Magazine of Civil Engineering. 2025. 18(3). Article No. 13509

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 624.011.1

DOI: 10.34910/MCE.135.9

CES-based model to predict the river rating curve

L.A.R. Alasadi ✉ , ***T.H. Khlif, F.A. Hassan***

Department of Structures and Water Resources – Faculty of Engineering, University of Kufa, Najaf, Iraq

✉ *laitha.alasadi@uokufa.edu.iq*

Keywords: Kufa River, CES model, conveyance estimation system, rating curve

Abstract. Effective control of irrigation schemes and water resources is heavily dependent on the exact river discharge estimates, which are usually estimated by measuring the water level through phase-deviation conditions or rankings. However, the direct measurement of the river flow is often impractical or prohibitively expensive, which reveals the need for a reliable future model. The study focuses on the KUFA River in Iraq and applies the Transport Stimulation System (CES) model to estimate its assessment curve. The CES model integrates hydraulic geometry, channel succession, and flow resistance parameters to generate stage-discharge curves, while its "uncertainty estimates" also stand for underlying uncertainties through the component. Model assumptions were validated against the area measurement collected in several cross sections along the Kufa River.

To assess the accuracy of the model, statistical indicators, including prejudice, absolute errors (MAE), and Nash-Sutcliffe Efficiency (NSE) were calculated. The results revealed a strong agreement between CES-PRE-prescribed assessment curves and the observed field data, with most measured values falling within the limit. This river shows the reliability of the CES model to capture complex interactions between river morphology and flow resistance, even under different field conditions.

Conclusions suggest that the CES model is a valuable tool for hydraulic engineers and managers of water resources, which enables more informed decisions on the design and operation of river control, irrigation planning, and hydraulic structures. The ability to accommodate changes in channelling and morphology supports its application in the dynamic environment where the functions of the river develop seasonally or are caused by man-made effects. Overall, the CES model increases the future accuracy and supports the use of permanent water in the Al-Kufa River Basin.

Citation: Alasadi, L.A., Khlif, T.H., Hassan, F.A. CES-based model to predict the river rating curve. Magazine of Civil Engineering. 2025. 18(3). Article no. 13509. DOI: 10.34910/MCE.135.9

1. Introduction

Estimating water levels (stages) and river discharges is essential for effective water engineering management. Measuring the flow at a river's cross-section is usually impractical or highly costly. On the other hand, stages can be monitored continuously or at regular short periods with a relatively low amount of effort and cost. The relation between the stage and the discharge is known as the stage-discharge relation or the stage-discharge rating. Both terms refer to the same concept. This relationship can only exist at a specific location and a particular time [1].

Superficial stage-discharge relationships exist, in which discharge depends only on stage. Complex stage-discharge relationships arise when additional variables, such as the slope of the energy line or the stage change rate over time, are needed to define the relationship. An orthogonal plot of the experimental stage and discharge data can be used to determine whether a specific rating curve is necessary. This can be done by displaying the data on the graph. Because of the scatter on the plot, a reasonably precise estimate of the stage-discharge relationship required for the cross-section can be obtained.

As part of the stage-discharge method, a discharge is assumed to be identified for each stage. The rating curve changes with time whenever there is a change in the influencing factors, such as the growth of weeds at the cross-section and the exposure of the canal section to erosion and sedimentation factors. Rating curve errors can result from misidentifying patterns of change over time or mischaracterizing the curve at a certain point.

One of the 2D models used in estimating the rating curve at a specific cross-section is called Conveyance Estimation System (CES). The modeling equations contain various terms that correspond to the inputs for this two-dimensional method, such as the river's geometry and its parameters. On the other hand, the roughness coefficient plays a crucial role in establishing the grading curve. Several different approaches can be taken to anticipate this roughness factor. Empirical equations are taken into consideration in the published research. These equations require easily quantifiable variables that reliably exhibit both on-site and between-site impacts on resistance, and they necessitate that these variables be consistent [2]. Equations that can be used to forecast the roughness factor often have a margin of error of roughly 30 percent because they were generated by taking the typical variance across multiple sites as their starting point [3]

The form the rating curve takes and the changes the channel undergoes over time are rarely fully characterized by the gauges available in practice [4–6].

Used the current stage and discharge data to forecast discharge by combining stage, antecedent stages, and antecedent discharge values [7, 8]. Employed the Generalized Reduced Gradient (GRG) technique to find the rating curve's parameters. The rating curve for use at two different gauging locations in the United States, Walton on the Choctawhatchee River and Philadelphia on the Schuylkill River, was modeled using a spreadsheet-based nonlinear optimization approach. The stage-discharge correlations for the two sites were also created using a Genetic Algorithm (G.A.) and the more conventional approach of rating curves. According to the findings, rating curve equations established with the GRG approach are just as successful as those developed with the G.A. method. They are more accurate than the conventional rating curve method [9].

To measure the theoretical stage-discharge relationship in British Columbia for four field locations, a one-dimensional model is employed; each of these locations has varying sediment supply, hydrology, bed structure, and bed stability at different levels. The calculations were carried out at four other locations in British Columbia. The findings are consistent with the observations made by the Canada Water Survey, and the spatial diversity of the geomorphology within the channel reach produces variations in stage-discharge correlations. The presence of high silt accentuates these alterations. Alfa et al. developed a stage-discharge relationship for the Nigeria River (Ofu), where streamflow data are scarce. This was done because the design of water resource projects has been hindered by the lack of information [10–12]. The discharge was measured using a Valeport Current Meter from February 2016 to January 2017, and the stage measurement was obtained with a staff gauge at the Oforachi Bridge hydrometric station. Both measurements were taken simultaneously. Using regression analysis, we used the results of the discharge and stage measurements to specify the coefficient of the curve and the equation of the rating curve for the river at this specified station. Because the Oforachi Bridge acts as a constant control, the curvature may be relied upon. Water level discharge in a straight channel was estimated using the CES model. Use the CES model to confirm the assessment curve through experimental function. When using CES models and uncertainty estimates, the assessment curve was estimated using geometric and hydraulic data from experimental studies. Conclusions suggest that the step discharge curve manufactured by the CES model can match experimental values.

Analyzed the CES model to explore its capabilities for prediction [13–15]. The researchers demonstrate that using a suitable description of roughness is crucial. For instance, the optimum model result is achieved by using a roughness factor that has been calibrated for the entire cross-section, and the roughness magnitude is determined for banks using the CES roughness advisor. The current study aims to predict the water level-discharge curve to the Al-Kufa River using the CES. The importance of studying the rating curve of the Al-Kufa River stems from its significance in providing irrigation water for the agricultural lands it passes through and the population gatherings it serves. Therefore, it is considered the primary water source in the study area. And suffers from the impact residues of agricultural and civil activities [16–18].

The shape of the rating curve determines how well the rated channel characteristics resist flow. The more excellent the resistance, the deeper the water must transport a particular flow volume in a given amount of time. The measured phases are converted into the relevant discharges using the established rating relationship. A rating curve can be graphically depicted in its simplest form, as shown in Figure 1, by the average curve fitting, at any river section, the plot of scatter type between discharge (as abscissa) and water level (as ordinate) [19, 20].

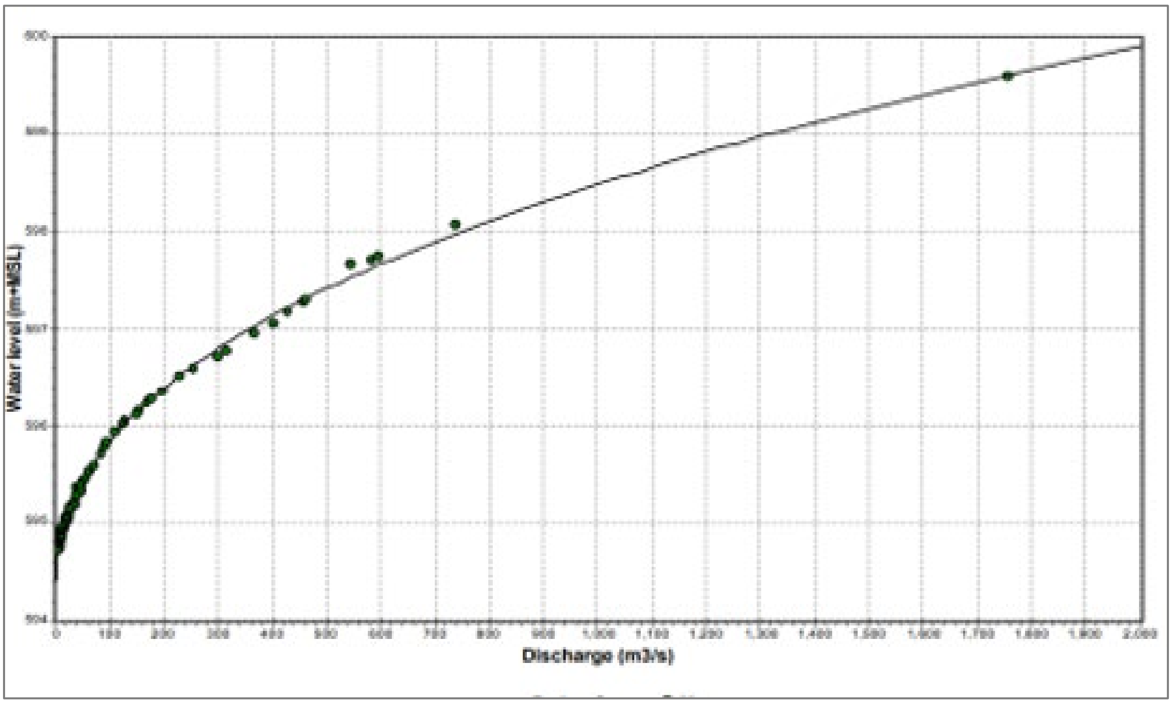


Figure 1. Typical simple rating curve.

The relationship can be represented analytically as $Q = f(h)$, where $f(h)$ is a function of water level. If we consider h and Q to be the water level and discharge, respectively, then the relationship between them can be presented as follows. Compared to an algebraic relationship, a graphical stage-discharge curve makes it much simpler to visualize the relationship and manually convert stages to discharges. However, an algebraic relationship is preferable for use in analytical transformation. The calibration of the rating curve equation is accomplished using field observations of water level and discharge [21, 22].

The stage-discharge rating's mathematical equation, known as Equation 1, establishes a connection between the actual channel control design and the shape of the rating curve [8, 23]. The variables that determine the relationship in this equation between stage (H) and discharge (Q) are a coefficient (C_o), an offset (e), and an exponent. These characteristics, in turn, relate to the channel's size, flow resistance, control level, and control form (Equation 1):

$$Q = C_o(H - e)^{\beta}. \quad (1)$$

The rating equation is primarily founded on the continuity equation, which may be found in Equation 2:

$$Q = V * A. \quad (2)$$

When applied to situations that involve open channels, the stage-discharge connection can be described as the product of a stage-velocity function and a stage-area function [4]. The geometry of the control section dictates the stage-area function, whereas flow resistance forms primarily determine the stage-velocity function. The geometry of the control section controls the stage-area function.

According to [3], the flow refers to the velocity of the cross-section being affected by elements that can be represented in the friction loss equation in its general form. Which is Equation 3:

$$V = C_1 R^x S^y, \quad (3)$$

where velocity(V) will be calculated by the product of C_1 (factor of flow resistance), S (friction slope), and R (hydraulic radius), the symbols *x* and *y* are exponents utilized to symbolize channel conditions in different cases [3].

With exponents of 0.5 and 0.67, respectively, for *y* and *x*, the Manning variation (also known as Gauckler–Manning or Gauckler–Manning–Strickler variation) (Equation 4) is the one that can be relied upon the most when dealing with open channel control situations:

$$V = \mu^{-1} R^{0.67} S^{0.5}. \quad (4)$$

In the Manning equation, the flow resistance factor is not the coefficient of friction as one might expect, but rather the inverse of the friction factor (C_1). When it comes to field measurements, the unlimited values of friction factor and slope in Equation 4 are not nearly as essential as the net change in flow resistance with time; instead, what counts most is the net change.

As shown by Equation 5 (Equation 4), the friction loss equation can simplify its complexity by combining the friction factor and slope components into a single element. This simplification is demonstrated by equation (C_2):

$$V = C_2 R^{0.67}\ . \tag{5}$$

Generally, it is safe to assume that the coefficient C_2 (net flow resistance) will fluctuate around the unity value when referring to alluvial channels [24]. During such times when C_2 does not change, the value of V is a function of the hydraulic radius. A modified friction loss equation (Equation 6) is derived to enhance the functional usefulness of removing an offset value (i.e., $H - e$) and utilizing the monitoring stage as a continuous measure of depth:

$$V = C_2 (H - e)^{0.67} \tag{6}$$

2. Materials and Methods

2.1. Description of the Case Study (Al-Kufa River)

Al-Kufa River, which branches from the Euphrates River, is about 5 km south of the city of Al-Kifl, and it enters the Najaf Governorate at the center of the Al-Kufa district after branching. It is called a local name (Shatt al-Kufa) concerning the area, in which it is located. It passes through it, as its length within the governorate is 28 km, and it flows through the Shatt al-Kufa in the center of the Al-Kufa district, with the outflows controlled by the Al-Kufa Barrage. The current study's scope extends from the Al-Kufa Barrage to the Al-Kufa Bridge, covering a distance of 17.7 Km. The average bed slope ranges from 7 to 12 centimeters per kilometer. The total area of agricultural lands that benefit from the waters of the Al-Kufa River is estimated at 150 acres. The barrage's intended outflow is 1400 m^3 /sec, and the upstream water level is 25.70 m above sea level. There are 7 slots, each measuring 6.312 m in length. The importance of studying the rating curve of the Al-Kufa River comes from its significance in providing irrigation water for the agricultural lands it passes through and the gatherings of the population. Therefore, it is considered the primary water source in the study area. And suffers from the impact residues of agricultural and civil activities, extending from the AL-Kufa Barrage to the Al-Kufa Bridge, as depicted in Figure 2.

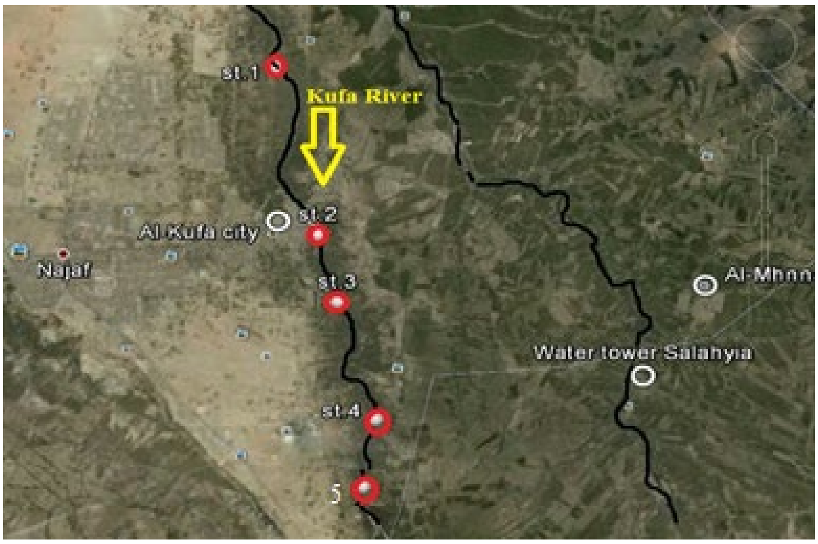


Figure 2. The selected reach from Al-Kufa Barrage to Al-Kufa Bridge.

2.2. CES Rating Curve Model

In the CES, the conveyance is estimated using gravitational acceleration, channel slope, surface friction, and stream morphology. CES comprises a "Roughness Advisor", which advises on resistance, and a "Conveyance Generator", which evaluates the roughness and morphology of the channel to arrive at a capacity estimate for the channel. In addition, the CES consists of a third component known as an "Uncertainty Estimator", which is responsible for indicating the uncertainties connected to the conveyance calculations. Outputs of the CES model include the uncertainty estimator, the roughness advisor (which provides roughness values), the conveyance generator (which provides stage-flow values), and the roughness values (upper and lower bounds for the stage-flow curve). The channel's degree of unevenness is the primary line of defense against pressure imbalances or other influences that can impact fluid flow. The resistance is equal to the aggregate of the effects caused by all the resisting materials present in the channel, including things like the size of the bed material, the relative roughness of the bed, vegetation, impediments, fluctuations in channel width and depth, and channel curvature (e.g., relative bed roughness, material size, obstructions, vegetation, variations in channel depth and width, and channel curvature). The nature of this resistant force needs to be understood to determine the water level accurately. This is because a more significant resistance will result in a slower flow and a higher water level.

To reduce the uncertainty in water levels, the Department of Environment, Food and Rural Affairs created CES model. To help the decision makers make better decisions, they decided the level of uncertainty around the water level with a special flow rate and conveyed the uncertainty in a way that it was easy to understand. The CES model uses the average Navier–Stokes equations for flow, and its data processing method is controlled by deeply integrated Reynolds. The parameters of the model, including the secondary flow and Eddy viscosity, appear to remain stable based on the calibration basis within CES model. These parameters are put on their best performance values after completely analyzed. Consequently, the roughness field is the roughness values and their cross-sectional experts are calibrated. Therefore, changes in the roughness level have the most impact on the water level. [25].

This article collects all relevant hydraulic and geometric data on the Al-Kufa River. Cross sections are produced using displacement (*x*) and height (*Z*) data. The top and lower values of the roughness coefficient for staffing working in the CES model were determined by grain rumors, cross-sectional rule of control, murder patterns and access to pool point rod (Table 1). The equation adopted by the CES model was used to estimate the unity of the device:

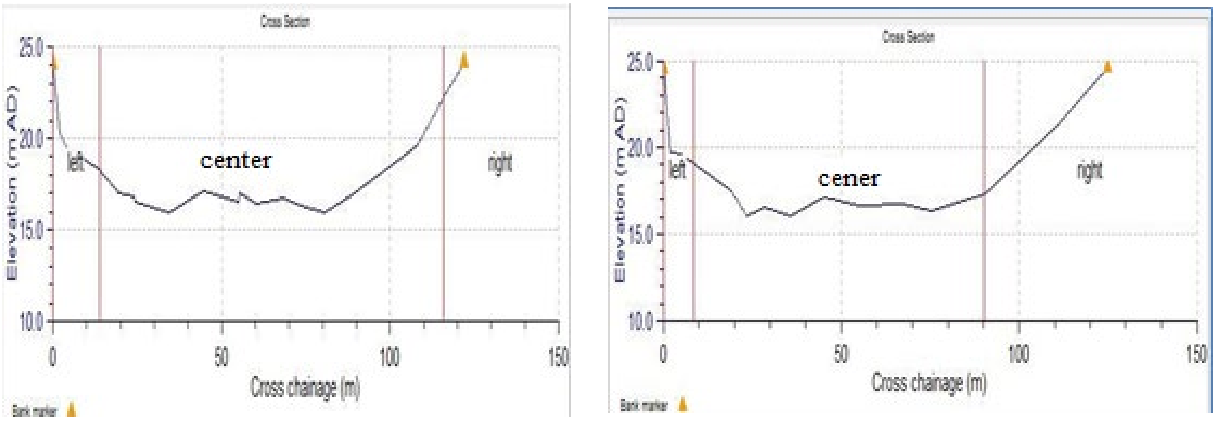
$$n^* = (n_{or}^2 + n_{IRR}^2 + n_{veg}^2)^{1/2}, \quad (7)$$

where n_{sur}, n_{IRR} and n_{veg} represent roughness values, respectively, caused by vegetation, surface materials and irregularities.

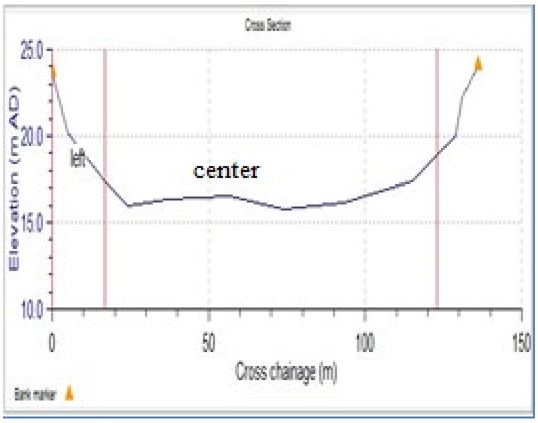
Table 1. The selected minimum and maximum roughness values.

Zone type	Feature	Lower resistance	Unit roughness*	Upper resistance	Unit roughness*
River bed	skin friction	0.018	0.0196*	0.03	0.036*
	bed form	0.008		0.02	
Right and left banks	skin friction	0.017	0.026*	0.029	0.043*
	deposition and pool	0.020		0.033	

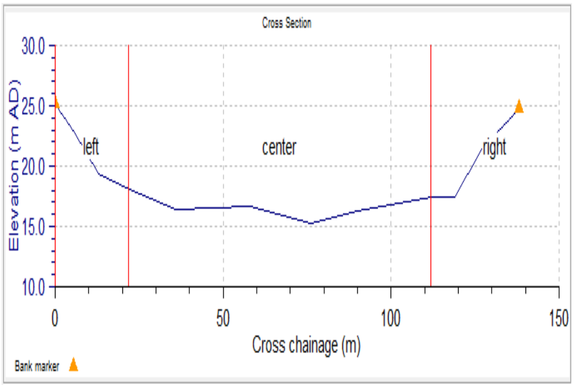
Figure 3 illustrates the distribution of roughness zone for the selected five cross-sections. When all the hydraulic and geometric variables have been allocated, it is possible to estimate the CES stage-discharge curve.



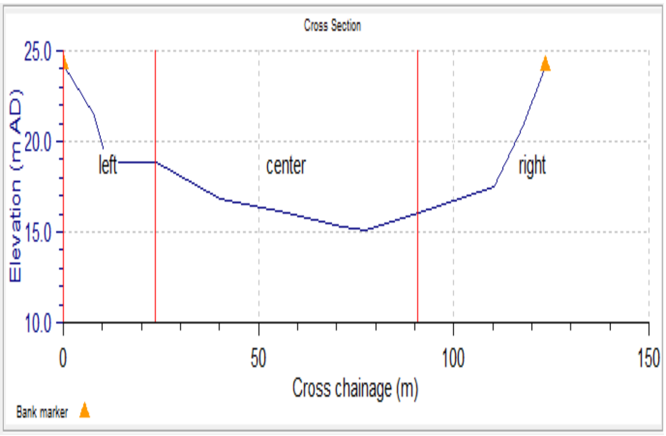
CS1 **CS2**



CS3



CS4



CS5

Figure 3. Cross sections CS1, CS2, CS3, CS4, and CS5.

3. Results and Discussion

3.1. Results of the CES Model

The data used for CES validation were taken from a measured rating curve in five cross-sections, which were compared with the model's outcomes. Five cross-sections (CS1, CS2, CS3, CS4, and CS5) were used in constructing the stage-discharge curves, which encompassed both the lower and top regions of roughness uncertainty (i.e., the maximum and minimum values of Manning roughness). The terms "central", "upper", and "lower" are used to refer to these three curves. The higher and lower curves, both caused by roughness uncertainty, are presented concurrently with the center rating curve to highlight the impact of roughness uncertainty on the central rating curve. Figures 4 through 8 present a comparative analysis of the rating curves for the various cross-sections.

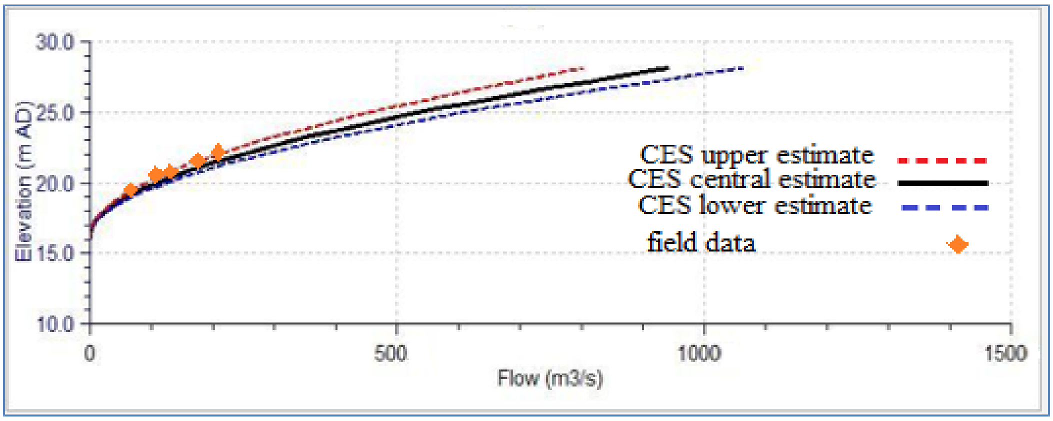


Figure 4. CES stage-discharge curve for CS1.

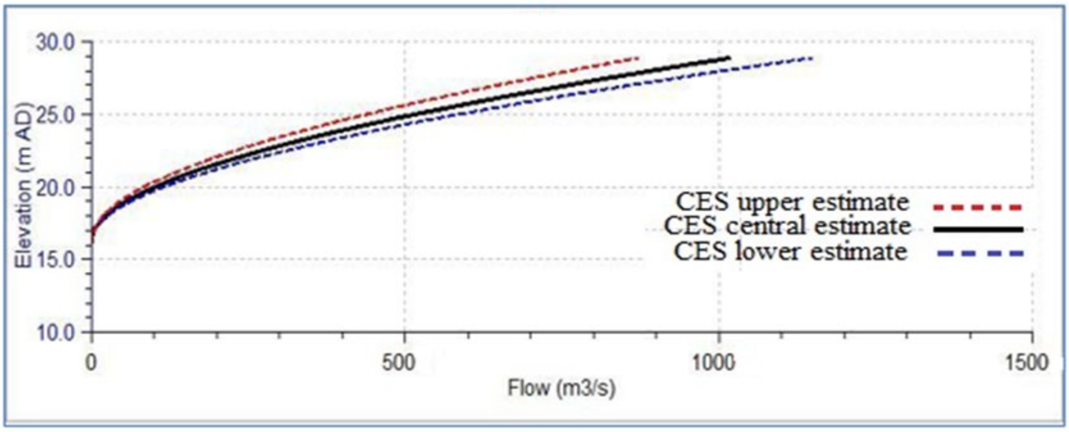


Figure 5. CES stage-discharge curve for CS2.

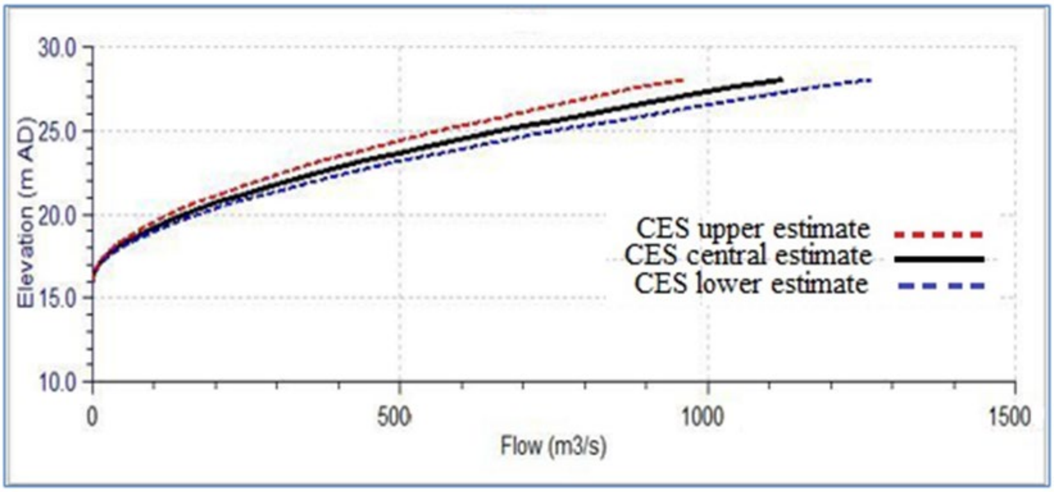


Figure 6. CES stage-discharge curve for CS3.

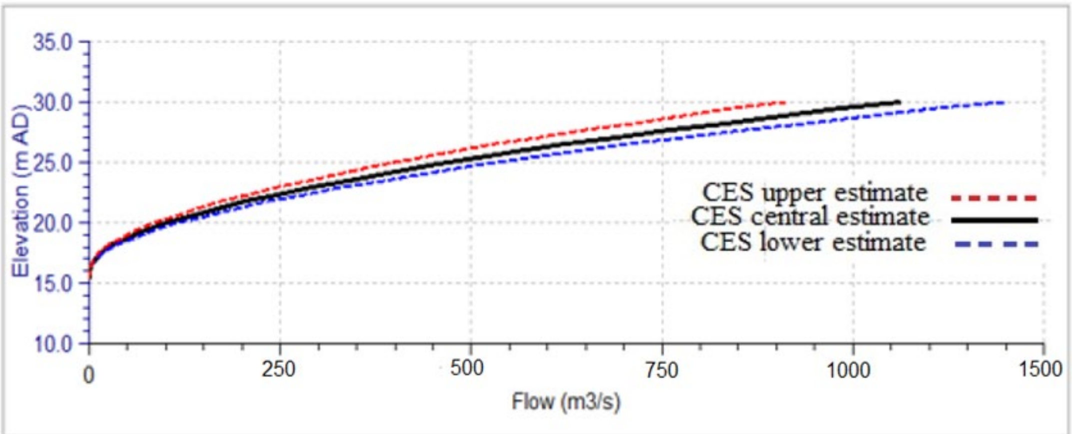


Figure 7. CES stage-discharge curve for CS4.

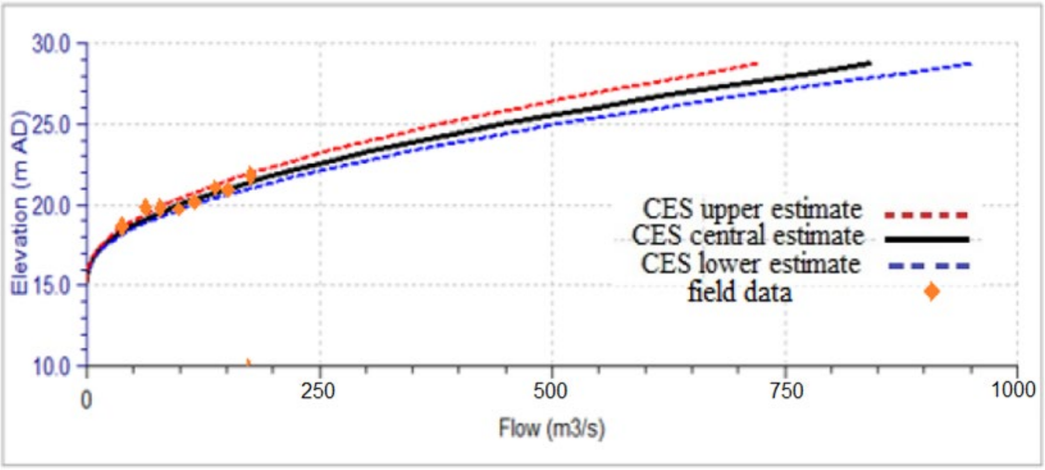


Figure 8. CES stage-discharge curve for CS5.

The findings of the CES were compared to the field data in the study's cross-sections (CS1 and CS5). These cross-sections were selected because field data is available on the water level and the discharge. Figure 4 illustrates that the computed and measured data match and that the field data falls within the uncertainty limits. Additionally, the uncertainty ranges are displayed. However, it is getting closer and closer to the maximum allowed. Figure 8 illustrates the distribution and trend of field data in comparison to the stage-discharge curve predicted for CS5.

On the other hand, the data collected in the field are located inside the uncertainty ranges and are thus much closer to the central estimate. The simulations demonstrate that the CES model can generate a curve of stage-discharge agree with the findings obtained in the field. According to the data presented, an increase in the forecasted roughness value leads to increase in both the water level and discharge, and vice versa. Despite some inconsistencies throughout the process at various phases, the CES model produced satisfactory results. Exploring the possibility of a better cross-sectional description of roughness leads to an accurate estimate of the discharge data and the water depth, which in turn helps make informed decisions in water management, particularly in the irrigation sector and other water uses, especially in areas where water is scarce.

3.2. Statistical Analysis

The Bias, Mean Absolute Error (MAE), and Nash–Sutcliffe Efficiency (NSE) are three statistical indicators used to assess the accuracy of the model results. These indicators were calculated using the following equations:

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(X_{estimate} - X_{field}) \tag{8}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|X_{estimate} - X_{field}\right| \tag{9}$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{N}\left(X_{field} - X_{estimate}\right)^2}{\sum_{i=1}^{N}\left(X_{field} - X_{field}\right)^2}\right] \tag{10}$$

$X_{estimate}$ and X_{field} denote the estimated and field values, respectively, while the number of measured data is represented by N. The best value for $BIAS$ is 0; positive values indicate a propensity to overpredict, while negative values indicate a tendency to underpredict the actual values observed. $BIAS$ evaluates the tendency of the anticipated values to be larger or smaller than their actual values. An ideal fit is denoted by a mean absolute error value of zero. Came up with the concept of the NSE, which demonstrates how well the plot of observed values vs. anticipated values follows the 1:1 line (line of perfect agreement) [26]. The number 1 represents the NSE that is ideal. However, acceptable performance levels are often between 0 and 1. In contrast, levels below 0 imply that the mean observed value is a better predictor than the simulated value, which indicates undesirable performance [27]. This suggests using this indication.

The statistical assessment of anticipated values for chosen cross-sections is presented in Table 2. The estimated NSE, MAE, and $BIAS$ values revealed acceptable agreement between the central rating curve and the field one.

Table 2. The statistical evaluation.

Cross section	Stage		
	NSE	MAE	$BIAS$
1	0.86	0.013	0.0011
5	0.91	0.053	0.00021

4. Conclusions

The estimated central rating curve and the field one agreed reasonably well, though a slight difference was noted at some stages. This subtle difference was caused by the significant variation of hydraulic and geometric values measured in the field. Good estimation at the stage and acceptance at discharge result from an adequate resistance coefficient. This study concluded that the CES model could be used as an estimation tool for the water engineering field to help in making informed decisions regarding the policies for designing and operating water systems, especially in rivers that are subject to continuously changing the roughness of the sections due to seasonal changes as well as changing the nature of flow in those rivers. It was also recommended to test the model in rivers that suffer from severe meandering to demonstrate its validity for use in those rivers.

References

1. Al-Yousefi, H.A., Kadhem, A.A., Alasadi, L.A.R. Effect of upstream side slope of crump weir on discharge coefficient. Kufa Journal of Engineering. 2024. 15(4). Pp. 69–77. DOI: 10.30572/2018/KJE/150404
2. Ferguson, R. Flow resistance equations for gravel- and boulder-bed streams. Water Resources Research. 2007. 43(5). Article no. W05427. DOI: 10.1029/2006WR005422
3. Bathurst, J.C. At-a-site variation and minimum flow resistance for mountain rivers. Journal of Hydrology. 2002. 269(1–2). Pp. 11–26. DOI: 10.1016/S0022-1694(02)00191-9
4. Manfreda, S. On the derivation of flow rating curves in data-scarce environments. Journal of Hydrology. 2018. 562. Pp. 151–154. DOI: 10.1016/J.JHYDROL.2018.04.058
5. Alasadi, L.A.R., Khlif, T.H., Hassan, F.A. Experimental investigation for the local scour around V-shaped spur-dikes. Scientific Review Engineering and Environmental Sciences. 2023. 32(1). Pp. 69–86. DOI: 10.22630/srees.4506
6. Williams, M.R., Penn, C.J., King, K.W. Hydrologic pathways and nutrient loading in the headwaters of the Western Lake Erie Basin. Journal of Hydrology: Regional Studies. 2025. 58. Article no. 102275. DOI: 10.1016/J.EJRH.2025.102275
7. Al-Abadi, A.M. Modeling of stage–discharge relationship for Gharraf River, southern Iraq using backpropagation artificial neural networks, M5 decision trees, and Takagi–Sugeno inference system technique: a comparative study. Applied Water Science. 2016. 6. Pp. 407–420. DOI: 10.1007/s13201-014-0258-7
8. Chen, B., Lu, Y., Imran, M., Adam, N.A., Jang, J. Evaluating and transferring social value of ecosystem services in urban wetland parks using the SolVES model. Ecological Indicators. 2025. 172. Article no. 113270. DOI: 10.1016/J.ECOLIND.2025.113270
9. Galarza, J.S.C., Castro, L.M.T., Alvarado, E.P.S., Martínez, A.O.A. On the Effect of the Refinement of the Roughness Description in a 2D Approach for a Mountain River: a Case Study. La Granja. 2021. 33(1). Pp. 91–102. DOI: 10.17163/LGR.N33.2021.08
10. Blair, T. Stage discharge estimation using a 1d river hydraulic model and spatially-variable roughness (T). University of British Columbia. Vancouver, 2009. VIII + 64 p. DOI: 10.14288/1.0068608
11. Nguyen, T.T.H., Vu, D.Q., Doan, N.P., Chi, H.T.K., Li, P., Binh, D.V., An, Y., Dung, P.T., Hoang, T.A., Son, M.T. Reconstructing suspended sediment concentrations in the Mekong River Basin via semi-supervised-based deep neural networks. Science of the Total Environment. 2024. 955. Article no. 176758. DOI: 10.1016/J.SCITOTENV.2024.176758
12. Xu, H., Wang, H., Liu, P., Zhang, X., Liu, W., Zhou, C., Ye, H., Lei, H., Liu, Y. What is the near-natural catchment? An application of hydrological signatures assessment. Ecological Indicators. 2025. 171. Article no. 113209. DOI: 10.1016/J.ECOLIND.2025.113209
13. Havaei, M.A., Malekitabar, H. Spherical sustainability in construction and demolition: How aligned are policies, goals, regulations, markets, and stakeholder mindsets? Cleaner Environmental Systems. 2025. 16. Article no. 100256. DOI: 10.1016/J.CESYS.2025.100256
14. Mihalakakou, G., Paravantis, J.A., Nikolaou, P., Menounou, P., Tsangrassoulis, A.E., Malefaki, S., Fotiadi, A., Papadaki, M., Giannakopoulos, E., Romeos, A., Escobar-Hernandez, H.U., Souliotis, M. Earth-sheltered buildings: A review of modeling, energy conservation, daylighting, and noise aspects. Journal of Cleaner Production. 2024. 472. Article no. 143482. DOI: 10.1016/J.JCLEPRO.2024.143482
15. Stelmaszczyk, P., Białkowska, K., Wietecha-Posłuszny, R. Paper-supported polystyrene membranes for micro-solid phase extraction of date-rape drugs from urine: A sustainable analytical approach. Analytica Chimica Acta. 2024. 1316. Article no. 342874. DOI: 10.1016/J.ACA.2024.342874
16. Maatooq, J., Hameed Alwaeli, L. Estimation of reliable Stage-Discharge Curve in meandering river using Conveyance Estimation System (CES) Model. IOP Conference Series: Materials Science and Engineering. 2020. 737. Article no. 012149. DOI: 10.1088/1757-899X/737/1/012149
17. Renfrew, D., Vasilaki, V., Katsou, E. Indicator based multi-criteria decision support systems for wastewater treatment plants. Science of The Total Environment. 2024. 915. Article no. 169903. DOI: 10.1016/J.SCITOTENV.2024.169903

18. Armenta-Castro, A., Núñez-Soto, M.T., Rodriguez-Aguillón, K.O., Aguayo-Acosta, A., Oyervides-Muñoz, M.A., Snyder, S.A., Barceló, D., Saththasivam, J., Lawler, J., Sosa-Hernández, J.E., Parra-Saldívar, R. Urine biomarkers for Alzheimer's disease: A new opportunity for wastewater-based epidemiology? Environment International. 2024. 184. Article no. 108462. DOI: 10.1016/J.ENVINT.2024.108462
19. Rataj, O., Alcorta, L., Raes, J., Yilmaz, E., Riccardo, L.E., Sansini, F. Sustainability vs profitability: Innovating in circular economy financing practices by European banks. Sustainable Production and Consumption. 2025. 53. Pp. 1–16. DOI: 10.1016/J.SPC.2024.11.025
20. Dietzel, M., Boch, R. Precipitation of $CaCO_3$ in natural and man-made aquatic environments – Mechanisms, analogues, and proxies. Geochemistry. 2024. 84(4). Article no. 126206. DOI: 10.1016/J.CHEMER.2024.126206
21. World Meteorological Organization (WMO). Technical Regulations. Basic Documents No. 2. Volume III – Hydrology. WMO. Geneva, 2002. 40 p. URL: https://library.wmo.int/records/item/35631-technical-regulations (reference date: 16.07.2025).
22. Alasadi, L.A.R., Albahrani, H.S., Alwaeli, L.K. Parametric Study for Design and Analysis of Box Culvert by Using Newton's-Raphson Method and MATLAB Software. Key Engineering Materials. 2020. 870. Pp. 11–19. DOI: 10.4028/www.scientific.net/KEM.870.11
23. Lang, M., Pobanz, K., Renard, B., Renouf, E., Sauquet, E. Exptrapolation des courves de tarage par modélisation hydraulique, avec application à l'analyse fréquentielle des crues [Extrapolation of rating curves by hydraulic modelling, with application to flood frequency analysis]. Hydrological Sciences Journal. 2010. 55(6). Pp. 883–898. DOI: 10.1080/02626667.2010.504186
24. Chen, B., Lu, Y., Imran, M., Adam, N.A., Jang, J. Evaluating and transferring social value of ecosystem services in urban wetland parks using the SolVES model. Ecological Indicators. 2025. 172. Article no. 113270. DOI: 10.1016/J.ECOLIND.2025.113270
25. Hamilton, S. Maynard, R., Kenney, T. Comparative Investigation of Canadian, US, and Australian Stage-Discharge Rating Curve Development. Australian Hydrographers Association. Canberra, 2016. 24 p.
26. Fisher, K.R., Dawson, F.H. Reducing Uncertainty in River Flood Conveyance: Roughness Review. Project W5A-057 – DEFRA Flood Management Division & Science Directorate, & Environment Agency. 2003. 204 p.
27. Nash, J.E., Sutcliffe, J.V. River flow forecasting through conceptual models part I – A discussion of principles. Journal of Hydrology. 1970. 10(3). Pp. 282–290. DOI: 10.1016/0022-1694(70)90255-6
28. ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management Committee, Irrigation and Drainage Division. Criteria for Evaluation of Watershed Models. Journal of Irrigation and Drainage Engineering. 1993. 119(3). Pp. 429–442. DOI: 10.1061/(ASCE)0733-9437(1993)119:3(429)

Information about the author:

Layth Abdulrasool Alasadi, *Doctor of Engineering*
ORCID: https://orcid.org/0000-0001-6244-7965
E-mail: laitha.alasadi@uokufa.edu.iq

Tagreed Hameed Khlif,
ORCID: https://orcid.org/0000-0002-0429-796X
E-mail: tagreedh.alabedi@uokufa.edu.iq

Fadhel Abdulabbas Hassan,
ORCID: https://orcid.org/0000-0003-1020-5133
E-mail: fadhil.alshitali@uokufa.edu.iq

Received 15.02.2023. Approved after reviewing 19.10.2023. Accepted 30.01.2025.