The Extreme Flood Capacity of Al-Majjarah Canal and Regulator Within Al-Ramadi Project System

Amro. S. Al-Tameemi[1], Hayder A. Al-Thamiry[2*]

Authors affiliations:
1) Dept. of Water Resources Eng., College of Engineering, University of Baghdad, Baghdad, Iraq.
amr.abd2110m@coeng.uobagdad.edu.iq

2*) Dept. of Water Resources Eng., College of Engineering, University of Baghdad, Baghdad, Iraq.
hy_hyder@coeng.uobaghdad.edu.iq.

Paper History:

Received: 15th July. 2023

Revised: 9th Aug. 2023

Accepted: 28th Aug. 2023

Abstract

It is essential to review and develop a system of water control structures and canals that can be used to manage high-flow discharges and the flood control plan requirement to modify the system's capacity. Al-Ramadi Project System is considered one of the main flood control projects on the Euphrates River within Anbar Governorate, Western Iraq. This study will focus on Al-Majjarah Canal and Regulator, which is part of Al-Ramadi Project and has the function of a link canal between Al-Habbaniyah and Al-Razazza lakes, and describe the capacity of the canal under typical operating conditions and during floods. The study used HEC-RAS 6.1 software to run a numerical model to simulate this canal. According to previous research studies near the research region on the Euphrates River, for the main canal, the roughness coefficient was taken at 0.026, and for the flood plain, it was taken at 0.03. The same parameter value was applied to Al-Majjarah Canal. Due to the study region's similar geology and nature. Moreover, a sensitivity analysis was made of the roughness coefficient and its influence on the water surface elevation for the canal.

The model result indicated in the current situation of Al-Majjarah Canal can pass a flow rate of 1300 m^3/s when Al-Razazza Lake is at an average water level that has been approved by the Ministry of Water Resources at 32.02 m.a.m.s.l.. If the water level in Al-Razazza Lake is in the semi-filled position of 40 m.a.m.s.l., it causes floods for the canal because the water level rises above the banks of the canal at the last kilometer from the canal, even when passing a few discharges through the canal. Accordingly, it is not possible to safely pass the flow rate for a flood wave with a 500-year return period predicted by the "Study of Strategy for Water and Land Resources in Iraq (2014)", which is 2000 m^3/s for this canal, without making modifications to the expansion of Al-Majjarah Regulator by adding additional gates, expanding the entrance and exit of the Regulator, reshaping and expanding some cross-sections, and raising some of the banks for the canal. The above-mentioned modification were applied for the purpose of passing the expected discharge from the canal, while maintaining a freeboard of 1 m between the water surface and the canal banks.

Keywords: Al-Majjarah Canal, Euphrates River, HEC-RAS 6.1, Al-Ramadi Project System, Al-Majjarah Regulator, The Extreme Capacity.

السعة الفيضانية القصوى في قناة وناظم المجرة ضمن منظومة مشروع الرمادي

عمرو سرمد التميمي ، حيدر عبد الامير الثامري

الخلاصة:

من الضروري مراجعة وتطوير منظومة التحكم في المياه والقنوات التي يمكن استخدامها لإدارة تصريفات التدفق العالي ومتطلبات خطة التحكم في الفيضانات لتعديل سعة المنظومة، وتعتبر منظومة مشروع الرمادي من أهم مشاريع السيطرة على الفيضان على نهر الفرات ضمن محافظة الأنبار غرب العراق، فإن هذه الدراسة ستركز على قناة وناظم المجرة التي هي جزء من مشروع الرمادي وظيفتها كقناة رباطة بين بحيرتي الحبانية والرزازة. وستصف قدرة القناة في ظل التشغيل النموذجي وأثناء الفيضانات. استخدمت الدراسة برنامج HEC-RAS 6.1 لتشغيل نموذج رقمي لمحاكاة هذه القناة. وبحسب دراسات بحثية سابقة تمت دراسته بالقرب من منطقة هذه

NJES is an **open access Journal** with **ISSN 2521-9154** and **eISSN 2521-9162**

الدراسة على نهر الفرات، بالنسبة للقناة الرئيسية تم اخذ معامل الخشونة ٠,٠٢٦، وبالنسبة لسهل الفيضان تم اخذه ٠,٠٣.، تم تطبيق ذات قيمة المعامل على قناة المجرة بسبب تماثل الطبيعة والجيولوجيا في منطقة الدراسة. علاوة على ذلك تم اجراء تحليل حساسية لمعامل الخشونة وتأثيره على مستوى سطح الماء للقناة.
أشارت نتيجة النموذج إلى ان الوضع الحالي لقناة المجرة يمكن أن تمرر معدل تدفق ١٣٠٠ متر مكعب/ثانية، عندما تكون بحيرة الرزازة عند منسوب المياه الاعتيادي المعتمد من قبل وزارة الموارد المائية ٣٢,٠٢ متر فوق مستوى سطح البحر. إذا كان منسوب الماء في بحيرة الرزازة شبه ممتلئ ٤٠ متر فوق مستوى سطح البحر، فأنها ستتسبب في فيضان القناة لأن منسوب المياه يرتفع فوق ضفاف القناة عند الكيلومتر الأخير من القناة حتى عند امرار تصريف قليل للقناة. وفقًا لذلك، لا يمكن تجاوز معدل التدفق بأمان لموجة فيضان مع فترة عودة تبلغ ٥٠٠ عام والمتوقعة من قبل "دراسة استراتيجية موارد المياه والأراضي في العراق (٢٠١٤)"، والتي تبلغ ٢٠٠٠ متر مكعب/ثانية لهذه القناة. دون اجراء التعديلات من توسعة ناظم المجرة بإضافة بوابات إضافية وتوسيع مدخل ومخرج الناظم وإعادة تشكيل وتوسيع بعض المقاطع العرضية ورفع بعض سدود القناة. تم جراء التعديل المذكور أعلاه لغرض امرار التصريف المتوقع في القناة مع الحفاظ على حد الطفو لمسافة ١ متر بين سطح الماء وسداد القناة.

1. Introduction

Al-Majjarah Canal is a part of Al-Ramadi Project System, which is considered one of the main control systems on Euphrates River. The project plays an essential role in reducing flood risks for Euphrates River by diverting excess water to Al-Habbaniyah Lake and returning it to Euphrates River from Al-Thiban Regulator during the summer season or diverting it to Al-Razazza Lake from Al-Majjarah Canal and Al-Majjarah Regulator [1].

Water limitations brought on by a dip in recent rainfall levels and a reduction in the amount of water entering from upstream countries. led to the stoppage of water discharges to Al-Razzaza Lake via Al-Majarrah Canal during the course of the previous 4 years, as demonstrated by the hydrological data for the Head Office of Al-Ramadi Barrage, HORB, 2023 [2].

Hashim and Azzubaidi, 2023 [3] developed a one-dimensional hydraulic model for Euphrates River between Al-Haditha Dam and Al-Ramadi Barrage by HEC-RAS software. The calibration result showed roughness coefficients of 0.026 from Al-Haditha Dam to Al-Ramadi Barrage, as well as 0.03 over the whole study reach for the flood plain. The results show that Euphrates River in this reach exceeds 3000 m^3/s both with and without lateral inflow. However, the results also show that Euphrates River cannot safely pass the anticipated discharge of 4000 m^3/s for a flood wave with a 500-year return period, without modifying the cross-sections.

Shayea and Al-Thamiry, 2020 [4] evaluated a one-dimensional hydraulic model on Euphrates River in Al-Nasiriyah City in Iraq, using HEC-RAS software. The results revealed that the maximum capacity of Euphrates River under its current conditions is 300 m^3/s and that after applying the modifications showed the capacity may increase to 800 m^3/s in a short term and 1,300 m^3/s in a long term.

Al-Kazwini, et al. 2011 [5] created a mathematical model to look at how flood waves behave along the meandering course of Euphrates River from Al-Haditha Dam to Al-Heet City. They demonstrated how the river's meandering affects the flood wave results, water surface elevation, and arrival time. The results showed that flood wave water height and discharge increased, but that the meandering of the river decreased the arrival time along it.

Al-Zaidy and Al-Thamiry, 2020 [6] simulated a one-dimensional hydraulic model by using HEC-RAS software for the flow of Euphrates River and its arms Al-Atshan and Al-Sabeel with a length of 20, 21, and 5 km, respectively within Al-Assamawa City in Iraq. The primary goal of the study is to determine the present capacity of Euphrates River and its tributaries, Al-Atshan and Al-Sabeel, as well as raising the ability of Euphrates and Al-Sabeel to deal with flooding during flood seasons without the need to modify Al-Atshan River. According to the results, the maximum discharge achievable under the current situation of Euphrates River and its arms Al-Atshan and Al Sabeel is 750 m^3/s and 500 m^3/s, respectively. Following the development of cross-sections, it is practical to discharge 1300 m^3/s to Euphrates and 1200 m^3/s to Al-Sabeel.

Tasen and Al-Thamiry, 2022 [7] used a one-dimensional model by HEC-RAS software to study the evaluation and development of (Hilla – Daghara) Rivers System branches from Euphrates River, Shatt Al-Daghara's Manning's coefficient (n) was found to be 0.022. the results showed the current circumstances allowed for 200 m^3/s and 50 m^3/s of flow rates in Shatt Al-Hilla and Shatt Al-Daghara, respectively. After scenario development, the flow rate of Shatt Al-Hilla could pass discharge at 303 m^3/s and Shatt Al-Daghara at 75 m^3/s. The software calculated the amount of development for earthworks in Shatt Al-Daghara and Shatt Al-Hilla 5.89 and 0.54 Mm^3, respectively.

Ali and Al Thamiry, 2023 [8] analyzed Shatt Al-Arab River's capability to control flood discharge using a one-dimensional unsteady-state model created to look at river flood capacity simulation in Shatt Al-Arab River and its tributaries by HEC-RAS software. The result of the study showed a roughness coefficient value of 0.029, and it was predicted that the maximum safe flow rate was roughly 850 m^3/s.

AbdUlameer and Al-Sulttani, 2023 [9] applied the HEC-RAS program to determine the minimum flow rate of Shatt-Al Hillah River in the Babylon Governorate. There are three possible scenarios. The findings indicated that using a 3-day irrigation interval, every irrigation network intake along the river in the research region may discharge 99 m^3/s with a demand discharge of 48.67 m^3/s. An irrigation interval of two days per week may discharge 83 m^3/s for all intakes, with a consumption discharge of 32.5 m^3/s. Given that the river flow rate at the head regulator is 90 m^3/s, the third scenario, with 83 m^3/s and a two-day irrigation service interval, is suggested.

Jassam and Abed, 2021 [10] evaluated a one-dimensional hydraulic model by using HEC-RAS software. In order to analyze the morphology and sediment movement on the Diyala River from the Diyala Weir to the confluence of the Tigris and Diyala River, the model was calibrated for five years, from 2014 to 2019 findings were compared to the 2019 cross-section data. The inversion changes from the sediment model's simulation for the river's actual state between 2018 and 2019 varied from 0.2 m to 0.6 m. While the results of the simulations for the five flood years showed invert values ranging from -1.25 to 1.4 m, the river's capacity was increased by raising the riverbank level in some sections of the reach and modifying some cross-sections.

Mustafa et al., 2017 [11] made a model to estimate the conveyance of sediment from Euphrates River downstream of Al-Haditha dam to Al-Heet station. Using the HEC-RAS software version 4.1. The model was calibrated and verified, and the value of the Manning's Coefficient (n) was 0.033. Because the discharge rose in that region, the sediment load quantity at Al-Heet station was 551.76 ton/day, which was less than the value of the previous research. 189.041×10^3 ton/day, measured in 1988.

Ghali and Azzubaidi, 2021 [12] used HEC-RAS software to simulate a flood wave in the Diyala River, and create a flood escape on this river so that the flood wave may be discharged via it. Two roughness coefficients of (0.035 and 0.028) were used. As a boundary requirement, the Diyala River upstream was subjected to an outflow that fluctuated between 1100 and 1800 m^3/s downstream of the Hemrin Dam. The findings of a one-dimensional hydraulic model created for the river and the escape indicated that a weir could be built at the escape entrance and that this case would offer safe discharge to the Diyala River if a flood wave of 1500 m^3/s were released from Hemrin Dam.

Since no studies have been done before on Al-Majjarah Canal's discharge capacity, this study will analyze the canal's capacity as part of the research. to bring the flood wave under control. The overall goal of this research is to use a one-dimensional model by HEC-RAS 6.1 software to estimate flow at current conditions for various scenarios and to identify the improvements that are required to the discharge capacity in order to safely reach the maximum discharge from the canal that was envisioned in the "Study of Strategy for Water and Land Resources in Iraq", SWLRI, 2014 [13] from the canal in order to achieve the development target.

2. Description of Research Region

Al-Majjarah Canal is an artificial canal linking the south of Al-Habbaniyah Lake to the north of Al-Razazza Lake (Figure (1)); it was completed in 1943, and the purpose of its establishment was to discharge the surplus water from Al-Habbaniyah lake into Al-Razazza Lake. While it cannot divert the water from Al-Habbaniyah Lake to Al-Razazza Lake due to the topographical nature of the area. Al-Razazza Lake is located in a lower area than Habbaniyah Lake. The canal length is 7 km and the top width of the cross-section is changing from 50 to 150 m. There is a canal fall which is a solid masonry structure constructed downstream of Al-Majjarah Regulator (Figure (2)). Since the natural ground slope is steeper than the designed canal bed slope, the bed slope at Al-Majjarah canal is 27 cm/km. The bed level for the canal varies between 42.5 m.a.m.s.l. at the upstream and 31.5 m.a.m.s.l. at the downstream, **MoWR, 2022 [14].**

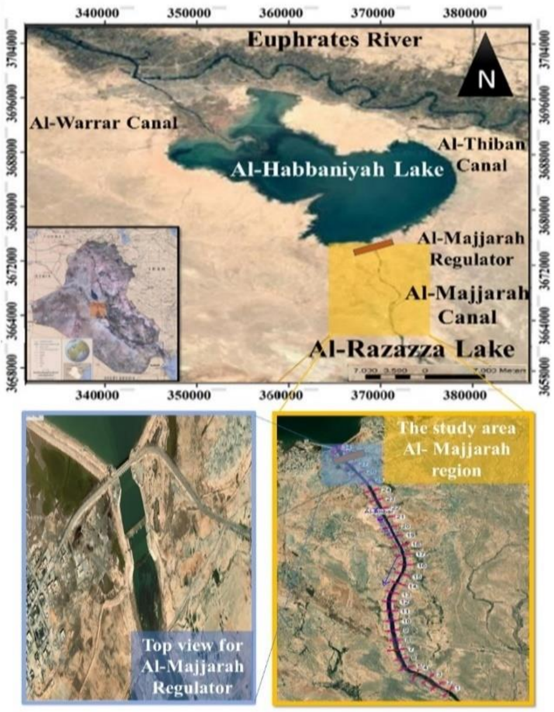

Figure (1): The reach Al-Majjarah Canal within Al-Ramadi Project system. From using Google Earth Pro, ArcMap 10.7.1, and HEC-RAS windows.

Al-Majjarah Regulator is a concrete structure (Figure (2)). It is located 30 km south of Al- Fallujah City, west of Karbala Governorate. It was constructed in 1942 by the British company (Balfour Beatty), CEB, 2011 [15]. It diverts the water of Al-Habbaniyah Lake into Al-Razazza Lake through Al-Majjarah canal during flood season. The regulator was designed by Code and Partners with a designed water surface elevation of 51 m.a.m.s.l. and a design discharge of 1300 m^3/s. the sill level is 44.5 m.a.m.s.l. The regulator consists of 8 vertical sliding gates with dimensions of 6 m width x 6.5 m height, and the number of supports is 7 supports with a width of 2 m per support, MoWR, 2022 [14].

Figure (2): Snapshots showing the downstream of Al-Majjarah Regulator. Provided by, HORB, 2023[2]

Al-Habbaniyah Lake is an old natural lake that had high saline water before it was connected to the Euphrates River and used to store flood water and provide water for irrigation. Al-Habbaniyah Lake is situated on the right side of the Euphrates River in the southeast of the city of Ramadi 70 km to the west of Baghdad City and 15 km west of Al-Fallujah City (Figure (3)). It is a shallow lake with an average depth of 1.8 m. It has maximum extended dimensions of 26 km in length and 16 km in width. Water is diverted from the Euphrates River to Al-Habbaniyah Lake through Al-Warrar Canal, which is controlled by Al-Warrar Regulator. Al-Habbaniyah Lake system has two outlets that are designed to discharge water into Euphrates River and Al-Razazza Lake. It discharges water back again to the Euphrates River through Al-Thiban Canal, which is controlled by Al-Thiban Regulator. Also, Al-Habbaniyah Lake discharges its excess water during a flood to Al-Razazza Lake through Al-Majjarrah Canal which is controlled by Al-Majjarrah Regulator.

The maximum surface area and water storage of the lake are 426 km^2 and 3.28 billion m^3, respectively, at the maximum water surface elevation of 51 m.a.m.s.l.. The live storage is 2.61 billion m^3, and the dead storage is 0.67 billion m^3. The ground surface elevation of the lake about 36 m.a.m.s.l. , CEB, 2011 [15]. The maximum recorded water surface elevation in the lake was 50.64 m.a.m.s.l. in June 1993 according to the annual reports of the National Center of Water Resource Management, MoWR, 2022 [14].

Al-Razazza Lake is one of the biggest lakes in Iraq where it is located at 80 km southwest of Baghdad and 15 km northwest of Karbala Governorate (Figure (3)). Al-Razazza Lake is 60 km in length and 30 km in width. The surface area at an elevation of 27 m.a.m.s.l. is 1810 km^2. This Lake consists of two depressions; the first is located in its western part and is called Al-Malih and the second is located in its southeast part and called Abu Dibbis Marsh. The water within these two depressions is connected when the water level reaches 21 m.a.m.s.l. In 1970, the lake capacity was increased to 26 million m^3 to accommodate more of the Euphrates River flood water, and the drainage water of nearby irrigation projects in Karbala by increasing the protection berms level to 43 m.a.m.s.l.. The maximum recorded water surface elevation in Al-Razazza Lake was 38.22 m.a.m.s.l. during the spring of 1988. This lake has no discharge outlet to drain out its water. The storage and the surface area of Al-Razazza Lake at the maximum water level of 40m.a.m.s.l. are 26000 million m^3 and 1810 km^2, respectively. CEB, 2011 [15]. At the water level of about 16 m.a.m.s.l. , there is no storage for water in the lake. Many water sources feed Al-Razazza Lake. Al-Razazza Lake is connected to Al-Habbaniyah Lake by Al-Majjarrah Canal, which is controlled by Al-Majjarrah Regulator, which was mentioned above. Also, Al-Karbala Main Drainage system drains the excess groundwater from Karbala City and the irrigation projects into Al-Razazza Lake at its southeast boundary.

Figure (3): The region of Al-Habbaniyah and Al-Razazza Lake. From using Google Earth Pro. in the year 1989.

3. Available Hydrological Data Within the Research Region

Based on the information provided by, MoWR, 2022 [14], The design discharge of Al-Majjarah Canal 850 m^3/s. As for the design discharge of Al-Majjarah Regulator 1300 m^3/s.

The volume-elevation curves of Al-Habbaniyah and Al-Razazza Lakes are shown in (Figures (4) & (5)), respectively, the volume-elevation curves will help to show the impact of the water levels from the two lakes on Al-Majjarah canal inside Al-Ramadi Project System, as well as how this has a reflection on the dimensions of the required cross-sections to pass the required discharge.

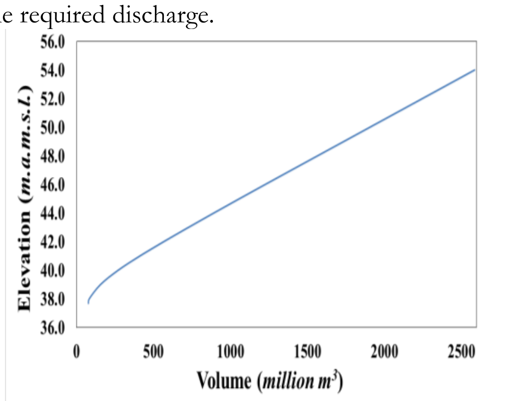

Figure (4): The Volume-Elevation curve for Al-Habbaniyah Lake, MoWR, 2022 [14]

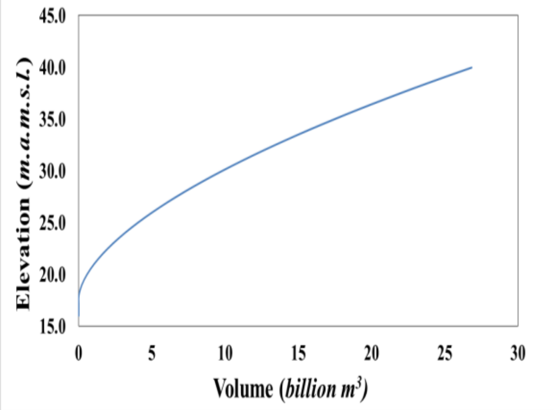

Figure (5): The (Volume-Elevation) curve for Al-Razazza Lake, MoWR, 2022 [14]

4. The Implementation of the Numerical Model

To assess and simulate steady-state and unsteady-state flow in rivers, lakes, and other open channels, the Hydrologic Engineering Center of the United States Army Corps of Engineers has included the widely used HEC-RAS 6.1 software. This software is also very good at modeling water quality and sediment transport, in order to obtain (energy grade lines, and water surface elevations). HEC-RAS 6.1 software simulates the procedures for estimating the gradually variable flow in (steady and unsteady states) at one-dimensional simulation. The flow for numerous equations, including (the resistance equation, continuity equation, and energy equation), has been more thoroughly solved. In open-channel hydraulics, the Froude number is also used. "HEC-RAS User Manual, U.S. Army Corps of Engineers", 2021 [16], contains explanations and details for use with this program.

The HEC-RAS software requires a variety of variables to create a model for steady-state flow, providing entire cross-sections along the region's reach, flow rate, and water surface elevation information at the boundary, as well as Manning's coefficient (n). Data on cross-sections and longitudinal profiles, as well as other aspects of the findings, are included in the figures or tables used to show the findings.

5. Input Data

The following data were utilized in the model to create the steady-state model flow for the 7 km length of Al-Majjarah Canal by HEC-RAS 6.1 software. (Figure (6)) illustrates schematic diagram of Al-Majjarah Canal within Al-Ramadi Project System. It was drawn in the direction of the flow. Al-Majjarah Canal extends from Al-Habbaniyah Lake upstream Al-Majjarah Regulator to the station 7km downstream Al-Majjarah Regulator at Al-Razazza Lake, the zero station being Al-Majjarah Regulator. Each of these locations was set up to satisfy the continuity equation.

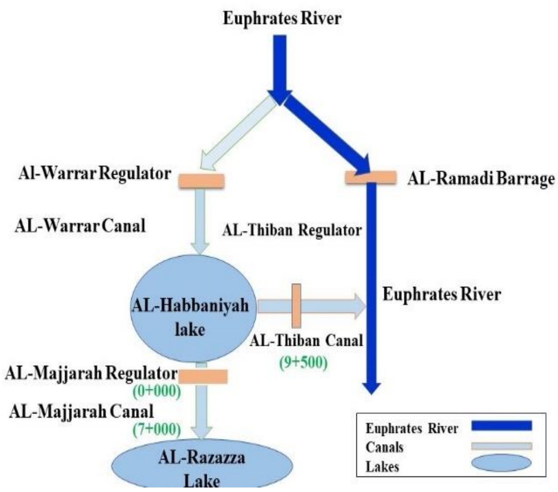

Figure (6): Diagram of Al-Majjarah Canal within Al-Ramadi Project System, **MoWR, 2022 [14]**

More than Thirty-four cross-sections are included in the model's geometry. The station data, elevation of surfaces, Manning's coefficient (n), lengths between embankments in each cross-section, expansion, and contraction of the canal, and the right and left banks are all included in these cross-sections as shown in (Figure (7)).

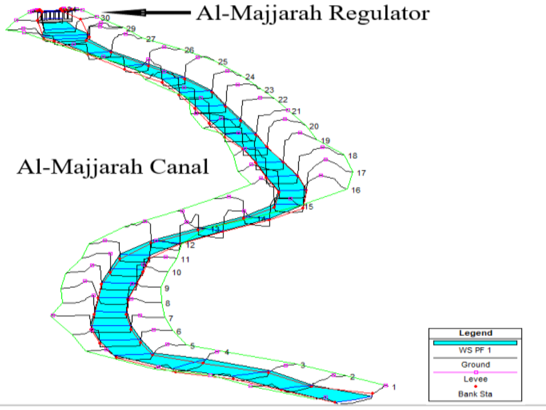

FIGURE (7): A 3-D perspective plot shows the cross-sectional and longitudinal sections of Al-Majjarah Canal, within the window of HEC-RAS software

The HEC-RAS model includes cross-section interpolation to improve accuracy in predicting water surface elevation and Manning's coefficient (n) [17], with a maximum distance of 250 m between two sections. The hydraulic structure of Al-Majjarah Regulator was represented in the model as an inline structure by the HEC-RAS software, the information provided by, MoWR [14] (Figure (8)).

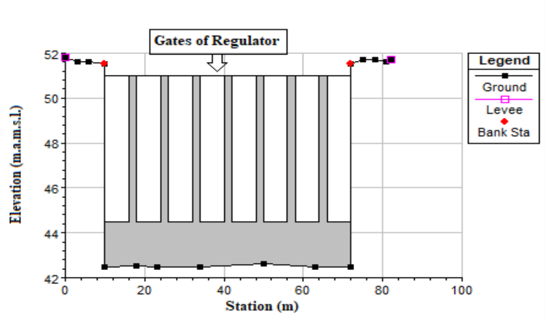

Figure (8): The hydraulic structures data in inline structure within the window of HEC-RAS software

In addition to the boundary conditions, HEC-RAS model also needs the discharge at upstream, and known water surface elevation downstream during the run [18-19-20]. This study article will give further details.

6. The Runs Design

The method of canal assessment requires representing it at various operating flow rates for various periods [21]. The HEC-RAS software was employed to simulate and evaluate the water flow through Al-Majjarah Canal based on the available flow data and the surveyed cross-section. To determine the appropriate roughness coefficient, a prior study's findings were relied on. and sensitivity analysis to roughness coefficient to show influence on the water surface elevation for Al-Majjarah Canal. Based on the survey results for cross-sections and the available information, the simulation aims at estimating the highest discharge that may safely flow through Al-Majjarah Canal at current condition. Later, if modifications are required to pass discharges of 2000 m^3/s, this is the maximum discharge that can be forecast for SWLRI [13] at this level. To predict the current capacity and after modification for Al-Majjarah Canal, various scenarios were run in the model by increasing the flow rate upstream of the canal to reach the critical discharge that could lead to a flood. (Table (1)), displays the scenarios that were simulated to investigate the steady-state discharge of Al-Majjarah Canal inside Al-Ramadi Project System.

Table (1): The Description of the scenarios of the steady-state flow condition for Al-Majjarah Canal.

Scenario	Description
CC	Calculate the value of discharge that will be passed in the current condition for the canal at: - water level in Al-Razazza Lake at (32.02m.a.m.s.l.), scenario **CC-1.** - the water level in Al-Razazza Lake is (40m.a.m.s.l.), scenario **CC-2.**
MC	In modification conditions after the expansion of Al-Majjarah Regulator by additional agates and reshaping and expanding some cross-sections, and raising some of the banks for the canal. find the discharge value at the water level in Al- Razazza Lake at (40 m.a.m.s.l.) will safely pass from the Canal and achieves the goal of development.

7. Results and discussions:

Due to the lack of observed discharges and water levels in past years, as well as the fact that Al-Majjarah canal is regarded as a flood escape canal, it has not been possible to calculate Manning's coefficient (n) in this canal. Therefore, the selected value of Manning's coefficient (n) was based on a recent research that has been carried out near the research region by Hashim and Azzubaidi in 2023 [22]. They used HEC-RAS software to accurately compute Manning's coefficient (n) in Euphrates River Reach among Al-Haditha Dam and Al-Ramadi Barrage. The calibration result indicated roughness coefficients of 0.026 at reach from Al-Haditha Dam to Al-Ramadi Barrage, and for reach's whole flood plain, it recorded a roughness coefficient of 0.03. The same parameter value was applied to Al-Majjarah Canal. Due to the study region's similar geology and nature. (Figure (9)) shows the sensitivity analysis to the roughness coefficient and its influence on the water surface elevation for Al-Majjarah Canal [23]. Using a flow rate of 1000 m^3/s, these values range between 0.02 and 0.03. discharged from downstream of Al-Majjarah Regulator, the water surface elevation increased with various values of Manning's coefficient (n) the analysis showed when the flow rate is 1000 m^3/s. When Manning's coefficient (n) was raised by a step of 0.001 between a range of 0.02 to 0.03, it was observed that the average water surface elevation was raised by around 8 cm.

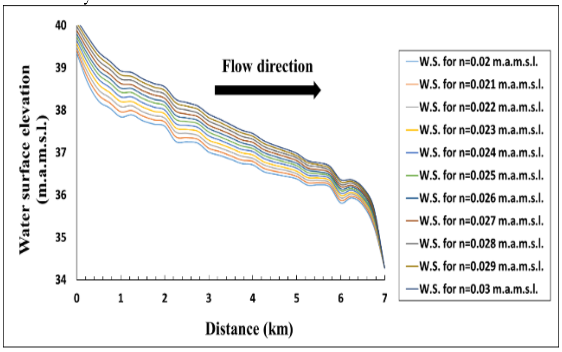

Figure (9): The variation of water surface profile with different Manning's coefficients **(n)** along Al-Majjarah Canal under a flow rate of 1000 m^3/s.

7-1.Current Capacity of Al-Majjarah Canal

To find the capacity results for the canal, requires knowledge of the water level in Al-Habbaniyah Lake upstream of Al-Majjarah Regulator, as well as the water level in Al-Razazza Lake downstream of the canal, and the value of height opening for gates Al-Majjarah Regulator, taken into consideration when running scenarios Al-Majjarah Canal for current capacity.

The boundary condition depended on the discharge inlet from the lake and the known water level in Al-Razazza Lake. To ensure Al-Majjarah Canal operated safely, many various simulations were used under the current condition. Two scenarios of discharge were applied. In the first scenario, CC-1, when Al-Razazza Lake is at a standard level of 32.02 m.a.m.s.l., and Al-Majarrah Regulator Gates are open to a height of 3.6 m, the canal can discharge 1300 m^3/s, and water surface elevation along the canal's reach was maintained at this discharge at least 1m below the canal's banks (Figures (10)). In this case, the canal can accommodate the design discharge of Al-Majjarah Regulator, although there are high velocities in some sections of the canal, but the flow is subcritical. When the water level in Al-Razazza Lake reaches the semi-filled position of 40 m.a.m.s.l. in the second scenario, CC-2, it can safely pass a discharge of 850 m^3/s and use the canal's design discharge up to the station (6+000 km). After this station, flooding occurs because the water surface elevation in Al-Razazza Lake is higher than the canal's embankment level by more than 1 m from the station (6+000 km) to station (7+000 km) (Figures (11)). There is an opinion to condition this distance a part of the lake and extension of it, and it's not for the canal, but in the event that they are considered part of the canal and protecting their shoulders is necessary, it is recommended that the maximum water level in the lake is kept lower than 38 m.a.m.s.l.

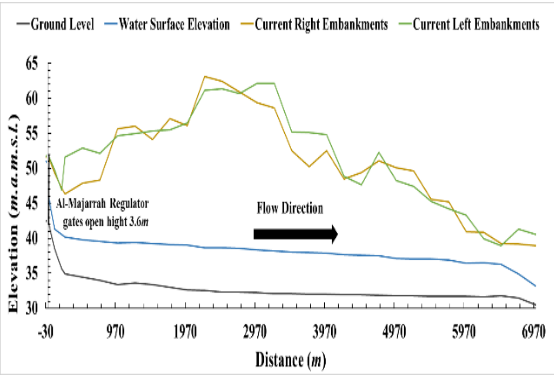

Figure (10): Water surface elevations for Al-Majjarah Canal at a discharge of 1300 m^3/s, at W.L. at Al-Razazza Lakes (32.02 m.a.m.s.l.), scenario CC-1, according to the current condition, first scenario.

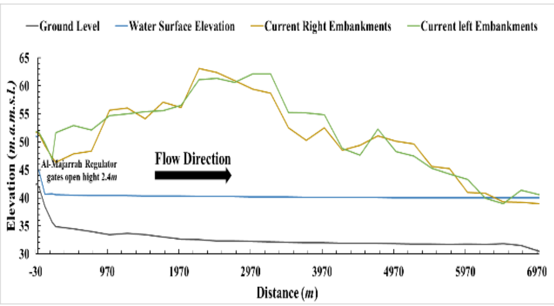

Figure (11): Water surface elevations for Al-Majjarah Canal at a discharge of 850 m^3/s, at W.L. at Al-Razazza Lakes (40 m.a.m.s.l.), scenario CC-2, according to the current condition, second scenario.

According to the current scenario, there are high velocities in some sections of the canal, showed in the simulation results, they increased when the flow rate rose. which required an expansion of the canal in order to reduce these flow velocities.

7-2. Development of Al-Majjarah Canal

In order to pass part of the extreme flood wave to Al-Razazza Lake, it is necessary to increase Al-Majjarah Regulator and Canal's discharge capacity, because the current design discharge for them is not equivalent to the value of Al-Warrar Canal's capacity to pass an amount of the predicted flood wave, as well as Al-Habbaniyah Lake can't accommodate a flood wave with a 500-year return period due to its limited storage capacity. The development of Al-Majjarah Canal includes increasing the discharge from 850 m^3/s to 2000 m^3/s, when water level in Al-Razazza Lake at a semi-filled position of 40 m.a.m.s.l., and increased the design discharge of the Regulator to 2000 m^3/s instead of 1300 m^3/s, by expansion of the regulator through the installation of five additional gates and the expansion of the entrance and exit of the regulator. Twenty-nine cross-sections were specified along Al-Majjarah Canal within the study area and were modified by reshaping to trapezoidal and either expanding or raising the required banks [24-25-26-27], (Figure (12)) shows the expansion of the regulator by addition of additional gates and (Figures (13) & (14)), shows a sample modified cross-sections numbers (34) and (14) located at stations 0+020 *km*, upstream Al-Majjarah Regulator concert inlet for Regulator and 3+750 km, downstream Al-Majjarah Regulator. Respectively.

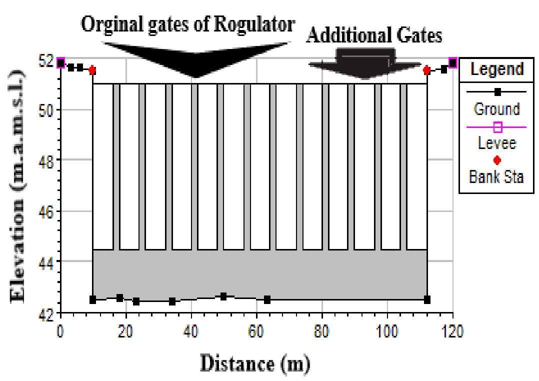

Figure (12): the expansion of Al-Majjarah Regulator by the addition of four additional gates. within the window of HEC-RAS software

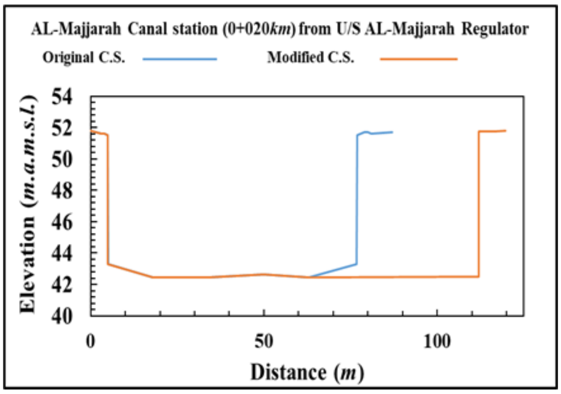

Figure (13): Modified cross-section numbers (34) located at stations 0+020 km, upstream Al-Majjarah Regulator.

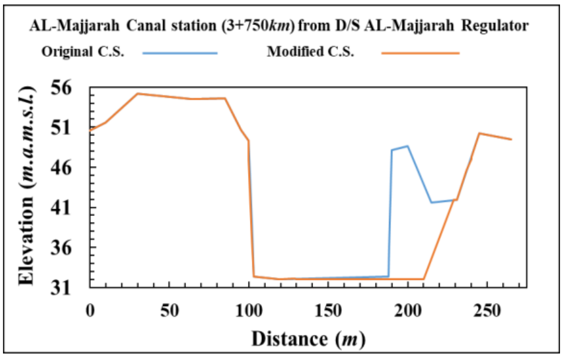

Figure (14): Modified cross-section numbers (14) located at stations 3+750km, downstream Al-Majjarah Regulator.

After completing the necessary development of the cross-sections and regulator, it appeared the speed of water flow was reduced in the cross-sections that included improvement. according to scenario **MC** at a discharge of 2000 m^3/s, and Al-Majarrah Regulator Gates are open to a height of 3.4 m and could be safely passed from downstream of Al-Majjarah Regulator, as shown in (Figure (15)).

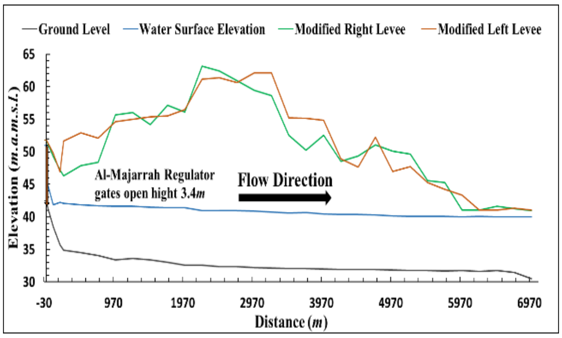

Figure (15): Water levels along Al-Majjarah Canal after modifying the cross-sections and Regulator for a discharge of (2000m^3/s), scenario **MC**

8. Conclusions:

Based on the results, the following main conclusions were reached:

1- Under the current conditions, the maximum discharge that can be passed in Al-Majjarah Canal is 1300 m^3/s when the water level in Al-Razazza Lake is at the average surface water level of 32.02 m.a.m.s.l. If the surface water level in Al-Razazza Lake is at a semi-filled position of 40 m.a.m.s.l., it can pass a design discharge of 850 m^3/s, if consider the last sections of the canal as a connection to Al-Razazza Lake.

2- The improvement included the expansion of Al-Majjarah Regulator by adding (5) gates additional, expanding the entrance and exit of the Regulator, reshaping and expanding some cross-sections, and raising some of the banks for the canal from station (6+000 km) to station (7+000 km) with keep a free-board 1 m between the water level and the canal's banks. To achieve the maximum benefit from the available storage capacity of Al-Razzazza Lake.

3- The required volumes of cut and fill for Al-Majjarah Canal are 1.4 and 0.086 Mm^3, respectively without the works of expansions for the concrete structure of the regulator.

9. References:

[1] Abdullah, M., Al-Ansari, N. "Irrigation projects in Iraq". Journal of Earth Sciences and Geotechnical Engineering, 11(2): 35-160. https://doi.org/10.47260/jesge/1123, November 2020.

[2] Head Office of Al-Ramadi Barrage, **HORB**, the Hydrological data and the recorded discharges and water level, Unpublished Data, Anbar, Iraq, 2023.

[3] Hashim, L.I., Azzubaidi, R.Z.," Discharge Capacity of Euphrates River from Haditha Dam to Ramadi Barrage". International Journal of Design & Nature and Ecodynamics, 18(2): 415-420. https://doi.org/10.18280/ijdne.180219, April 2023.

[4] Shayea, A.G., Al Thamiry, H.A. "Effect of tail regulators on Euphrates River Flood Capacity at Al Nassiriyah City". Journal of Engineering, 26(1): 43-54, January 2020. https://doi.org/10.31026/j.eng.2020.01.05.

[5] Al-Kazwini, M.J., Al-Suhaily, R.H., Al-Fahdawi, S.A. "Numerical modeling of flood wave behavior with meandering effects (Euphrates River, Haditha-Hit)". Eng. & Tech. Journal, 29(7): 1227-1240, 2011 https://doi.org/10.30684/%20etj.29.7.1.

[6] Al-Zaidy, H.S.A., Al-Thamiry, H.A.K, "Prediction capacity of Euphrates River at Assamawa City". Journal of Engineering, 26(4): 111-122, April 2020 https://doi.org/10.31026/j.eng.2020.04.08.

[7] Alsaadi, T.S., Al Thamiry, H.A. "Evaluation and Development of the (Hilla – Daghara) Rivers System". Journal of Engineering, 28(2): 46–62, February 2022. https://doi.org/10.31026/j.eng.2022.02.04.

[8] Ali, A.A., Al Thamiry, H.A. "Evaluation of the capability of Shatt Al-Arab River to control flood discharge", AIP Conference Proceedings, 2651, 020040, March 2023. https://doi.org/10.1063/5.0107121,

[9] AbdUlameer, A.H., Al-Sulttani, A.O.," Evaluation of the Minimum Instream Flow: A Case Study of Shatt-Al Hillah River in Babylon Governorate". International Journal of Design & Nature and Ecodynamics, 18(2): 485-491, April 2023. https://doi.org/10.18280/ijdne.180229.

[10] Jassam, W. A., Abed, B. Sh., "Assessing of the Morphology and Sediment Transport of Diyala River", Journal of Engineering, 27(11): (47-63), Nov. 2021. https://doi.org/10.31026/j.eng.2021.11.04.

[11] Mustafa, A. S., Sulaiman, S. O., and Al-Alwani, K. M., "Application of HEC-RAS Model to Predict Sediment Transport for Euphrates River from Haditha to Heet". Al-Nahrain Journal for Engineering Sciences (NJES),20(3): 570-577, June 2017. https://nahje.com/index.php/main/article/view/247/193.

[12] Ghali, H. M., Azzubaidi, R. Z., "Flood Management of Diyala River", Journal of Engineering, 27(8): 32-42, August 2021. https://doi.org/10.31026/j.eng.2021.08.03.
[13] Ministry of Water Resources. The "Study of Strategy for Water and Land Resources in Iraq" (SWLRI), Unpublished Document, Baghdad, Iraq, 2014.
[14] Ministry of Water Resources, MoWR, The Recorded Discharges and Water Level, Unpublished Documents, 2022.
[15] University of Baghdad- College of Engineering-Consulting Engineering Bureau **(CEB),** Lakes Testing, Unpublished Study, 2011.
[16] US Army Corps of Engineers. HEC-RAS, User Manual. Hydrologic Engineering Center, Version 6.1. USA, 2021.
[17] Hadi, Z. N., Almansori, N. J.," Estimation of Manning's coefficient (n) for the section between Al-Hindiya barrage and Al-Kufa barrage utilizing HEC-RAS", Materials Today: Proceedings , 80(3): 2595-2601, 2023. https://doi.org/10.1016/j.matpr.2021.06.417.
[18] Mardookhpour, and Jamasbi, J., "Flood zoning estimation and river management by using HEC-RAS and GIS model", Int. J. Energ. Water Resour., 1(1), 13-18. Winter 2017 https://journals.srbiau.ac.ir/article_10014_9cafdb02996a4b05295860664fbb4e75.pdf.
[19] Kamran, M., Yousaf, W., Rajapakse, R. L. H. L., Kareem, Awan, W., Riaz, M., Asif, N. M., Umar, M., and Shah, U. T., "Innovative initiative for effective operation and monitoring using HEC-RAS modeling of Hakra Branch Canal System, Pakistan"**,** Irrig. and Drain., Available at: https://doi.org/10.1002/ird.2524, September 2020.
[20] Daham, M. H., "A Prediction Formula for The Estimation of Sediment Load in The Upper Reach of Al-Gharraf River", Journal of Engineering, 5(27): 63-74, May 2021 https://doi.org/10.31026/j.eng.2021.05.05.
[21] Abed, B.Sh., Daham, M.H., Al Thamiry, H.A. "Assessment and Modelling of Water Quality along Al-Gharraf River (Iraq)". Journal of Green Engineering (JGE), 10(12): 13565-13579, December 2020. http://www.jgenng.com/wp-content/uploads/2020/15/volume10-issue12-60.pdf,
[22] Hashim, L.I., Azzubaidi, R. Z., "Roughness Coefficient in Euphrates River Reach between Haditha Dam to Ramadi Barrage". Journal of Engineering, 29(3): 117-124. https://doi.org/10.31026/j.eng.2023.03.08, March 2023.
[23] Te Chow, V., 1959, Open-channel hydraulics, McGraw-Hill, New York.
[24] Abbas, M.S., Azzubaidi, R.Z. "Current and modified flood discharge capacity of a reach of Tigris River between Kut and Amarah Barrages". Journal of Engineering, 26(2): 129-143. https://doi.org/10.31026/j.eng.2020.02.10, February 2020.
[25] Raslan, A. M., Peter, H. R., and Mona, A. H., "1D hydraulic modeling of Bahr El-Baqar new channel for northwest Sinai reclamation project, Egypt", Ain Shams Engineering Journal, 11(4): 971-982. https://doi.org/10.1016/j.asej.2020.02.005, December 2020.
[26] Azzubaidi, R. Z., Al Thamiry, H. A., Khafaji, M. S., "Developing Flood Discharge Capacity of Kmait River", Eng. & Tech.,26(9): 1097-1097 , https://www.iasj.net/iasj/download/140dac8e34beb8ac, 2008.
[27] Jassam, W. A., Abed, B. Sh., "Hydraulic characteristics of the lower part of Diyala River", IOP Conference Series: Materials Science and Engineering, 1105 (1): (1-14) June 2021.https://iopscience.iop.org/article/10.1088/1757-899X/1105/1/012107/pdf.