Evaluation of Flood Routing Models and Their Relationship to The Hydraulic Properties of The Diyala River Bed

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Abstract. In this study, four types of flood routing approaches were studied which give significantly varied results represented by the differences between computed and observed flows and also differ considerably on the friction coefficient and bed slope of the channels. First two approaches use a hydraulic solution to solve the equations of unsteady flow, while the third approach uses the hydrological solution, and the fourth algorithm solves Muskingum approach with seven parameters. All these approaches were run with the same input parameters, the results were compared and tested with four Error Measurement Indices, Sum of Squared Deviations, Error of Peak Discharge, Variance Index, and agreement index. Diyala River was selected for this application. Dynamic wave method gave accurate results, followed by the characteristic method, and then the linear Muskingum-Cunge method, but Symbiotic Organisms Search Algorithm not gave any senses due to change in roughness or bed slope and gave very identical values with recorded outflow in all conditions, which means that the hydraulic solution is better compared to the hydrological solution. The results also showed that the difference between the calculated and observed flows diminished with a decrease in the coefficient of friction and an increase in the bed slope channel.

1. Introduction

Applications of flood routing are based on the use of the unstable flow theory (long waves or surges) or the basic water storage equation. A flood hydrograph is calculated at a given point in a channel based on a known hydrograph of a location at the upstream or downstream and using known channel characteristics and lateral flow or outflow characteristics,([1], [2], [3] and [4]). The analysis of empirical relationships between inflow and outflow is the starting point for flood routing studies. Mathematical methods used for more accurate predictions of flood wave motion have been developed. The development can be divided into two approaches (hydrological and hydraulic approaches), ([5],[6], [7], [8] and [9]).

Hydrological models have the distinction of being less complex than the hydraulic models, but they have some disadvantages as they require configuring observed inflow and outflow hydrographs from a reach to determine the routing parameters at a particular flow section, as well as not taking into account the effects of the back-water impacts from streams, large tributary flows, dams, and bridges, ([10], [11] and [12]). The physical processes of water movement in the natural channels are the basis for hydraulic models,([13] and [14]). A one-dimensional theory of flood wave propagation was developed by Saint Venant,([15], [16], [17] and [18]). The numerical approach, which does not require any radical simplification, is another method for finding solutions to the equations of unsteady flow, ([19] and
It replaces the derivatives in partial differential equations with finite differences, making the equations appear as simple algebraic equations. Despite the fact that the method deals only with simple algebraic equations, the number of equations is enormous, much greater than empirical methods. To tackle optimization issues, the Symbiotic Organisms Search Algorithm (SOS) is presented as an evolution optimization model. This method employs a population-based search that is divided into three stages. The SOS algorithm mimics symbiotic relationships between two species, allowing one to choose the best partner.

The aim of the research is to prepare an evaluation study of hydraulic models (dynamic wave, the characteristic approaches), hydrological models (linear Muskingum-Cunge approach), and optimization algorithm (SOS) to solve the nonlinear Muskingum approach with seven parameters in flood routing and their relationship to the hydraulic properties of the natural channel basin, and the Diyala river is chosen for its typical flow properties as a case study.

2. Mechanism of the Hydraulic and Hydrological Models

2.1. Dynamic Wave Approach

The implicit nonlinear approximation of the finite difference used to solve the equations of unsteady dynamic flow is referred to as the dynamic wave approach. This approach has been updated to suit the conditions and objectives of this research. To find results, the procedure uses an implicit finite difference, as shown in Figure 1.

![Figure 1: Finite difference approximation method.](image)

$K = 0.5\beta \left[ k_{i+1}^{j+1} + k_{i}^{j+1} \right] + 0.5(1 - \beta) \left[ k_{i+1}^{j} + k_{i}^{j} \right]$  \hspace{1cm} (1)

$\frac{\partial k}{\partial x} = \frac{\beta}{\delta x} \left[ k_{i+1}^{j+1} + k_{i}^{j+1} \right] + \left\{ \frac{1 - \beta}{\delta x} \right\} \left[ k_{i+1}^{j} - k_{i}^{j} \right]$  \hspace{1cm} (2)

$\frac{\partial k}{\partial t} = \frac{1}{2\delta x} \left[ k_{i+1}^{j+1} + k_{i}^{j+1} - k_{i+1}^{j} - k_{i}^{j} \right]$  \hspace{1cm} (3)

Where $\beta$ is a weighting factor.

The continuity equation is classified as a derivative of conservation of mass and momentum, so the equations can be written as follows:

$F(u, y) \frac{\partial u}{\partial t} + \frac{A}{\tau} \frac{\partial u}{\partial x} + U \frac{\partial y}{\partial x} = 0$  \hspace{1cm} (4)

$G(u, y) \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + g \frac{\partial y}{\partial x} + g(S_f - S_o) = 0$  \hspace{1cm} (5)

The finite-differences formula can be used for equations (4) and (5), where I and j denote distance and time phase, respectively.
2.2. Characteristics Approach

According to the characteristics approach, a flood wave is a disturbance of the free water surface, ([22], and [26]). Any interruption in the flow of the open channel spreads in two directions, upstream and downstream at a certain point. In the x-t plane, a pair of turbulence paths can be plotted to move downstream and upstream from point A at time \( t = 0 \). The paths are known as the characteristic lines \( C_1 \) and \( C_2 \). The region between a pair of \( C_1 \) and \( C_2 \), and point A at time \( t > 0 \) represents the turbulence control range. Inversely, one can describe turbulence that can affect the condition at point D by looking back in time, as shown in figure 2. Solutions of unsteady flow can be found using the concepts of characteristic line, control spectrum, and field, [9].

![Figure 2. Influence field and domain. (26).](image)

The mathematical definition of the total derivative shows the following:

\[
\frac{dy}{dx} dx + \frac{dy}{dt} dt = \frac{dy}{dt} \frac{dy}{dt} + \frac{dy}{dt} \frac{dy}{dt} \quad (6)
\]

\( y \) is a function of \( x \) (distance) and \( t \) (time). Equation (6) will show the variation of \( y \).

\[
\frac{du}{dt} = u \pm c \quad (7)
\]

\[
\frac{du}{dt} \pm \frac{1}{c} \frac{dy}{dt} + g(Sf - so) = 0 \quad (8)
\]

In which,

\[
C = (\frac{64k}{T})^{0.5} \quad (9)
\]

Equations (7, 8 and 9) represent the characteristic forms of the unsteady flow equation. In order to find solutions to these equations, the finite difference approximation method is used (either a rectangular grid or a distinct grid of \( C_1 \) and \( C_2 \)).

2.3. Linear Muskingum-Cunge Approach

The Muskingum-Cunge approach ([7], [8], [3] and [17]) is based on mass conservation (i.e., the continuity equation) and the relationship between inflow, outflow, and storage (i.e., storage equation), as follows:

**Continuity procedure:**

\[
\frac{ds}{dt} = I - O \quad (10)
\]

**Storage equation :**

\[
S = K\{Ix + (1 - x)O\} \quad (11)
\]

which : \( S \) = absolute storage within the reach, \( I \) = inflow, \( O \) = outflow, \( x \) = weighing factor,
K= a value related to the time lag or time of the flood wave’s transit across the reach, and the storage gradient against the weighted flow curve. These equations contribute to determining the discharge of the outflow, as follows:

\[ O = C_1 O_n^m + C_2 O_{n+1}^{m+1} + C_3 O_{n+1}^m \]  \hspace{1cm} (12)

\[ C_1 = \left( \frac{\Delta t / k}{\Delta t / k + 2(1-x)} \right) \]  \hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} (13)

Using the kinematic wave equation and assuming a single-value phase discharge relationship, Cunge, ([27] and [12]) developed equation (11), finding that K and x can be calculated using the following formulas:

\[ K = \frac{\Delta X}{C} \]  \hspace{1cm} \hspace{1cm} \hspace{1cm} (14)

\[ X = 0.5 \left\{ 1 - \frac{\text{ow}}{C_5 \Delta X} \right\} \]  \hspace{1cm} (15)

\[ C = \frac{dO}{dA} \]  \hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} \hspace{1cm} (16)

The main aim of computation in any approach is always to produce an accurate response to match the calculated flow result with the observed flow. The method for determining \( \Delta x \) value influencing Muskingum parameter values, is one attempt to achieve an accurate result. As shown in previous studies ([11], [28] and [29]), that the parameter x varies between 0.0 and 0.5, so the following criteria were established to ensure positive outflow for any positive inflow sequences:

\[ X \leq 0.5 \frac{\Delta t}{k} \leq (1 - x) \quad \text{for } x \leq 0.5 \]  \hspace{1cm} (17)

So \( \Delta x \) has to be constrained as follows:

\[ \left( C \Delta t - \frac{\text{ow}}{C_5 \Delta X} \right) \leq \Delta X \leq \left( C \Delta t + \frac{\text{ow}}{C_5 \Delta X} \right) \]  \hspace{1cm} (18)

### 2.4. Symbiotic Organisms Search (SOS) Algorithm

It is one of the presumptive algorithms presented on the basis of interactive behavioral simulation. The use of the SOS as one of the novel meta heuristic approaches for estimating parameters of the nonlinear Muskingum model was investigated in this study. To test the proposed algorithm’s performance, the results of its implementation were compared to those of other approaches such as the Dynamic wave approach, the Characteristic methodology, and the Muskingum-Cunge attitude. The SOS (figure 3), like other population-based algorithms, produces a population of alternatives periodically in order to identify the best answer in the total range of replies. The SOS algorithm starts with a population known as the ecosystem, [30]. A set of decision variables is randomly created in the search space in the first ecosystem. The degree of compliance with the aim is determined by each living creature as a candidate for the solution associated with a specific fit (the value of the objective function). In each iteration, all meta heuristic algorithms use an alternate function to solve a problem and generate a new solution for the next iteration. The algorithm’s overall trend is as follows:

Initialization → Repetition → Mutualism → Commensalism Parasitism → End procedure

after the maximum number of iterations has been reached.
2.4.1. Model Formulation and Optimization

The Non-linear model of type 5 (NL5) ([31] and [32]) is an enhanced variant of this model. The steps to obtain the NL5 model are outlined below:

\[ S_1 = b \left( \frac{I}{d_1} \right)^{m/n_1} \]  \hspace{1cm} (19)

\[ S_o = b \left( \frac{O}{d_2} \right)^{m/n_2} \]  \hspace{1cm} (20)

Where \( d_1 \) and \( n_1 \) represent the river’s upstream depth–flow relationship, and \( d_2 \) and \( n_2 \) represent the river’s downstream depth–flow parameters, substituted \( S_I \) and \( S_o \) from equations (14) and (15) in \( S = [X S_I + (1-X) S_o]^\alpha \)

Simplifying the equation (16) produced,

\[ S = k \left[ X (C_1 I^{\beta_1}) + (1 - X) (C_2 O^{\beta_2}) \right]^\alpha \]  \hspace{1cm} (NL5)  \hspace{1cm} (21)

Where:

\[ K = b^\alpha \]  \hspace{1cm} (22)

\[ \beta_1 = m/n_1 \]  \hspace{1cm} (23)

\[ \beta_2 = m/n_2 \]  \hspace{1cm} (24)

\[ C_1 = \left( \frac{1}{d_1} \right)^{\beta_1} \]  \hspace{1cm} (25)

\[ C_2 = \left( \frac{1}{d_2} \right)^{\beta_2} \]  \hspace{1cm} (26)

Where:

\( I, O \): inflow and outflow rate (m³/s)
K: constant which is larger than (0)
X: The dimensionless weight coefficient for the river is between 0 and 0.5, showing the relative impacts of the input and outflow flow.

β₁, β₂ and α: are the zero-valued exponential parameters. Fixed parameters C₁ and C₂ are both zero.

The Non-Linear model of type 5 contains seven parameters: X, K, β₁, β₂, α, C₁, C₂. One of the other non-linear models is more difficult in this regard. Optimization models are used to optimize these parameters.

2.4.2. Simulation Technique for the Proposed NL5 Model
This study employs [33], to simulate flood routing technique using the NL5 model. The observed inflow, calculated outflow, and computed storage during the iₜth time period in the NL5 model are Iᵢ, Qᵢ* and Sᵢ respectively, where (i = 0, 1, 2..., N) represents the simulation time periods. The following are the steps of the proposed NL5 flood simulation model:

1. Assume the seven hydrologic parameters values (X, K, β₁, β₂, α, C₁, C₂):
   \[ S_0 = k \left[ X(C_1 I^{β_1}) + (1 - X)(C_2 O^{β_2}) \right]^\infty \]
   \[ i=0 \]  (27)

2. Calculate the starting storage S₀ by setting the initial computed outflow to the same value as the initial observed inflow (Q₀* = I₀):
   \[ \Delta S_i \Delta t = I_i \left[ \left( \frac{1}{C_2(1-X)} \right) \left( \frac{S_i}{K} \right)^{1/β_2} - \left( \frac{1}{C_2(1-X)} \right) \left[ \alpha(C_1 I^{β_1}) \right] \right]^{1/β_2} \]
   (28)

3. Calculate the storage volume’s time rate of change during time period i (beginning with i = 1):
   \[ S_{i+1} = S_i + \Delta t \left( \frac{\Delta S_i}{\Delta t} \right) \]
   (29)

4. Calculate the storage at time i

5. Calculate the outflow for period i:
   \[ \Delta S_i \triangleq \left[ \left( \frac{1}{C_2(1-X)} \right) \left( \frac{S_i}{K} \right)^{1/β_2} - \left( \frac{1}{C_2(1-X)} \right) \left[ \alpha(C_1 I^{β_1}) \right] \right]^{1/β_2} \]

6. Repeat steps (3)–(5) until the simulation reaches time N. Increment the index I by one ([34]:[35]).

2.5. Error measurement Indices
2.5.1. Sum of Squared Deviations (SSD)
In this study, the SSD index is utilized as the objective function. The total squared discrepancies between observed and actual discharges are calculated using the following index, [36].

\[ \text{Min}\ (SSQ) = \sum_{t=1}^{N}(Q_t - Q_{ct})^2 \]
(31)

2.5.2. EP index (Error of peak discharge)
EP index is a metric that quantifies the difference between anticipated and observed discharges, [37].

\[ EQ_p = [\left| Q_o^p - Q_{r_0}^p \right|] / Q_o^p \]
(32)

Where:
Q₀^p: observed outflow peaks(m³/s)
Qᵣ₀^p: routed outflow peak (m³/s)

2.5.3. Varex Q (Variance Index)
This metric displays how close predicted and observed hydrographs are to one other.

\[ \text{VarexQ} = \left[ 1 - \frac{\Sigma (Q_o - Q_{o_{mean}})}{\Sigma (Q_o - Q_{o_{mean}})} \right] \times 100 \]
(33)

Where (Q_o_{mean}) is the observed mean discharge, the closer the coefficient is to one, the more accurate the prediction of the flood.
2.5.4. Agreement Index (d)

Based on the following equation, the model’s performance is well demonstrated, since the value of the index may fluctuate from 0 to 1, [38].

\[
    d = 1 - \frac{\sum (Q_o - Q_{ro})^2}{\sum (|Q_{ro} - Q_{av.ob}| - |Q_{ob} - Q_{av.ob}|)}
\]  

(34)

where:

\(Q_o, Q_{ro}\): observed outflow (m³/s) and routed outflow (m³/s) respectively

\(Q_{av.ob}\): average observed outflow (m³/s)

3. Study Area

The Diyala River is one of the important water sources in Iraq, and it is characterized by its typical flow characteristics. The southern part of it was chosen for a case study. The aforementioned river is classified as one of the tributaries that flow into the Tigris River, and its estuary point in the Tigris River, located south of Baghdad (the capital of Iraq). The catchment area of the Diyala River is divided into two parts, one in Iran (the neighboring country) and the other in Iraq. The area of Diyala River is 33,240 square kilometers with a total length of 574 kilometers, 25% of this area is located in Iran and the majority is in Iraq, figure 4, [39].

![Figure 4. Layout of Diyala River, [39].](image)

The comparison test of the three routes was applied to the flows of the Diyala River, with simulated and observed flows. The computed outflows were compared with each other and the target discharge for each group of bed slope and the Manning’s coefficient (n) values. To achieve this, the data of observed flows from the Diyala River for the period from 1993 to 2017 were used, where the general monthly average of these discharges was adopted as shown in table 1, [40], in addition to the slope of the river bed (So) and the Manning’s coefficient (roughness) for three locations in the southern part of Diyala River, illustrated in table 2, [41]. The monthly averages of the observed water discharges for the selected period were marked by their regularity, accuracy, and idenity compared to the readings of other time periods.
Table 1. General monthly average of discharge for Diyala River for the years (1993-2017), ([39] and [40]).

| Month     | Q (m$^3$/s) |
|-----------|-------------|
| October   | 56          |
| November  | 101         |
| December  | 140         |
| January   | 198         |
| February  | 273         |
| March     | 413         |
| April     | 420         |
| May       | 220         |
| June      | 97          |
| July      | 65          |
| August    | 57          |
| September | 52          |

Table 2. Hydraulic properties for several locations in Diyala River, [41].

| Location | Location’s name       | Length of river in the location(km) | Manning coefficient (n) | Bed slope ($S_o$, cm/km) |
|----------|-----------------------|-------------------------------------|-------------------------|-------------------------|
| A        | North of Baquba city  | 43                                  | 0.027                   | 43                      |
| B        | Center of Baquba city | 85                                  | 0.089                   | 17                      |
| C        | South of Baquba city  | 75                                  | 0.038                   | 26                      |

4. Results analysis and discussion
One of the most fascinating and difficult unsteady flow phenomena is flood routing, which involves tracking the complex motion of a flood wave flowing through the channel. It is difficult to estimate the nonlinear Muskingum model parameters via trial and error. Various approaches have been used to estimate these parameters during the last two decades. One of the strategies that have been successful in estimating these parameters is met heuristic techniques. In this study, the nonlinear Muskingum model's parameters were estimated using a search method for symbiotic organisms. To assess the performance of the symbiotic creature search algorithm, the results of its implementation were compared to those of other hydraulics and hydrologic approaches such as a (Dynamic Wave and Characteristics approaches) and hydrological (Linear Muskingum-Cunge approach) models. In order to find the best values of the outflow for the Diyala river, the most accurate and identical of the computed flow with the observed flow were shown. Figures 5, 6 and 7 illustrate the ranges of congruence for the hydrographic plans resulting from the computed and observed flows. The statistical indices SSQ, EQP, varex Q, and d were used to assess the algorithms. This shows that the search method for symbiotic organisms is working properly in calculating the values of the nonlinear Muskingum model to find the optimal values of the outflow and more compatible with the calculated outflow with all other methods without any senses to change n and $S_o$. The hydrograph computed using the dynamic wave approach gave a great match to the observed outflow values, and this method achieved the required compatibility at the computed peak flow time with the observed flow. Whereas in other approaches applications, it achieved peak flows earlier than the observed outflow time. As a result of the dynamic wave approach achieving the required synchronization condition, the differences between the computed and observed flow were much smaller than what happened in the other approaches. The results show that the use of hydraulic models to achieve the correspondence between the computed and observed flows as well as the required synchronization at the peak flow is better compared to the hydrological model represented by the linear Muskingum-Cunge approach, as it was difficult to meet the requirements of equations (12) to (17) for a steep bed slope, table 3. The interval remains short enough that $\Delta x$ can satisfy the condition and ensure positive outflows. So due to the previously mentioned requirements, the Muskingum-Cunge approach failed to obtain an adequate result when applied to a channel with bed slope ($S_o$) = 0.0050 and Manning’s coefficient (n) =0.035.
It is also noted that this study confirmed what was stated in previous studies ([6], [7], [8], [16], [3] and [18]) that hydrological models are less complex than hydraulic models, but they also have some defects. Since they require observed inflow and outflow hydrographs from a reach to determine the routing

Figure 5. Comparison results to recorded outflow hydrograph with various methods to location (A)

Figure 6. Comparison results to recorded outflow hydrograph with various methods to location (B)
coefficients, they are generally limited in application, backwater effects of tides, major tributary inflow, dams, and bridges are not taken into account.

After determining the dynamic wave approach as the best method in flood routing, the effect of both Manning’s coefficient (roughness coefficient) and bed slope on this method was studied using different values. The results showed that the difference between the computed and observed flows diminished with a decrease in the coefficient of friction and an increase in the bed slope channel.

5. Conclusion

In this study, the performance of the symbiotic creature search algorithm was used to assess the results of its implementation compared to those of other hydraulics and hydrologic approaches such as a (Dynamic Wave and Characteristics approaches) and hydrological (Linear Muskingum-Cunge approach) models in flood routing and their relationship to the hydraulic properties of the natural channel bed.

The results of the comparison indicated that the use of hydraulic models to achieve compatibility between the calculated and observed flows, as well as the required synchronization at the peak flow, is better than the application of hydrological models. The study showed that the dynamic wave approach achieved a significant match between the calculated flow and the observed outflow values and gave an accurate synchronization of the time of the peak flow with the observed outflow. Also, it is noted that the symbiotic organisms search (SOS) Algorithm did not give any sense due to changes in roughness or bed slope and gave very identical values with recorded outflow in all conditions, which means that the hydraulic solution is better compared to the hydrological solution. The use of the dynamic wave approach showed that the difference between the calculated and observed flows decreases as the Manning coefficient decreases and the channel bottom slope increases.

Figure 7. Comparison results to recorded outflow hydrograph with various methods to location (C)
### Table 3.

The estimated outflow values for all methods used.

| Time (day) | I(cm/s) | O(cm/s) | Dynam ic wave | Muski -ngum | Chara c- | SOS | Dynam ic | Muski - | Chara c- | SOS | Dynam ic | Muski - | Chara c- | SOS |
|------------|---------|---------|---------------|-------------|--------|-----|----------|---------|--------|-----|----------|---------|--------|-----|
| 0          | 56      | 45      | 46            | 55          | 44     | 30  | 45       | 45      | 35     | 30  | 25       | 20      | 35     | 30  |
| 40         | 101     | 60      | 60            | 60          | 51     | 55  | 60       | 45      | 45     | 55  | 20       | 20      | 30     | 55  |
| 80         | 140     | 80      | 100           | 100         | 110    | 100 | 110      | 125     | 130    | 100 | 30       | 32      | 60     | 100 |
| 120        | 198     | 120     | 140           | 180         | 100    | 135 | 135      | 160     | 110    | 135 | 70       | 60      | 70     | 135 |
| 160        | 273     | 200     | 220           | 270         | 250    | 200 | 210      | 265     | 240    | 200 | 125      | 130     | 130    | 200 |
| 200        | 413     | 270     | 280           | 360         | 320    | 310 | 265      | 350     | 340    | 310 | 165      | 250     | 130    | 310 |
| 240        | 450     | 350     | 370           | 425         | 330    | 365 | 350      | 460     | 430    | 365 | 260      | 230     | 190    | 365 |
| 280        | 220     | 380     | 390           | 360         | 350    | 375 | 380      | 340     | 300    | 375 | 400      | 340     | 440    | 375 |
| 320        | 97      | 320     | 325           | 150         | 200    | 325 | 400      | 160     | 230    | 325 | 400      | 320     | 330    | 325 |
| 360        | 65      | 100     | 210           | 180         | 170    | 225 | 400      | 170     | 190    | 225 | 360      | 240     | 210    | 225 |
| 400        | 150     | 220     | 120           | 100         | 90     | 130 | 170      | 120     | 120    | 130 | 270      | 200     | 170    | 130 |
| 440        | 100     | 130     | 115           | 100         | 80     | 125 | 130      | 110     | 100    | 125 | 140      | 110     | 70     | 125 |
| 480        | 80      | 120     | 90            | 80          | 50     | 120 | 75       | 60      | 45     | 120 | 155      | 100     | 80     | 120 |
| 500        | 70      | 100     | 50            | 30          | 30     | 100 | 45       | 35      | 30     | 100 | 80       | 40      | 25     | 100 |
| SSD        | 4.995   | 22.42   | 21.05         | 2.112       | 5.221  | 22.52 | 21.03    | 2.012   | 5.001  | 22.11 | 20.13    | 2.725   |
| EQ_0       | 0.0004  | 0.001   | 0.001         | 0.000       | 0.0005 | 0.002 | 0.001    | 0.000   | 0.0004 | 0.001 | 0.001    | 0.000   |
| Verx       | 96.85   | 90.45   | 91.02         | 98.91       | 95.95  | 90.00 | 91.52    | 98.91   | 96.85  | 90.56 | 92.12    | 98.92   |
| d          | 0.95    | 0.91    | 0.92          | 0.98        | 0.94   | 0.89  | 0.92     | 0.985   | 0.94   | 0.89  | 0.93     | 0.99    |

Estimated outflow (m³/s)

- n = 0.027, S_o = 43 cm/km
- n = 0.089, S_o = 17 cm/km
- n = 0.38, S_o = 26 cm/km
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