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Simulation of Bed Change in Al-Musayyab Canal using HEC-RAS Software

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ABSTRACT

This study focuses on the simulation of the bed change and total sediment concentration in the Al-Musayyab Canal, which is a vital irrigation system located in the central region of Iraq, using HEC-RAS V 6.3 software. The 49.5 km canal, with 13 branches, faces challenges from sediment influx originating from the Euphrates River. The primary objective is to analyze sedimentation, erosion patterns, and sediment discharge variations to support effective canal management. Field sampling collected suspended and bed load samples for laboratory tests, providing input data for the sediment transport model. Simulation results show steady flow water surface elevations ranging from 26.32 to 33.16 m.a.s.l, with velocities from 0.24 to 0.98 m/s. Significant sediment deposition and erosion variations are observed as data for 2019 and 2020 are analyzed. Notable changes in the canal's invert levels occurred in both years, with maximum deposition depths reaching 14 cm in 2019 and 21 cm in 2020. Erosion depths ranged from 3 to 15 cm in 2019 and 5 to 25 cm in 2020. The total sediment discharge for 2019 in the Al-Musayyab Canal amounted to 17 tons/day, while 22 tons/day in 2020.

Keywords: Al-Musayyab Canal, HEC-RAS software, Sediment transport, Steady flow.

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محاكاة تغيير الارضية في قناة المسيّب باستخدام برنامج HEC-RAS

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الخلاصة

يتمحور هذا البحث حول محاكاة تغيير منسوب قاع القناة وتركيز الرواسب الكلية في قناة المسيّب، وهي نظام ري حيوي يقع في المنطقة الوسطى من العراق، باستخدام برنامج HEC-RAS V 6.3. هذهِ القناة تمتد على مسافة 49.5 كيلومترًا وتتضمن 13 فرعًا. يواجه تامين الجريان في هذهِ القناة تحديات ناتجة عن تدفق الرواسب القادمة من نهر الفرات. الهدف الرئيسي من هذهِ الورقة البحثية هو تحليل أنماط الترسيب والتآكل، بالإضافة إلى تغيرات تصريف الرواسب، من أجل دعم إدارة القناة بكفاءة. تم جمع عينات ميدانية للرواسب العالقة ورواسب القاع لإجراء اختبارات في المختبر، وهذه البيانات تمثل المدخلات لنموذج نقل الرسوبيات. اظهرت نتائج المحاكاة لحالة الجريان الثابت ان ارتفاعات سطح المياه تتراوح بين 26.32 و33.16 مترًا فوق مستوى سطح البحر، مع سرعات تتراوح بين 0.24 و0.98 متر/ثانية. من خلال تحليل البيانات لعامي 2019 و2020، يُلاحظ تغيرات كبيرة في الترسيب والتآكل. تمثل التغيرات البارزة في مستويات قاع القناة في كلا العامين ارتفاعًا بحد أقصى بلغ 14 سم في عام 2019 و21 سم في عام 2020. أما أعماق التآكل فتراوحت بين 3 و15 سم في عام 2019 وبين 5 و25 سم في عام 2020. كما بلغ إجمالي تصريف الرواسب لعام 2019 في قناة المسيّب 17 طنًا يوميًا، في حين بلغ 22 طنًا يوميًا في 2020.

الكلمات المفتاحية: قناة المسيب، HEC-RAS، نقل الرسوبيات، جريان ثابت.

1. INTRODUCTION

Worldwide, water resource systems have been subject to various inconsistencies resulting from climate change and human interventions. These interventions mainly consist of constructing hydraulic structures for various objectives. An evident consequence of these transformations is the modification of the physical characteristics of rivers, which is observed through the erosion of riverbanks and floodplains and the deposition of sediment within the river channel. The changes considerably affect the ability of rivers to carry high discharges, that results in flooding effects along the river basin.

The principles of sediment transport can provide a prediction for the process of soil particle movement in natural streams. So, these basics can provide a comprehensive description of fluvial processes in various rivers. Two important parameters must be considered in studying the stream morphology the Sediment Transport Potential and the capacity of sediment transport. These basics descibe the transport of sediment mass for specific grain types of sediment which can be hydrualicly transported **(Nama et al., 2022)**. Moreover, the maximum load of sediment transport can be represented as the capacity of sediment discharge in streams **(Nama et al., 2022)**. Important studies have utilized field and laboratory-based methods to predict the potential capacity of sediment transport in natural

streams, **(Aziz and Prasad, 1985; Finkner et al., 1989; Celik and Rodi, 1991; Yang and Wan, 1991; Chanson, 1999; Merten et al., 2001; Yang, 2005; Ali et al., 2012; McPherson, 2020; Zhang et al., 2021)**.
Computer software has simplified the facilitated calculation and evaluation of the hydrodynamic-based parameters of sediment transport by utilizing simulation models. One of the significant software, HEC-RAS, provided the identification of sediment transport capacity. Locally, numerous researchers **(Al-Khafaji, 2008; Al Zubaidy et al., 2008; Nama and Abdulhussain, 2015; Al-Khafaji et al., 2016; Maatooq and Kadhim, 2016; Sharif et al., 2016)** have conducted studies with the use of HEC-RAS software. Various studies have been implemented addressing multiple subjects related to the hydraulics of sediment engineering. Other studies investigate the performance of hydraulic simulation like **(Maatooq and Kadhim, 2016)**. In addition, other researchers have examined the impact of floating debris in natural streams and their effect on the local scour occurring near bridge piers and abutments. As well as the modeling micro-hydroelectric modeling at power plants has been considered especially those used in artificial falls.
(Molinas and Wu, 2001) investigated a comparative relation between simulated and measured values of sediment concentrations to verify the sediment transport capacity, (STC). The results of investigations indicate that transport formulas such as Engelund and Hansen, Ackers and White, and Yang were unsuitable for large rivers. So, satisfactory accurate results were achieved in estimating sediment transport capacity using Toffaleti's method in such rivers. **(Nama, 2011)** studied the employing of the one-dimensional hydraulic model to simulate flow conditions and determine the sediment transport capacity in Tigris River within Mosul City. **(Kim et al., 2011)** employed HEC-RAS software to investigate the feasibility of using and restoring abandoned streams in the South Korean, Mangyeong River. With the use of HEC-RAS software, many researchers analyze the restoration of channels' potential benefits of flood control. Moreover, a comparative investigation was conducted by **(Hummel et al., 2012)** to conduct a comparison of the performance of the simulation results, using the QHRM model, quasi-unsteady HEC-RAS, and the one-dimensional Finite Volume Method simulation model (FVMM). They simulated the flow conditions and they estimated the capacity of sediment transport in the Pantano Wash River in the United States. The results reflect an accurate prediction of bed morphology obtained using nominated software methodologies . A close agreement between results was obtained using the QHRM simulation model and field measurements, in particular with the use of Yang's and Engelund-Hansen's sediment transport formulas.
(Talreja et al., 2013), have used sets of experimental flume flow data to estimate STC using the HEC-RAS model. The predicted values which were determined by employing the "Englund-Hansen and Ackers-White" formulas were compared to the measured values and they revealed a quite suitable for the prediction of sedimentation process in the Soni River, Japan. **(Khassaf and Jaber, 2015)**, employed the HEC-RAS model to simulate the STC in a six-kilometer reach upstream of the Al-Shamia Barrage, Diwaniya City, Iraq. The predicted results of HEC-RAS software showed an accurate estimation of the sediment transport capacity, and they provided helpful tools for effective management and sustainable maintenance of the river stretch. Moreover, results indicated that the Englund-Hansen formula gives an accurate estimation of sediment transport capacity in the specified location of the river.
(Abduljaleel et al., 2016) have investigated the flow conditions and estimated the sediment transportation using the HEC-RAS model in the Tigris River within Baghdad City, Iraq. He concluded that the best results can be obtained using Toffaleti formula for estimating

sediment transport, as well as he predicted the sites of low capacity of sediment transport in the reach. **(Mohammed et al., 2018)** estimate the sedimentation process with the flow conditions using HEC-RAS software and verify the numerical results by comparing them with the field measurements downstream Al-Abbasia barrage at the Euphrates River. He also defined the various capacities of sediment transport that occur with various flow conditions. **(Asaad and Abed, 2020)** studied the capacity of sediment transport by applying HEC-RAS software along a reach of 50 kilometers along the Tigris River, and they accurately identified areas with the lowest water transport capacity using the Toffaleti formula. In a study conducted by **(Daham and Abed, 2020)** on the Al-Gharraf River, the researchers investigated the deposition and erosion that occurred over a length of 58.2 km of the river. In another study, **(Jassam and Abed, 2021a; Jassam and Abed, 2021b)** investigate the morphology of the Diyala River to evaluate the characteristics of the stream flow capacity, also the hydraulic aspect using the HEC-RAS program. Additionally, the HEC RAS software provides numerous features, such as the ability to assess water quality characteristics, as well as, the sediment transport in the multiple reaches of numerous rivers **(Abed et al., 2020; Asaad and Abed, 2020; Hussein and AL-Thamiry, 2022; Azzubaidi, 2020; Abed et al., 2021; Ali and Al Thamiry, 2021)**. Al-Musayyab Irrigation Project's main Canal, located within Babylon Governorate in Iraq, faces significant challenges due to the continuous sedimentation processes along the canal and the transfer of sediment from the Euphrates River. Moreover, the absence of lining in the canal makes erosion and sediment take place during water flow, which ultimately alters the cross-section dimensions. Over time, a substantial amount of silt has accumulated in various canal sections, leading to a noticeable decrease in transportation capacity. The hydrodynamic and sediment transport aspects of this canal were not investigated before. Therefore, this paper aims to develop a simulation model using HEC-RAS software to investigate and analyze the changes in this channel's canal bed and sediment aspects.

2. MATERIAL AND METHOD

2.1 Study Area

Al-Musayyab Canal, is the main canal of the important Musayyab irrigation project located in central Iraq, approximately sixty-five kilometers to the south of Baghdad. Musayyab irrigation project is administratively affiliated to the Babylon Governorate and lies along the left bank of the Euphrates River. It is considered as primarily an agricultural project, and the canal plays a crucial role in providing irrigation water to the cultivated lands in the region. The canal is extended for a length of 49.5 km. Thirteen branch canals branch off from the main canal that distributes water to large cultivated areas. The permanent maintenance of the main canal system has played play pivotal role in fostering the growth of the local agricultural sector in the region and providing a primary source of livelihood for loal rural communities **(Al-Dabbas and AL-Ali, 2016).**

The northbound of the Mussayab project is the main drain, and the Wasit Governorate is bound to the east, as illustrated in Fig. 1. Geographically it stretches between longitudes 44° 11' and 44° 36' in the east. Latitudes 32° 18' and 32° 30' in the north. It first began in 1951 and became an operational service in 1955. The main canal, which draws water from the Euphrates River upstream of the Al-Hindiyah Barrage at kilometer 9.6, irrigates nearby areas. Along the canal, a number of hydraulic structures were built to regulate the flow of water, such as bridges, head regulators, and three cross regulators.

Thirteen primary irrigation branches draw water from the canal to ensure distribution across neighborhood areas. Moreover, a complex network is formed by six irrigation canals on the bank and other canals on the opposite bank that facilitate comprehensive water distribution for agricultural purposes. The complex system of branches and channels throughout the project area ensures that the water supply for irrigation is spread evenly.
Several necessary data have been collected for the study area in order to obtain a greater understanding of the Al-Musayyab Canal's hydrological and morphological aspects include flowrate data that ranged from 10 m3/s to 45 m3/s, and the average flow velocities were 0.3 m/s. The water surface elevations vary between 26 and 33 meters above sea level. At the upstream of the Al-Musayyab Canal, Measurements taken at the canal indicate an energy slope of 10 centimeters per kilometer, the canal width varying between 10.45 and 21.5 meters and its depth ranging from 1.8 to 2.45 meters **(MoWR, 2019)**. Based on the hydrometer examination and distribution of grain size examination, the unified classification system for soils has classed the soil in this location as sandy clay bed material, as demonstrated by laboratory experiments **(Kalinski, 2011)**.

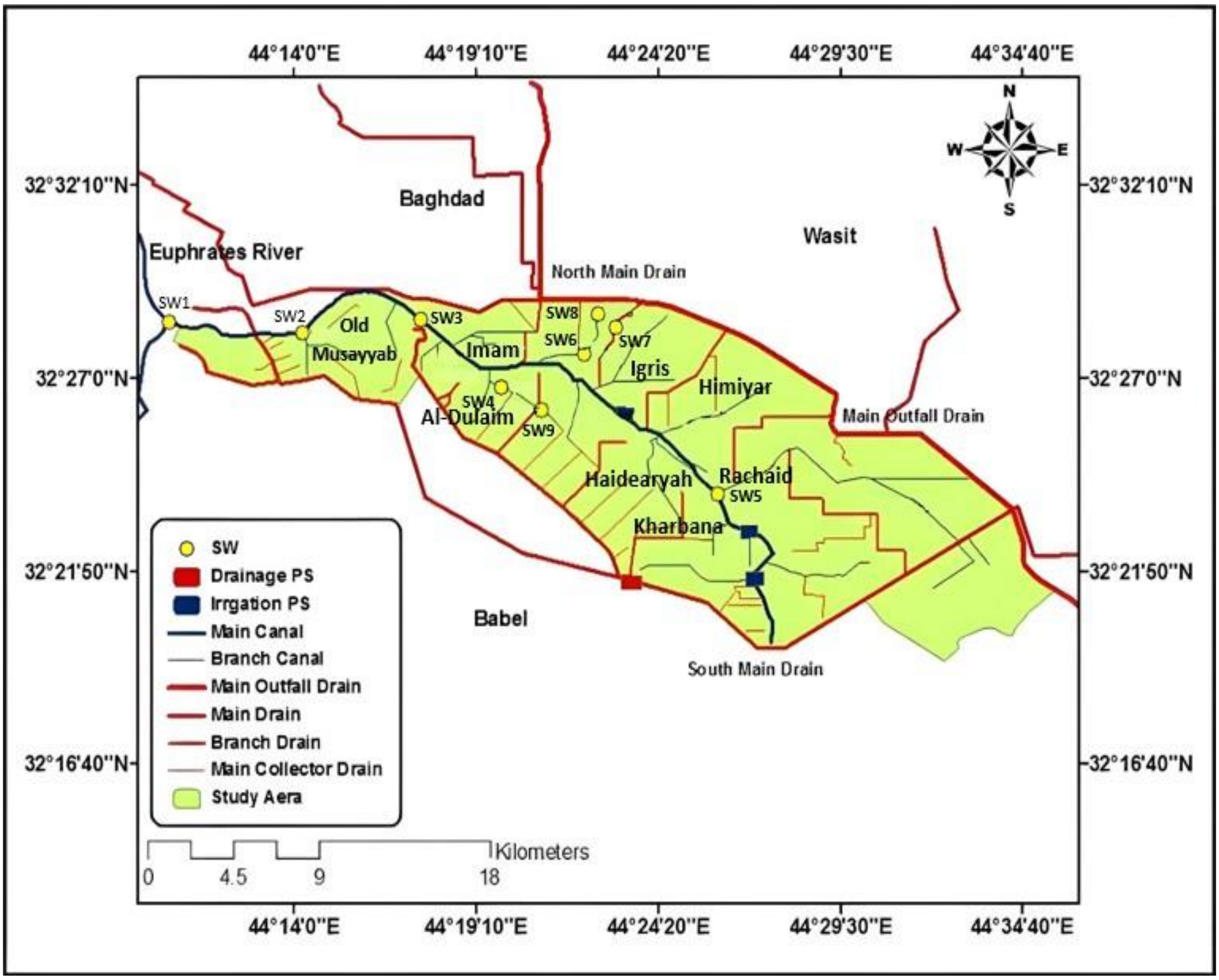


Figure 1. Al-Musayyab Canal in the Babylon Governorate.

2.2 MATHEMATICAL FORMULATIONS FOR HYDRODYNAMIC AND SEDIMENT TRANSPORT SIMULATION MODEL

In their evolving work, **(Brunner and Gary, 2016)** developed a set of fundamental equations regulating hydraulic modeling and sediment flow in river systems The sediment continuity equation holds particular significance in the mathematical framework of a simulation model that encompasses hydrodynamics and sediment transport Grounded in fluid dynamics and hydraulic principles, this model employs computational methods and the Saint-Venant equations to replicate diverse aspects of river systems, encompassing sediment dynamics and water surface profiles
The energy equation governing steady one-dimensional open channel flow is established through Bernoulli's equation, which is expressed as follows:

$$Y_1+(\alpha_1 V_1^2)/2g+Z_1+h_e=Y_2+(\alpha_2 V_2^2)/2g+Z_2 \quad (1)$$

where:
Y_1, Y_2 is the depth of flow in m.
α_1 and α_2 are the velocity weighting coefficients, dimensionless.
V_1, V_2 is the average velocities in m/s.
g is the gravity acceleration in m/s^2.
Z_1, Z_2 is the elevation of the channel bed in m.
h_e is the energy head losses in m.
The energy head loss (h_e) between two cross sections comprises friction and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e=LS_f+C\left(a_2\frac{V_2^2}{2g}-a_1\frac{V_1^2}{2g}\right) \quad (2)$$

where:
L is the discharge weighted reach length in m.
S_f is the representative friction slope between two sections, dimensionless.
C is the expansion or contraction loss coefficient, dimensionless.

There are basic equations concerning sediment transport in rivers. Firstly, the sediment continuity equation.

$$-\frac{\partial q_s}{\partial_x}=\left(1-\lambda_p\right)b\frac{\partial_\eta}{\partial_T} \quad (3)$$

where:
b is the channel thickness, m.
η is the channel altitude, m.
λ_p is the porosity, dimensionless.
q_s is the sediment discharge, tones/day.
This equation captures the essential characteristics of sediment transport and is widely used in sediment dynamics.

$$c_m = 0.01\,\gamma\,\left(\frac{d_s}{D}\right)1.167\,\left(\frac{\tau_o}{\tau_c}-1\right)f\left(\frac{u^*}{\omega}\right) \quad (4)$$

where:
γ is the water-specific weight, kg/m^3.
d_s is the mean diameter of sediment, mm.
D is the Effective depth for the flow, m.
τ_o is the shear tension of channel bottom, Pa.
τ_c is Critical shear stress of channel bed, Pa.
ω is the fall velocity of the deposit, m/s.
u^* is the Shear velocity, m/s.
c_m is the concentration of deposit flow rate, tones/day.

3. SETUP OF THE HEC-RAS MODEL

An in-depth examination of the development of a one-dimensional flow model for the Al-Musayyab Canal, originating from station 49500 m upstream of the head regulator in Al-Musayyab City and terminating in Jabla City with 13 branching supplying water to cultivated areas, necessitates a comprehensive understanding of the essential input data requirements. When preparing a hydraulic model utilizing the HEC-RAS software, the pivotal dataset encompasses topographic information, flow data, Manning's coefficients, and intricately detailed cross-sectional data. These constituents collectively serve the fundamental purpose of defining the geometric characteristics of the channel, enabling the realization of a realistic hydraulic model, and guaranteeing precision in the representation of cross-sectional configurations.
Moreover, a unique set of requirements appears to be the key to accomplishing a precise sediment transport simulation when including a sediment transport model into the framework. Essential requirements data included hydraulic data such as flowrate, water surface elevation, sediment transport equations, and establishing initial conditions, as well as sediment data like grain size distribution and concentration of suspended solid. Each of these components is essential to maintaining the accuracy and legitimacy of the sediment transport model, which improves the overall modeling capacity and dependability.

3.1 Geometric Data

HEC-RAS software required many of the necessary data to create hydraulic and sediment models such as creating a river system schematic, cross-section date, manning roughness coefficient, junction information, and performing cross-section interpolation.
The river system is the first and basic step in the HEC-RAS program, it plays an important role in understanding the interconnection between the parts of the system. The channel geometric included many of essential cross-section data such as bottom bed, bank station, and top width. The hydraulic structures such as weirs, culverts, bridges, and spillways are also considered necessary input in geometric window.
For the Al-Musayyab canal analysis, a hydraulic model that included 175 cross-sections was utilized. Survey cross-sections were separated at intervals ranging from 90 to 1,250 meters, and the cross-sectional data was acquired from the Ministry of Water Resources **(MoWR, 2016)**. The number of cross-sections utilized depends on site-specific characteristics, such as channel linearity, meander degree, longitudinal slope, and cross-sectional uniformity.

Once the canal schematic is drawn **(Fig. 2)**, the next step involves inputting the surveyed cross-sections, bank sides, downstream reach length, Manning roughness value for the main channel, and other relevant reach information. These data were input using the order in the major menu, as shown in **Fig. 3**.

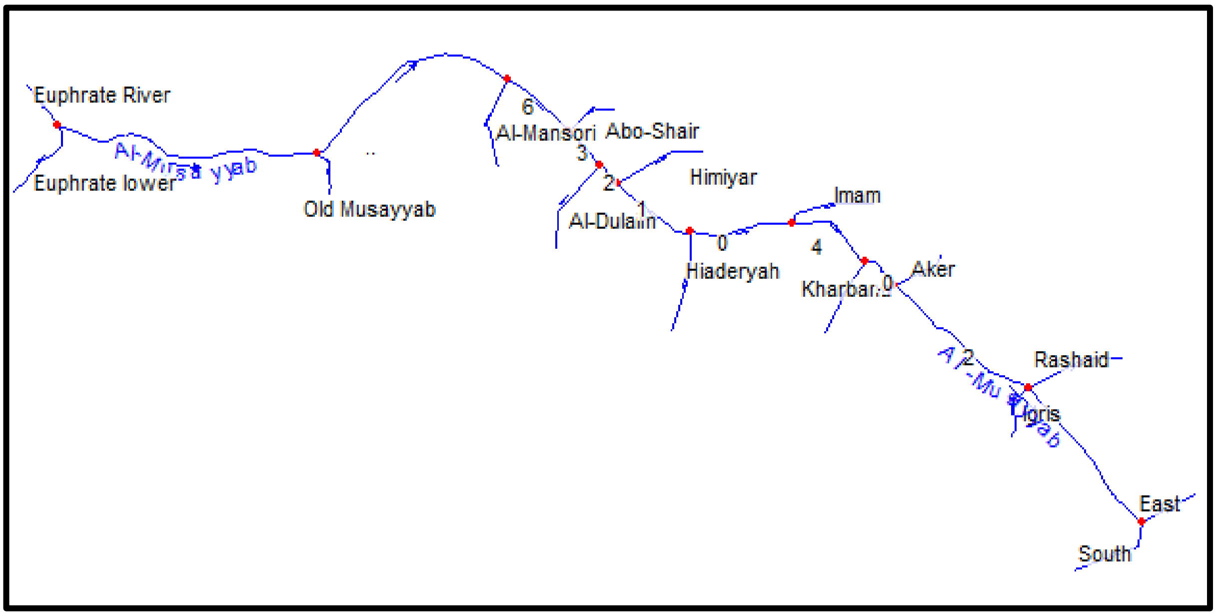


Figure 2. The canal reaches the schematic system.

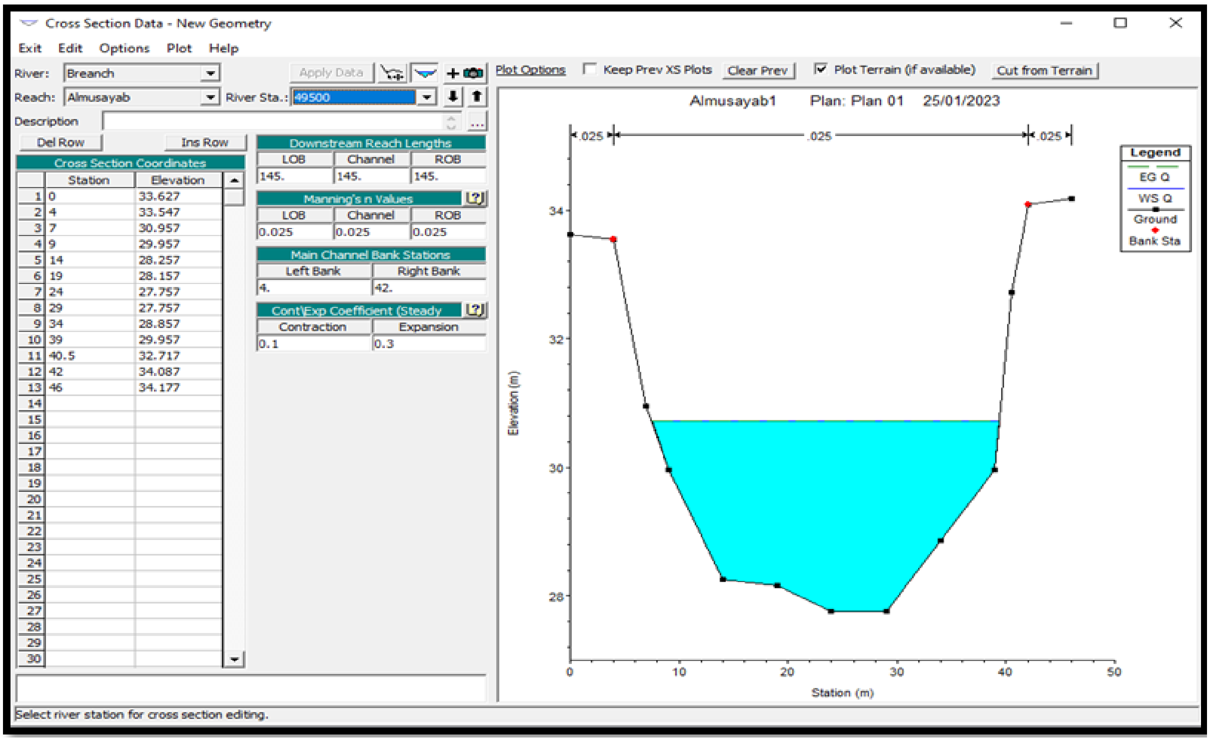


Figure 3. Exemplary Input of Geometric Data for Cross-Section Upstream from the Al-Musayyab Head Regulator.

3.2 Steady Flow Data

Steady flow data is a fundamental requirement in hydraulic modeling for accurately determining the steady water surface profile under specific flow conditions in river systems. This data type encompasses various factors, including the number of profiles to be computed, flow data, and river system boundary conditions. Each reach within the river system must have at least one specified flow condition, and it is possible to vary flow conditions at different locations within the system.
Three primary flow regimes can occur within a river system: supercritical, subcritical, and mixed. The selection of the appropriate flow regime to model depends on the characteristics of the river system under investigation and the objectives of the analysis. In the specific study focusing on the Al-Musayyab canal, a subcritical flow regime was chosen for modeling purposes based on its suitability for representing the flow behavior in the canal accurately. To ensure the accuracy of our modeling, a calibration process was undertaken using various Manning's roughness coefficient (n) values. Also, the most suitable value was selected, which yielded results closest to field measurements. Subsequently, this optimal Manning coefficient was utilized in the verification phase to validate the model's results against additional field measurements, specifically water surface elevations. Steady flow data was meticulously collected to simulate calculating a steady water surface profile for the Al-Musayyab Canal. This data collection involved obtaining a range of discharge values from 25-45 m^3/s with an increase of 5 m^3/sec required as a boundary to perform the model, one value each time, as given in **Table 1.** The normal depth was used as a boundary condition in the downstream. The adopted normal flow slope was 10 cm/km **(MoWR, 2016). Fig. 4** shows steady-flow data with boundary conditions in the input menu.

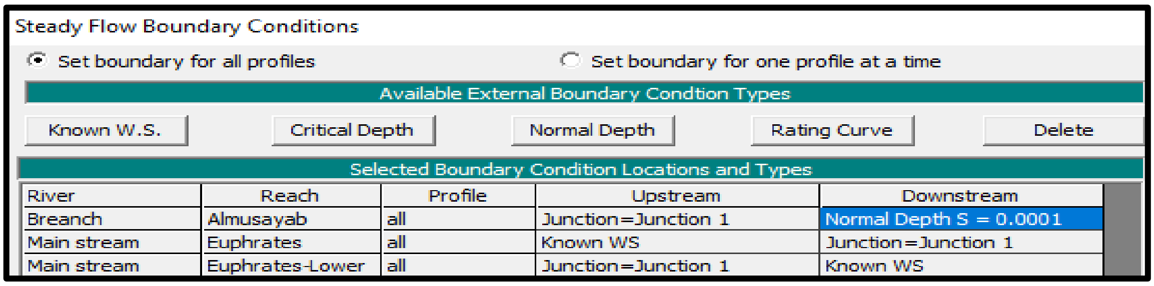


Figure 4. Steady flow boundary conditions.

3.3 Flow Data and Boundary Conditions

Modeling sediment transport is a crucial aspect of predicting the behavior of river and channel systems. Evaluating the potential impacts of natural and anthropogenic factors on these systems is essential. HEC-RAS, as a widely used software for river and stream hydraulic analysis, provides two main methods for sediment transport analysis: Quasi Unsteady Flow and Unsteady Flow. Modeling unsteady flow can be complex and susceptible to errors, especially regarding changes in inverted depth.
Since the quasi-unsteady flow method provides a more straightforward approach than unsteady flow modeling, it was selected for the current study's simulation of sediment transport in the Al-Musayyab canal. Based on recorded flow rates from the canal during a field sampling period that spanned from January 1, 2021, to May 1, 2021, a flow series was chosen for the upstream boundary condition. **Table 2** shows that the measured flow rates,

as reported by MoWR in 2021, varied from 10 to 25 m^3/s. For a year, the second model used simulated discharge values between 25 and 45 m^3/s. The Al-Musayyab Canal's actual conditions for the year 2020 were used in the third model. By combining real operation data for the gate openings with gate time series boundary conditions, the hydraulic structures within the canal were modeled. A normal depth boundary condition was used at the study reach's last station, taking into account an energy slope of 10 cm/km. This number was chosen in accordance with the **(MoWR, 2016)** guidance. Moreover, the quasi-unsteady flow model used the measured temperature of 20°C that was noted during sediment sampling as input data.

Table 1. The discharge values across the canal exceed under steady flow conditions.

Reach	Field measurement discharge m^3/s	Q1 m^3/s	Q2 m^3/s	Q3 m^3/s	Q4 m^3/s	Q5 m^3/s
Upstream of the canal	17.66	25	30	35	40	45
Old Musayyib Branch	3.21	4.1	4.21	4.32	4.41	4.6
Al-Mansori Branch	0.7	0.9	0.85	0.8	0.82	0.63
Abu-Shair Branch	0.65	0.44	0.49	0.6	0.45	0.44
Al-Dulaim Branch	0.66	0.9	0.75	0.88	0.67	0.9
Al-Himiyar Branch	0.82	1.1	1.5	2.1	3.2	1.1
Al-Haidearyah Branch	0.94	1.4	2.6	3	2.2	2
Imam Branch	1.16	2.3	2.7	2.5	3	3.3
Kharbana Branch	0.87	2.6	3.1	3.3	2.4	2.6
Aker Branch	0.68	2.7	3.4	2.9	4.3	5.2
Rachaid Branch	0.9	1.7	1.5	2.3	3.9	6.6
Igris Branch	0.84	0.75	0.8	0.9	4.4	5.8
South Branch	3.15	4	5.2	6.2	6.25	6.3
East Branch	3.08	3.01	2.9	5.2	4	5.53

3.4 Sediment Data

Three crucial files are required in the utilization of simulation models they are; the geometry file, the quasi-unsteady flow file, and the sedimentation information file, they represent the necessary input data. Also, it required specifying the transport formula with careful selection due to their high affecting sensitivity of results. The current investigation considered a characterization of the canal bed soil as sandy clay type. Then, The Laursen-Copeland transport function was selected as the most suitable formula based on the criteria for sediment transportation functions outlined by **(Brunner and Gary, 2016).**

The upstream boundary condition was defined as a rating curve for this study. The computation of the sediment flow rate is essential depending upon the utilization of the flow rate rating curve. It is contingent upon factors such as the water discharge, grain size distribution, and sediment load unique to the upstream region. In addition, the sediment record necessitates incorporating grain size distribution information for every transect, which is acquired via laboratory examination of bed material specimens. **Fig. 5** illustrates the comprehensive grain-size distribution curve for the material at the bottom of the canal.

Table 2. Values of the flow series in C.S No175, upstream of Al-Musayyab canal (Computation increment in hours).

Simulation time	Flow duration (hr)	Flow (m^3/s)	Simulation time	Flow duration (hr)	Flow (m^3/s)
01/01/2021	192	20	06/03/2021	1728	15
09/01/2021	384	20	14/03/2021	1920	15
17/01/2021	576	20	22/03/2021	2112	25
25/01/2021	768	10	30/03/2021	2304	25
02/02/2021	960	17	07/04/2021	2496	25
10/02/2021	1152	17	15/04/2021	2688	25
18/02/2021	1344	25	23/04/2021	2880	20
26/02/2021	1536	25	01/05/2021	3072	20

Seven-bed gradation templates were utilized to simulate the specific sections where bed material samples were collected. In addition, seven suspended load samples were collected during the study. Three separate suspended sediment samples were collected upstream of the Al-Musayyab Canal. Subsequently, these samples were transferred to the laboratory and utilized as input data in the sediment transport analysis to quantify the areas experiencing deposition and erosion. The results of the laboratory test are depicted in **Table 3**.

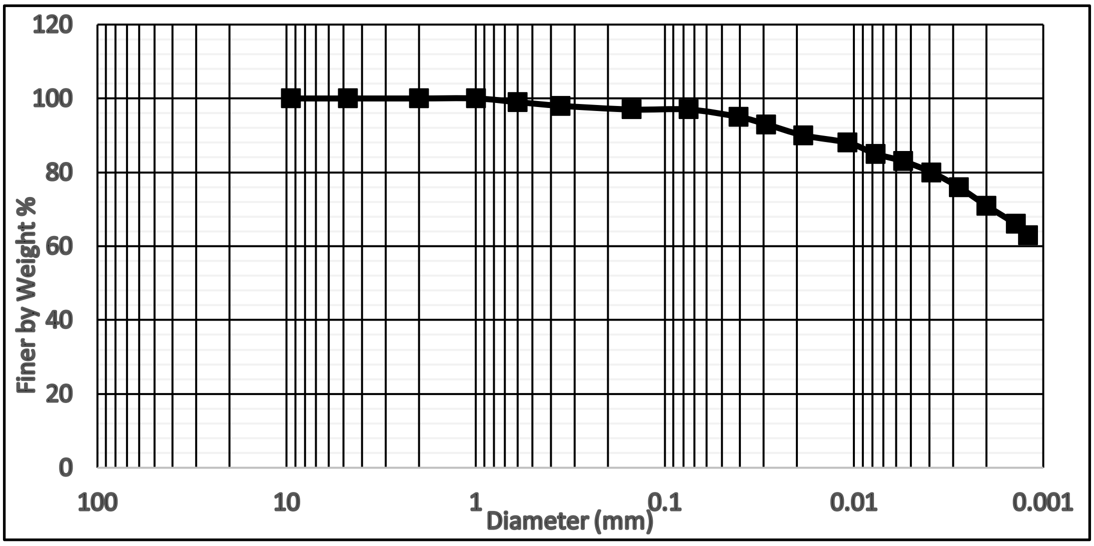


Figure 5. The grain size distribution curve for bed material upstream of the study reaches at station 49.5 km.

Table 3. The result of the concentration of suspended sediment along the canal reach.

Cross-section number	E	N	The concentration of suspended sediment mg/L
1	433742	3628300	80
35	443252	3627364	65
41	444420	3628571	44
65	450592	3629927	57
118	450553	3629846	32
129	465043	3622677	73
151	469878	3618814	25

4. RESULTS AND ANALYSIS

4.1 Result of Steady Flow

A comparative analysis was conducted on the measured discharges along the canal, as depicted in **Fig. 6**. The calibration results demonstrate standardized Manning's roughness coefficient (n) values along the primary canal and its banks, with a consistent value of 0.025 being applied. Through careful examination, a reasonable agreement was observed between the calculated water surface elevation values and the measured water surface elevation values along the canal reach.

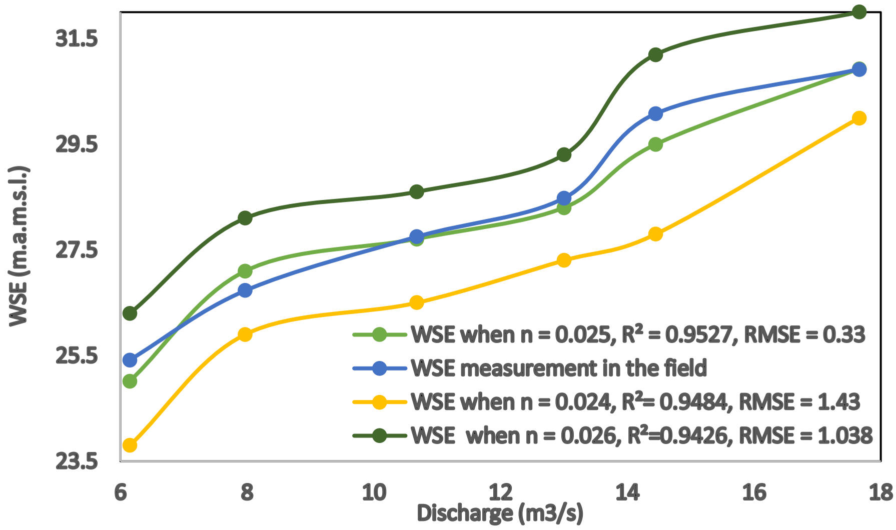


Figure 6. Calibration of steady-state flow model along the canal reach by observed date in 2023.

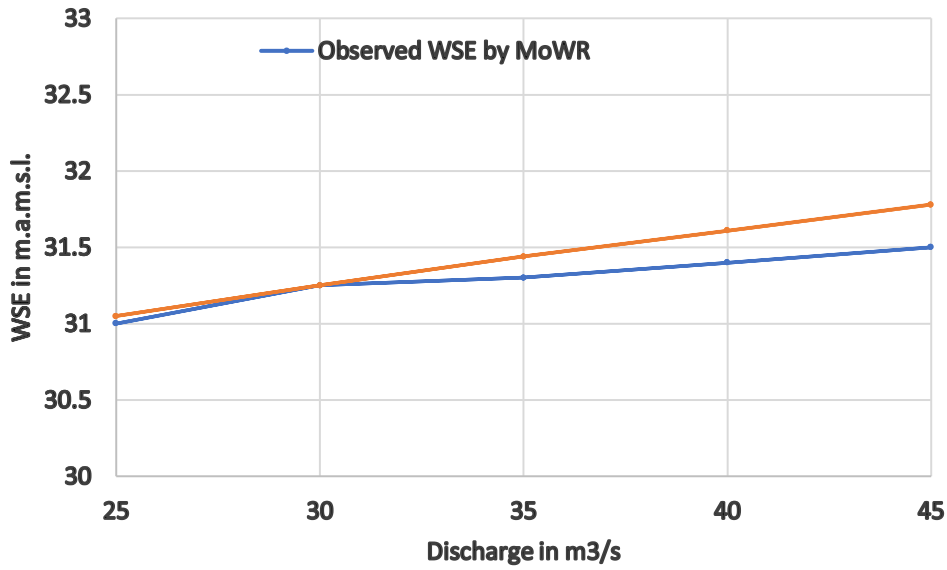
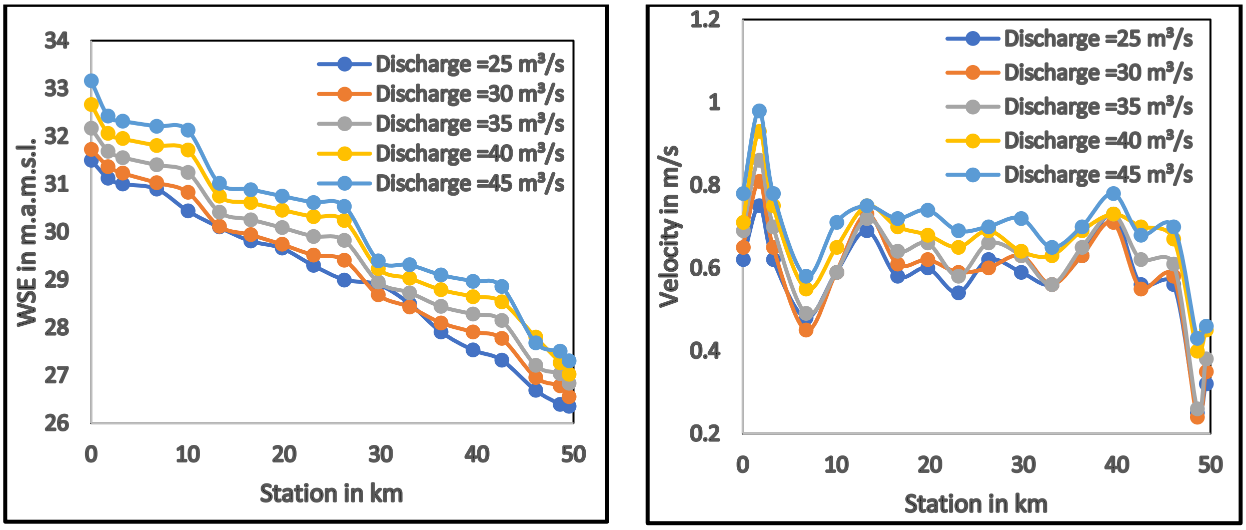


Figure 7. Validation of the steady-state flow model in the study's reach from April to August 2020.

The validation process was conducted using the measurement data from April to August 2020 at the Musayyab Head Regulator measured by MoWR, as shown in **Fig. 7**. The water surface elevation ranged between 31 to 31.5 m. The suitable value of the Manning roughness was 0.025 for the steady-state, the coefficient of determination value was 0.9986, and the RMSE value was equal to 0.171 m.
The obtained Manning roughness coefficient was employed in simulating the hydraulic steady-state conditions of the Al-Musayyab Canal under various flow scenarios. The results when the flow rate ranged from 25 m^3/s to 45 m^3/s showed that the water surface elevation (WSE) and velocity along the reach of the canal ranged from 26.32 m to 33.16 m and from 0.24 m/s to 0.98 m/s, respectively, as depicted in **Fig. 8**.



(A) (B)

Figure 8. Results of the 1D steady-state model, discharge= 25 to 45 m^3/s. (A) Water surface elevation along the canal, (B) Flow velocities along the canal.

4.2 Result of Bed Change

It is appropriate to simulate the sediment transport based on the measured flow data in the Al-Musayyab Canal. This can be achieved by utilizing the collected field data, sample test results, and hydraulic data obtained during the field measurement period from 1/1/2021 to 1/3/2021. The cumulative sedimentation results in the Al-Musayyab Canal during that specific period are depicted in **Fig. 9**. Sedimentation occurs in specific reaches of the Al-Musayyab canal, specifically from station 2.75 to 7.00 km, 15.00 to 18.75 km, and 40.00 to 49.50 km. The maximum depth of sedimentation, reaching up to 12 cm, is observed upstream of the Musayyab head regulator. Conversely, scouring occurs from 0.25 to 2.50 km, from 7.50 to 14.75 km, and from 19.00 to 39.75 km, with scour depths ranging from 4 to 10 cm. The sediment discharge in the canal varies between 15 and 45 tons per day. Furthermore, the simulation of the actual condition of the Al-Musayyab Canal over one year revealed variations in invert change values ranging from -0.15 m to 0.14 m (as illustrated in **Fig. 10**).

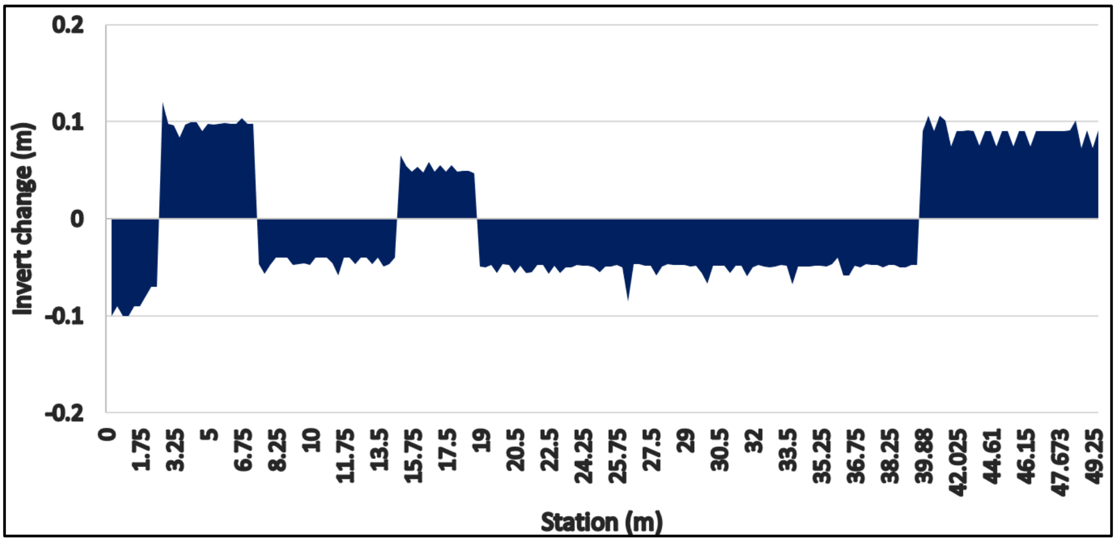


Figure 9. Variations in Invert Bed Depth along the Al-Musayyab Canal for the period (1/1/2021 to 1/3/2021).

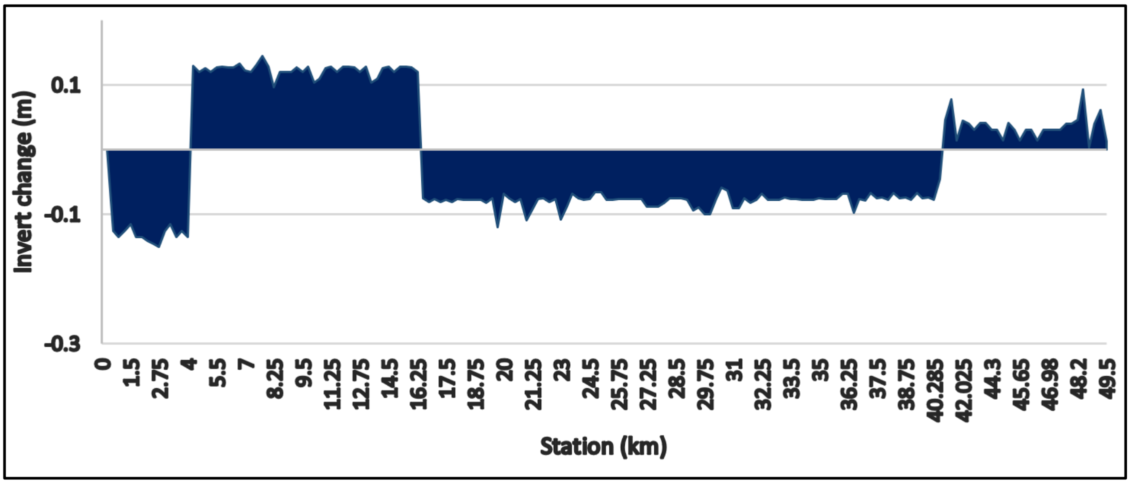


Figure. 10. Variations in Invert Bed Depth along the Al-Musayyab Canal in 2019.

The maximum deposition depth was observed at station 8 km, reaching 14 cm. Along the canal profile, erosion depths varied between 3 and 15 cm. It is worth mentioning that the total sediment discharge for the year 2019 in the Al-Musayyab canal amounted to 6205.5 tons/year.

The simulation results for the year 2020 provide valuable insights into the sediment dynamics within the Al-Musayyab Canal. **Fig. 11** illustrates the variations in invert change values, which ranged from -0.25 m to 0.21 m. Notably, the maximum deposition depth of 21 cm was observed at a distance of 8 km from the upstream Musayyab Head Regulator. Along the canal's profile, erosion depths ranged from 5 to 25 cm. Significantly, the total sediment discharge for 2020 in the Al-Musayyab Canal amounted to 22 tons/day.

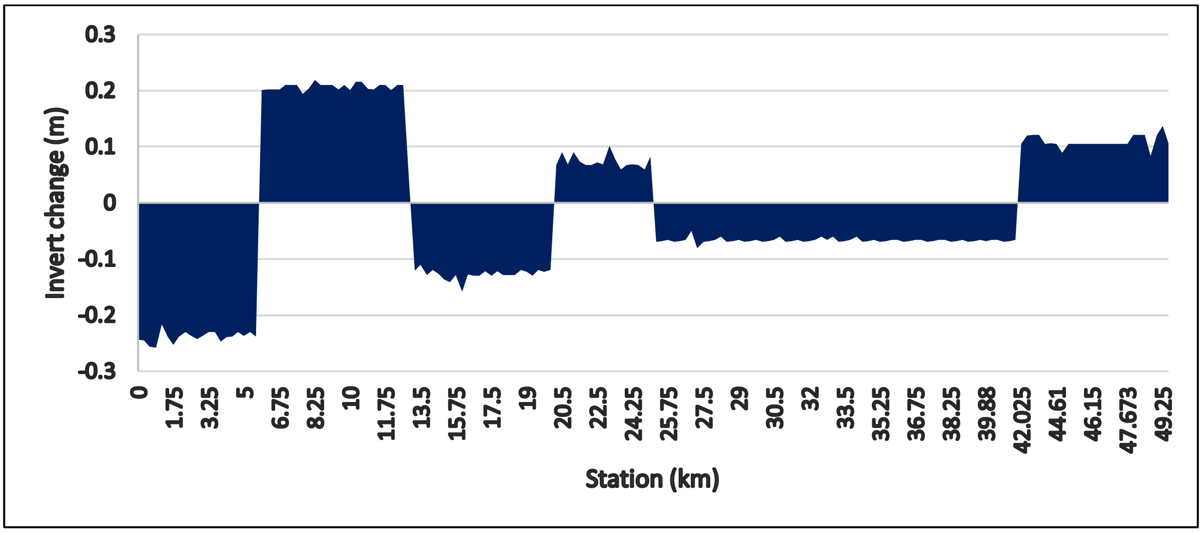


Figure. 11. Variations in Invert Bed Depth along the Al-Musayyab Canal in 2020.

5. CONCLUSIONS

Following is an analysis of the results that were obtained, which led to the following main conclusions:

- The Manning roughness coefficient for the steady state was set at 0.025, which yielded the most accurate results based on the root mean square error (RMSE). Furthermore, a strong agreement was observed between the measured data and the simulation results, as indicated by a high coefficient of determination (R^2) value.
- For the steady-state conditions, with a discharge ranging from 25 to 45 m^3/s, the water surface elevation ranged from 26.32 to 33.16 m, while the velocity varied from 0.24 to 0.98 m/s.
- Sedimentation and erosion patterns: Sedimentation occurs in specific canal reaches, namely from 2.75 to 7.00 km, 15 to 18.75 km, and 40 to 49.5 km. The maximum depth of sedimentation, reaching up to 12 cm, is observed upstream of the Musayyab Head Regulator. On the other hand, scouring takes place from 0.25 to 2.5 km, 7.5 to 14.75 km, and 19 to 39.75 km, with scour depths ranging from 4 to 10 cm. These observations indicate the presence of localized sediment deposition and erosion zones within the canal.
- Sediment discharge: The sediment discharge in the canal varies between 15 and 45 tons per day. This indicates significant sediment transport within the Al-Musayyab Canal, which can affect the canal's capacity and maintenance requirements.
- Yearly sediment dynamics: The simulation results for 2019 and 2020 provide insights into the annual variations in sediment deposition and erosion. In both years, there were notable changes in the invert levels along the canal. The maximum deposition depths reached 14 cm in 2019 and 21 cm in 2020, while erosion depths ranged from 3 to 15 cm in 2019 and 5 to 25 cm in 2020.
- Total sediment discharge: The total sediment discharge for 2019 in the Al-Musayyab Canal amounted to 17 tons/day, while 22 tons/day in 2020. These figures provide quantitative information about the overall sediment load and emphasize the importance of understanding sediment dynamics for effective canal management.

NOMENCLATURE

Symbol	Description	Symbol	Description
b	channel thickness, m	q_s	sediment discharge, tones/day
C	expansion or contraction loss coefficient, dimensionless	γ	water-specific weight, kg/m^3
D	effective depth, m	η	channel altitude, m
g	gravity acceleration, m/s^2	λ_p	Porosity, dimensionless
he	energy head losses, m	τ_c	critical shear stress of channel bed, Pa
L	discharge weighted reach length, m	τ_o	shear tension of channel bottom, Pa
S_f	friction, dimensionless	ω	fall velocity of the deposit, m/s
V_1, V_2	average velocities, m/s	u*	shear velocity, m/s
Y_1, Y_2	depth of flow, m	c_m	concentration of deposit flow rate, tones/day
Z_1, Z_2	elevation of the channel bed, m	α_1, α_2	velocity weighting coefficients, dimensionless
d_s	mean diameter of sediment, mm		

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Credit Authorship Contribution Statement

Hasan Khalid Razzaq made the experiments in the College of Engineering/ University of Baghdad and writing the draft version. Basim Sh. Abed. Anmar Joudah Jasim Al-Saadi contributed to the development, revision, and refinement of the manuscript

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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