

Research Article

Rehabilitating Heritage Canals in Semi-Arid Cities: A Civil 3D–Based Redesign and Cost Estimation of the Al-Dakair Canal, Basra, Iraq

Ali Dhafer Abed ^{1,*} , Hussein K. Khalaf ² , Nuridah Binti Sabtu ³ 

¹ Department of Water Resources Engineering, College of Engineering, Mustansiriyah University, Baghdad, 10052, Iraq

² Department of Civil Engineering, College of Engineering, Mustansiriyah University, Baghdad, 10052, Iraq

³ School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, Penang, 14300, Malaysia

*Corresponding Author: Ali Dhafer, Abed, E-mail: ali.dhafer@uomustansiriyah.edu.iq

Article Info	Abstract
Article History	This research will redesign the cross-sections of the Al-Dakair Canal in Basrah City, southern Iraq, and calculate the earthwork volumes for the proposed canal route, along with the rehabilitation costs, to preserve the city's heritage. This redesign is consistent with the flow characteristics of the upstream and downstream waters, while preserving its characteristics as an important heritage canal in the city. The research relies on an analytical approach using Civil 3D to analyse topographic survey data for the current cross-sections. The volume difference between the natural ground and the proposed cross-sections will then be calculated by subtracting the areas of each cross-section. The final volume of the earthworks resulting from excavation can be calculated. The research concluded that most cross-sections require extensive excavation, with a total cut volume of 18,800 cubic meters and a total fill volume of 60.33 cubic meters. The estimated cost of rehabilitating the canal, based on the impact parameters on the earthworks, reached \$1274079. The study recommended redesigning the cross-sections of adjacent rivers to ensure a correlation between depth and flow.
Received Aug 30, 2025	
Revised Dec 19, 2025	
Accepted Dec 25, 2025	
Keywords	
Redesign cross-sections	
Earthwork costs	
Heritage rehabilitation	
3D modeling	
Al-Dakair Canal	



Copyright: © 2026 Ali Dhafer Abed, Hussein K. Khalaf, and Nuridah Binti Sabtu. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) license.

1. Introduction

Recently, urban waterways in cities in arid and semi-arid regions have been deteriorating and drying up due to harsh climatic conditions, sediment accumulation, neglect by residents, and unplanned urban expansion. Since most of these waterways were previously used for irrigation, their deterioration has reduced hydraulic efficiency and altered water flow and velocity, rendering them unable to maintain the required water level for their intended purpose. Consequently, their water quality has declined, and they have become neglected rivers, losing their former environmental and heritage value. Therefore, there is an urgent need for international programs dedicated to rehabilitating urban waterways that possess historical and heritage value, are intrinsically linked to the urban fabric of historic cities, and are restored to their

former function as suitable irrigation channels and to meet urban needs.

Rehabilitating urban waterways in accordance with urban standards requires the preparation of highly accurate surveys and engineering designs, supported by hydraulic and quantitative analyses to estimate economic costs, particularly the volume and cost of earthworks, which significantly impact the allocated budget for rehabilitation. 3D digital modelling software and Geographic Information Systems (GIS) tools are among the most widely used tools for preparing and managing surveys and designs for this purpose. They allow for the analysis and testing of design alternatives, highly accurate volume calculations, and realistic simulations to arrive at the most suitable and feasible solution within environmental and financial constraints. Many developing countries in the Middle East with harsh climates still lack applied research integrating analysis and design tools and software into practical frameworks for rehabilitating heritage waterways in urban areas.

In this context, Basra is a prime example of a historical city located in one of the harshest regions, with high temperatures. These conditions affect its numerous waterways, which have been used for centuries for irrigation, navigation, and the city's urban development across successive generations. The Al-Dakair Canal is one of Basra's most important heritage waterways, possessing significant historical value. Currently, it suffers from deteriorating design and hydraulic conditions, resulting in increased sedimentation and a change in its shape. The selection of this canal as a case study is not aimed at finding solutions to a local problem, but rather at building a global scientific methodology for analysing, designing, and calculating the volumes and costs of waterways, which can be applied and generalised to similar canals in their hydraulic and climatic conditions in other cities.

Various criteria are used to classify canals, the most important of which are the water source, the size of the water reservoir, the water surface's characteristics, the alignment, the function for which they are designed, and their economic feasibility. Permanent canals, used for year-round irrigation, feature a continuous water supply from a dam, weir, or barrier. Temporary canals, also known as flood canals, have seasonal flows when the river level is high. Size also plays a role in the classification of canals, ranging from main canals, which receive water directly from reservoirs or rivers, to subsidiary, distribution, and feeder canals, which gradually distribute water to agricultural areas. Canals can also be classified by surface treatment into lined and unlined canals. Lined canals have impermeable beds and side slopes to prevent seepage, while unlined canals rely on natural materials, which may be clay or stony.

Regarding alignment, gravity irrigation is used in some catchment canals that align with hills to irrigate both sides. In natural terrain with curves, canals follow a contour system, in which the channels of the Gambian slopes align perpendicularly to the contour lines [1]. The design of water canals begins with determining their purpose and function, selecting the appropriate route location and layout, and conducting feasibility studies. Water quality, flow, and purity must be considered, along with obtaining the necessary permits and approvals from regulatory and governmental authorities. Implementing the design requires the responsible authorities to contract with a qualified contractor to carry it out in accordance with the design specifications and standards. This is followed by ongoing monitoring and maintenance by the responsible authority to ensure optimal performance [2]. Important factors affecting the design and construction of canals include the water flow rate, the width and length of the canal, and the type of construction materials. Water quality also influences the necessary treatment methods and the type of materials used [3]. Canal dimensions are significantly affected by water pressure, which requires consideration of environmental factors such as climate, soil type, and temperature. Economic feasibility, material costs, and labour play a fundamental role in making the appropriate implementation decision. In addition, aesthetic considerations, such as the canal's shape, colour, and texture, help it blend naturally with its surroundings. Safety measures ensure protection against flooding and soil and bank erosion to protect people and property. Finally, maintenance requirements, including dredging and routine repairs, must be considered to ensure the long-term efficiency and flow of the canal [4].

The hard boundary canal is designed to maintain a constant flow, accounting for key factors such as the canal bed roughness (represented by the Manning coefficient), the permissible water velocity, the free boundary, and hydraulic efficiency. The minimum water velocity to prevent sedimentation and vegetation growth in the canal path should be between 0.75 and 0.9 m/s. Higher water velocities reduce costs on the one hand and lead to bank erosion on the other, requiring a careful balance between velocity and structural stability [5].

To avoid erosion or siltation, open irrigation canals must be designed with optimal flow velocity, uniform levels and slopes along their length, and sufficient volume to carry the required amount of water. Hydraulic conditions must facilitate efficient water distribution to agricultural areas while maintaining a constant lateral slope. Minimising water loss is essential, and flow behaviour follows the Chezy equation.

The largest cost factor in canal construction is excavation and earthworks, especially when the canal

path passes through hard terrain that does not require lining. Excavation costs are affected by the size and depth of the excavation, soil type, and the distance to the site of transportation [6]. The cost function calculates excavation costs per unit length, accounting for material properties and economic feasibility [7].

From a hydraulic perspective, the most efficient canal section is the one that minimises the wetted perimeter for a given flow area, thus maximising discharge capacity. However, the section with the best hydraulic performance doesn't always correspond to the lowest earthwork cost [8]. The most economical canal cross-section is determined by minimising costs per unit length while still maintaining an adequate design discharge. The final optimal section shape balances hydraulic efficiency, cost-effectiveness, and structural stability, ensuring the long-term sustainability of the water channel's construction and operation [9].

Basra is one of Iraq's most renowned cities, known for its rivers and waterways that branch from the Shatt al-Arab, which flows directly into the Arabian Gulf. Recently, Basra's rivers have suffered significant neglect, leading to pollution, declining water levels, and altered cross-sectional shapes due to siltation and rising riverbed levels [10]. This has prompted numerous studies on rehabilitating the rivers of Basra. The first study of Basra's rivers was conducted in 1965 by Max Locke, who developed a new 20-year development plan for Basra. He considered the city's rivers to be the main drivers of growth and proposed preserving them by constructing gates to control water flow and maintain boat navigation. Locke's study was followed by several others aimed at developing Basra's rivers, most notably the 1974 Basra Development Plan. This plan proposed creating greenbelts along the riverbanks, maintaining a continuous flow of water through regulators, and lining the waterways [11]. This study was followed by the Basra Land Use Master Plan of 2000 and, in 2010, the Basra Master Plan Update Strategy. Both studies focused on Basra's heritage rivers, particularly the Al-Dakair canal and its tributaries, aiming to rehabilitate and line them, and increase the flow and velocity of water entering them from the Shatt al-Arab. This involved detailed cross-sectional designs and minimising earthwork costs [12]. However, none of these studies was implemented due to the lack of actual detailed designs for these rivers and the absence of approximate cost estimates for excavation, backfilling, and silting work. This lack of data prevented the awarding of contracts to companies capable of executing the work at reasonable costs.

This research aims to redesign the Al-Dakair Canal in the centre of Basra. The canal has been neglected due to the accumulation of large quantities of waste and solid materials at its bottom. This

accumulation results from the direct discharge of sewage from adjacent buildings, as well as from its previous use as a shipyard for vessels navigating the Shatt al-Arab waterway. Many sunken or dilapidated boats and river vessels now litter its banks. All these problems have led to an uneven water level at the canal bed, obstructing the flow of tides entering the canal from the Shatt al-Arab and preventing water from reaching certain areas of the river. The canal has been redesigned using Civil 3D software, in accordance with standards that optimise water velocity and flow, making it suitable for boat navigation, fishing, and testing manufactured boats; the primary cost of rehabilitation has also been estimated.

2. Study Area

The study area is located in the City of Basra (South of Iraq), in the Al-Dakair district, between the Ashar and Al-Khandaq rivers, with geographic coordinates of $47^{\circ} 50' 15.27''$ E and $30^{\circ} 31' 33.05''$, as shown in Figure 1. This area was selected for study due to its unique location, directly overlooking the Shatt Al-Arab. The canal is a small U-shaped waterway, 742 meters long and 32 to 45 meters wide. The area surrounding the canal is home to small factories that manufacture optical boats, which are transported via the canal to the Shatt Al-Arab [12]. The Al-Dakair Canal is fed by the Shatt al-Arab tidal flow, with the tide pushing water into the canal, while the ebb draws water into the Shatt al-Arab. The term tide refers to the surge of waves from the Shatt al-Arab towards the Al-Dakair Canal, so that the water reaches its highest level in the canal. The term ebb refers to the withdrawal of waves from the Al-Dakair Canal towards the Shatt al-Arab, so that the water reaches its lowest level. This means that the tide constantly replenishes the water in this canal. Recently, the water level at the bottom of this canal has risen, its cross-sections have changed, and it has become more like an abandoned drain, where stagnant water, old boats, and dilapidated docks accumulate [13].

Therefore, the Al-Dakair Canal must be rehabilitated according to the standards set by the Ministry of Municipalities and Public Works for the rivers of Basra, the most important of which is that the flow in the canals and rivers of Basra should be continuous, so that minimum water depth 4.5 m and flow $\geq 10 \text{ m}^3/\text{s}$ to accommodate the draft of the boats that will sail in it. The cross-section coordinates, which represented the channel shape every 100 meters, were obtained from the Ministry of Water Resources. A Leica GS18 differential GPS device collected the survey data with an accuracy of up to 1-5 mm. The survey data is accompanied by correction and calibration reports that document the monitoring times, accuracy, and device type used, which support and confirm the survey data's accuracy.

These coordinates will be used to create a three-dimensional surface that illustrates the shapes of the cross sections, the riverbed, and its banks at 100-meter intervals using Civil 3D. Trapezoidal cross-sections will be designed to the canal's width and with a depth conforming to boat navigation standards. Earthwork volumes, including excavation and backfilling, will be calculated to obtain regular trapezoidal cross-sections using Civil 3D software.



Figure 1. Canal of study area in Al-Dakair district.

3. Methodology

3.1. Generalised Workflow

For the purposes of estimating the cost of Al-Dakair Canal rehabilitation, the general workflow diagram (survey → Civil 3D TIN → cross-section redesign → Manning flow check → prismatic cut/fill → cost estimation, validated with ArcMap) shown in Figure 2 will be applied to the study area and is also applicable to other canals and rivers in similar contexts and circumstances.

3.2. Calculating the Volume of Earthworks for the Canal According to Design Specifications

This section will calculate the volume of the water path in the Al-Dakair area. This will be done after the design cross-section that aligns with the flow characteristics of the water source. Civil 3D software will be used to calculate the volume of the earthworks (cut and fill) based on the topographic coordinates of the study area. The volumetric difference between the natural land cross-sections and the proposed cross-

sections will then be determined. The area of each cross-section will be calculated, and then the final volume and cost of the earthwork will be computed using the prismoidal rule.

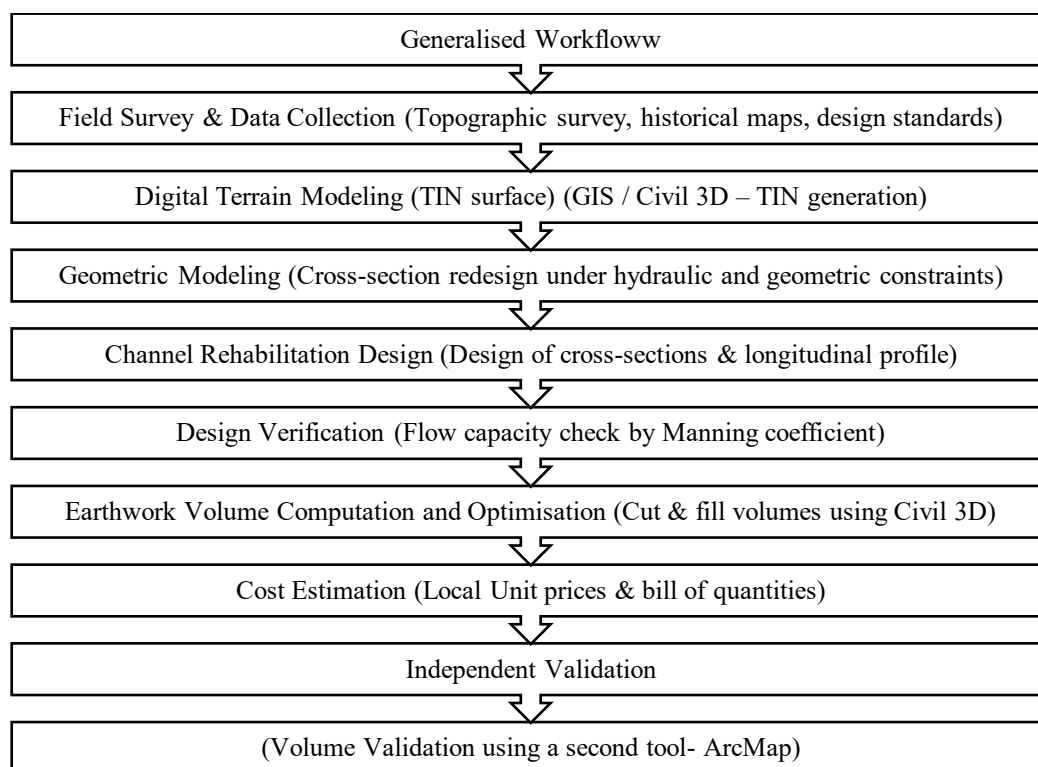


Figure 2. General workflow adopted in this study

To calculate the volumes of the earthworks for the water canal in the Al-Dakair area in the Civil 3D software, and based on the topographic survey points of the canal cross-sections, the following steps were taken:

- 1) A new project was created in the program, with the units of measurement set to meters, and the coordinate system configured to WGS84-UTM-ZONE38 N for the study area. The topographic survey points for the cross-sections were imported into Civil 3D. The settings for the points were adjusted and organised so that each point appeared in its correct location, with a description specified for each (e.g., riverbank, centre of the river, or one of its edges), as shown in Figure 3.

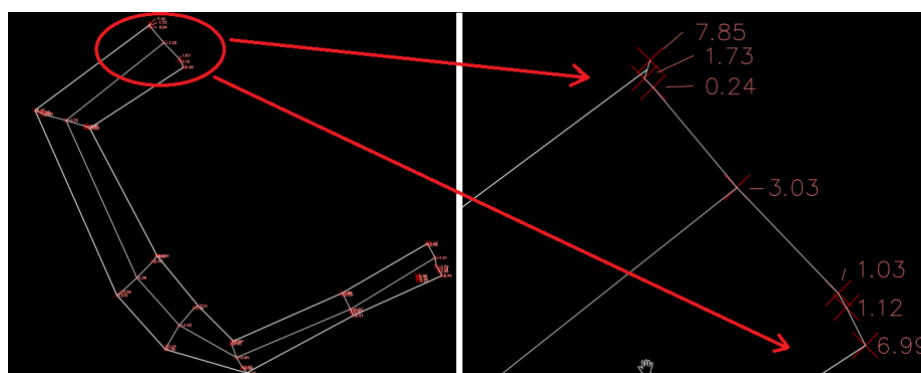


Figure 3. Coordinates of survey point for all cross sections of Al-Dakair canal.

- 2) The A TIN (Triangulated Irregular Network) surface was constructed from the topographic survey points. This surface was modified to ensure that profiles and cross-sections could be accurately extracted at the correct levels. After defining the river's centerline as a "U" shape and its banks, the longitudinal profile and cross-sectional profiles were extracted, as shown in Figure 4.

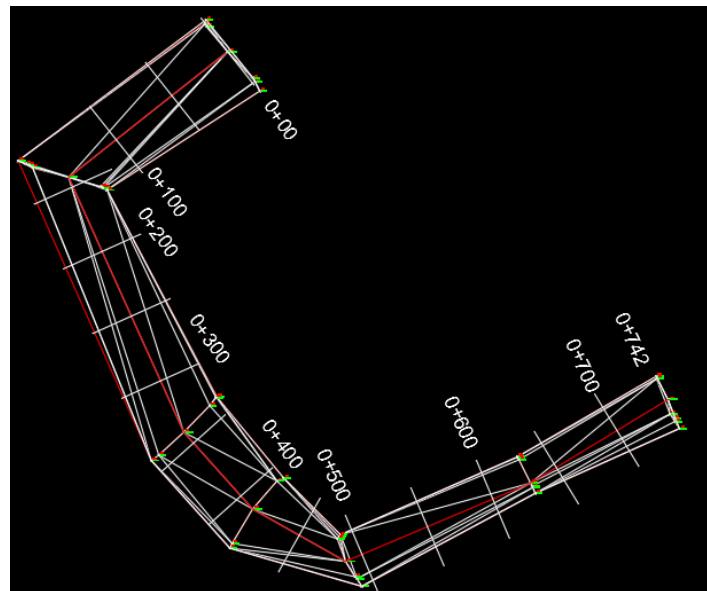


Figure 4. TIN (Triangulation Irregular Network) linked between survey points of Al-Dakair canal

- 3) A longitudinal section of the river's path, which is 742 m long and 38 to 54 m wide, was produced. This section shows the variation in the river's levels as well as the change in the levels of the two banks according to the following steps:
- The specific path representing the river's centre was defined in the longitudinal section. Then, the definition of the longitudinal section is used for the purpose of showing it in the form of a map, as in Figure 5.1, Figure 5.2, Figure 5.3, and Figure 5.4. These figures illustrate the irregular changes in riverbed level and show the tidal levels at the highest and lowest points. It also demonstrated how the riverbed rises above the water level in certain sections, causing water retention and preventing the completion of the flow cycle at tide and ebb periods. The high riverbed level in some sections of the Al-Dakair Canal is due to the accumulation of solid waste and sunken river vessels, as well as the clay soil type in the Shatt al-Arab, which allows continuous intrusion of silt and clay into the canal. This high riverbed level increases the volume of earthworks required because the cross-sectional area must be increased to provide reasonable water flow and velocity within the canal, thus preventing sedimentation and vegetation growth.
 - River bottom elevations range between the lowest elevation of - 0.933 and the highest elevation of 2.83m

above mean sea level (M.S.L), and average tidal levels range from 1.889 m at high tide to -0.710 m at low ebb. A design elevation for the river bed will be proposed at -0.5 m relative to M.S.L. The elevation has been proposed to meet the standards adopted for the design of the rivers of Basra, where the minimum water depth in the section is not less than 2 m to allow the boat's draft to pass. Its slope will be equal to (0) in order not to allow water to collect in a specific area within the river and rush to the end of the river with the phenomenon of tides and exit with the phenomenon of ebb. Furthermore, a zero gradient allows the tide to flow towards the river's end without resistance.

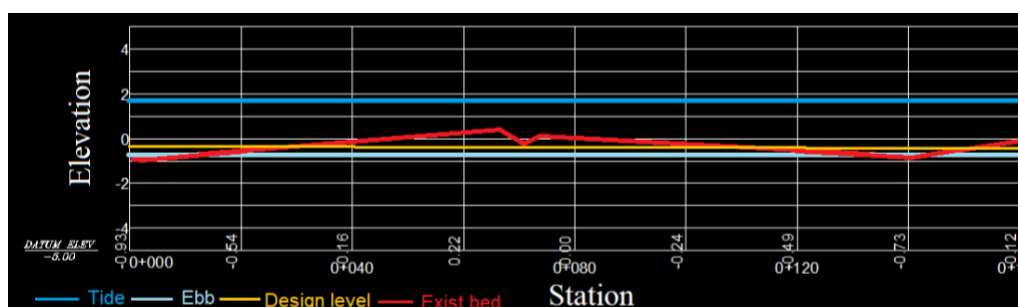


Figure 5.1. 1st part of profile for the river path starting from station 0+00 to station 0+160

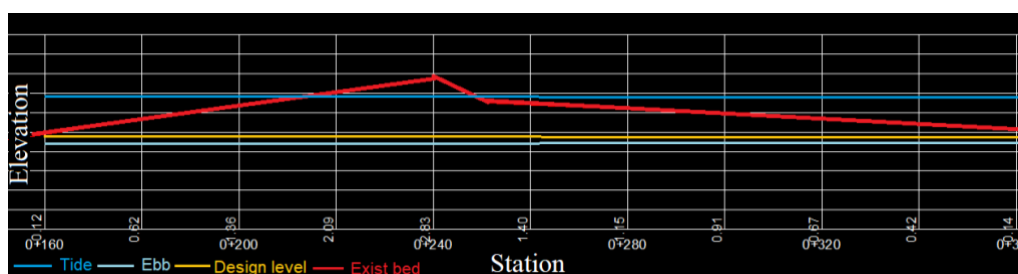


Figure 5.2. 2nd part of the profile for the river path starting from station 0+160 to station 0+360

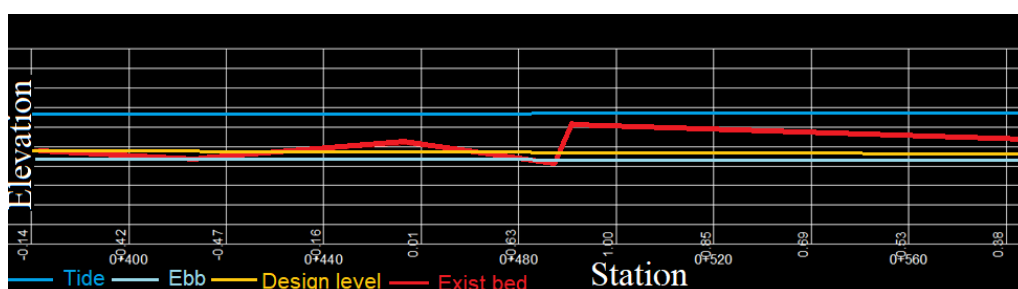


Figure 5.3. 3rd part of the profile for the river path starting from station 0+360 to station 0+580

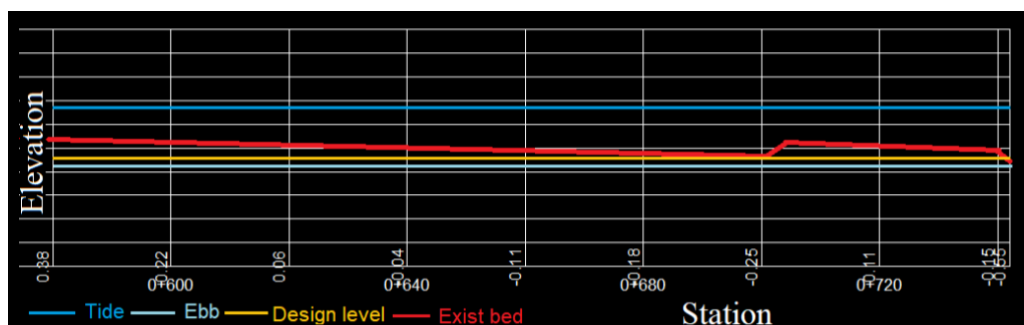


Figure 5.4. 4th part of the profile for the river path starting from station 0+580 to station 0+742

- 4) A design cross-section was created in the shape of a trapezoid, with a base distance of 26 meters, minimum excavated depth 4.5 m, and a side slope of 2:1. All design elements of the cross-section were defined in the Civil 3D software in the (Cross Section), (Template), and (Design Control) menus. The existing and newly created cross-sections are shown in Figures 6.1-6.4. The channel's sections are designed to maintain a water depth of at least 2 meters throughout the channel at low tide and during ebb. The force that causes the water to flow into the channel is the surge of the tidal wave, at a slope of 0.002, from the Shatt al-Arab towards the channel, and the subsequent receding water flows back into the Shatt al-Arab during low ebb.
- 5) The Total Volume and Volume Table tools in Civil 3D were used to calculate earthwork volumes using the prismoidal method. The program first calculated the area of each cross-section and then calculated the volumes between the cross-sections, as shown in Table 1. To reach the proposed design level, the total calculated cut volume was 18,800.21 m³, while the calculated fill volume was a small 60.33 m³ compared to the excavation. To verify the accuracy of the calculated volumes, ArcMap was used to calculate volumes from the same survey data independently. TIN surface analysis was used to convert the topographic survey points and the proposed design points into two raster surfaces. Raster-based cut/fill analysis was performed using the current ground surface and the design surface, which represent the same cross-section data in the Civil 3D program, and the volumes of earthwork between the two surfaces were calculated. The cut volume was 18,833 m³, and the fill volume was 59 m³, indicating convergence between the calculated results and those of the Civil 3D program.
- 6) The water flow in each design cross-section was calculated using Manning's equation (Q) after defining the equation coefficients (slope of water surface at tide (S) equal to 0.002, hydraulic radius (R) calculated according to the design cross-section area (A) and wetted perimeter (P), and Manning's coefficient (n) which was suggested to be 0.012 considering the proposed bottom in the design cross-section is concrete. Table 2 shows the calculated values for Manning's equation, assuming equal cross-sectional areas because the cross-section shape is constant along the length of the channel.

$$Q = V * A = \frac{1}{n} A R^{2/3} S^{1/2} \quad (1)$$

- 7) Figure 7, which illustrates the difference in flow before and after the proposed design cross-section, it is noted that the flow pattern is irregular along the channel path due to the varying bottom depth and high roughness coefficient (when calculating the Q for the channel's pre-design state, an n value of 0.035 was

used for an irregular clay bottom with irregular cross-sectional areas). After proposing a regular cross-section for the channel, the flow line is regular due to uniform bottom levels, a reduced roughness coefficient, and a uniform slope.

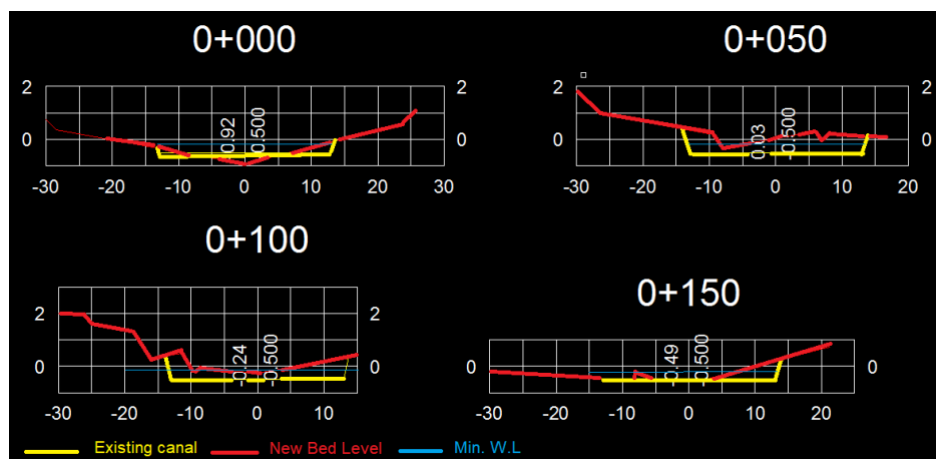


Figure 6.1. 1st part of the river existing cross sections after adding designed cross section

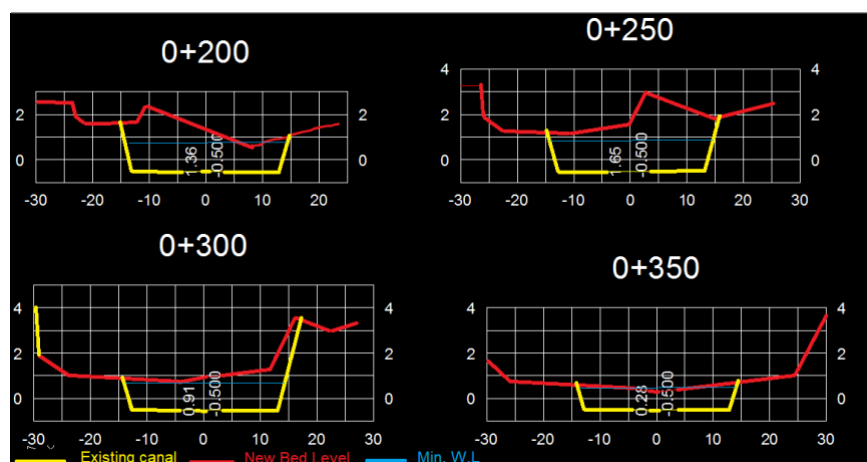


Figure 6.2. 2nd part of the river existing cross sections after adding designed cross section

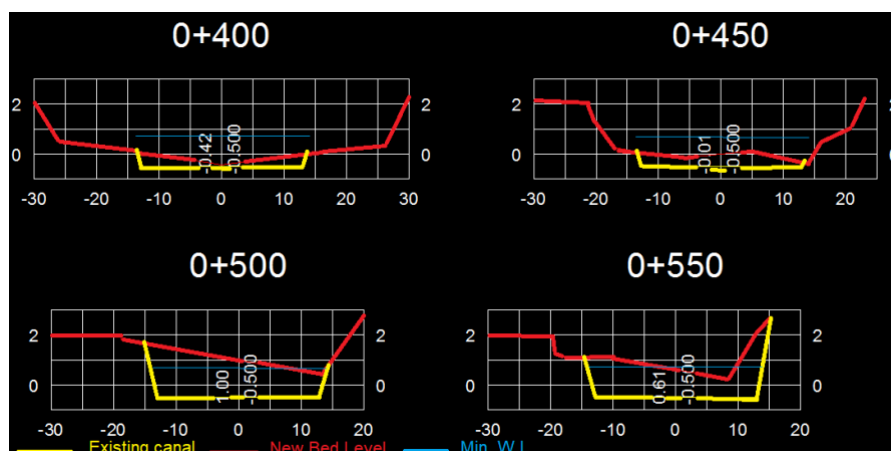


Figure 6.3. 3rd part of the river existing cross sections after adding designed cross section

8) The cost of rehabilitating the Al-Dakair Heritage Canal was calculated using Table 3, based on the average local prices for materials, equipment, and labour in Basra for 2025, as per the Ministry of

Municipalities and Public Works price lists and contractor bids. This table calculates the costs for excavation, backfilling, soil removal, levelling, compaction, and lining, and includes additional costs such as water pumps, removal of encroachments, technical and administrative expenses, laboratory tests, and quality control. Table 3 shows that the total cost of rehabilitating the Al-Dakair Canal reached approximately \$1,274,079, based on average local prices in the Iraqi market.

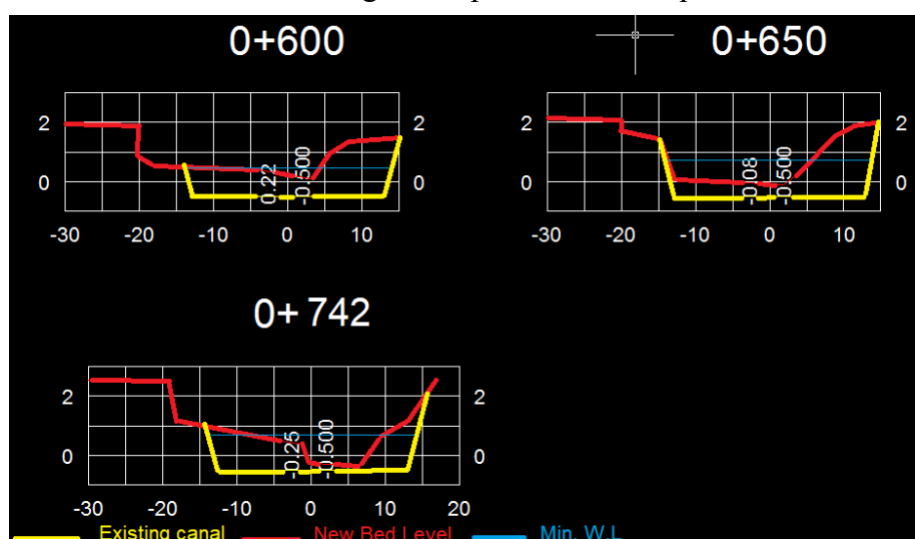


Figure 6.4. 4th part of the river existing cross sections after adding the designed cross section

Table 1. Table of volume for the designed cross sections of the river path

Station	Areas m ²		Volumes m ³		Cumulative Volumes m ³	
	CUT	FILL	CUT	FILL	CUT	FILL
0+000	1.78	3.37	372.65	56.24	372.65	56.24
0+050	15.34	0.0	569.85	0.0	942.5	56.24
0+100	7.86	0.0	376.65	2.05	1319.15	58.29
0+150	7.21	0.12	1317.37	2.05	2636.51	60.33
0+200	52.4	0.0	2959.74	0.0	5596.25	60.33
0+250	66.26	0.0	2778.29	0.0	8374.55	60.33
0+300	45.52	0.0	1766.54	0.0	10141.09	60.33
0+350	26.04	0.0	810.17	0.0	10951.26	60.33
0+400	8.07	0.0	485.42	0.0	11436.68	60.33
0+450	11.44	0.0	1252.26	0.0	12688.94	60.33
0+500	41.82	0.0	1997.07	0.0	14686.01	60.33
0+550	38.1	0.0	1677.0	0.0	16363.01	60.33
0+600	29.18	0.0	1266.88	0.0	17629.89	60.33
0+650	21.68	0.0	1170.32	0.0	18800.21	60.33
0+742	25.18	0.0	0.0	0.0	18800.21	60.33

Table 2. Calculate the flow in cross-sections using Manning's equation

Station	A (m ²)	P (m)	R=A/P (m)	Q (m ³ /s)
0+000	157.5	46.2	3.409091	59.46
0+050	157.5	46.1	3.416486	59.55
0+100	157.5	46	3.423913	59.63
0+150	157.5	45.92	3.429878	59.70
0+200	157.5	45.77	3.441119	59.83
0+250	157.5	45.63	3.451677	59.95
0+300	157.5	45.51	3.460778	60.06
0+350	157.5	45.3	3.476821	60.24
0+400	157.5	45.66	3.449409	59.93
0+450	157.5	45.82	3.437364	59.79
0+500	157.5	45.97	3.426147	59.66
0+550	157.5	46.12	3.415004	59.53
0+600	157.5	46.18	3.410567	59.48
0+650	157.5	46.23	3.406879	59.43
0+742	157.5	46.24	3.406142	59.43

Table 3. Cost of rehabilitating the Al-Dakair heritage canal

Item	Unit	Quantity	Unit Price (USD)	Partial Value (USD)
Channel excavation	m ³	18800.21	2-6 (3.5)	65800.74
Canal Burial	m ³	60.33	1-3 (2)	120.66
Loading and transporting excavated soil to the quarry	m ³	18800.21	0.7-2.4 (1.6)	28800.34
Levelling and compaction	m	742	5-8 (6.5)	4823
Paving with sub-base material (10 cm)	m ³	29680	3-6 (4.5)	133560
Concrete lining of the sub-base	m ³	29680	25-35 (30)	890400
Water drainage pumps	day	45	250-350 (300)	12600
Removal of encroachments and violations	Lump Sum	1	3000-4000 (3500)	3500
Administrative expenses	%	10-12	11%	125357
Quality Control and Laboratory Testing (QC)	%	0.6-1.2	0.8%	9117
Total				1274079 \$

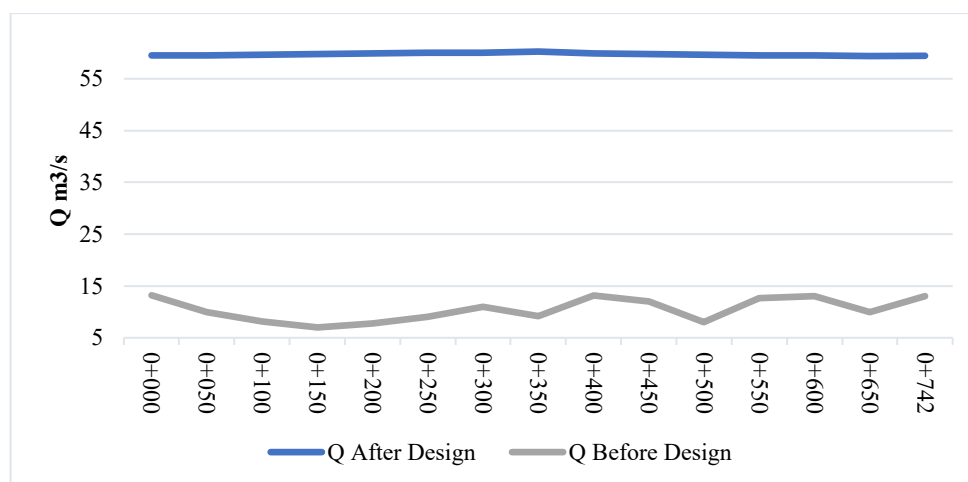


Figure 7. Water flow before and after the proposed design cross-section

4. Conclusions and Recommendations

This study presents a quantitative methodology for calculating earthwork costs for rehabilitating an important heritage canal, such as the Al-Dakair Canal, by modelling topographic surveys of existing and designed cross-sections in Civil 3D. The modelling results revealed clear, inconsistent differences between the actual and design elevations, which were translated into excavation and backfill volumes and their associated costs. This reflects the deterioration of the cross-sectional shape due to environmental and topographic conditions.

Despite the high accuracy of the numerical calculations, the scientific significance of this study lies in demonstrating the importance of integrating 3D surface modelling before and after design to obtain reliable estimates of volumes and costs. This facilitates the development of more realistic rehabilitation plans and reduces uncertainty during implementation.

However, some limitations identified by the research must be considered. The accuracy of the results depends primarily on the precision of the instruments and monitoring methods used in the topographic survey of the canals. The accurate representation of the actual change in the longitudinal and transverse sections of the canal depends on the quality of the data; inaccuracies lead to discrepancies in some locations.

On the other hand, a significant limitation of the analysis's comprehensiveness is that the constructed model cannot predict future hydraulic changes or long-term structural impacts.

From a practical and technical standpoint, the model results can be used to estimate the initial project costs and to support rehabilitation decisions, especially in critical sections of the canal's course that require extensive earthworks. The methodology employed in this research applies to any waterway within the city

of Basra, particularly those of historical significance. However, generalising the experiment to canals outside Basra requires adjusting the model parameters, such as soil type and the required water flows and velocities.

Based on the research findings, the following conclusions can be drawn:

- 1) From calculations in Civil 3D, it is evident that most cross-sections require cutting, with only two (0 and 150) requiring filling.
- 2) The largest cut area was in the "250+0" section, measuring 66.26 m², while the smallest was in the "0+000" section, measuring 1.78 m².
- 3) The total volume of cut along the canal path was 18,800 m³, and the total volume of fill was 60.33 m³.
- 4) To compare the calculated results and ensure their accuracy, ArcMap was used to calculate the earthwork volumes for the Al-Dakair Canal using the same survey data. The cut volume was 18,833 m³, and the fill volume was 59 m³. This indicates that the calculated results are very accurate and can be relied upon for implementation.
- 5) The estimated cost of rehabilitating the Al-Dakair Heritage Canal was calculated based on the main factors affecting the earthworks, amounting to US\$1,274,079.
- 6) Using Civil 3D software to calculate earthwork volumes significantly increased the speed and accuracy of cross-section design. It also improved the accuracy of representing the actual conditions of the site, saving time, effort, and money compared to traditional methods that require calculations and plans to be drawn.
- 7) The approximate cost of digging the Al-Dakair Canal ranges from \$3 to \$ 5 per cubic meter. That means the estimated cost to dig the canal ranges from \$56,400 to \$94,000.
- 8) The study recommends redesigning the cross-sections of nearby rivers to ensure a correlation between depths and flows.
- 9) The study recommends conducting future research using geographic information systems (GIS) software and satellite imagery to accurately map river paths and their banks.
- 10) The study suggests conducting further investigations into the type of bottom soil to determine the Manning coefficient, which affects the riverbed roughness and, in turn, influences water speed and flow.

Although this study focuses on the Al-Dakair canal, the design procedure and findings are relevant to many silted and underperforming heritage canals in arid and semi-arid cities. The combination of detailed

survey data, Civil 3D–based section redesign, and transparent cost estimation provides a replicable template that water agencies can adapt when preparing rehabilitation projects and funding applications. The research approach supports the fields of applied engineering, policy, and future research in the following ways:

- 1) For engineering practice: The findings support the use of Civil 3D and GIS as practical tools for planning canal rehabilitation in other data-limited cities.
- 2) For policy: Providing realistic cost estimates at the design stage can help municipal and national agencies prioritise and actually implement long-delayed rehabilitation projects.
- 3) For research: Future work could apply this workflow to multiple canals, integrate sediment and water-quality modelling, and test alternative cross-section shapes under climate-change and demand scenarios.

Acknowledgment: The authors gratefully acknowledge Mustansiriyah University, Baghdad, Iraq, for its support during the preparation of this work.

Data Availability Statement: Data Availability Statement: All data generated or analysed during this study are included in this article. Additional supporting data are available from the corresponding author upon reasonable request.

Funding: The authors declare that no funding was received for this research.

Declaration of Competing Interest: The authors declare that they have no known competing interests.

Research Involving Human/Animal Participants: This article does not involve any studies conducted by the authors on animals or human participants.

References

- [1] A. S. Chandio, T. S. Lee, and M. S. Mirjat, "Simulation of horizontal and vertical drainage systems to combat waterlogging problems along the Rohri Canal in Khairpur District, Pakistan," *Journal of Irrigation and Drainage Engineering*, vol. 139, no. 9, pp. 710-717, 2013, doi: [https://doi.org/10.1061/\(ASCE\)IR.1943-4774.0000590](https://doi.org/10.1061/(ASCE)IR.1943-4774.0000590).
- [2] J. H. Cui, Z. Q. Xie, and H. J. Xiao, "Cause analysis on the cracks in concrete plate of canal lining," *Applied Mechanics and Materials*, vol. 405-408, pp. 2596-2599, 2013, doi: <https://doi.org/10.4028/www.scientific.net/AMM.405-408.2596>.
- [3] H. I. Mohammed, S. M. A. Mohamed, O. M. Abbas, and A. D. Elfadil, "Selection of optimum land leveling design method for surface irrigation," *International Research Journal of Multidisciplinary Technovation*, vol. 5, no. 2, pp. 1-9, 2023, doi: <https://doi.org/10.54392/irjmt2321>.
- [4] F. N. Cantero-Chinchilla, O. Castro-Orgaz, S. Dey, and J. L. Ayuso, "Nonhydrostatic dam break flows. I: Physical equations and numerical schemes," *Journal of Hydraulic Engineering*, vol. 142, no. 12, p. 04016068, 2016, doi: [https://doi.org/10.1061/\(ASCE\)HY.1943-7900.0001205](https://doi.org/10.1061/(ASCE)HY.1943-7900.0001205).
- [5] M. Králík, T. Kašpar, and M. Mildner, "Flow of the curve of the Podkrusnohorský canal [Proudení v oblouku Podkrusnohorského přivodece]," *Vodohospodarske technicko-ekonomické informace*, vol. 59, no. 1, pp. 28-31, 2017, doi: <https://doi.org/10.46555/VTEI.2016.11.004>.

- [6] E. N. Bromhead, *Reflections on Slope Stability Engineering*. Boca Raton, FL, USA: CRC Press, 2023, doi: <https://doi.org/10.1201/9781003428169>
- [7] K. Shibano *et al.*, "Evaluation of surface damage for in-service deteriorated agricultural concrete headworks using 3D point clouds by laser scanning method," *Paddy and Water Environment*, vol. 22, no. 2, pp. 257-269, 2024, doi: <https://doi.org/10.1007/s10333-023-00965-3>.
- [8] G. K. e.V., "Kontrolle der Erdarbeiten im Zuge der Eigenuberwachung: Kanalbau in offener Bauweise - Verdichtungsprufungen, Teil 1," *GWF Wasser/Abwasser*, vol. 163, no. 1, pp. 24-25, 2022.
- [9] C. A. Rodriguez Gonzalez, A. M. Rodriguez Perez, J. J. Caparros Mancera, and J. A. Hernandez Torres, "Mechanical and functional improvement in an irrigation channel modeled with HEC-RAS," in *Advances in Design Engineering III*, Lecture Notes in Mechanical Engineering: Springer, 2023, pp. 173-182, doi: https://doi.org/10.1007/978-3-031-20325-1_13
- [10] A. D. Abed and S. M. Jaafer, "Detect the water flow characteristic of the Tigris River by using HFC-RAS program," *IOP Conference Series: Earth and Environmental Science*, vol. 754, no. 1, p. 012003, 2021, doi: <https://doi.org/10.1088/1755-1315/754/1/012003>.
- [11] A. D. Abed and N. B. Sabtu, "Urban context analysis according to the concept of Spencer's biological theory using GIS: Balad City case study," *Journal of Engineering and Sustainable Development*, vol. 28, no. 2, pp. 190-212, 2024, doi: <https://doi.org/10.31272/JEASD.28.2.4>.
- [12] A. D. Abed and M. A. M. Said, "Urban river restoration strategies to reach a sustainable river environment - Venice of Arab a case study," *AIP Conference Proceedings*, 2023, doi: <https://doi.org/10.1063/5.0148127>
- [13] A. D. Abed, "Urban upgrading of slums: Baghdad and London slums as study models for urban rehabilitation," *Computational Urban Science*, vol. 3, no. 1, p. 31, 2023, doi: <https://doi.org/10.1007/s43762-023-00106-w>.