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Hydraulic Simulation for Flow One Dimension of Shatt Al-Hilla River

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Keywords:
Flooding, HEC-RAS 6.0.1, Manning Coefficient, Shatt Al-Hillah, Unstable Flow.

Highlights:
- *The hydraulic model indicated a shift in the river's movement.*
- *Develop the river to carry the designed discharge.*
- *Flooding scenarios were done using Hec-ras 6.0.1.*

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Abstract: Floods are considered the most serious disaster among all-natural catastrophes because they occur more frequently than any other natural hazard and strongly impact more individuals than all other natural disasters. Therefore, it is necessary to study flood risk. Hillah River is critical in securing industrial, agricultural, and civil water in three Iraqi governorates: Babil, Diwaniyah, and Muthanna. Its primary source is the Euphrates River, which extends approximately 100 kilometers within Babil Governorate – the study area. This research aims to evaluate and study the river's capacity and predict future floods by developing scenarios for anticipated events. Also, a hydraulic model was developed to assess the manning coefficient for Shatt Al-Hillah. The one-dimensional HEC-RAS 6.0.1 program has been used to simulate water flow in the river, incorporating over 350 cross-sections spaced at 250-meter intervals surveyed in 2018 by the Department of Water Resources in Babil Governorate. The model was calibrated using observed discharge data from 2004 to 2022 in Shatt al-Hillah. Subsequently, it was compared with a range of water levels by varying manning factors. The calibration results indicated that a roughness coefficient of 0.023 was suitable for unstable flow conditions, and the least mean square root error between the measured and simulated water levels was 0.053. The simulation results showed that the current capacity of Al-Hilla River was 205 m^3/s, such that it cannot pass the design discharge of 303 m^3/s. After conducting scenarios greater than 205 m^3/s, the results showed that increasing the discharge increased the areas exposed to flooding so that when the discharge was 450 m^3/s, flooding of the submerged areas increased. With a percentage of 92.2%, the northern side of Babil Governorate will be more vulnerable to flooding than the southern side because the southern part levels are lower than the northern part.

محاكاة هيدروليكية للجريان الاحادي الابعاد في شط الحلة

بنين محمد هلال [١]، فائز حسين المرعب [٢]

قسم الهندسة المدنية /كلية الهندسة/جامعة بابل / الحلة – العراق.

الخلاصة

يمكن اعتبار الفيضانات أخطر كارثة بين جميع الكوارث الطبيعية، لأنها تحدث بشكل متكرر أكثر من أي خطر طبيعي آخر، وتؤثر سلبًا على عدد أكبر من الأفراد مقارنة بجميع الكوارث الطبيعية الأخرى مجتمعة، لذلك من الضروري دراسة مخاطر الفيضانات. يعد نهر الحلة رافداً رئيسياً لتأمين المياه وبجميع استخداماتها الصناعية والزراعية والمدنية لثلاث محافظات عراقية هي الديوانية والمثنى وبابل منبعه الرئيسي نهر الفرات ويمتد نحو ١٠٠كم ضمن منطقه الدراسة في محافظة بابل. تهدف الدراسة الى تقييم ودراسة استيعابية النهر والتنبؤ بالفيضانات المستقبلية من خلال عمل عده سيناريوهات متوقعة الحدوث وكذلك اختبار معامل ماننغ لشط الحلة من خلال تطوير نموذج هيدروليكي احادي البعد باستخدام برنامج Hec-Ras 6.0.1 لنمذجة جريان الماء في النهر من خلال استخدام أكثر من ٣٥٠ مقطع عرضي بمسافة ٢٥٠ م تم مسحها في سنة ٢٠١٨من قبل دائرة الموارد المائية في محافظه بابل. وتمت معايرة النموذج باستخدام التصاريف المرصودة من سنة ٢٠٠٤ الى ٢٠٢٢ في شط الحلة حيث تمت مقارنتها مع مجموعه من المناسيب وباستخدام قيم مختلفة من معامل الخشونة وقد بينت نتيجة المعايرة ان معامل الخشونة المناسب للجريان الغير مستقرهو٠,٠٢٣ وان اقل معدل لجذر التربيعي للخطأ بين المناسيب المقاسة والمناسيب الناتجة يساوي ٠,٠٥٣. وبينت نتائج المحاكاة ان السعة الحالية لشط الحلة هي٢٠٥m^3/sبحيث لا يمكنه تمرير التصريف التصميمي ٣٠٣m^3/s.وبعد عمل سيناريوهات مختلفة أكبر من ٢٠٥ m^3/s اوضحت النتائج ان زيادة التصريف تؤدي الى زيادة المناطق المعرضة للفيضان بحيث عند التصريف ٤٥٠m^3/s يزاد فيضان المناطق المغمورة بنسبه 92.2% وكذلك الجانب الشمالي من محافظة بابل سيكون أكثر عرضه للفيضان من الجانب الجنوبي لكون المناسيب في الجزء الجنوبي اقل من الشمالي.

الكلمات الدالة: الفيضان، هيكراس٦,٠,١، معامل الخشونة، شط الحلة، الجريان الغير مستقر.

1.INTRODUCTION

Water resources management is an approach that enables people to manage water resources effectively in the present and future. It aims to reduce the risk of floods and ensure water availability when needed [1]. In their study, Chow et al. [2] presented a straightforward method to process the output of the hydraulic model HEC-RAS, enabling the mapping and analysis of floodplains in two and three dimensions within the ArcView geographic data system. Agnihotri and Patel [3] analyzed the Tapi River in Surat, India, and proposed the development of river cross-sections using the HEC-RAS program to increase the river's capacity to carry water and reduce flood risks. They created a flood immersion map of Surat using the HEC-Geo-RAS program. The researchers [4] divided the river reach into 24 cross-sections perpendicular to the flow direction, numbered them from 1 to 24, and utilized a LANDSAT image of the area to study steady flow simulations in the Anambe River basin. ArcGIS software was employed to obtain bathymetry data for each cross-section. They discovered various flow characteristics that decreased from upstream to downstream and areas with high and low flow characteristics. The primary objective of [5] was to assess the vulnerability of different hydraulic structures within the reach of the river Yamuna using the HEC-RAS model to simulate water surface profiles in the study area. The HEC-RAS model was calibrated and validated, then applied to simulate water surface profiles during the 2010 and 2013 floods. Raslan et al. [6] researched and recommended using HEC-RAS software to provide hydraulic solutions for the planned Baher Al-Baqer draining system canal. Hamdan et al. [7] studied the flow simulation of the SHATT AL-ARAB RIVER and some of its tributaries using the most recent HEC-RAS model (v5.0.3). Hamad and Mohamed [8] focused on analyzing one-dimensional unsteady flow in an open channel, employing the HEC-RAS program. Abbas et al. [9] evaluated the cross-sectional area, water discharge, and velocity of the upstream Al-Amarah Barrage in Iraq using a Doppler instrument (ADCP) to determine an appropriate Manning's coefficient of roughness value. Managing flood hazards is crucial in identifying and minimizing risks in specific areas, understanding pre-existing dangers, and predicting potential flood occurrences [10]. Proposing flood management initiatives necessitates a comprehensive understanding of floods, which can be achieved through two approaches. First, one can rely on on-site flood observations [11]. However, on-site observations may not always be feasible, prompting the need for an alternative approach: assessing floods using remote satellite sensing data [12,13]. Nevertheless, this method is limited to momentary actions during a flood event. Several numerical models, such as HEC-RAS (developed by the United States Army Corps of Engineers) [14,25], MIKE (developed by DHI, Denmark), and Sobek (developed at Delft Hydraulics), can solve equations in 1D and 2D. For this analysis, the HEC-RAS model is employed to simulate flooding. Studied flood risks and devised plans to protect against future floods [15]. Floods pose a risk that spans from being isolated to a specific region on Earth to becoming widespread globally [16,17,24]. Shatt Al-Hillah, a branch of the U/S Hindiyah Barrage, originates from the left bank of the Euphrates River. This paper examines the floodplain conditions of Shatt Al-Hillah. The capacity of Shatt Al-Hillah to discharge water has been reduced due to a lack of maintenance and sediment accumulation in the river's mainstream, rendering it unable to achieve its designed discharges. Given the absence of hydraulic studies applicable to the research area, conducting a specific study and developing a one-dimensional hydraulic model to evaluate the hydraulic conditions in Shatt Al-Hillah and identify necessary modifications is essential. The current discharge of Shatt al-Hilla is 150-200 m³/s. This research aims to increase the discharge capacity of Shatt al-Hilla to accommodate the designed discharge and use the model to simulate the flow under flood scenarios potential to determine their impact on the riverbanks while utilizing HEC-RAS 6.0.1 to find appropriate solutions.

2.STUDY AREA AND DATA

2.1.*Study Area*

Shatt al-Hillah, the focus of this study, is situated between the upstream of the Al-Hindiya Barrage and the downstream Daghara head regulator. Its primary source is the Euphrates River, which originates from the northern borders of Babylon Governorate. The Babylon Governorate covers a total area of 5,119 km², constituting approximately 1.3% of Iraq's total land area [18]. The waterway, Shatt Al-Hillah, spans 100 km within the boundaries of Babylon Governorate, flowing southeast through the province of Babylon and into the province of Al-Diwaniyah. Shatt Al-Hillah is a vital water supply for Babylon, meandering through an extensive area and dividing into various rivers and streams [19, 20]. The river is 100 km long and serves multiple purposes, including agriculture, drinking water supply, and as a significant tourist attraction (See Fig.1).

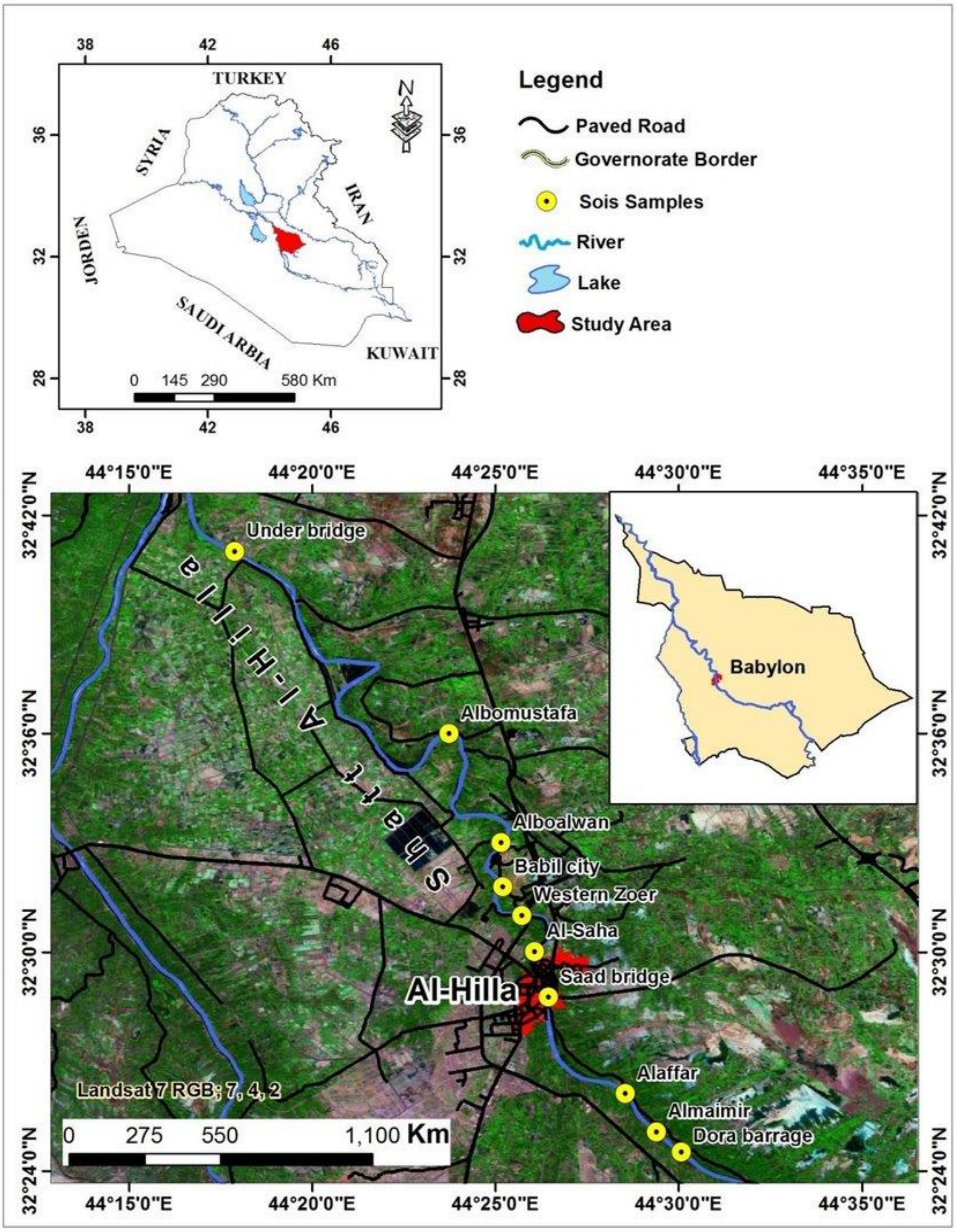


Fig. 1 Shatt Al-Hillah within the Studied Area.

2.2. Data Collection

The two main types of data are geographic data, which describes the area's geography, and flow data, which offers specific information about the Al-Hillah River's flow. The geographic data were obtained from the Shuttle Radar Topography Mission (SRTM), based on the Digital Elevation Model (DEM). The research focused on the region between the upstream point of Al-Hindiya Barrage (32° 43′ 43′′ N latitude, 44° 15′ 43′′ E longitude) and the downstream point (32° 8′ 26′′ N latitude, 44° 3′ 4′′ E longitude). Flow data was derived from the daily records of Shatt Al-Hillah, provided by the Water Resources service of Babil Governorate [23]. Measurements of 100 significant cross-sections along Shatt Al-Hillah using GPS (Global Positioning System) after surveying these cross-sections were conducted. Fig. 2 displays the cross-sectional image for Shatt Al-Hillah. Fig. 3 displays the upstream cross-section at station 0.00 km and the downstream cross-section at station 100.00 km. Fig. 4 illustrates the editing geometry window of the HEC-RAS model.

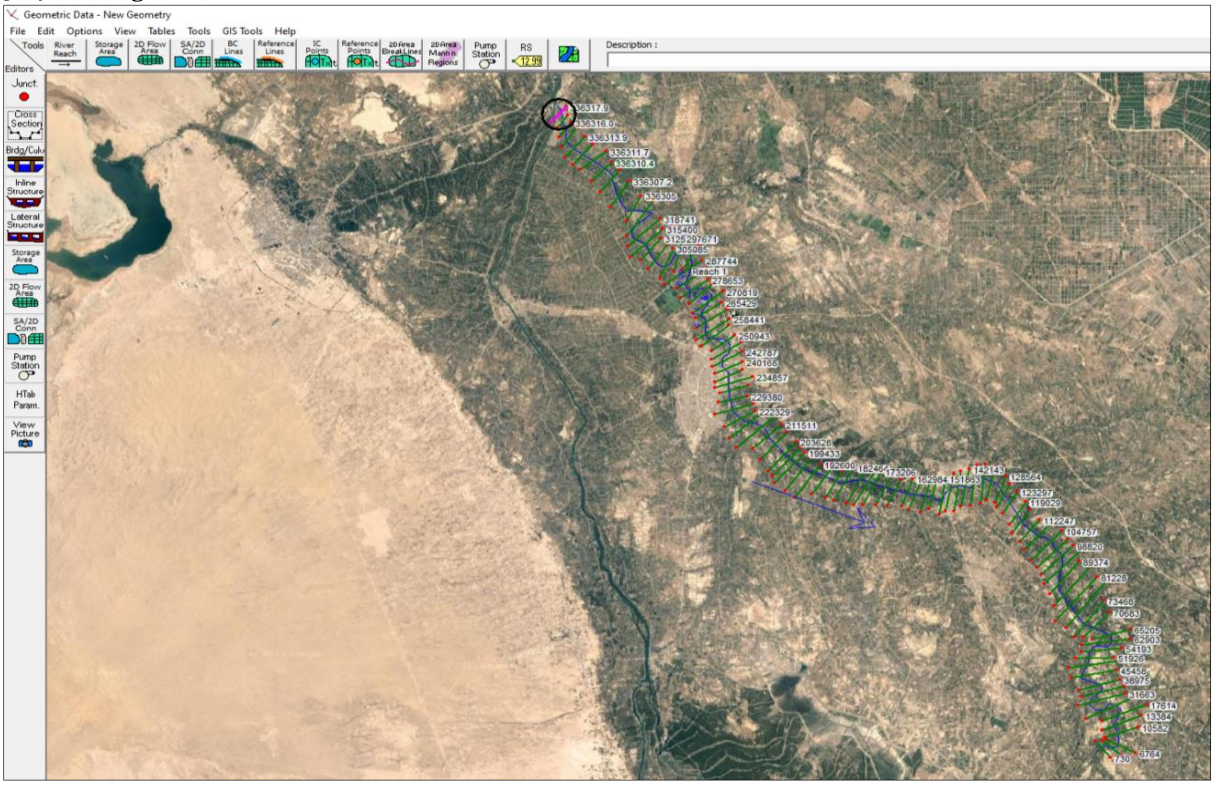
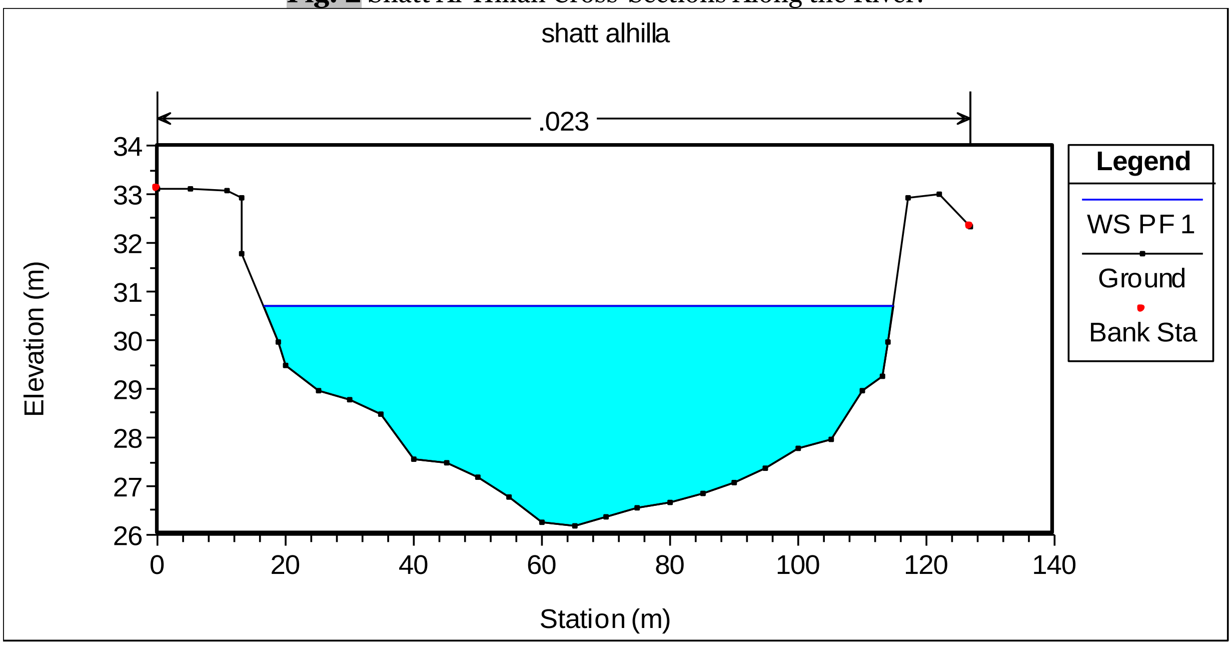
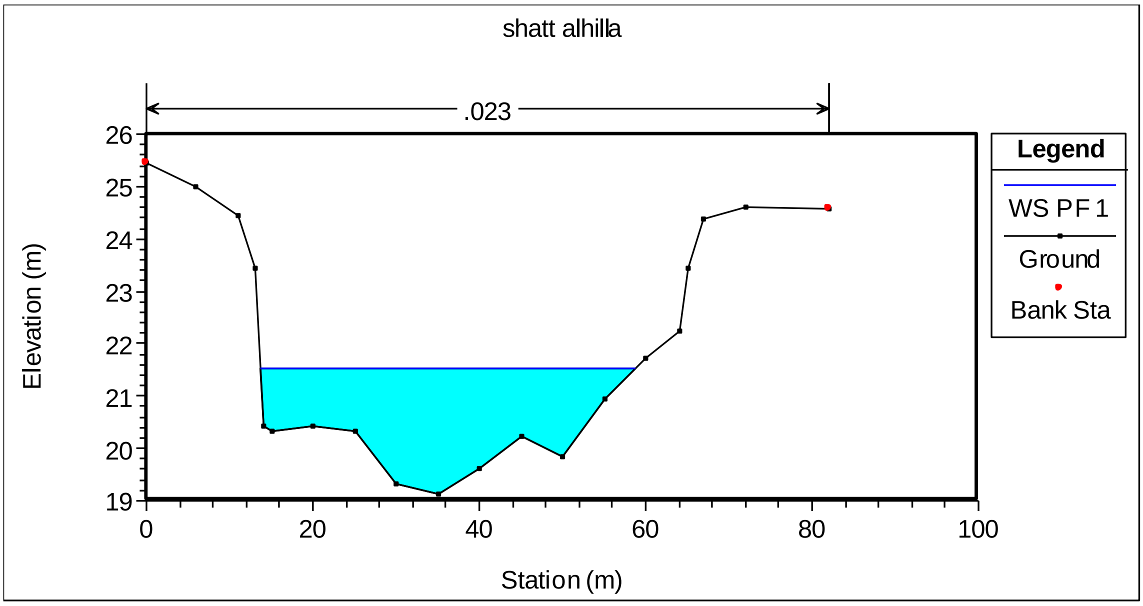


Fig. 2 Shatt Al-Hillah Cross-Sections Along the River.



(a)



(b)

Fig. 3 Cross-Sections: (a) Up-Stream Cross-Section at Shatt Al-Hillah (0.00km), (b) Down-Stream Cross-Section (100. 00km).

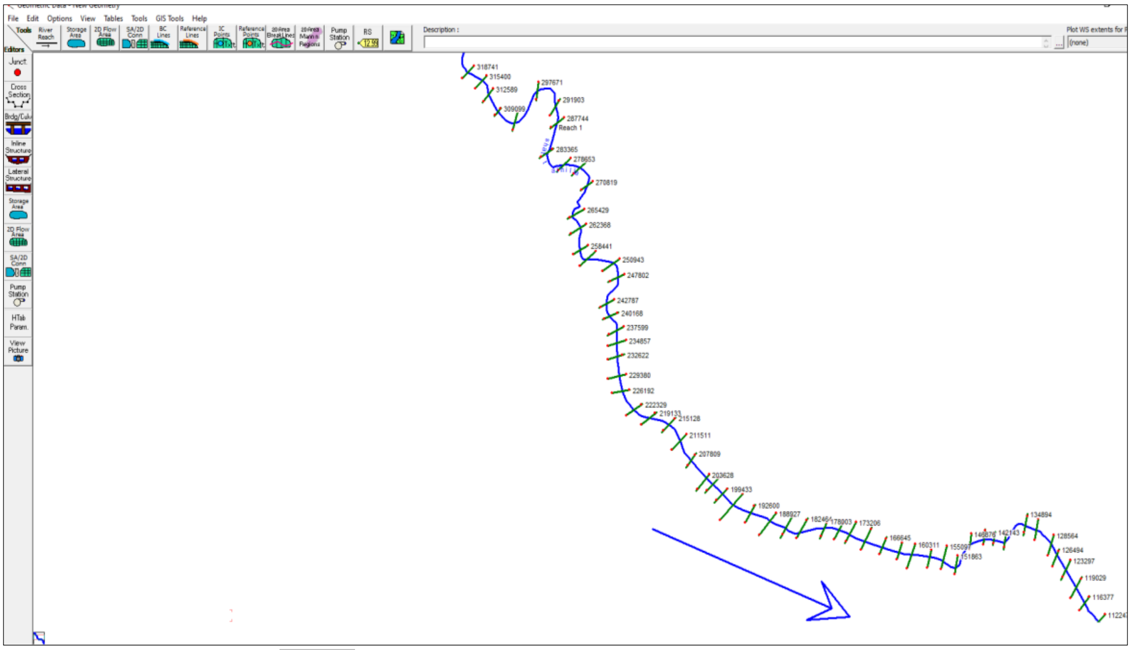


Fig. 4 HEC-RAS Model Edit Geometry Window.

3.METHODOLOGY

3.1.Governing Equations

The 1D hydraulic model computes cross-sectional average water surface elevation (WSE) and velocity at discrete cross-sections by solving a full version of 1D Saint-Venant equations using the implicit finite difference method.

1. Continuity Equation

The one-dimensional form of the Saint-Venant continuity equation can be written in the following form [21].

$$\frac{dQ}{dt} + \frac{dA}{dt} = ql \qquad \textbf{(1)}$$

2.Momentum Equation

One-dimensional momentum equation [21] can be expressed as:

$$\frac{dQ}{dt} + \frac{dv.Q}{dx} + gA\left(\frac{dy}{dx} + s_o + sf\right) = 0 \qquad \textbf{(2)}$$

where A = cross-sectional area of flow, V = an average water velocity, x = distance along the channel, y = channel height, B = width of water surface, g = gravitational acceleration, qL = lateral flow to each unit length of the channel, t = time, Sf= slope of friction, and So= channel bed slope. HEC-RAS (Hydrologic Engineering Centers-River Analysis System) is a widely used software for modeling and analyzing river hydraulics, including 1D flow scenarios and flood forecasting. Fig. 5 shows a step-by-step methodology for simulating 1D flow scenarios under current conditions and forecasting floods in the future using HEC-RAS.

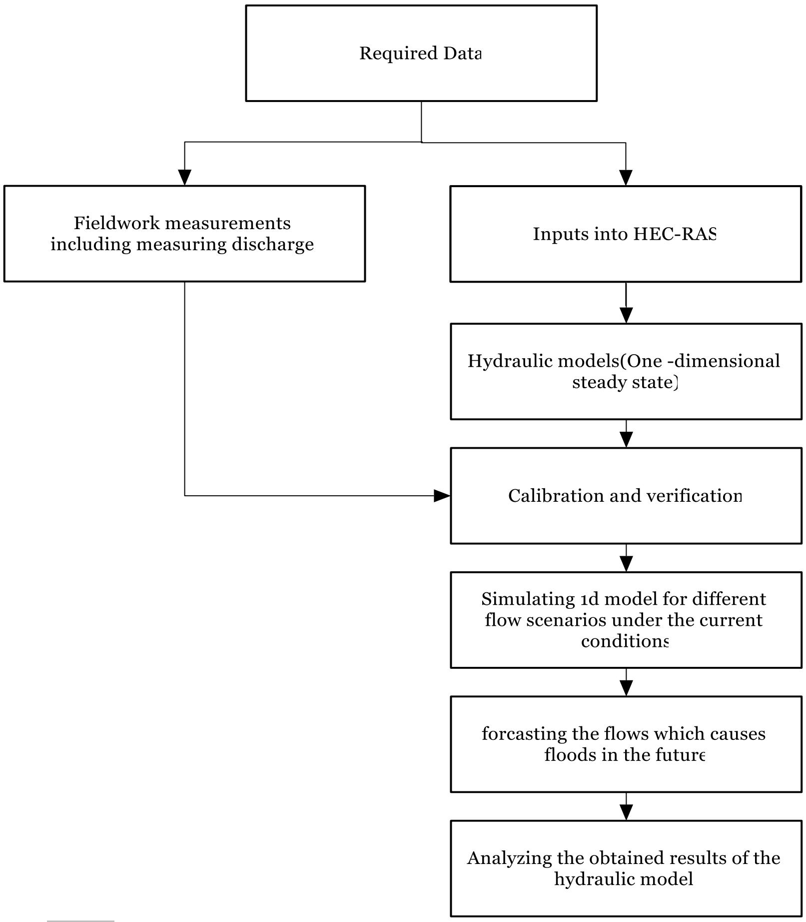


Fig.5 The Schematic Diagram of the Research Methodology.

3.2.The Calibration of the HEC-RAS Model

Manning's roughness coefficient is the most sensitive parameter in river simulation. It must be carefully checked to calibrate Manning's roughness coefficient value for a river by modeling the flows using the HEC-RAS model and considering the study distance. Calibration involves an inverse mathematical problem, which requires determining the original and local parameters that describe a function based on specific variables within a given measurement dataset. Initially, hydrodynamic model calibration was performed manually. This calibration involves modifying parameter settings to minimize the target function while accurately representing the river and considering the parameter ranges for various flow conditions. The Root Mean Square Error (Eq. 1) and the Nash-Sutcliffe Efficiency Criteria (Eq. 2), which compare the observed and simulated data, are the most used objective functions [22].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(oi - si)^2} \qquad \textbf{(3)}$$

Where n= number of data, oi =observed water level, and si = Simulated water level.

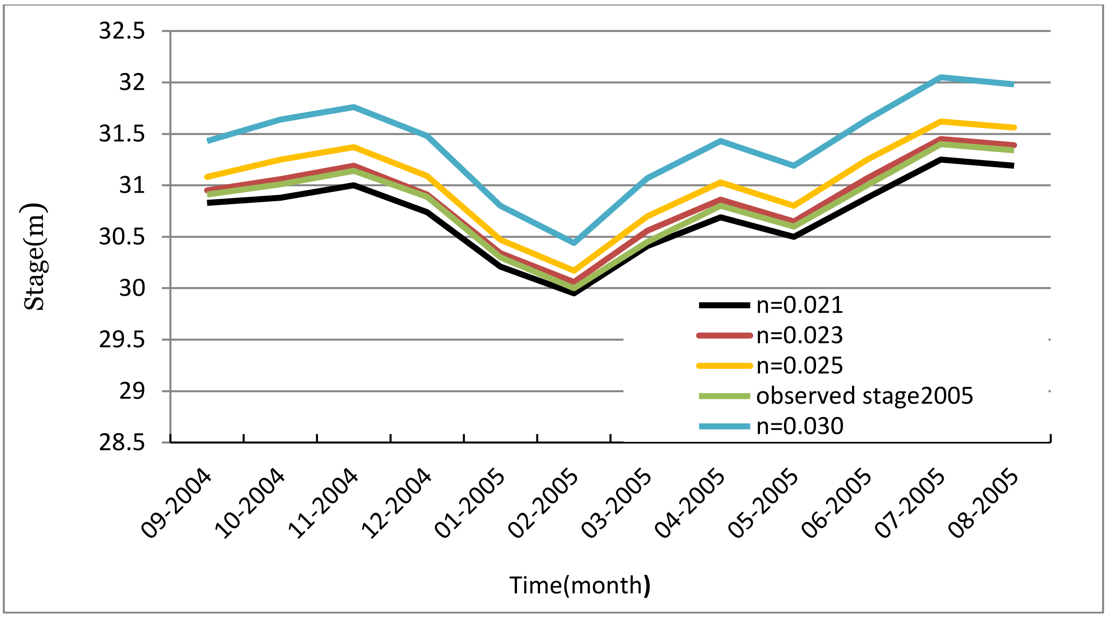
$$NSE = 1 - \frac{\sum_{i=1}^{n}(oi - si)^2}{\sum_{i=1}^{n}(oi - \bar{o})^2} = 1 - (\frac{RMSE}{SD})^2 \qquad \textbf{(4)}$$

where $\bar{O}$ = the mean of the observed values, and SD = the standard deviation of the observations.

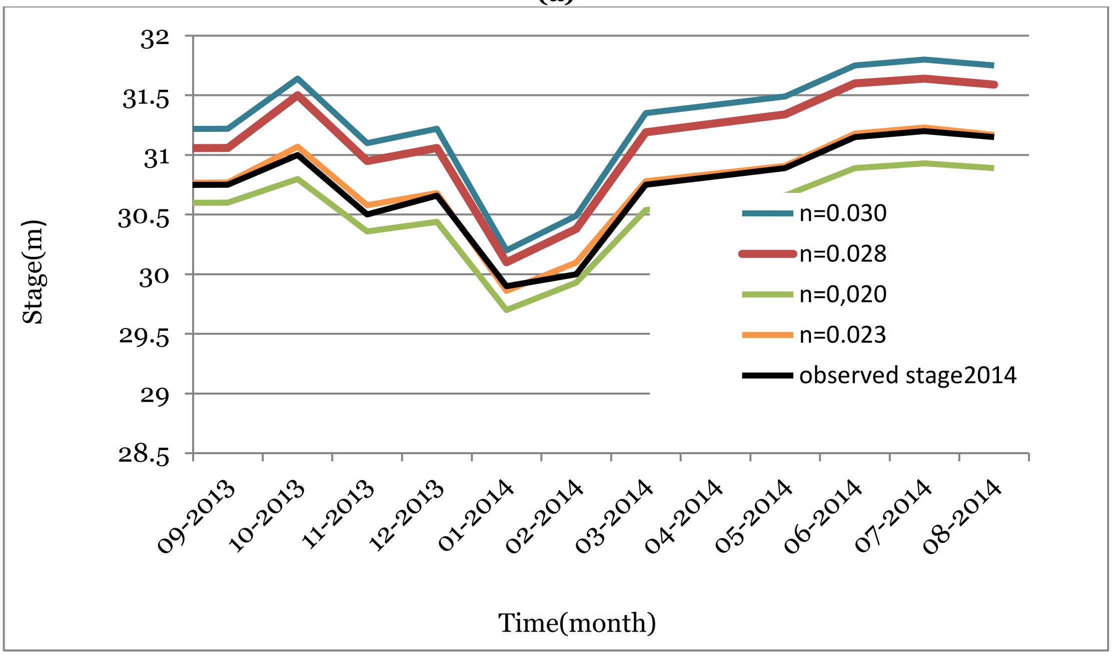
4. RESULTS AND DISCUSSION

4.1.Calibration and Verification

The unsteady flow HEC-RAS model results showed that the 'n' values fall within the range of 0.020 to 0.030 for Shatt Al-Hillah. The river's measurement stages were subjected to several uncertainties, typically associated with hydrographic data. Fig. 6 displays a comparison between the simulated and observed stages for various values of Manning's roughness coefficient (n), where the specific value for Shatt Al-Hillah was 0.023. A statistical test was employed to compare the computed results with the corresponding observed ones. The Root Mean Square Error (R.M.S.E) test, Eq. (1), and the Nash-Sutcliffe Efficiency Criteria (NSE) were used to compare the computed and observed stages. Table 1 presents the model results for these values of 'n' and a specified time step (Δt = 1 month), including calibration results for the statistical test.



(a)



(b)

Fig. 6 Comparison between the Calculated and Observed Stage Hydrographs for Shatt Al-Hillah Different Values of Manning's Roughness **(a)** During the Water Year 2005, **(b)** During the Water Year 2014.

Table 1 The calibration results of the Statistical Test for the Shatt Al-Hillah Cross-Section.

The values of 'n'	R.M.S.E. values	NSE values
0.020	0.205	0.77
0.021	0.115	0.917
0.023	0.058	0.979
0.025	0.214	0.712
0.028	0.407	0.098
0.030	0.593	-1.196

4.2.The Capacity of The Shatt Al-Hillah River and Forecasting Future Floods

Increases in assumed discharge and various lateral inflow and outflow scenarios were employed to estimate the discharge capacity of Shatt Al-Hillah until critical discharge levels could lead to flooding. It was determined that the main channel of the reach can fully accommodate discharges below 205 m^3/s. Water surface elevations reach the floodplain at multiple points when discharges exceed 205 m^3/s. This finding applies to both scenarios: no lateral inflows were detected in the first case, while a lateral inflow was observed in the second case. The water surface elevations along the affected locations are depicted in Fig. 7. At a discharge of 205 m^3/s, clearly demonstrating that the water levels enter the floodplain at several points. As the discharge surpassed 205 m^3/s, the hydraulic model indicated a shift in the river's movement. Certain sections within the study area start experiencing water overflow. This phenomenon intensifies as the discharge continues to rise. A critical threshold was reached at a discharge of approximately 450 m3/s. Beyond this point, a significant portion of the river's sections became susceptible to overflow, resulting in widespread floods. Fig. 7 visually represents the river's behavior under various discharges, emphasizing the critical point at which many sections become inundated. This insight is essential for comprehending the river's flood dynamics and implementing effective flood mitigation strategies in the region. Figs. 8, 9, and 10 illustrate the anticipated flooding in several cross-sections at a discharge of 313 m3/s within the HEC-RAS model.

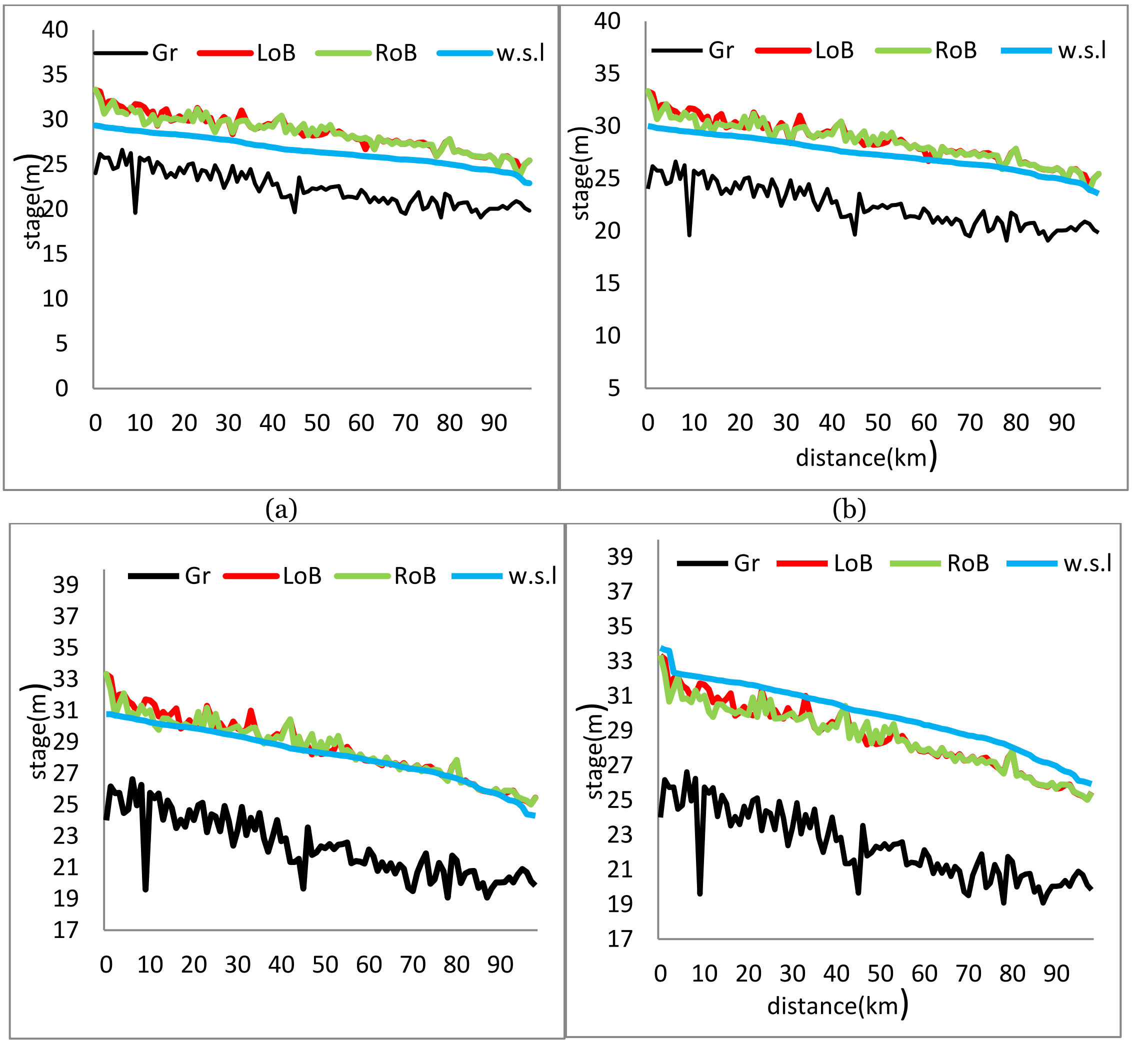


Fig. 7 Shatt Al-Hillah's Water Surface Elevation at the Current Condition Scenario:(a) with a Discharge of 150 m^3 /s, (b) with a Discharge of 205 m^3 /s, (c) with a Discharge of 303m^3 /s, and (d) with a Discharge of 450 m^3 /s.

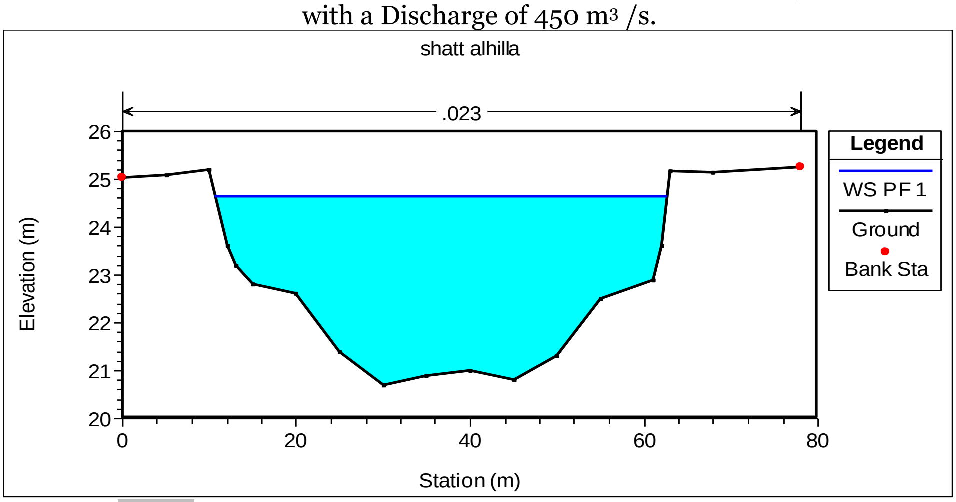


Fig.8 The Output of Cross Section Profile at Station 96+000.

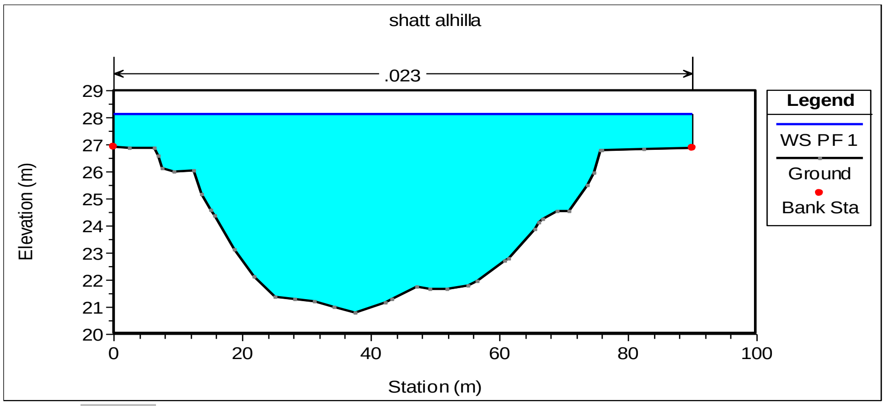


Fig. 9 The Output of Cross Section Profile at Station 66+500.

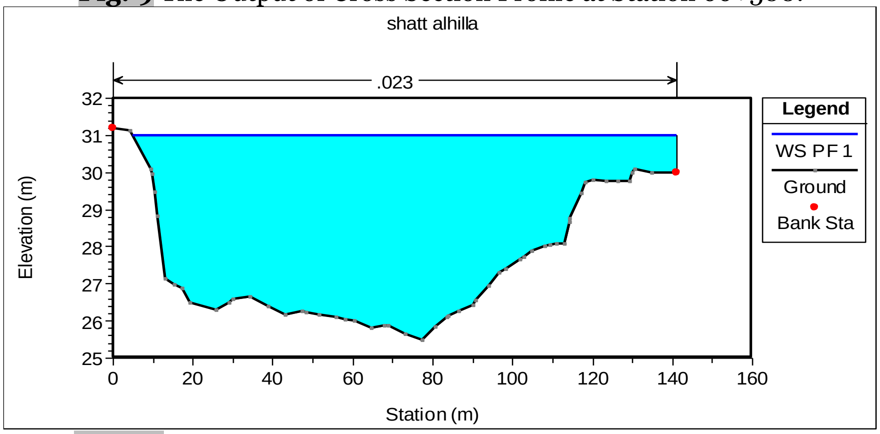


Fig. 10 The Output of Cross Section Profile at Station 10+750.

4.CONCLUSIONS

In conclusion, this paper comprehensively analyzed the Hillah River's movement under different flow scenarios, identified critical discharge thresholds, and provided valuable insights for flood management and mitigation efforts in the studied region. Combining field data collection and hydraulic modeling using HEC-RAS contributes to a better understanding of flood risk and informs decision-making for future flood preparedness and response. The following major conclusions have been driven through the results analysis:

- The calibrated model identified a suitable roughness coefficient (0.023) for unstable flow conditions, with a minimal mean square root error (0.058) and the Nash-Sutcliffe Efficiency (0.979) between the measured and simulated water levels.
- The simulation revealed that Shatt Al-Hillah could handle discharges up to 205 m^3/s without causing flooding. Beyond this threshold, water levels increased, resulting in flooding in various sections of the river.
- A critical discharge of approximately 450 m^3/s was identified as the point where many river sections became susceptible to overflow, resulting in widespread flooding.
- Visual representations (Fig. 7) showed the river's movement under different discharges, highlighting the critical threshold for flood scenarios. The current maximum discharge of Shatt al Hilla stands at 205m^3/s, falling short of the designed capacity of 303m^3/s. It is, therefore, necessary to develop the river to carry the designed discharge. Addressing this shortfall is crucial for optimizing the river's functionality and ensuring its effectiveness for various purposes, such as irrigation and flood control.
- This study provides essential insights into the flood dynamics of the Hillah River. It informs the development of effective flood and future mitigation strategies in the region, ensuring the safety and resilience of the communities it serves.
- The results have indicated that the north riverbanks are more susceptible to flooding than the south side of the study area, primarily because of the lower ground elevation along the south riverbank. The extent of these flooded areas would expand with higher river discharge levels.

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NOMENCLATURE

n	Manning's roughness
RMSE	Root Mean Square Error
NSE	Nash-Sutcliffe Efficiency Criteria
Gr	Ground level
LOB	Left of bank
ROB	Right of bank
w.s.l	Water surface level

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