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Hydraulic Implications of Canal Lining Types: A Case Study of the Bani Hassan Irrigation System

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ABSTRACT

The Canal lining is usually used to decrease seepage loss and raise water transport efficiency. Traditional unlined irrigation canals often suffer from significant water loss due to leakage and low water levels, negatively impacting hydraulic performance and irrigation efficiency. Despite the widespread use of irrigation canal lining, there have been few studies to evaluate the effect of different lining types in controlling seepage under varying conditions. This paper focuses on assessing the effect of two different types of concrete lining and concrete quilt on improving the hydraulic performance of the Bani Hassan irrigation canal. A one-dimensional steady-state hydraulic model was created using HEC-RAS version 6.6 software to simulate flow distribution in the canal. In this model, the hydraulic calculations are derived from a one-dimensional energy equation between the canal cross-section, relying on the canal geometry and the manning roughness coefficient. Thus, the software iteratively processes the water surface. The Manning's roughness coefficient for the concrete surface was calibrated using the root mean square error (RMSE) method. Seepage losses through the canal section were then calculated based on Darcy's law for both pre-lining and post-lining conditions. The results showed that unlined canal sections recorded seepage losses of 4,546 m^3/day, whilst concrete quilt lining reduced these losses to 599 m^3/day (≈92% reduction) and concrete lining to 588 m^3/day (≈95% reduction). The contribution of this study lies in analyzing the hydraulic efficiency of Iraqi irrigation systems represented by the Bani Hassan Canal, lined with concrete versus concrete quilt under identical conditions, using hydraulic modeling and seepage rate estimation to assess changes in efficiency.

Keywords: Bani Hassan canal, HEC-RAS software, Hydraulic performance, Lining canal, Steady flow.

1. INTRODUCTION

Over the past few decades, ensuring the sustainable use of water resources has become increasingly difficult, particularly in arid and semi-arid areas, as a result of rising irrigation

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needs and the impacts of climate change. **(Fasakhodi et al., 2010; Cao et al., 2020; Mariolakos, 2007).** With the current problem of water scarcity and the rising average temperatures due to global warming, the water demand is increasing, making it crucial to preserve all drop **(Li et al., 2020; Sivanappan et al., 2016)**. Since agricultural irrigation consumes the largest amount of water resources in some countries, a large amount of research has been addressed towards evaluating the importance and necessity to increase the efficiency of irrigation systems for sustainable agricultural water management **(Alonso et al., 2019; Hotchkiss et al., 2001; Kinzli et al., 2010; Koech and Langat, 2018; Wallace et al., 2000; Yue et al., 2018)**. The rising global population and food demand have intensified competition for this limited resource **(Kadhum and Abed, 2024).** The demand for this pivotal commodity, i.e., water, continues to rise, while its sources of supply are still limited or even depleting **(Sharief et al., 2021)**. Agricultural water accounts for nearly 70% of the total freshwater used worldwide, and this percentage can be elevated in developing countries **(Doungmanee, 2016).** Irrigation planners have contributed to the availability of water not only for agriculture but also for domestic use by rustic households **(Meijer et al., 2006).** Many irrigation systems contain unlined canals, which are losing water by seepage, resulting not only in lowered water for crops **(Snell et al., 2001).** Canals transport water extracted from the regular streams and reservoirs to the irrigation fields. It has been noted that a loss of water from the canals in leakage has been figured at 15 to 25% **(Al-Janabi et al., 2018; Ara et al., 2018; Yao et al., 2012).**

The volume of seepage in a canal is influenced by many factors, including section, the soil hydraulic permeability, the canal's wetted perimeter, and its slope banks **(Uchdadiya et al., 2014).** In general, more seepage loss occurs from canals built on very permeable soils and with a high wetted perimeter **(Ali, 2010; Mohammed and Ameen, 2024)**. A popular approach for seepage reduction is canal lining, which enhances canal efficiency by reducing water losses through seepage **(Eltarabily et al., 2023)**. Water conveyance efficiency is the proportion of inflow to the canal to the total amount of water transferred. Lining irrigation canals contributes to increasing the volume of water flowing through them, in addition to various advantages of lining. These advantages include reducing water loss through seepage, increasing drainage volume, stabilizing canal banks, and protecting the canal sides and bottom from erosion **(El-Molla and El-Molla, 2021; Eshetu and Alamirew, 2018)**. Using concrete to line irrigation canals is more efficient at reducing water loss, but it is expensive and difficult to maintain and install **(Zakir-Hassan et al., 2023)**. One of the maintenance and modernization procedures for irrigation canals is lining them with concrete **(Rehman and Ali, 2023).** This involves covering the inner surface of the canals with a layer of concrete, and this technical procedure provides several advantages, some related to the operation of the canals and others to their maintenance **(Yadav et al., 2023).** By applying a concrete lining, the canal’s structural integrity is improved, decreasing the risk of seepage and leakage **(Shah et al., 2020)**.

Accurate estimation of the roughness coefficient plays a vital role in studying open canal flow **(Hashim and Azzubaidi, 2023)**. Hydraulically, the amount of the Manning coefficient (n) should rely on the interaction between the hydraulic characteristics of the canal section, longitudinal canal slope, and discharge. Indeed, previous studies listed Manning coefficient (n) Values for a wide range of surface types in open canal flow **(Abd Elmoaty and TA, 2020) (Giménez and Govers, 2001).** It should be noted, however, that these values are valid only under steady and uniform flow **(Wong and Lim, 2006).** After the development of engineering programs, many numerical methods, such as finite element, are widely used with the HEC-RAS software **(Mahdi and Al-Hadidi, 2023).** The study ran a numerical model to simulate the multi-reach of this research using HEC-RAS (6.6) in one-dimensional steady state **(Al-Tameemi and Al-Thamiry, 2025; Serede et al., 2015).**

Although there are general studies on lining, there are no detailed studies linking lining to seepage and hydraulic performance in the Bani Hassan project specifically. The objective of this study is to evaluate the effect of various lining types (concrete and concrete quilt) compared to the unlined condition on seepage losses and hydraulic performance of the Bani Hassan Canal, using HEC-RAS steady flow simulations.

2. MATERIALS AND METHOD

2.1 Study Area

The Bani Hasan Canal diverged from the right side of the Euphrates River. It flows from Al-Hindiya Barrage on the Euphrates River and then heads towards the south in parallel to the right bank of Shatt Al-Hindiya for a distance of about 64.5 km, as shown in **Fig. 1**, passing via an agricultural area characterized by dense groves of fruit trees and date palms. The length of the influx in Karbala province is about 44.5 km, and 20.5 km is distributed between Najaf and Babylon provinces. The overall area which is irrigated by the river is about 114000 acres. The design discharge of the river is about 39 m^3/sec, and the peak flow during the high-demand period is 45 m^3/s **(Majeed, 2018)**. The study area, which is 1400 m long, was chosen as the only unlined part of the Bani Hassan Canal. To determine the best type of lining for this part, or leave it as is.

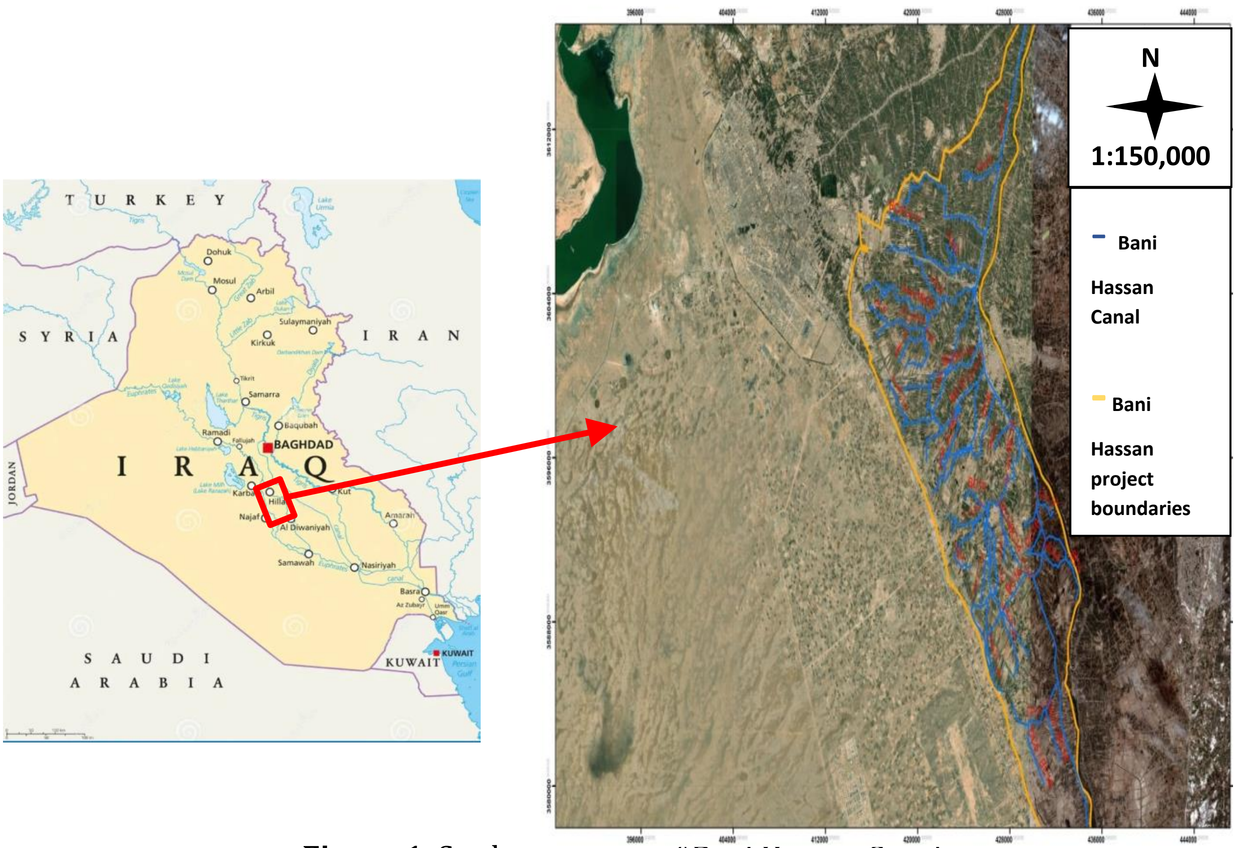

Figure 1. Study area map of Bani Hassan Canal.

The Bani Hasan canal has a trapezoidal section. The canal is lined with two types of lining (concrete and concrete quilt) as shown in **Figs. 2 and 3,** and distributed over different sections, as shown in **Table 1**.

Figure 2. Image of the concrete lining of Bani Hassan Canal.

Figure 3. Image of concrete quilt lining of Bani Hassan Canal.

Table 1. Lining type in Bani Hasan Canal**.**

Distance	Lining type
From 0 km→ to 1.5 km From 3.1 km → to 7.1 km From 11.5 km → to 64.5 km	Concrete lining
From 1.5 km → to 3.1 km From 7.1 km → to 10.1 km	Concrete quilt
From 10.1 km → to 11.5 km	Unlined

2.2 Simulation Model

2.2.1 HEC-RAS Hydraulic Model

The HEC-RAS River Analysis System, created by the Hydrological Engineering Center and modified by a U.S. Army group of engineers, is the most popular inventory for simulation and analysis of flow in open channels, rivers, and lakes **(Abed et al., 2021)**. It simulates water quality and sediment transport, and is characterized by its high representations of continuous gradual flow, such as one- and two-dimensional, uni-type steady (permanent) state. The fundamental hydraulic equations for open channels, which are the basis of hydraulic computations in HEC-RAS, are the continuity equation and the Froude equation, Eq. (1) and Eq. (2), respectively.

$$Q = AV \tag{1}$$

Where, Q: flow rate (m^3/s), A: cross-sectional area (m^2), V: velocity (m/s)

$$F_r = \frac{V}{\sqrt{gD}} \tag{2}$$

Where, Fr: Froud number, V: velocity (m/s), g: acceleration due to gravity (m/s^2), D: hydraulic depth(m). This can be solved using the standard step method (it is the method of calculating the flow in HEC-RAS), to simulate the shape of the water surface and the energy gradient. To form a hydraulic model, the HEC-RAS program demands initial values as input to this study, such as river bed levels (RBLs), discharge in m^3/s, river cross sections, system schematic, channel segments with their parameters of crest width, trough width, bank stations, and boundary conditions, and Manning coefficient **(Abed et al., 2020)** (e.g., discharges, water levels), as illustrated in **Fig. 4**. Additional details may include hydraulic constructions, such as canals, reservoirs, and bridges. Cross-sectional interpolation is also used to correct the geometry of the survey sections. The results are typically figures (and tables) including the water surface profile, cross sections , and longitudinal flow variations **(Hashim et al., 2023; Alsaadi and AL-Thamiry, 2022)**.

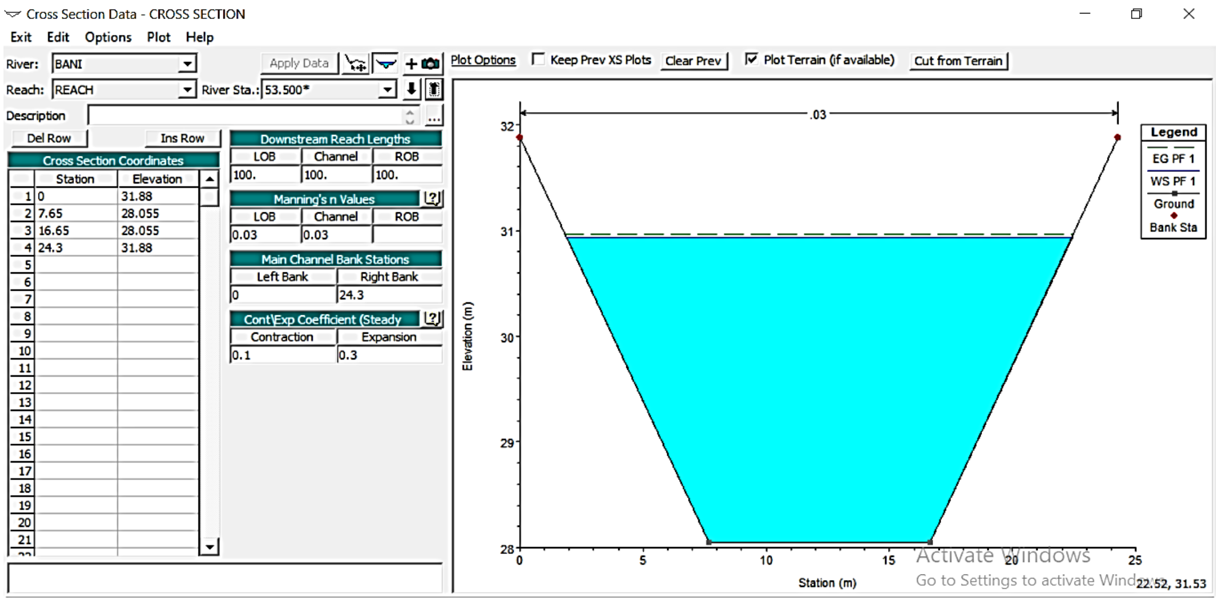

Figure 4. Input of geometric data for cross-section in HEC-RAS.

2.2.2 Steady Flow Settings

Constant flow settings, including the number of levels to be analyzed, discharge values, and limit conditions that define the characteristics of the conduit system, are essential in hydraulic modeling. A single discharge value should be assigned to each section of the conduit, and different discharge conditions can be assigned to other sections as needed **(Razzaq et al., 2024).**

In hydraulic systems, the flow can be subcritical, supercritical, or mixed **(Segal and Polikhov, 2008)**. The appropriate system is selected according to the purpose of the analysis and the hydraulic characteristics of the channel. In the case of the Bani Hassan Canal, the subcritical flow system was adopted in the HEC-RAS simulation because it realistically represents the flow conditions along the canal. The Root Mean Square Error (RMSE) test was applied to calibrate the steady flow model. Depend on the methodology described by **(Asaad and Abed, 2020).** The results were used for the simulation of the calculated water levels for each of the amounts of Manning roughness coefficient (n), with the observed water levels. Values of (n) were entered into the simulation software, and different water level values were obtained**.** This calibration confirmed that the computed water levels would correctly infer their hydraulic performance with any category of lining. The coefficient of determination R^2 was also used to assess the consistency between the observed values and those calculated for the water level using Microsoft Excel. A uniform value of the Manning coefficient n = 0.0155 was used in all sections of the HEC-RAS software to ensure consistency of the hydraulic simulation, and then the calculated water surface sections were analyzed to evaluate the effect of different lining types (unlined, concrete, and concrete-quilt) on flow velocity, depth, and top width.

2.3 Flow Data and Boundary Conditions

According to data from the Ministry of Water Resources, the design discharge rate of the Beni Hassan Canal is 39 m^3/s. However, under normal operating conditions during the irrigation season, a value of 39 m^3/s was used to run the model based on flow data and field observations. Using HEC-RAS software, the flow was analyzed assuming one-dimensional flow and applying a steady-state discharge methodology. The following inputs were defined for steady-state (1D) flow analysis:

- Flow Regime: Subcritical flow.
- Flow Rate: 39 m^3/s (uniform along the reach).
- Boundary Conditions.
- Upstream boundary: Flow rate defined at the inlet.
- Downstream boundary: Using the natural depth based on the previously determined slope, which is the slope of the canal bottom, which amounts to (8 cm/km or 0.00008 m/m).

These inputs were applied uniformly across all three cases:

- Unlined (earthen) section.
- Lined with a concrete quilt.
- Lined with concrete.

By conducting a test of how the flow behavior and shape of the channel sections change along their length, the effect of the unlined part of the channel, in addition to the two types of lining, on the hydraulic parameters (flow, speed, and area) was explained.

3. SEEPAGE LOSSES IN THE CANAL

Canal seepage is defined as the infiltration of water into soil layers through its wetted perimeter. After simulating a constant single-stage flow and completing the hydraulic model calibration, three scenarios were implemented to study seepage in the 1400m unlined section of the Bani Hassan Canal: when the section is unlined, when it is lined with concrete, and when it is lined with a concrete quilt. Using HEC-RAS software, each scenario was simulated to determine how each lining type affects seepage reduction and overall hydraulic performance.
This seepage loss is specified by Darcy's law, expressed by Eq. (3) **(Napan et al., 2009)**.

$$Q_{loss} = S.P.L \tag{3}$$

where
Q: seepage loss (m^3/s)
S: seepage rate ($m^3/m^2/day$)
P: wetted perimeter (m)
L: section length (m)

For a trapezoidal section expressed by Eq. (4).

$$P=b+2d\sqrt{1+z} \tag{4}$$

where
b: bottom width (m)
d: water depth (m)
z: side slope
The rates of the seepage are 0.020 – 0.057 $m^3/m^2/day$ for Concrete lining **(Kasali et al., 2020).** Seepage from unlined canals extends on the order of 0.1–1 m^3/day per m^2 of canal perimeter area **(Lund et al., 2023).** These values align with the typical design standards for irrigation canals.

4. RESULTS AND DISCUSSION

4.1 Result of Steady Flow

A steady flow simulation in HEC-RAS was carried out in several stages to ensure accuracy and represent the actual hydraulic behavior of the Bani Hassan Canal. **Fig. 5** illustrates the simulated water surface profiles along the Bani Hassan Canal for the different lining conditions.

4.1.1 Calibration of Manning's Coefficient (n)

Initially, a calibration process was performed by comparing the observed and the obtained water surface elevations, as shown in **Fig. 6**. Different trial values of Manning's n were tested, and the best agreement was obtained with an average value of n = 0.0155 based on the Root Mean Square Error (RMSE) results, as shown in **Table 2.** This value was then adopted for the concrete lining.

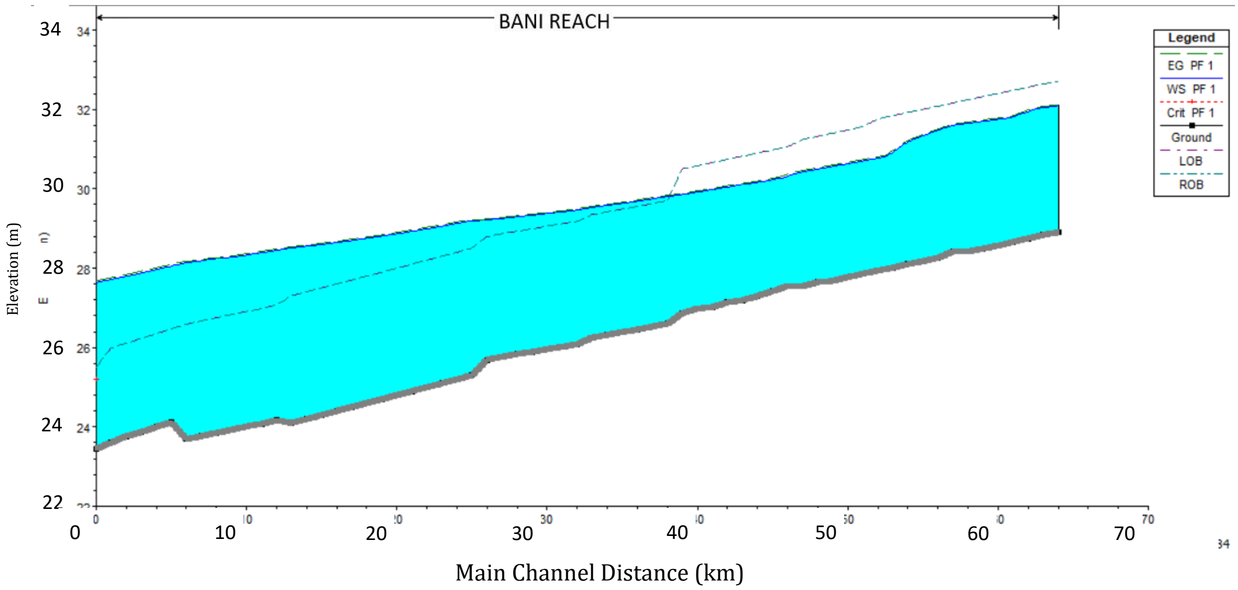

Figure 5. Water surface profiles for Bani Hassan Canal.

Table 2. The RMSE values calculated based on Manning's coefficient value.

n (Manning's coefficient)	RMSE
0.030	0.131477
0.028	0. 116593
0.026	0.099228
0.024	0.083103
0.022	0.064498
0.020	0.045893
0.018	0.026047
0.016	0.004961
0.0155	0.005581
0.015	0.006202
0.014	0.017365

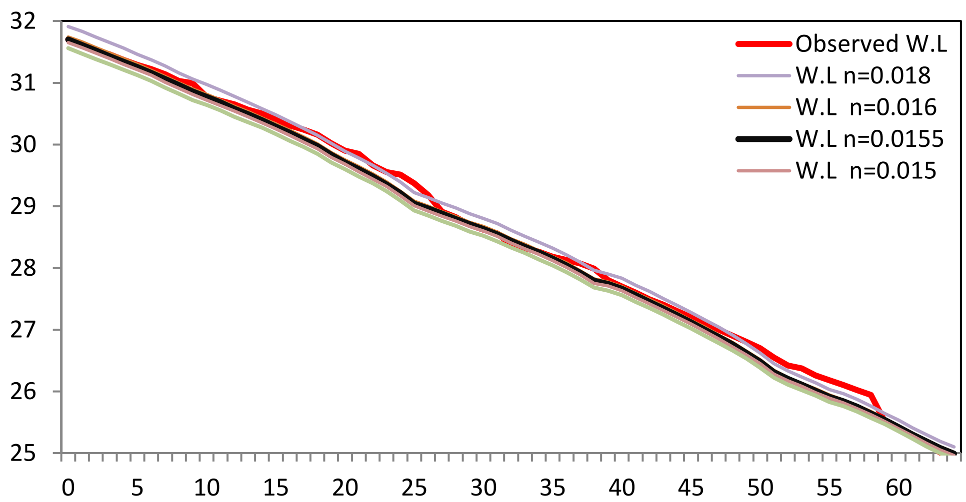

Figure 6. Comparing Manning's Roughness coefficient between observed W.l and obtained W.l.

The calculated value of the coefficient of determination is equal to 0.99726, and this indicates a strong correlation between the observed and the calculated water level when the Manning coefficient equals 0.0155.

4.1.2 Simulation of the Unlined Section

Results indicated water leakage increased, while the water scape decreased stability, which demonstrates the influence of soil permeability and high roughness, since (n ≈ 0.030) for an unlined canal

4.1.3 Simulation of Concrete Lining

The unlined portion was then modeled in an as-lined condition with concrete and alteration. Mannink exponent n=0.0155, and the hydraulic performances demonstrated a distinct enhancement of the section. The mathematical modelling discussed in the following section has indicated a significant reduction of seepage losses. This reduction is due to the impermeable property of the concrete lining. This ensures more efficient hydraulic conveyance. Sturdier velocity distributions and water depth compared to the unlined section.

4.1.4 Simulation of Concrete Quilt Lining

The last simulation, the third case, in which a concrete quilt when n=0.025 is used for its lining inside channel walls. This simulation shows better results when compared to the results for the unlined section, a reduction in seepage, and calmness in velocity and flow.

4.1.5 Interpretation of Water Surface Profile

The calculated simulated water levels were implemented in three different cases, see the graphical representation produced by **Fig. 7**.
Case 1: When the section is unlined, it exhibits wide oscillations in water level along the section because of increased seepage and roughness.
Case 2: When the composite lining is of concrete, the water level is more uniform and approaches the bottom of the section.
Case 3: When the section is lined with a concrete quilt will have less water level fluctuation versus the concrete lining case, because of the increased surface roughness.

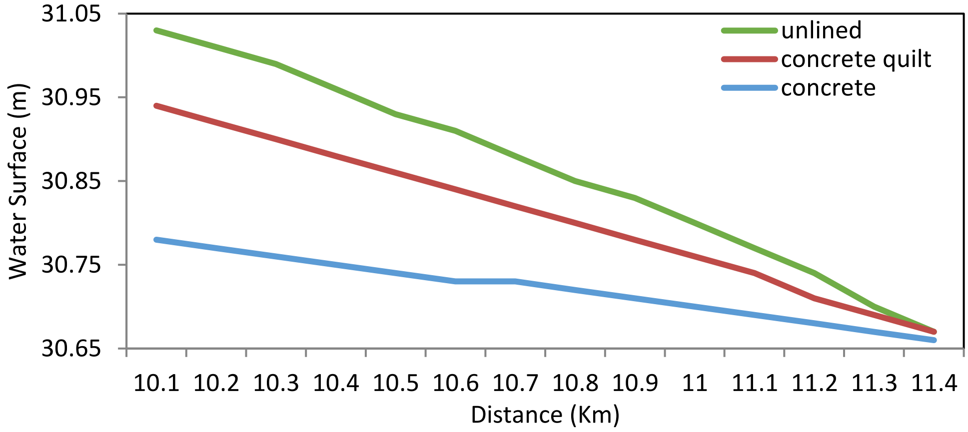

Figure 7. Water level for several lining types.

4.1.6 Interpretation of Velocity Distribution

A profile of the velocity distribution for the three cases is shown in **Fig. 8**, showing an obvious difference between them. The velocity profile in the unlined part is non-uniform with larger spatial changes due to the irregularly flat surface. When lined with concrete, velocity becomes more stable and uniform, which means energy losses are reduced and improved transport. The results with the concrete quilt were intermediate; the velocity was more stable than in the unlined section but slightly less uniform than in the concrete-lined section.

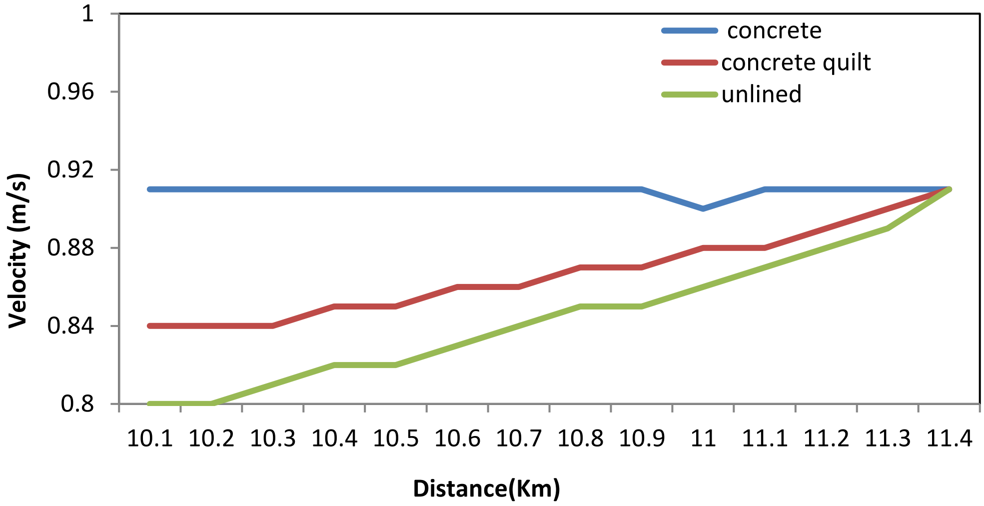

Figure 8. Velocity distribution along the canal for various lining types.

Synoptic, the similarity behavior of the three scenarios (unlined, concrete, and concrete quilt) demonstrated that the canal lining significantly improves the hydraulic performance of the Bani Hassan Canal by reducing seepage losses, stabilizing flow depths, and promoting conveyance efficiency. Concrete lining provided the greatest reduction, while quilt lining offered an effective and more economical alternative.

4.2 Seepage Outcomes

Lining canals can raise hydraulic efficiency by reducing the quantity of water that is lost before it reaches the fields. This can lead to an increase in the amount of water present for irrigation and can also improve the quality of the water by reducing the amount of sediment and other contaminants that are loaded in the canal. However, the effects of the canal lining on hydraulic competence can vary depending on the type of lining used and the specific circumstances of the canal. **Table 3** shows the amount of seepage losses obtained.

Table 3. Computed seepage losses for different lining types in the unlined section of the Bani Hassan Canal.

Segment	L(m)	Lining type	P(m)	S(m^3/m^2/day)	Q_{loss}(m^3/day)
1	1400	Unlined	21.64	0.15	4545.77
2	1400	Concrete	21.01	0.02	588.39
3	1400	Concrete Quilt	21.40	0.02	599.30

The unlined section exhibited the highest seepage losses of 4546 m^3/day, as shown in **Fig. 9**. These water losses, resulting from the absence of a seepage barrier, lead to significant water flow loss in unlined canals through their sides and bottoms. This reduces water conveyance efficiency, and spatial variations in seepage values are observed along the canal. This variation is attributed to differences in soil hydraulic properties and structure. Previous research confirms these findings, highlighting the substantial water losses caused by soil seepage and canal roughness in unlined irrigation canals. Therefore, canal lining is generally recommended as an effective solution for reducing seepage and improving hydraulic efficiency.

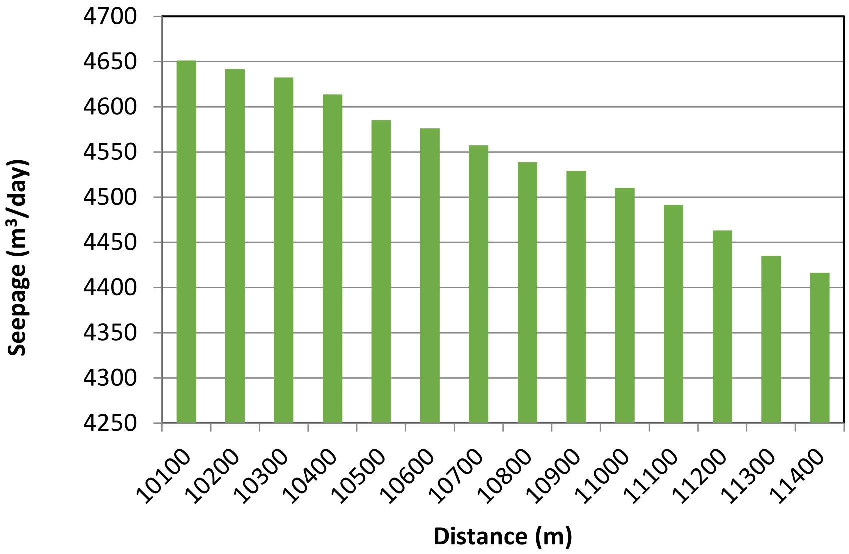

Figure 9. Seepage distribution for the unlined section of the Bani Hassan Canal.

In simulating the condition of concrete-lined canals, the greatest reduction in seepage was achieved, being less than that of unlined canals, resulting in a loss of 588 cubic meters per day, as shown in **Fig. 10.** This represents a reduction of approximately 95% compared to the unlined canal, because the water does not seep through the impermeable concrete layer.

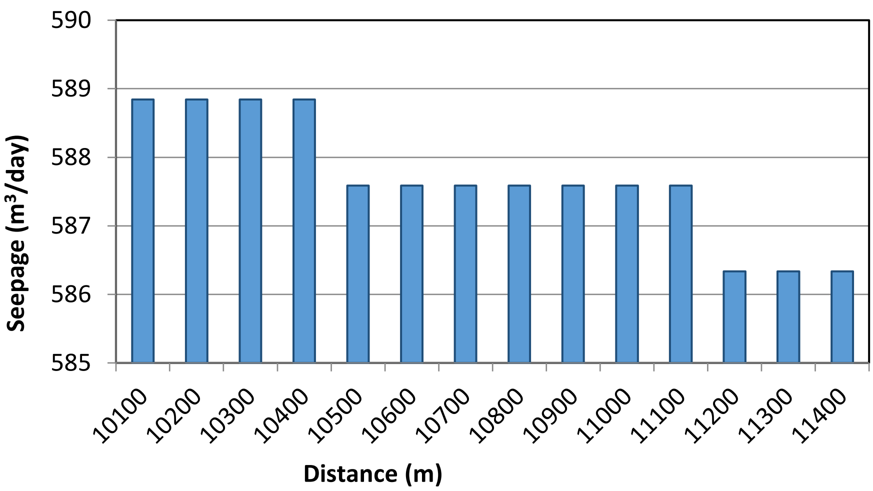

Figure 10. Seepage distribution for the concrete-lined section of the Bani Hassan Canal.

These improvements in seepage performance lead to increased water conveyance efficiency in the canal, confirming the results of numerous other studies on irrigation canals, where the reduction in water loss and the stabilization of hydraulic conditions are attributed to the use of concrete lining**.** Simulation results for this case show that using a concrete quilt significantly reduces water loss, with seepage losses reaching 599 m^3/d **(Fig. 9),** representing approximately a 92% reduction compared with the unlined section. This greatly reduces water loss compared to unlined sections, as the canal bed and banks are protected from seepage into the surrounding soil. Due to the structural elements of the concrete quilt, it is less efficient than a full concrete lining and allows only minimal water seepage. Nevertheless, the concrete lining has proven effective as a treatment to improve canal operation efficiency and reduce water loss through irrigation canals**.**

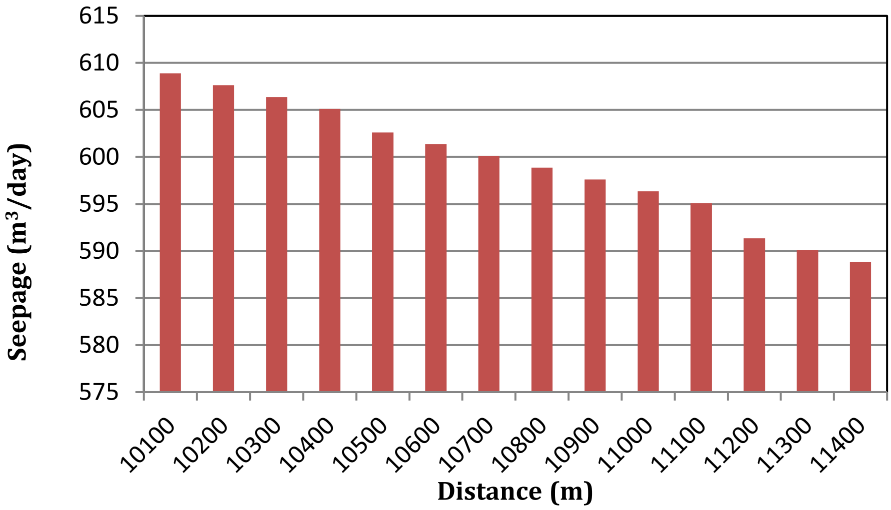

Figure 11. Seepage distribution for the concrete quilt-lined section of the Bani Hassan Canal.

Later, the seepage per section "s" was calculated, by using the formula $Q\_{loss(day)} = S. P.L$, where S is the specific seepage rate ($m^3/m^2/day$), P (m), and L is the section length (m), and P was calculated for individual sections according to the geometric dimensions $P=b+2d\sqrt{(1+z)}$ The values used for the seepage rate "S" for Unlined = 0.15 $m^3/m^2/day$ (silty-silt), Concrete liner = 0.02 $m^3/m^2/day$.

Results of the study show that canal lining significantly increased hydraulic performance and vastly reduced leaking in the Bani Hassan irrigation canal, with seepage reduced by 92% when lined with a concrete quilt and by 95% when lined with concrete. The unlined section showed the maximum seepage and flow instability, while both the concrete quilt and concrete showed a lower seepage rate and more stable flow. These losses were significantly reduced with reductions of 92 and 95 per cent. respectively.

This decrease in losses is due to the less rough and low-permeability surface lining that reduces the stagnation and leakage losses. Additionally, concrete quilt lining is a simpler and more cost-effective option in terms of maintenance when the need for concrete lining is urgent.

Despite significant findings, the study is limited by a constant flow simulation of 39 m^3/s and model calibration based solely on design measurements due to a lack of sufficient observed data. It proposes further research on the hydraulic performance and seepage behavior of different channel lining types, addressing the unsteady of flow conditions.

5. CONCLUSIONS

This study presents a hydraulic analysis for an irrigation canal, applied to Bani Hassan canal, Iraq, and compare between tow type of lining and unlined in terms of hydraulic performance and seepage calculation. The findings of this paper show the important effect of lining to increase hydraulic performance, decrease water loss from seepage in spite that there were some other leakage losses. The sections of the unlined 1400 meters were analyzed. The first instance was with the unlined earthworks. Results indicated that the unlined reach possessed the highest seepage and most unstable water surface as compared to the lined situations. In the second case, in which the section was concreted, it performed better; the water surface remained stable, and seepage losses decreased by about 95%. The third incident analyzed a new type of lining in Iraq called a concrete quilt. This liner didn't need the water to be shut off and was a cheaper, faster to install, and easier option. Reduced the seepage at 92% in the canal. Accordingly, the concrete quilt is more favorable for the renovation of the current irrigation system, and a practicality from economic and scientific perspectives can be acknowledged. Generally, the concrete quilt in either the second or third case is considered to be a good solution for solving the leakage problem and for better utilization of Bani Hassan irrigation canal. Future studies are recommended to ensure a more accurate study of the canal's condition under unsteady flow.

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Credit Authorship Contribution Statement

Nabaa Ayyad Haleem, Ali Omran Al-Sulttani, and Ameen Mohamed Salih Ameen: Writing–review & editing, Writing–original draft, Validation, Methodology.

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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تأثير أنواع التبطين على الأداء الهيدروليكي لقنوات الري: دراسة حالة لقناة بني حسن

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الخلاصة

تُستخدم بطانة القنوات عادةً لتقليل فقدان المياه بالتسرب ورفع كفاءة نقلها. غالبًا ما تعاني قنوات الري التقليدية غير المبطنة من فقدان كبير للمياه نتيجة التسرب وانخفاض منسوب المياه، مما يؤثر سلبًا على الأداء الهيدروليكي وكفاءة الري. على الرغم من الاستخدام الواسع النطاق لبطانة قنوات الري، إلا أن الدراسات التي تُقيّم تأثير أنواع البطانة المختلفة في التحكم بالتسرب في ظل ظروف متنوعة قليلة. تركز هذه الورقة البحثية على تقييم تأثير نوعين مختلفين من البطانة الخرسانية واللحاف الخرساني على تحسين الأداء الهيدروليكي لقناة بني حسن للري. تم إنشاء نموذج هيدروليكي أحادي البعد في حالة الاستقرار باستخدام برنامج HEC-RAS الإصدار 6.6 لمحاكاة توزيع التدفق في قناة بني حسن. في هذا النموذج, تشتق الحسابات الهيدروليكية من معادلة طاقة أحادية البعد بين المقطع العرضي للقناة, بالاعتماد على هندسة القناة و معامل خشونة مانينغ, وبالتالي يقوم البرنامج بمعالجة سطح الماء بشكل تكراري. تمت معايرة معامل خشونة مانينغ لسطح الخرسانة باستخدام طريقة جذر متوسط مربع الخطأ (RMSE). تم تقدير التسرب عبر مقطع القناة، وفقًا لقانون دارسي، قبل وبعد التبطين. أظهرت النتائج أن أجزاء القناة غير المبطنة سجلت خسائر تسرب بلغت 4546 مترًا مكعبًا في اليوم، بينما قللت البطانة الخرسانية هذه الخسائر إلى 599 مترًا مكعبًا في اليوم (انخفاض بنسبة 92%)، والبطانة الخرسانية إلى 588 مترًا مكعبًا في اليوم (انخفاض بنسبة 95%). قارنت هذه الدراسة الكفاءة الهيدروليكية لقناة بني حسن المبطنة بالخرسانة مقابل حالة التبطين باللحاف الخرساني في ظل ظروف متطابقة, باستخدام النمذجة الهيدروليكية وتقدير معدل التسرب لتقييم التغير في الكفاءة بعد عملية التبطين.

الكلمات المفتاحية: قناة بني حسن، تبطين القناة، الأداء الهيدروليكي، التدفق المستقر، برنامج HEC-RAS.