-	-	-	-	-
Basrah Silo	-	-	24	2	4	14
Abu Fluse Port	-	-	-	-	-	-

Flood Inundation Mapping

Figure-11 shows the maximum inundation of the north Basrah City after the release of 2, 000 m^3/s from the Al-Sweeb River (Scenario 2). Bank overflow occurs along the right bank of Basrah Silo. However, the flood extent is limited only to the low-lying locations closest to the river floodplain.

Figure-12 shows the inundation of Basrah City in case of releasing 2,250 m^3/s (Scenario 3). In this case, the maximum water level in the Basrah silo location reaches 2.64 m and the bank overflow occurs along the entire right bank between Basrah Silo and extends southward of Al-Ashar. The total flood area is estimated to be 1.7 sq. km, hence affecting a considerably large area and a high number of potential victims and an emergency plan must be activated (Awad, *et al*., 2022).

Figure-11. The inundation map at Basrah City after the release of 2,000 m^3/s from A-Sweeb River.

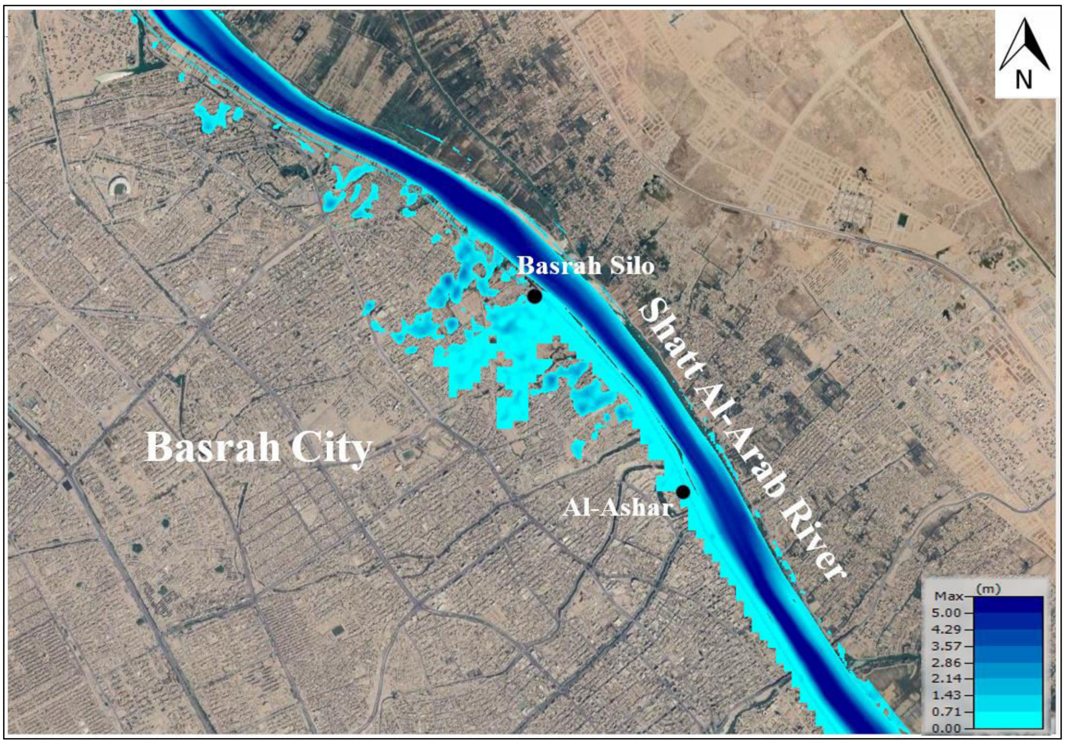

Figure-12. The inundation map at Basrah City after the release of 2,250 m^3/s from Al-Sweeb River.

Closer to the estuary near Al-Faw City, the Shatt Al-Arab River is subjected to strong tidal dominance. The maximum ebb water level recorded in the model for this location is 2.2 m (Figure-13) which is still below the bank level of Al-Faw City (at 2.7 m), hence there is no flooding. The results of the model showed that the maximum tidal discharge entering Shatt Al-Arab in early April before the arrival of the flood wave was -4,040 m^3/s, and the maximum ebb discharge was 4,530 m^3/s (Figure-14).

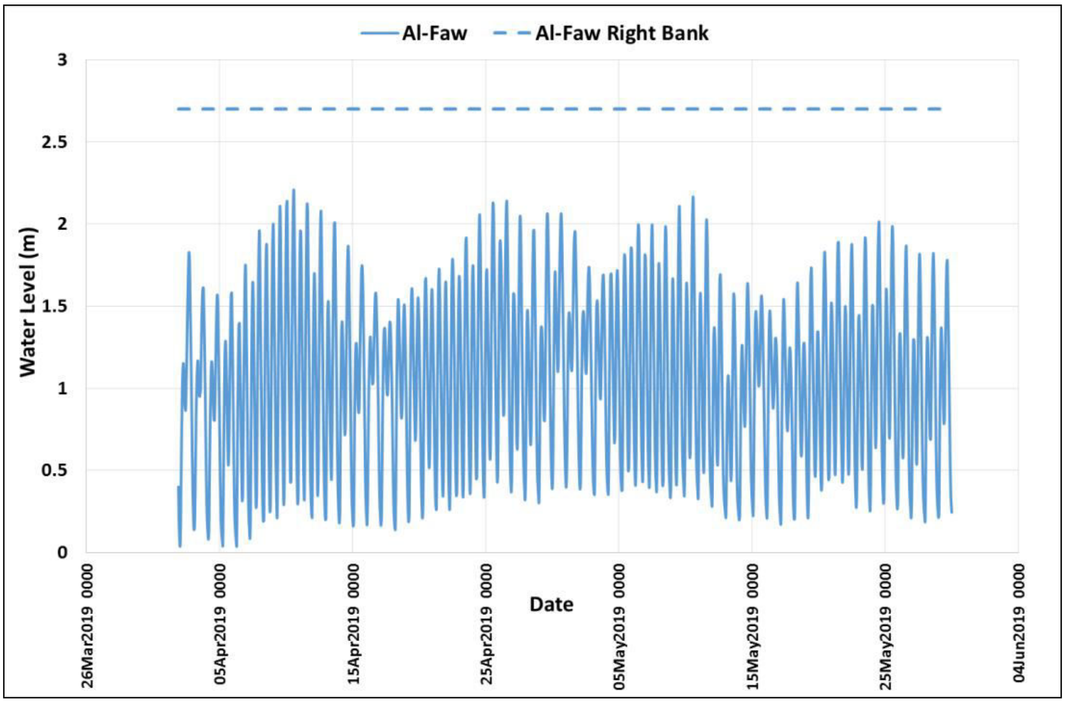

Figure-13. The stage hydrograph of Al-Faw city.

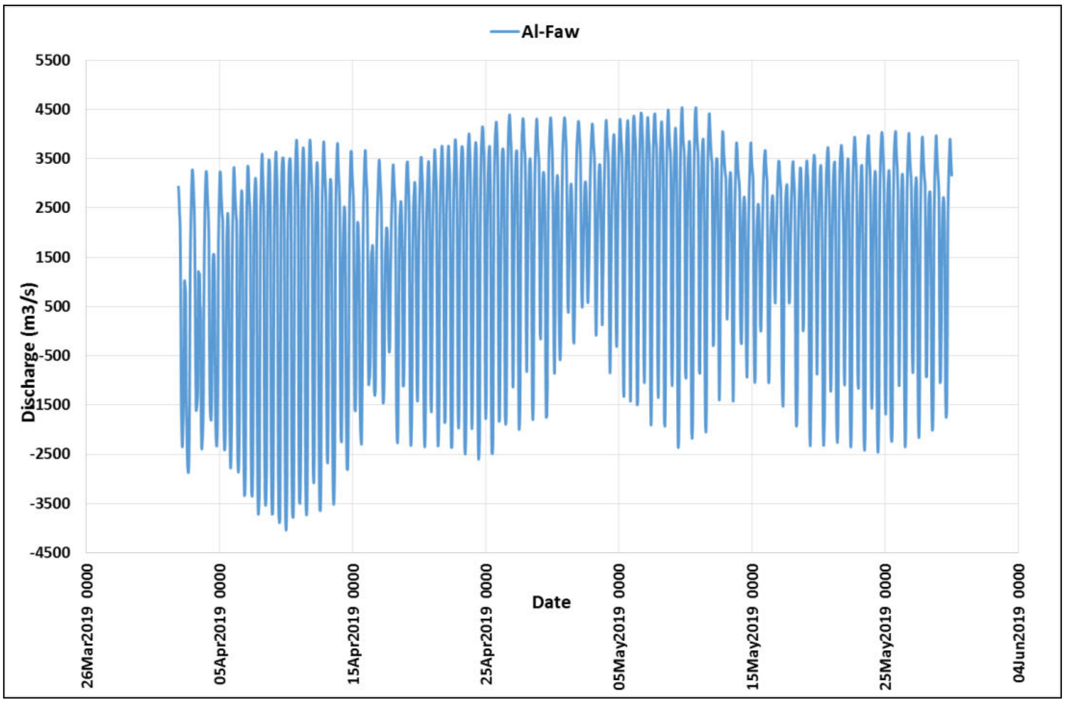

Figure-14. The flow hydrograph of Al-Faw city.

Simulated Flooding of Al-Hammar Marsh

Figure-15 shows the simulated flow from Shatt Al-Arab via the Garmat Ali River into the Al-Hammar marsh. The total volume that entered the marsh during this period (from 1 April to 30 May 2019) was estimated at 755 MCM (million cubic meters). Figure-16 shows the simulated water level in the Garmat Ali River 10 km from its confluence with Shatt Al-Arab. The water level increased from 1 m at the beginning of the season and reached a maximum of 1.96 m on 4 May and subsequently fluctuated with a mean of 1.75 m.

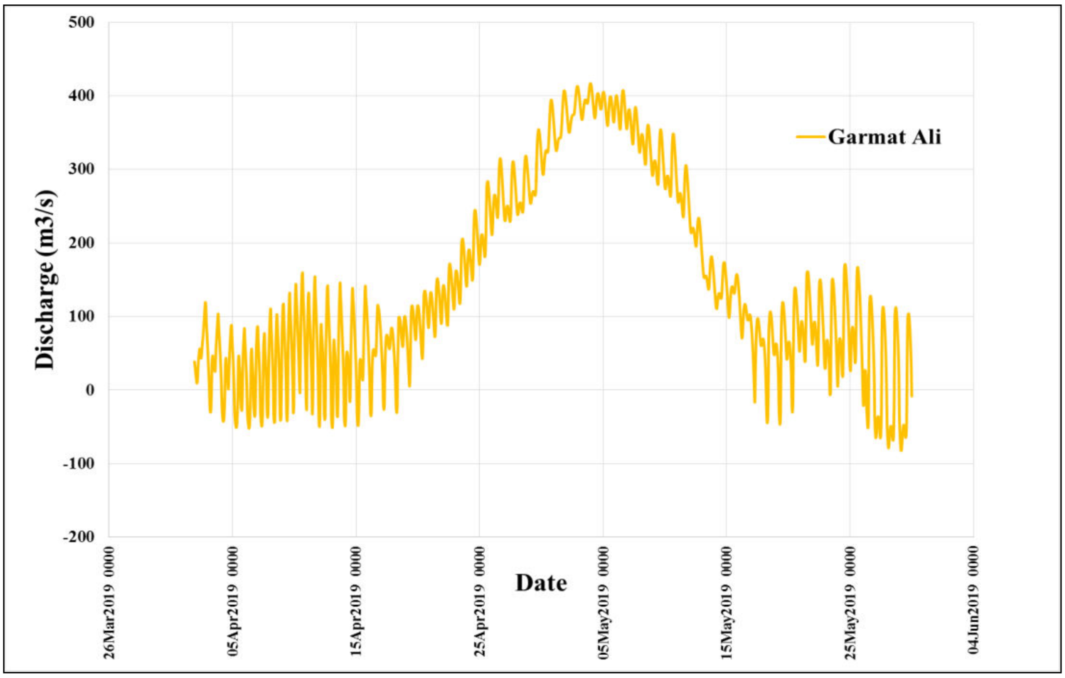

Figure-15. The inflow that entered the Garmat Ali River in the simulation period.

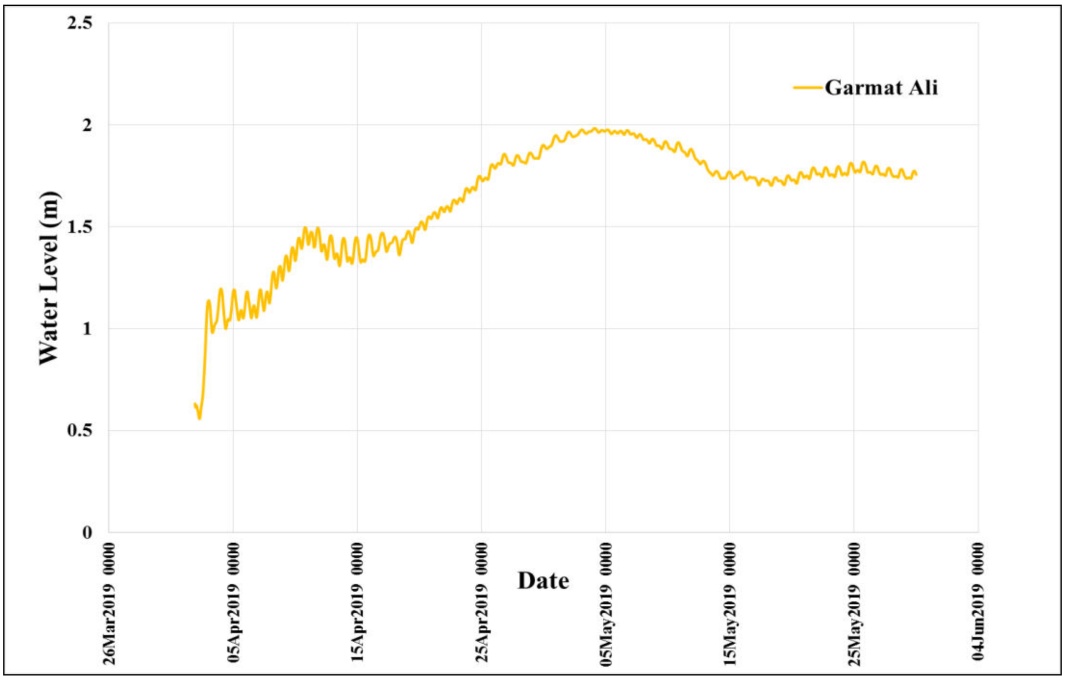

Figure-16. The water level in the Garmat Ali River at 10 km upstream of the confluence with Shatt Al-Arab.

Figure-17 shows the inundation map in the marsh during the simulated flood period. The total inflow of 755 MCM water throughout this period caused the water level in the marsh to increase by 1.4 m from the initial water level of 0.57 m, consistent with the simulated water level change in Figure-16. This amount of inflow from Shatt Al-Arab into Al-Hammar significantly replenishes the marsh during the season and is crucial in supporting the ecosystem of the marsh.

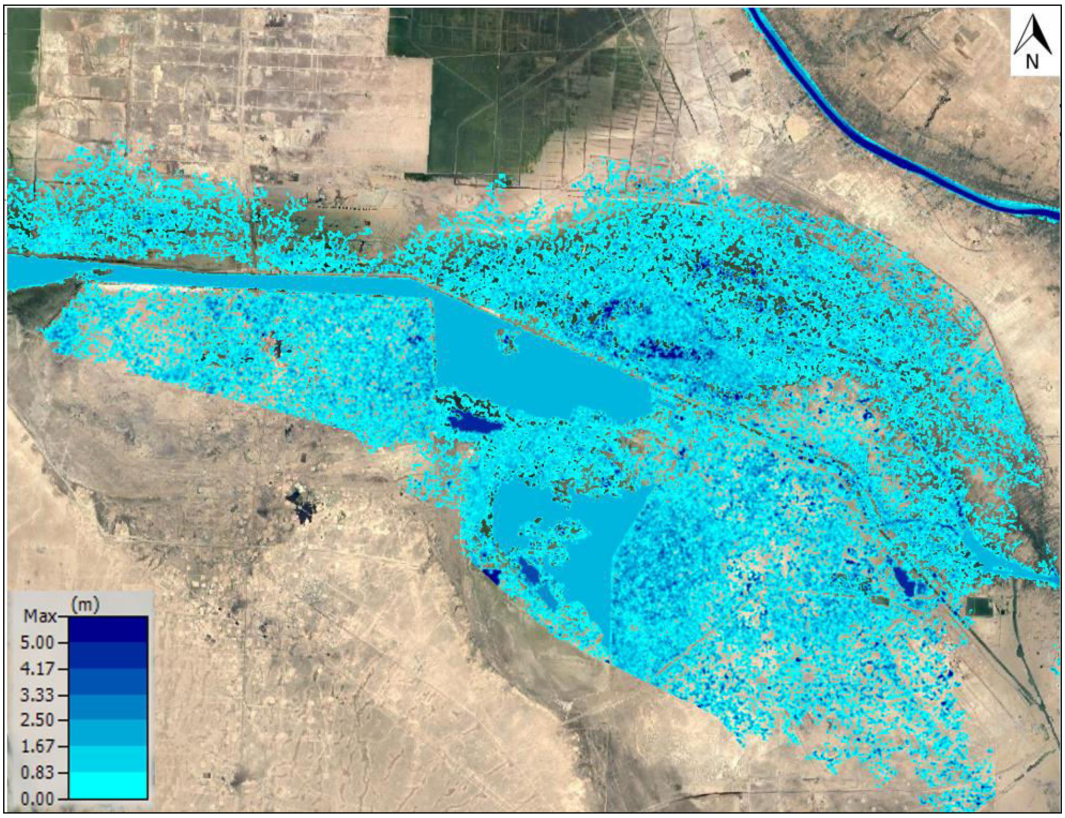

Figure-17. Marsh inundated the area during the simulation period.

CONCLUSIONS

Based on the study results, the following conclusions are made:

a) The study considers extreme runoff from the Al-Sweeb River up to 2,250 m^3/s based on past historical events. Model results showed that the riverbank overflow in Basrah City will happen when a flow of 2,000 m^3/s is discharged from the Al-Sweeb River into the Shatt Al-Arab River. There is no overflow to the Iran side on the left bank due to the higher bank level.
b) The results of discharging 2,250 m^3/s from Al-Sweeb indicate that the maximum flood wave at the Al-Sweeb can reach Basrah city as fast as after 4 hours when the flow hydrograph recording of 2,000 m^3/s in this scenario. Furthermore, the flood may last for up to 14 hours which can significantly impact the community along the river floodplain. It is thus recommended that an appropriate flood emergency plan be designed to address the occurrence of similar events in the future and minimize losses.
c) The simulation showed that the flood wave replenishes the Al-Hammar marsh significantly when water from the Shatt Al-Arab flows into the marsh via the Garmat Ali River. This storage is beneficial to the ecosystem and is also a precious water resource for irrigation and water supply purposes. Hence, suitable flood control and operation can maximize the storage for optimum benefit to the community.

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