Evaluation and development of Shatt Al-Diwaniya and the diversion canal of Shatt Al-Diwaniya

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Abstract. Shatt Al-Diwaniya branches from Shatt Al-Hilla and extends for about 112 km until the Al-Rumaitha district within the study area located in Al-Diwaniya Governorate, Iraq. It is considered the main source for providing drinking water and supplying irrigation projects to the cities Al-Diwaniya and Al-Rumaitha. The study aims to evaluate, study, and develop Shatt Al-Diwaniya, as well as the new lined canal branching from Shatt Al-Diwaniya which. It is called Shatt Al-Diwaniya Diversion Canal. Field measurements of the discharge and water level were monitored, six sets for Shatt Al-Diwaniya and three sets for Diversion Canal. A one-dimensional model was developed by using HEC-RAS 5.0.7 software, the model was calibrated and verified according to the field measurements, the Manning's coefficient ($n$) of Shatt Al-Diwaniya, and the Diversion Canal is 0.023 and 0.018, respectively. Five Scenarios were simulated to study the reach under the current conditions. It was found the discharge capacity in Shatt Al-Diwaniya is 60 m$^3$/s and the Diversion canal is 22 m$^3$/s. Other additional six scenarios were conducted for the modification of the reach included several cases, firstly, the development of Shatt Al-Diwaniya only, secondly, the development of the Diversion Canal only, as well as the development of the Shatt Al-Diwaniya with the development of Diversion. The results of development show that Shatt Al-Diwaniya can reach design discharge 96.2 m$^3$/s, and for the Diversion will pass the maximum discharge 45.5 m$^3$/s.

1. Introduction
Water Resources Management is the process that helps people to work on managing the available water resources in the present and the future, reduces the risks of floods; also, it helps to supply the required water at the right time and in the right place [Cosgrove and Loucks, 2015]. [Agnihotri and Patel, 2011], Studied the Tapi River, Surat, India, by HEC-RAS software river cross-section development was proposed to improve the carrying capacity of the river and reduce the risk of flooding. Also, by the HEC-Geo-RAS flood immersion map of Surat city was done. [Issac, et al., 2019], A hydraulic model of the Gurupura River, India was selected to conduct a steady flow analysis using the HEC-RAS Software to analyze the river flood and develop a flood inundation map of the river section. [Wara, et al. (2019)], Using the results from the HEC-RAS program to develop a rating curve for three water stations on two rivers in Kwale, Kenya. The data that was used in the model was established from cross-sections and information for hydraulic structures. The model was calibrated under an unsteady state and using Velocity Current Meter and Doppler device (ADCP) for measurement.
of the discharge. [Raslan, et al., 2020], Studied and proposed the required hydraulic solutions for the proposed new canal of the Bahr El-Baquer drainage by HEC-RAS Software. [Talib, et al., 2019]. Developed project water management for the Al-Kamaliya irrigation project, Karbala, Iraq by HEC-RAS to improve the operation of this project and choose the best irrigation scenario, and creating a good database for project management. [Shayea and Al Thamiry, 2020], Developed a one-dimensional hydraulic model of Euphrates River within Nasiriyya city, Iraq by the HEC-RAS Software to simulate discharge under the current conditions, and the results after applying the developments showed that the capacity could become 800 m3/sec in the short term developments and 1,300 m3/sec in the long term. [Sarmad, et al., 2020], The Doppler device (ADCP) was used to take field measurements, cross-sectional area, water discharge, and velocity of the Tigris River. U/S of the Amara Barrage, Iraq. The model was calibrated and validated to investigate an appropriate value for Manning's coefficient of roughness.

Shatt Al-Diwaniya is a part of the (Hilla-Diwaniyah-Daghara) rivers system which is considered one of the important and largest irrigation systems on the Euphrates River. Shatt Al-Diwaniya branch from Shatt Al-Hilla which branches from the left of the Euphrates River, U/S Hindiyah Barrage. In this paper, the Shatt Al-Diwaniya and Shatt Al-Diwaniya Diversion Canal will be studied, the lack of maintenance and the accumulation of sediment in the mainstream of Shatt Al-Diwaniya reduced the discharge capacity of this river. Also, the Diversion Canal is not able to pass the designed discharges. So, these problems led to failure in satisfying the required water levels to irrigate the agricultural lands and drinking water stations in Diwaniya and Rumaitha cities. Due to the absence of any hydraulic study relating to the study area, it is necessary to conduct a specific study to evaluate the hydraulic condition in Shatt Al-Diwaniya and Diversion Canal by developing a one-dimensional hydraulic model. The model will simulate the flow under the current conditions for multiple scenarios by using HEC-RAS 5.0.7 software, and the required development to increase the discharge capacity of the Shatt Al-Diwaniya and the Diversion Canal. Also, the study on the operation with suggested developments to satisfy the study of strategy for Water and Land Resources in Iraq, 2014 which is conducted by the Iraq Ministry of Water Resources in Iraq.

2. Description of the study area

The study area extends between the governorate of Qadisiyah and Muthanna, as shown in Fig.1. It is considered an important system that supplies water to the two most irrigation projects in Diwaniya and Rumaitha, (Diwaniyah-Shafi’i and Rumaitha) irrigation projects. The total agricultural land irrigated from this system is 50700 hectares. The most important parts of this system are described below.

2.1. Shatt Al-Diwaniya

Shatt Al-Diwaniya is the right branch of the Shatt Al-Hilla, The beginning of the branching is located on 481925 m, Easting, and 3566651 m, Northing on UTM coordinates system. Extends for about 112 km until the Al-Rumaitha district within the study area located in Al-Diwaniya Governorate, Iraq. Then it starts branching into small branches. Shatt Al-Diwaniya is the main source for providing drinking water and supplying irrigation projects for civil and industrial consumption to the cities Al-Diwaniya and Al-Muthanna governorates and many villages scattered near the river.

2.2. Shatt Al-Diwaniya Diversion Canal

Branching from Shatt Al-Diwaniya the artificial new lined canal was constructed in 2011 and named Diversion Canal of Shatt Al-Diwaniya. It is located in the southwestern part of the city of Al-Diwaniya 478750 m, Easting, and 3546402 m, Northing on UTM coordinates system, with a length of 27.9 km. Extends from the Al-Sunni cross regulator from Shatt Al-Diwaniya at station (35 + 840) km and flows into Shatt Al-Diwaniya at station (62 + 000) km. The purpose of implementing the diversion to reduce the flood risk and groundwater levels in Shatt Al-Diwaniya within Al-Diwaniya city.
3. Fieldworks
The ADCP (Acoustic Doppler Current Profiler) M9 device was used to measure the discharge as shown in plate 2 and using the staff gauges at the points to record the water levels. The monitoring sites were determined according to the location when the discharges are changed, as well as the presence of level measuring staff gauges and the availability of a measuring boat or the availability of a nearby bridge for ease of measurement. Table 1 presents the locations and coordinates of the monitoring point.

The importance of fieldwork is to collect the necessary data for evaluating the system and investigate the hydraulic system within the study area. The data is used in preparing the hydraulic model using HEC-RAS software and in calibration and verification of Shatt Al-Diwaniya and Diversion Canal. The details are described in the following points.

1. Conducting sex sets of discharges and water levels measurements at five stations along Shatt Al-Diwaniya.
2. Conducting three sets of discharge and water level measurements at two sites along the Diversion canal.

![Figure 1. General layout of Shatt Al-Diwaniya and Diversion canal reach of understudy, by ArcGIS 10.2, ESRI. Condition.](image-url)
4. Developing the hydraulic model
The HEC-RAS 5.0.7 software was used to simulate a one-dimensional steady-state gradually varied flow of the study area under different conditions. The software presented by United State Army Corps of Engineers that is used to analyze the river system. Data of 866 cross-sections were provided by the [Iraqi Ministry of Water Resources, DWRD] for the mainstream of Shatt Al-Diwaniya and Diversion Canal were used in the hydraulic model. The boundary condition is the constant discharge at the upstream and the normal depth at the downstream.

5. Results and analysis
In this section, the results will be reviewed and analyzed of flow capacity for the studied area of Shatt Al-Diwaniya and Diversion Canal, which was simulated by using the HEC-RAS model, the analysis includes the calibration and verification of the Manning’s n, and the current and modified discharge capacity of the reach.

5.1. Calibration and Verification
Determination of Manning’s n coefficient is important in calculations of open channel flow, the variance in this factor has a clear effect on the calculations of discharge, depth, velocity [Chow V T, 1959]. The Root Mean Square Error, RMSE, was used to test and compare the Simulated and the observed water levels that are:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S_i - O_i)^2}$$

$N$= number of data,
$S_i$ = Simulated water level, m.a.m.s.l.

| River            | Location                  | Station         | UTM coordinates ,m | X, Easting | Y, Northing |
|------------------|---------------------------|-----------------|-------------------|------------|-------------|
| Shatt Al-Diwaniya| D/S Shatt Al-Diwaniya H.R | 00+100          | 481169            | 3566651    |
|                  | U/S Al-Sunnyia C.R        | 35+850          | 478802            | 3546524    |
|                  | Al-Sadeer sub-district    | 83+750          | 494126            | 3523252    |
|                  | Al-Hamza district         | 97+000          | 498267            | 3514175    |
|                  | Barshawia                 | 112+000         | 503717            | 3501751    |
| Diversion Canal  | D/S Diversion Canal H.R   | 00+050          | 478750            | 3546402    |
|                  | Pedestrian Bridge         | 20+850          | 490369            | 3532170    |

Figure 2. Snapshots showing the field works.

Table 1. Locations and coordinates of the monitoring stations.
Through many trial runs of the HEC-RAS simulation model using different values of Manning’s n during the calibration process along the Shatt Al-Diwaniya reach. The process was conducted by using sets of data that were obtained from field works. Four sets and two sets were used for calibration in Shatt Al-Diwaniya and Diversion Canal, respectively. The lowest RMSE of 0.090 was obtained with Manning’s n of 0.023 for Shatt Al-Diwaniya as shown in Table 2. The lowest RMSE of 0.085 was obtained with Manning’s n of 0.018 for the lined Diversion Canal as shown in Table 3. A comparison between the observed and simulated water levels during verification for Shatt Al-Diwaniya and Diversion Canal. The results of the verification process showed a very good agreement between the observed and simulated water levels with RMSE of 0.121 and 0.113 for Shatt Al-Diwaniya and 0.05 for Diversion Canal.

| Set number | Station (km) | Q (m$^3$/s) | Water Level (m.a.m.s.l) | RMSE |
|------------|--------------|-------------|-------------------------|------|
|            |              |             | Observed | Simulated n=0.023 |      |
| 1          | 00+100       | 40.4        | 23.16 | 23.05 |      |
|            | 35+850       | 31          | 20.66 | 20.64 |      |
|            | 83+750       | 16.6        | 16.4  | 16.47 | 0.101|
|            | 97+000       | 13.37       | 15.8  | 15.67 |      |
|            | 112+000      | 10          | 13.8  | 13.93 |      |
| 2          | 00+100       | 59.5        | 23.55 | 23.55 |      |
|            | 35+850       | 52.5        | 21.21 | 21.28 |      |
|            | 83+750       | 33.7        | 17.22 | 17.19 | 0.091|
|            | 97+000       | 21          | 16.15 | 16.05 |      |
|            | 112+000      | 14.24       | 14.08 | 14.24 |      |
| 3          | 00+100       | 62.5        | 23.74 | 23.61 |      |
|            | 35+850       | 44.73       | 21    | 20.97 |      |
|            | 83+750       | 30          | 17.17 | 17.11 | 0.145|
|            | 97+000       | 25.87       | 16.33 | 16.26 |      |
|            | 112+000      | 19          | 14.25 | 14.53 |      |
| 4          | 00+100       | 65          | 23.85 | 23.67 |      |
|            | 35+850       | 51          | 21.18 | 21.21 |      |
|            | 83+750       | 28.4        | 17.1  | 17.01 | 0.115|
|            | 97+000       | 20          | 16.12 | 16.01 |      |
|            | 112+000      | 13.5        | 14.08 | 14.19 |      |

$O_i =$ observed water level, m.a.m.s.l.
5.2. Current Capacity of the Reach

Estimating the discharge capacity of the Shatt Al-Diwaniya at present was made by assumed discharge at the head regulator and increasing it until the design discharge is reached, and for the Diversion Canal depends on the released discharge from Al-Sunnyia cross regulator, as well as the released discharge in the Diversion Canal and the total discharge arriving downstream the outfall of the Diversion Canal.

5.2.1 Shatt Al-Diwaniya

Determining the capacity of Shatt Al-Diwaniya under the current conditions is a difficult matter, because the irrigation by the private pumps scattered along the reach, and the operation of these pumps is outer of the ability of the government. Therefore, the consumption was distributed on the state of lowest consumption to know the capacity in the case of the worst conditions. It has been found after several different scenarios that discharge less than 60 m$^3$/s can be accommodated within the main channel, although at the discharge of 60 m$^3$/s the freeboard at some locations is less than 1 m or less than 50 cm. In the case of discharges of more than 60 m$^3$/s, flooding will occur. Fig. 3. Shows the (W.S.E.) of the discharge 60 m$^3$/s with the minimum consumption. The results of W.S.E for the discharge 96.2 m$^3$/s which is the design discharge of Shatt Al-Diwaniya with the lowest consumption as shown in Fig. 4. It is noted that flooding occurred in Shatt Al-Diwaniyah for different locations.

5.2.2 Shatt Al-Diwaniya Diversion Canal

Several different scenarios were worked out to reach the safe operation of the Diversion Canal with Shatt Al-Diwaniya. The scenario included of released 15 m$^3$/s discharge in the Diversion, with an increase of 5 m$^3$/s up to 45.5 m$^3$/s, with the release of the lowest possible discharge in Shatt Al-Diwaniya of 23 m$^3$/s. It has been found that the maximum discharge that can be released in the Diversion canal is 22 m$^3$/s, Fig. 5 shows the W.S.E along the reach of the discharge 22 m$^3$/s. Fig. 6 shows the W.S.E. when the discharge is increased to 45.5 m$^3$/s which is the design discharge of the Diversion, it was noticed that the occurrence of the backwater curve and extends for a distance of about 6 km from the Shatt Al-Diwaniya meeting point with the Diversion Canal. It is clear that in the discharge of more than 22 m$^3$/s a backwater curve will occur from the Shatt Al-Diwaniya to the Diversion Canal. This means that the total discharge that reaches arrive at the Shatt Al-Diwaniya reach after the mouth of the Shatt Al-Diwaniya Diversion Canal should not exceed 45 m$^3$/s. A scenario for operating the Diversion without Shatt Al-Diwaniya was conducted. The boundary conditions used in the scenario were the constant discharge at the upstream and the normal depth at downstream with a slope of 0.00007 and this scenario is under the current conditions to assess the condition of the Diversion canal. The result, as shown in Fig. 7 that the Diversion works normally without Shatt Al-Diwaniya. Accordingly, the design of the Diversion was done without considering the existence of the Shatt Al-Diwaniya, and this is why the backwater curve problem appeared when the Diversion canal was connected to the Shatt Al-Diwaniya.

| Set number | Station (km) | Q (m$^3$/s) | Water Level (m.a.m.s.l) | RMSE |
|------------|--------------|-------------|------------------------|------|
|            |              |             | Observed | Simulated n=0.018 |      |
| 1          | 00+050       | 10          | 19.7      | 19.69 | 0.092 |
|            | 20+500       | 4.7         | 19.15     | 19.02 |      |
| 2          | 00+050       | 6           | 19.45     | 19.45 | 0.085 |
|            | 20+500       | 3.5         | 19.2      | 19.08 |      |

Table 2. Comparison between observed and simulated water levels by using the calibrated Manning’s coefficients of 0.018 for Diversion Canal.
Figure 3. Shows the W.S.E along the reach of Shatt Al-Diwaniya under the current conditions for a discharge of 60 m$^3$/s for the assumed minimum consumption.

Figure 4. Shows the W.S.E along the reach of Shatt Al-Diwaniya under the current conditions for a discharge of 96.2 m$^3$/s for the assumed minimum consumption.

Figure 5. Shows the W.S.E along the reach of Diversion Canal under the current conditions for a discharge of 22 m$^3$/s.

Figure 6. Shows the W.S.E along the reach Diversion Canal under the current conditions for a discharge of 45.5 m$^3$/s.
5.3 Development of cross-sections of the study area

It was mentioned previously that the released discharge in Shatt Al-Diwaniya cannot exceed 60 m³/s under the current conditions, and this discharge is lower than the current and future requirements of agriculture in the Diwaniya Governorate and the Rumaita district. The strategy was based on developing the cross-sections by training the river and raising the banks in different locations. Regarding the development of the Diversion included redesigning the Diversion Bed level and raising its banks in different locations.

5.3.1 Shatt Al-Diwaniya

The maximum discharges to be released in Shatt Al-Diwaniya has been determined during the agricultural seasons through the year which are the months of April, June, and July [Iraqi Ministry of Water Resources, DWRD], and this consumption for these discharges is different for the areas distributed on Shatt Al-Diwaniya, Fig. 9 shows the W.S.E. in case of release and distribution of the discharge during April, June, and July. As well a scenario was also made in the case of releasing the design discharge in Shatt Al-Diwaniya and the water consumption along the Shatt Al Diwaniyah would be the least possible, reached 45 m³/s of the total design discharge in Shatt Al-Diwaniyah, 96.2 m³/s to ensure that Shatt Al-Diwaniya is safe in all operating cases. Fig. 8 shows the W.S.E. in case the consumption is minimal with released the design discharge of 96.2 m³/s with an F.B of 1 m.

5.3.2 Diversion Canal

The diversion is considered part of the Diwaniyah-Shafi’i irrigation project, and it is the main water-carrying canal that takes water directly from Shatt Al-Diwaniya. Therefore, its development is important to complete the large part of the Diwaniya-Shafi’i lands reclamation project, which is underway during this year. 2021 by the Ministry of Water Resources, but only the reclamation of 35,000 dunums of Shafi’i land which is located on the Diversion side, will take the water through the Diwaniyah-Shafi’i station located on the Diversion Canal with a total design discharge of 10 m³/s. The development of the Diversion also helps relieve pressure on the Shatt Al-Diwaniya by distributing the discharges between the Diversion and Shatt Al-Diwaniya and reducing the groundwater in the center of Diwaniya. The design discharge of 45.5 m³/s was released in the Diversion, and the discharge of the Shatt Al-Diwaniya was fixed at 23 m³/s. Four scenarios are adopted, as shown in Table 4, which were numbered with the symbol M. Fig. 10. Shows the W.S.E. in scenario M1. It was found that the maximum discharge is 30 m³/s with the F.B of 1 m and in the discharge 45.5 m³/s, the backwater curve effect will be less than the usual case in which the Shatt Al-Diwaniya remains without development. In scenario M2, it is possible to pass the design discharge in the Diversion, as shown in Fig. 11. In scenario M3 Fig. 12. The released discharge 45.5 m³/s is within the main canal with an F.B 1 m. However, the Shatt Al-Diwaniya reach downstream the outfall of the Diversion is not able to pass the total discharge of the Shatt Al-Diwaniya and Diversion Canal. Fig. 13. Shows the results of W.L in scenario M4, it is clear that the Diversion Canal can accommodate the design discharge of 45.5 m³/s with an F.B of more than 1 m, as well as the

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**Figure 7.** W.S.E along Diversion Canal under the current conditions without Shatt Al-Diwaniya for a discharge of 45.5 m³/s.
Shatt Al-Diwaniya reach downstream the outfall of the Diversion can pass the total discharge of Shatt Al-Diwaniya and Shatt Al-Diwaniya Diversion Canal.

**Figure 8.** W.S.E along the modified Shatt Al-Diwaniya cross-sections for a discharge of 96.2 m$^3$/s with minimum consumption.

**Figure 9.** W.S.E along Shatt Al-Diwaniya with the modified cross sections with maximum consumption during the agricultural seasons.

**Table 4.** Description of the expected scenarios in the operation of the Diversion Canal.

| Scenario | Shatt Al-Diwaniya | Diversion Canal |
|----------|-------------------|-----------------|
|          | Developed         | Developed       | Not Developed |
|          | Not Developed     | Raising Banks   |                |
| M1       | Shatt Al-Diwaniya | -               | -              |
| M2       | Shatt Al-Diwaniya | Diversion Canal | -              |
| M3       | Shatt Al-Diwaniya | -               | Diversion Canal|
| M4       | Shatt Al-Diwaniya | -               | Diversion Canal|
6. Conclusions

By analyzing the results, the following main conclusions were drawn.

- Through calibration and verification, it was found that Manning’s n coefficients for Shatt Al Diwaniya and the Diversion canal are 0.023 and 0.018, respectively.
- The current capacity of Shatt Al-Diwaniya and Diversion Canal are 60 m$^3$/s and 22 m$^3$/s, respectively. While the design discharges of them are 96.2 m$^3$/s and 45.5 m$^3$/s, respectively.
• The total discharge in Shatt Al-Diwaniya downstream the outfall of the Diversion Canal must be less than 45 m$^3$/s to avoid the reduction in the discharge of the diversion canal by the backwater curve.
• In the case of the development of Shatt Al-Diwaniya only, it became able to accommodate the design discharge of 96.2 m$^3$/s with different operating conditions, and the Diversion Canal capacity will be 30 m$^3$/s.
• Developing the Diversion Canal only will pass the design discharge, but the discharge of Shatt Al-Diwaniya must be less than 25 m$^3$/s to avoid the flood of Shatt Al-Diwaniya downstream the outfall of the Diversion Canal.

7. References
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