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The ITB* Unit Hydrograph Method: A Novel Approach to User-Defined Unit Hydrograph Development (Part II)

Advanced Applications with Adjustable Unit Duration and Calibration Capabilities

Dantje K. Natakusumah [1, 2 †], Waluyo Hatmoko [3], Dhemi Harlan [1], Eka O. Nugroho [1, 2], Arno A. Kuntoro [1, 4], Mohammad Farid [1, 4], Fitra Adinata [5], Jovian Javas [4]

[1] *Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung, 40132, Indonesia.*

[2] *Fluid Mechanics and Hydrodynamics Laboratory, Center for Industrial Technology, Institut Teknologi Bandung, Bandung, 40132, Indonesia.*

[3] *Universitas Jenderal Achmad Yani, Jalan Terusan Jenderal Sudirman, Cimahi, 40513, Indonesia.*

[4] *Water Resources Development Center, Institute of Technology Bandung, Indonesia Institut Teknologi Bandung, Bandung, 40132, Indonesia.*

[5] *PT. Sapta Adhi Pratama, Jalan. Dago Giri H-13, Bandung, West Java, 40132, Indonesia.*

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Abstract

This paper is the second part of a comprehensive two-part series on the ITB Unit Hydrograph (ITB-UH) Method, titled *The ITB Unit Hydrograph Method: A Novel Approach to User-Defined Unit Hydrograph Development*. Building on the foundational concepts introduced in Part I, this paper delves into advanced applications of the ITB-UH Method, emphasizing its adaptability, calibration capabilities, and real-world utility. The ITB-UH Method introduces novel derivations for the Peak Rate Factor (Kp) and Peak Discharge (Qp), along with a time-step normalization approach that enables flexible adjustments to unit rainfall durations and a systematic calibration process. These innovations significantly enhance the method's versatility and accuracy in modeling flood discharge across diverse hydrological conditions. The practical applicability of the ITB-UH Method is demonstrated through real-world flood discharge calculations in the Pinamula River, located in Buol District, Central Sulawesi Province. Three illustrative examples highlight the method's versatility: (1) analyzing flood hydrographs at a 1-hour time step to showcase its practical applicability for flood management; (2) recalculating flood hydrographs with a finer 0.5-hour time step to demonstrate its adaptability to varying temporal resolutions; and (3) refining model parameters to improve alignment with observed flood hydrographs, underscoring the method's capacity for calibration and optimization. To evaluate the method's performance, robust metrics such as the Nash–Sutcliffe Efficiency (NSE), Percentage Bias (PBIAS), and Index of Agreement (IA) are employed. These metrics confirm the ITB-UH Method's accuracy and reliability, with results consistently aligning closely with observed data. Collectively, the findings underscore the ITB-UH Method's suitability across diverse hydrological settings and its potential to enhance both the verification of existing SUH methods and the development of user-defined hydrographs. By enabling more accurate and effective flood management, the ITB-UH method represents a significant advancement in hydrological modeling, with broad implications for water resource management and infrastructure planning worldwide.

Keywords: ITB UH Method; Peak Rate Factor (Kp); Peak Discharge (Qp); Time Step Normalization (Tn); Calibration Method; Flood.

* The abbreviation "ITB" stands for Institut Teknologi Bandung, a government-funded university in Indonesia.

† Corresponding author: dkn@itb.ac.id

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1. Introduction

This study continues the exploration of the evolution and significance of the ITB Unit Hydrograph (ITB-UH) Method, as previously presented in Part I. The ITB-UH Method was first introduced by Natakusumah at a national seminar in Bandung, Indonesia, in 2009 [1]. It subsequently underwent various improvements, was published in a national journal [2], and was presented at an international seminar in 2013 [3]. The method was further refined in 2014 with the integration of exact and numerical techniques for Kp calculations [4], standardization efforts were emphasized in 2021 [5], verification, and development of simple user-defined unit hydrographs in 2025 [6].

The ITB-UH Method introduces an innovative approach to deriving key variables, notably the Peak Rate Factor (Kp) and Peak Discharge (Qp), using exact and numerical integration techniques. It also employs space transformations—commonly used in finite element analysis—to simplify the integration of complex hydrograph shapes. These features enable the generation of user-defined synthetic and natural unit hydrographs that accurately reflect the unique hydrological characteristics of different watersheds, enhancing their versatility in flood modeling and water resource management.

This study highlights innovations that improve the ITB-UH Method's applicability to real-world flood discharge calculations, demonstrated through three examples in the Pinamula River, Central Sulawesi. First, the method analyzes flood hydrographs at a 1-hour time step, showcasing its practical utility. Second, it recalculates hydrographs at a finer 0.5-hour resolution, demonstrating adaptability to varying temporal scales. Third, it refines model parameters to better align with observed data, emphasizing its calibration capabilities.

The method's performance is evaluated using robust metrics such as the Nash–Sutcliffe Efficiency (NSE), Percentage Bias (PBIAS), and Index of Agreement (IA), confirming its accuracy and reliability across diverse hydrological settings. These results underscore the ITB-UH Method's suitability for verifying existing SUH methods and developing user-defined hydrographs, enabling more accurate flood management worldwide.

By addressing challenges ranging from practical flood management to detailed hydrological analysis, the ITB-UH Method demonstrates its adaptability and effectiveness in improving flood risk assessments and water resource planning.

2. Generation of the ITB Synthetic Unit Hydrographs

The ITB method for generating Synthetic Unit Hydrographs is founded on a combination of theoretical principles and practical applications, aiming to accurately model flood discharges. Its success hinges on careful consideration of three key elements:

- ***The Equation Defining the Synthetic Unit Hydrograph Curve***: This equation governs the shape of the SUH, determining its rise, peak, and recession limbs.
- ***The Time Parameter***: The time parameter, typically represented by the unit rainfall duration (Tr), controls the duration of the hydrograph.
- ***The Peak Variables***: The peak variable, often represented by the peak discharge (Qp) or the peak rate factor (Kp), determines the maximum flow rate of the hydrograph.

2.1. The Equation Defining the Synthetic Unit Hydrograph Curve

The Equation for ITB-1b and ITB-2b Synthetic Unit Hydrograph Curve uses the dimensionless time t = T/Tp on the horizontal axis and the dimensionless discharge q = Q/Qp on the vertical axis. The range of q = Q/Qp extends from 0 to 1, while t = T/Tp ranges from 0 to ∞ or limited to an upper limit b = 20. The latest form of the ITB-1b and ITB-2b Synthetic Unit Hydrograph Curve equation is as follows [4].

- The ITB-1b Synthetic Unit Hydrograph curve is represented by one equation ($0 \leq t < \infty$):

$$q(t) = \{t \times \exp(1 - t)\}^{\alpha C_p} \quad \alpha = 3.7 \tag{1}$$

- The ITB-2b Synthetic Unit Hydrograph curve is represented by two equations:
  - Rising limb ($0 \leq t < 1$):

$$q(t) = t^{\alpha} \qquad \alpha = 2.4 \tag{2-a}$$

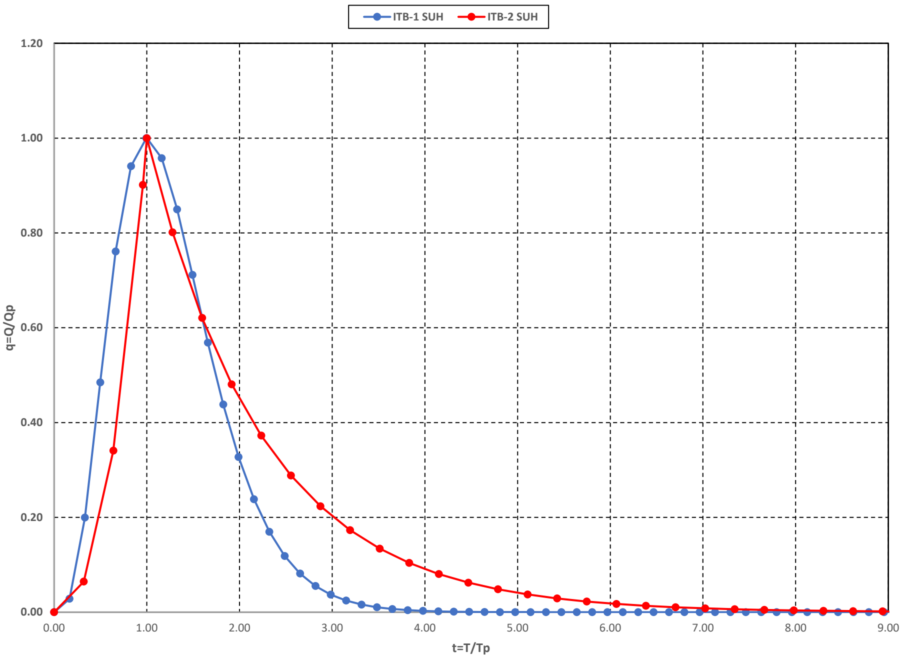
  - Falling limb ($1 \leq t < \infty$):

$$q(t) = \exp\{(1 - t) \times \beta \times C_p\} \qquad \beta = 0.80 \tag{2-b}$$

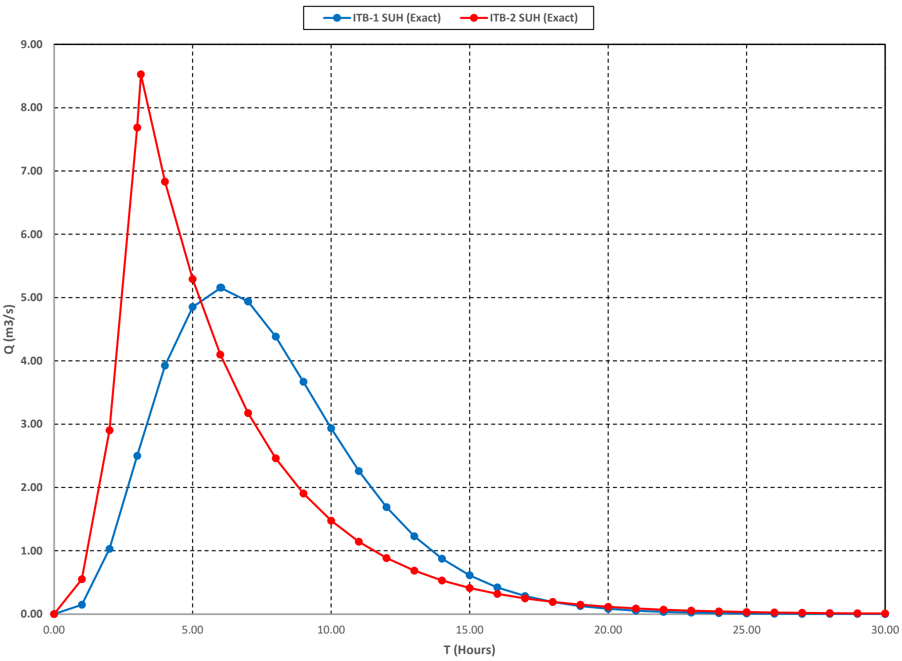
In the ITB-1b SUH, the parameter α is set at 3.7. For the ITB-2b SUH, the parameters are designated as α = 2.4 and β = 0.80. The calibration process, which includes instructions on adjusting α and β, will be elaborated in Section 3 (Parameter Calibration).

Figure 1-a illustrates the dimensionless ITB-1b and ITB-2b Synthetic Unit Hydrographs, applicable to any catchment area. For specific applications, such as the Ciliwung River at Katulampa Weir, the time axis (t) and discharge axis are scaled by peak time (Tp) and peak discharge (Qp), respectively, transforming the dimensionless hydrograph into a site-specific dimensional ITB-1b and ITB-2b SUH, as depicted in Figure 1-b. For other locations, the detailed shapes of the dimensional ITB-1b and ITB-2b unit hydrographs will differ, but their general shapes will remain similar.

***Note*:** Earlier versions of the ITB method are often referred to as ITB-1/ITB-1a and ITB-2/ITB-2a in the literature. This study utilizes the revised ITB-1b and ITB-2b equations, which offer improved integrability compared to their predecessors. Unlike ITB-1a, which requires numerical methods for integration, the revised ITB-1b and ITB-2b equations can be integrated both numerically and exactly.



(a) Dimensionless form of ITB-1b and ITB-2b SUH (applicable to any catchment area)



(b) Dimensional form of ITB-1b and ITB-2b SUH (for a specific catchment)

Figure 1. Shape of Dimensionless and Dimensional ITB-1b and ITB-2b Synthetic Unit Hydrograph

2.2. Time Parameters

The ITB method utilizes several key time parameters to model the flow of water through a catchment and estimate flood hydrographs. These parameters are determined by both physical characteristics of the catchment and can be adjusted for calibration.

- **Time Lag (T_L):** Represents the time taken for runoff to reach the catchment outlet. Two formulas are used depending on the chosen variant:

$$\text{ITB-1b: } T_L = Ct \times 0.81225 \times L^{0.6} \tag{3}$$

$$\text{ITB-2b: } T_L = Ct \times (0.0394 \times L + 0.201 \times L^{0.5}) \tag{4}$$

where T_L is Time lag (hours), Ct is Adjustable time coefficient (explained in Section 3 (Parameter Calibration)), and L is River length (km).

- **Time to Peak (Tp):** Represents the time at which peak discharge occurs. Time to Peak for both variants is calculated as:

$$Tp = T\_L + 0.50 \times Tr \tag{5}$$

where Tr is Unit rainfall duration (hours).

- **Time Base (Tb):** Represents the length of the hydrograph recession. The length of the hydrograph recession, theoretically infinite for large catchments but practically estimated as

$$Tb = 20 \times Tp \tag{6}$$

2.3. Peak Variables

The ITB method uses the peak rate factor (Kp) to calculate the peak discharge (Qp) resulting from a rainfall distribution with a specified unit duration. This rainfall is assumed to be uniformly distributed across a catchment of defined size.

- **Peak Rate Factor (Kp):** The Peak Rate Factor (Kp) in Synthetic Unit Hydrographs (SUHs) serves as a dimensionless scaling factor that relates the peak discharge (Qp) of the hydrograph to the unit rainfall (R) and the area under the dimensionless Synthetic Unit Hydrograph curve (ASUH). In simpler terms, it tells how efficiently a catchment converts rainfall into peak flow.

$$Kp = \frac{1}{3.6 \times A_{SUH}} \quad \text{(dimensionless)} \tag{7}$$

where Kp is Peak Rate Factor (dimensionless), and A_{SUH} = Area of dimensionless Synthetic Unit Hydrograph curve

It's worth noting that the discovery of the general formula for Peak Rate Factor (Kp) is a significant finding. This discovery clearly illustrates the relationship between the shape of the unit hydrograph curve and Kp.

- **Peak Discharge (Qp):** The Peak Discharge (Qp) in a Synthetic Unit Hydrograph represents the maximum flow rate experienced during the runoff period of the hydrograph. It signifies the most significant volume of water flowing out of the catchment at any given moment after a unit rainfall event.

$$Qp = Kp \times \frac{R \times A_{CA}}{Tp} \quad (m^3/s) \tag{8}$$

where Qp = Peak discharge of the unit hydrograph (m^3/s), R is Unit rainfall (1 mm), Tp is peak time (hour), and ACA = Catchment area (km^2).

- **Remarks:**

  The development of Equations 7 and 8 for the ITB Synthetic Unit Hydrograph marks a significant advancement in unit hydrograph analysis.

  - ***Applicability***: Equations 7 and 8, developed for the ITB Synthetic Unit Hydrograph, are applicable to all synthetic unit hydrograph methods based on equations or tables. This allows for standardized calculations across all analytical equation-based or tabular based synthetic unit hydrographs. The universality of these equations eliminates the need for separate calculations for various unit hydrograph types, promoting consistency and simplifying the process.

- ***A_{SUH} Calculation*:** The area under the dimensionless Synthetic Unit Hydrograph curve (A_{SUH}) is essential for determining peak discharge through the Peak Rate Factor (Kp) and Peak Discharge (Qp) formulas. This area represents the overall runoff volume from unit rainfall excess and ensures mass conservation (i.e., total runoff equals total rainfall minus losses). This area can be calculated exactly using Equation 10, Equation 11 or numerically, using Equation 12.
- ***Kp is Significant*:** The discovery of the general formula for the Peak Rate Factor (Kp) is a significant finding. This formula explicitly demonstrates the direct relationship between the shape of the unit hydrograph curve and its peak discharge. By simply calculating the area under the dimensionless unit hydrograph curve, it becomes possible to verify the accuracy of Kp values for other similar types of unit hydrographs, facilitating a more rigorous evaluation of their performance.

2.4. Exact Integration of Peak Rate Factor (Kp)

This paper presents the exact integration of the dimensionless Synthetic Unit Hydrograph (SUH) curves, specifically for ITB-1b and ITB-2b. This integration method enables accurate determination of the area under the curves for these ITB-1b and ITB-2b SUHs. The method is carried out as follows:

2.4.1. Exact Integration of ITB-1b Synthetic Unit Hydrograph Equation

The ITB-1b SUH curve is represented by a single dimensionless from Equation 1 ($q(t) = \{t \times \exp(1-t)\}^{\alpha Cp}$), $0 \le t < \infty$). Equation 1 is derived from the model introduced by Nash [7] and is based on linear reservoir theory, which assumes the water storage in a river catchment can be modeled as a series of linear reservoirs. The author adopts this equation for the ITB-1b SUH and has successfully found its exact integral. The exact area of the dimensionless SUH resulting from the integration of Equation 1 has been determined.

For example, if $m = \propto \times Cp$, the exact value of the integration can be found using symbolic integration software (older version) as follows:

$$A_{SUH} = \int_0^{\infty} \{t \times \exp(1-t)\}^m \, dt = \frac{e^m \times \Gamma(m+1,0)}{m^{m+1}} \tag{9}$$

2.4.2. Exact Integration of ITB-2b Synthetic Unit Hydrograph Equation

The equation curves of the ITB-2b Synthetic Unit Hydrograph are proposed by the author, which is expressed in Equation 2. The exact integration of this equation can be performed manually, and the exact value of the integration is known. For instance, if m equals α, n equals $\beta \times C_p$, and the upper limit of integration is b, then the exact value of the integration of these equations is as follows:

$$A_{SUH} = \int_0^b q(t)\, dt = \int_0^1 t^m dt + \int_1^b \exp\{1-t\} \times n \, dt = \frac{1}{m+1} + \frac{1}{n} - \frac{\exp(-(b-1)\times n)}{n} \tag{10}$$

If $b = \infty$, then the exact value of the integration in Equations 2-a and 2-b above is given by:

$$A_{SUH} = \frac{1}{m+1} + \frac{1}{n} \tag{11}$$

2.5. Numerical Integration of The Synthetic Unit Hydrograph Curve

When the equation of the unit hydrograph curve is known but exact integration is not feasible, numerical integration becomes the method of choice. The trapezoidal rule is commonly employed for numerical integration of the unit hydrograph curve, as depicted in Figure 2.

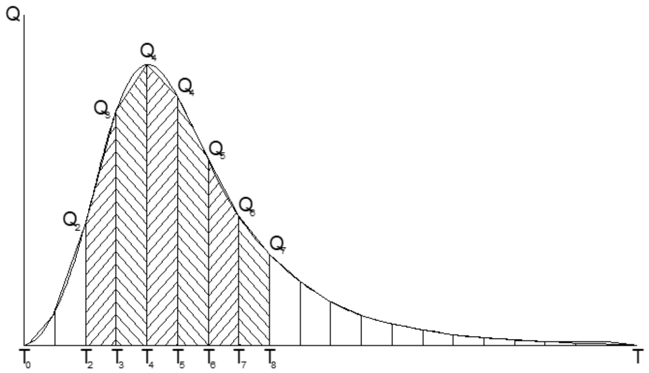


Figure 2. Numerical integration of the hydrograph curve using the trapezoidal method

In this approach, the curvilinear curve is approximated by multiple straight-line segments, forming a piecewise linear approximation. The numerical integration of the unit hydrograph curve, illustrated in Figure 2, is performed using the trapezoidal rule, expressed by the equation:

$$A_{SUH} = \frac{1}{2}\sum_{i=1}^{N}(T_{i+1} - T_i) \times (Q_{i+1} + Q_i) \tag{12-a}$$

If the intervals are made equal $\Delta T = (T_{i+1} - T_i)$ and the peak of the Synthetic Unit Hydrograph curve, Qp, is not included in the calculation because the value of Tp is not always a multiple of ΔT, then:

$$A_{SUH} = \Delta T \sum_{i=1}^{N} Q_i \tag{12-b}$$

In the context of the Synthetic unit hydrograph curve, it's important to note that the values of Q_0 and Q_N are both equal to zero.

3. Parameter Calibration

In the ITB Synthetic Unit Hydrograph method, two calibration stages are involved. The first is the initial calibration conducted by Natakusumah et al. [2], which aims to establish the fundamental parameters of the method. The second stage of calibration is performed by users, allowing adjustment of these parameters to better suit the specific conditions of the watershed being analyzed. This two-stage calibration process enhances the flexibility and adaptability of the ITB method across various hydrological contexts.

3.1. The Initial Calibration

The parameters α and β values for the ITB-1b and ITB-2b Synthetic Unit Hydrographs initially cover an Infinite range, with most values likely exceeding physical plausibility. Therefore, an initial calibration step is crucial to ensure parameters fall within a realistic range. Unlike some methods, which relies on extensive field data and intricate non-linear equations to determine key parameters for its unit hydrograph.

In contrast, the ITB method, being an equation-based SUH, streamlines calibration. It defines its curve using one or two equations, significantly reducing the need for extensive hydrograph observations. Only one or two field observations are necessary to establish initial parameters. This approach simplifies and expedites the calibration process for the ITB Synthetic Unit Hydrograph.

The initial calibration for finding the initial parameters for the ITB-1b and the ITB-2b Synthetic Unit Hydrograph is as follows:

- The ITB-1b Synthetic Unit Hydrograph is a Synthetic Unit Hydrograph method used to estimate flood hydrographs in ungauged watersheds. During initial calibration, the focus was on matching the peak discharge of the ITB-1b Synthetic Unit Hydrograph with that of the SCS Curvilinear SUH, a well-established method. This matching was achieved by adjusting the α parameter, which controls the shape of the ITB-1b SUH.
- Similarly, for the initial calibration of the ITB-2b Synthetic Unit Hydrograph, the values of parameters α and β were experimented to match the dimensioned (dimensionalized) peak discharge of ITB-2b Synthetic Unit Hydrograph with that of the Nakayasu Synthetic Unit Hydrograph, a commonly used Synthetic Unit Hydrograph Method in Japan, Southeast Asian nations and in Indonesia.
- Based on these initial calibration results, the parameter value for the ITB-1b Synthetic Unit Hydrograph was set at $\alpha = 3.7$, while for the ITB-2b Synthetic Unit Hydrograph, the parameter values were determined as $\alpha = 2.4$ and $\beta = 0.80$.

3.2. Calibration Performed by Users

Upon completing the flood hydrograph calculation, it's important for the user to compare the results, if available. Differences between the calculated and observed hydrographs may necessitate calibration to align the results more closely. This calibration process includes adjusting the time to peak (Tp) by altering Ct and modifying the peak discharge (Qp) by changing Cp, as depicted in Figure 3.

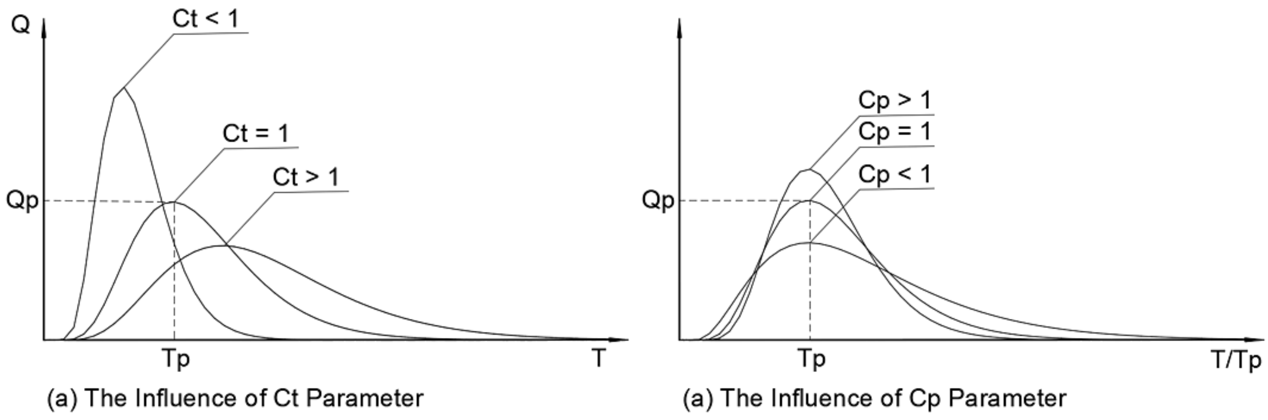


Figure 3. Time and peak discharge calibration by changing values of Ct and Cp

When the observed data is available, the calibration procedure for peak time and peak discharge is conducted as follows:

1) If the peak time (Tp) of the measured and calculated hydrograph is not similar, the Ct coefficient in Equation (3) and/or Equation (4) is adjusted to equalize the peak time. A Ct value less than 1.0 reduces the peak time, while a Ct value greater than 1.0 increases it.
2) If the peak discharge (Qp) of both hydrographs is not similar, the Cp coefficient in Equation (1) and Equation (2) is adjusted. A Cp value less than 1.0 reduces the peak discharge, whereas a Cp value greater than 1.0 increases it.

3.3. Statistical Performance Metrics

When comparing observed and calculated curves, several common statistical metrics are used to assess model fit and accuracy. This paper will focus on three statistical performance metrics: [8-11].

- **Nash-Sutcliffe Efficiency (NSE)**: Assesses the predictive skill of a model relative to the mean of the observed data, with values closer to 1 indicating better performance:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs}(i) - Q_{sim}(i)\right)^2}{\sum_{i=1}^{n}\left(Q_{obs}(i) - \overline{Q_{obs}}\right)^2} \tag{13}$$

- **Percentage Bias (PBIAS):** Expresses the bias as a percentage of the observed data, providing a normalized measure of bias.

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}\left(Q_{obs}(i) - Q_{sim}(i)\right)}{\sum_{i=1}^{n} Q_{obs}(i)} \tag{14}$$

- **Index of Agreement (IA):** A normalized measure ranging from 0 to 1, where 1 means perfect agreement between predicted and observed values.

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}\left(Q_{obs}(i) - Q_{sim}(i)\right)}{\sum_{i=1}^{n} Q_{obs}(i)} \tag{15}$$

Each formula uses Q_{obs} is Observed discharge, Q_{sim} is Simulated discharge, $\overline{Q_{obs}}$ is mean of the observed discharge, and n is Number of computed and observed values.

4. The Practical Application of the ITB SUH Method

This section showcases the practical application of the ITB SUH method. To demonstrate the fundamental concepts and innovative features introduced in Section 1 (Generation of ITB Synthetic Unit Hydrograph), real-world flood discharge calculations are performed for the Pinamula River, situated in Buol District, Central Sulawesi Province, on the Island of Sulawesi (see Figure 4).

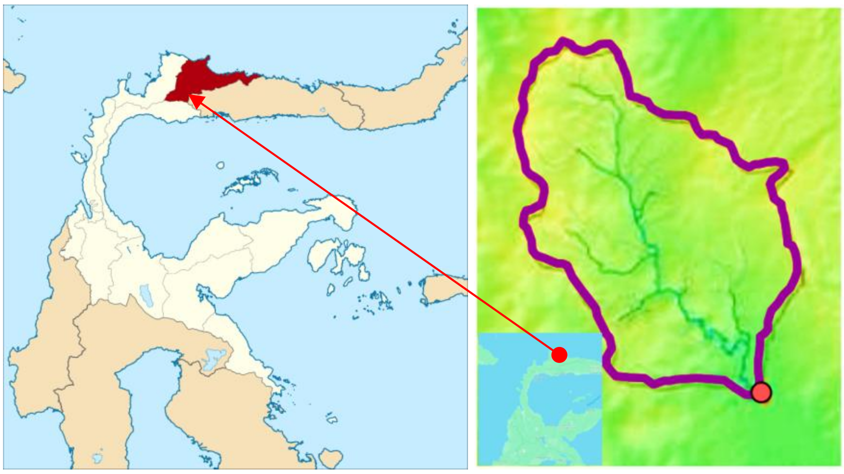


Figure 4. Pinamula River located in Buol District, Central Sulawesi Province (Indonesia), as adapted from Tunas (2017) [12]

The following examples highlight the versatility and practical applications of the ITB Method in flood analysis by simulating various scenarios. The focus is on demonstrating its adaptability and precision in different contexts. For this case study, the Pinamula River, located in Buol District, Central Sulawesi Province, serves as the reference watershed**:**

- **Standard Application:** Analysis of Flood Hydrographs at the Pinamula River with a 1-Hour Time Step. This scenario showcases the application of the ITB method for analyzing existing flood hydrographs at the Pinamula River using a standard time step of 1 hour.
- **Adapting to Different Time Steps:** Recalculating Flood Hydrographs at the Pinamula River with a 0.5-Hour Time Step. This example highlights the method's flexibility by recalculating flood hydrographs for the Pinamula River using a finer time step of 0.5 hours, enhancing temporal resolution.
- **Fine-Tuning for Accuracy:** Calibration of Flood Hydrographs with Measured Data. This example illustrates the ITB method's capability to improve accuracy by calibrating model parameters to align calculated flood hydrographs with measured data. Calibration utilizes rainfall and flood discharge records from the Pinamula catchment.

4.1. Analysis of Flood Hydrographs for Pinamula River with Tr = 1.0 hour

This example demonstrates the use of the ITB method for calculating the flood hydrograph of the Pinamula River, located in the District of Buol, Province of Central Sulawesi, on the Island of Sulawesi. The Pinamula River drains an area of 49.35 square kilometers (km^2) and stretches for a length of 15.636 kilometers (km), with a river slope (S) of 34.22 meters per kilometer (m/km). Despite its smaller size, managing flood risks for the Pinamula River poses significant hydrological challenges, impacting local infrastructure and communities in Sulawesi. The rainfall and discharge data for this catchment are sourced from Tunas (2017) [12].

Assuming a runoff coefficient (C) of 0.60, Table 1 presents the calculated values for total rainfall, infiltration, and effective rainfall for a unit rainfall duration (Tr) of 1 hour. This essentially means the table shows how much rainfall becomes runoff (effective rainfall) considering the infiltration characteristics of the watershed.

Table 1. Total rainfall, infiltration, and effective rainfall for Tr = 1 hour

Hour	R (mm)	Infil (mm)	Reff (mm)
0.00	0.000	0.000	0.000
1.00	10.896	4.358	6.537
2.00	16.207	6.483	9.724
3.00	88.890	35.556	53.334
4.00	23.104	9.242	13.863
5.00	12.903	5.161	7.742
6.00	9.524	3.810	5.714
7.00	0.000	0.000	0.000

4.1.1. Creating Tables of ITB-1b and ITB-2b Synthetic Unit Hydrograph

The calculation steps, which involve numerous lines of computation, figures, and tables, are best conveyed visually through a figure rather than a table. These steps are meticulously outlined in Table A1 for the ITB-1b SUH and Table A2 for the ITB-2b SUH; both tables are located in the Appendix I. Despite the detailed and extensive calculations, all the steps are performed only once using Excel. Once the Excel file containing these steps is created, there is no need to repeat the entire process.

To provide a clear framework for these calculations, the workflow is divided into five sequential parts, each focusing on key components that form the basis of the Synthetic Unit Hydrograph.

Part I details the collection of essential input data for hydrological analysis. This includes the characteristics of the watershed and rainfall, such as the name of the river, station data, watershed area (A), the length of the main river (L), unit rainfall height (R), and the duration of unit rainfall (Tr). These variables are integral to calculating the Time Lag in hydrological modeling.

Part II involves defining the Time coefficient (Ct), calculating the Time Lag (tP), Time to Peak (TP), and Base Time (TB). The equations used are highly dependent on the Synthetic Unit Hydrograph being utilized.

Part III calculates Tn (Normalized Unit Rainfall Duration), Cp (Peak Coefficient), Alpha and Beta (which shape the Synthetic Unit Hydrograph), ASUH (the Synthetic Unit Hydrograph area), Kp (Peak Rate Factor), and Qp (Peak Discharge).

Referring to Table A1 for the ITB-1b SUH and Table A2 for the ITB-2b SUH; the detailed steps of the calculations in Part III are outlined as follows:

- **Normalized Unit Rainfall Duration**

The ITB Method enables flexible time step adjustments through rainfall unit duration normalization by time to peak (Tn = Tr/Tp) as explained in Section 2.2 (Time Parameters), ensuring accuracy without the need for extensive recalculations, a feature not commonly found in other methods.

- ITB-1b

$$\mathrm{Tn} = \frac{\mathrm{Tr}}{\mathrm{Tp}} = \frac{1}{4.72894} = 0.21146$$

- ITB-2b

$$\mathrm{Tn} = \frac{\mathrm{Tr}}{\mathrm{Tp}} = \frac{1}{2.25779} = 0.44291$$

- **Coefficient of Peak (Cp)**

Before calibration, the Peak Discharge Coefficient (Cp) was initially set at 1.0 for both the ITB-1b and ITB-2b Synthetic Unit Hydrographs.

- **Coefficient of α and β, for both ITB-1b and ITB-2b**

The α and β coefficients for both the ITB-1b and ITB-2b Synthetic Unit Hydrographs are provided. The default values are as follows: for ITB-1b, α = 3.70, and for ITB-2b, α = 2.4, β = 0.8.

- **Area of ITB-1b Dimensionless Synthetic Unit Hydrograph**
  - ***Exact Area of ITB-1b Synthetic Unit Hydrograph***

If $\mathrm{m} = \propto \times \mathrm{Cp}$, the formula is:

$$\mathrm{A_{SUH}} = \frac{\mathrm{e^m} \times \Gamma(\mathrm{m}+1,0)}{\mathrm{m^{m+1}}}$$

For α = 3.7 and Cp = 1.0, m = 3.7, and the values of Gamma function Γ(m+1,0) is computed using Excel function:

Γ(m+1,0) = EXP(GAMMALN(m+1))*(1-GAMMADIST(0,m+1,1,TRUE)) = 15.4314116

Consequently,

$$\mathrm{A_{SUH}} = \frac{\mathrm{e^{3.7}} \times \Gamma(3.7+1.0)}{3.7^{3.7+1}} = 1.3327452$$

  - ***Numerical Area of ITB-1b Synthetic Unit Hydrograph***

$$\mathrm{A_{SUH}} = \mathrm{Tn} \times (\text{Sum of Column 3 of Part V, in } \textbf{Table A.1}) = 1.3327838$$

- **Area of ITB-2b Dimensionless Synthetic Unit Hydrograph**
  - ***Exact Area of ITB-1b Synthetic Unit Hydrograph***

    For α = 1.6, β = 0.8, and Cp = 1.0, the formula for exact integration of ITB-2b Synthetic Unit Hydrograph is

    $A_{SUH} = \frac{1}{m+1} + \frac{1}{n} - \frac{\exp(-(b-1)*n)}{n}$

    With n = 0.80 and upper integration limit b = 20, thus

    $A_{SUH} = \frac{1}{1.6+1} + \frac{1}{0.8} - \frac{\exp(-(20-1)*0.8)}{0.8} = 1.5441176$

  - ***Numerical Area of ITB-2b Synthetic Unit Hydrograph***

    $A_{SUH} = \text{Tn} \times (\text{Sum of Column 3 of Part V, in } \textbf{Table A.2}) = 1.5520706$

- **Peak Rate Factor (Kp)**

The ITB method rigorously adheres to the Mass Conservation Principle by comparing numerical and exact Peak Rate Factors, a feature not commonly found in other methods.

  - ***The Kp value for ITB-1b Synthetic Unit Hydrograph***

    $Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.3327452 = 0.2084252$ (Exact)

    $Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.3327838 = 0.2084192$ (Numerical)

    The difference from exact and numerical value is around 0.0097%

  - ***The Kp value for ITB-2b Synthetic Unit Hydrograph***

    $Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.5441176 = 0.1798942$ (Exact)

    $Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.5520706 = 0.1789724$ (Numerical)

    The difference from exact and numerical value is around 0.591%

The difference in Kp between the exact and numerical values of ITB-2b is more significant than that of ITB-1b due to a larger neglected portion around the peak of the hydrograph. This substantial difference will be illustrated in the subsequent section in Figure 5.

- **Peak Discharge (Qp)**

The ITB method rigorously adheres to the Mass Conservation Principle by comparing numerical and exact Peak Discharge values, a feature not commonly found in other methods.

  - ***The Qp value for ITB-1b Synthetic Unit Hydrograph***

    $Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.208425 \times 1.0 \times 49.350}{4.72894} = 2.17507$ (Exact)

    $Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.208419 \times 1.0 \times 49.350}{4.72894} = 2.17486$ (Numerical)

    The difference from exact and numerical value is around 0.0097%.

  - ***The Qp value for ITB-2b Synthetic Unit Hydrograph***

    $Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.1798941 \times 1.0 \times 49.350}{2.25779} = 3.93206$ (Exact)

    $Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.17989724 \times 1.0 \times 49.350}{2.25779} = 3.95532$ (Numerical)

The difference from exact and numerical value is around 0.591%.

Part IV, The ITB method applies the Mass Conservation Principle by calculating the volume of excess rainfall of 1 unit (mm) falling in the catchment (V_{CA}) and the volume of the unit hydrograph (V_{SUH}). It then ensures that the ratio, $R = V_{SUH}/V_{CA}$, equals 1.

Part V, to construct ITB-1b and ITB-2b Synthetic Unit Hydrograph, this section offers a detailed calculation of the curve shape, represented by the coordinates of the ITB-1b and ITB-2b dimensionless unit hydrographs in columns (2) and (3), respectively, along with the dimensional unit hydrograph in columns (4) and (5).

- ***ITB-1b Synthetic Unit Hydrograph***

The column operations for the ITB-1b SUH calculation are presented in the lower section of Part V of Table A1, with further details provided in Table 2.

Table 2. Column operation of ITB-1b calculation

Column Operation	Unit
Column (1) = n = Integer numbers from 0 to as necessary	dimensionless
Column (2) = t = Column (1) * Tn Part III Point a)	dimensionless
Column (3) = q(t) = (t * EXP(1 - t))$^{(\alpha * Cp)}$ (ITB-1b Eq.)	dimensionless
Column (4) = T = Column (2) * Tp	hour
Column (5) = Q = Column (3) * Qp (numerical)	m^3/sec

Note: In Column (5), Qp represents the numerical value of Qp, not the exact value.

- ***ITB-1b Synthetic Unit Hydrograph***

Similarly, the column operations for the ITB-1b SUH calculation are illustrated in the lower section of Part V of Table A2, with further details provided in Table 3.

Table 3. Column operation of ITB-2b calculation

Column Operation	Unit
Column (1) = n = Integer numbers from 0 to as necessary	dimensionless
Column (2) = t = Column (1) * Tn Part III Point b)	dimensionless
Column (3) = q(t) =MIN(t$^{\alpha}$, EXP((1-t)*(β*Cp))) (ITB-2b eq.)	dimensionless
Column (4) = T = Column (2) * Tp	hour
Column (5) = Q = Column (3) * Qp (numerical)	m^3/sec

Note: In Column (5), Qp represents the numerical value of Qp, not the exact value.

4.1.2. Graphing Dimensional Synthetic Unit Hydrograph

The process of generating dimensional and dimensionless coordinates for the ITB-1b and ITB-2b SUHs for Pinamula Catchment is outlined in Table A1 for the ITB-1b SUH and Table A2 for the ITB-2b SUH. The numerical values for the dimensionless coordinates are presented in Columns 2 and 3, while the dimensional coordinates are shown in Columns 4 and 5 of both tables. The resulting dimensional SUH coordinates for the ITB-1b SUH can be found in Table 4, and those for the ITB-2b SUH are provided in Table 5.

The dimensional coordinates provide the basis for plotting the SUHs and are essential for understanding how the unit hydrograph behaves for a specific watershed. Tables 4 and 5 both present the results of the dimensional ITB-1b and ITB-2b SUHs. These tables highlight the time (T) and discharge (Q) values, representing the discharge at various times.

When plotting the dimensional coordinates for the ITB-1b and ITB-2b Synthetic Unit Hydrographs alongside their exact dimensional curves, the results closely resemble those shown in Figure 5. This figure clearly illustrates the peak coordinates (Tp, Qp) for both SUHs, indicating the exact time to peak (Tp) and the peak discharge (Qp). In both ITB-1b and ITB-2b, the time to peak (Tp) is not always an exact multiple of the unit rainfall duration (Tr), leading to an approximation in the convolution process.For ITB-1b, the numerical and exact curves align closely throughout, showing minimal discrepancy. This indicates that the numerical method effectively captures the key characteristics of the ITB-1b SUH. However, more significant divergence becomes evident in the ITB-2b SUH, particularly around the peak, because the numerical approximation method used to compute Qp does not capture the exact value of Qp.

Table 4. Dimensional ITB-1b SUH generated numerically

ITB-1b Synthetic Unit Hydrograph			
T (hour)	**Q(m^3/s)**	**T (hour)**	**Q(m^3/s)**
0.000	0.000000	37.000	0.000000
1.000	0.128215	38.000	0.000000
2.000	0.761990	39.000	0.000000
3.000	1.562025	40.000	0.000000
4.000	2.070916	41.000	0.000000
5.000	2.162373	42.000	0.000000
6.000	1.941343	43.000	0.000000
7.000	1.570386	44.000	0.000000
8.000	1.177003	45.000	0.000000
9.000	0.832229	46.000	0.000000
10.000	0.562014	47.000	0.000000
11.000	0.365680	48.000	0.000000
12.000	0.230738	49.000	0.000000
13.000	0.141886	50.000	0.000000
14.000	0.085354	51.000	0.000000
15.000	0.050384	52.000	0.000000
16.000	0.029255	53.000	0.000000
17.000	0.016742	54.000	0.000000
18.000	0.009459	55.000	0.000000
19.000	0.005284	56.000	0.000000
20.000	0.002921	57.000	0.000000
21.000	0.001600	58.000	0.000000
22.000	0.000869	59.000	0.000000
23.000	0.000469	60.000	0.000000
24.000	0.000251	61.000	0.000000
25.000	0.000133	62.000	0.000000
26.000	0.000071	63.000	0.000000
27.000	0.000037	64.000	0.000000
28.000	0.000019	65.000	0.000000
29.000	0.000010	66.000	0.000000
30.000	0.000005	67.000	0.000000
31.000	0.000003	68.000	0.000000
32.000	0.000001	69.000	0.000000
33.000	0.000001	70.000	0.000000
34.000	0.000000	71.000	0.000000
35.000	0.000000	72.000	0.000000
36.000	0.000000	73.000	0.000000

Table 5. Dimensional ITB-2b SUH generated numerically

ITB-2b Synthetic Unit Hydrograph			
T (hour)	**Q(m^3/s)**	**T (hour)**	**Q(m^3/s)**
0.000	0.000000	37.000	0.000018
1.000	0.560197	38.000	0.000013
2.000	2.956735	39.000	0.000009
3.000	3.040663	40.000	0.000006
4.000	2.133464	41.000	0.000004
5.000	1.496933	42.000	0.000003
6.000	1.050315	43.000	0.000002
7.000	0.736947	44.000	0.000001
8.000	0.517075	45.000	0.000001
9.000	0.362803	46.000	0.000000
10.000	0.254558	47.000	0.000000
11.000	0.178610	48.000	0.000000
12.000	0.125320	49.000	0.000000
13.000	0.087930	50.000	0.000000
14.000	0.061696	51.000	0.000000
15.000	0.043289	52.000	0.000000
16.000	0.030373	53.000	0.000000
17.000	0.021311	54.000	0.000000
18.000	0.014953	55.000	0.000000
19.000	0.010492	56.000	0.000000
20.000	0.007361	57.000	0.000000
21.000	0.005165	58.000	0.000000
22.000	0.003624	59.000	0.000000
23.000	0.002543	60.000	0.000000
24.000	0.001784	61.000	0.000000
25.000	0.001252	62.000	0.000000
26.000	0.000878	63.000	0.000000
27.000	0.000616	64.000	0.000000
28.000	0.000432	65.000	0.000000
29.000	0.000303	66.000	0.000000
30.000	0.000213	67.000	0.000000
31.000	0.000149	68.000	0.000000
32.000	0.000105	69.000	0.000000
33.000	0.000074	70.000	0.000000
34.000	0.000052	71.000	0.000000
35.000	0.000036	72.000	0.000000
36.000	0.000025	73.000	0.000000

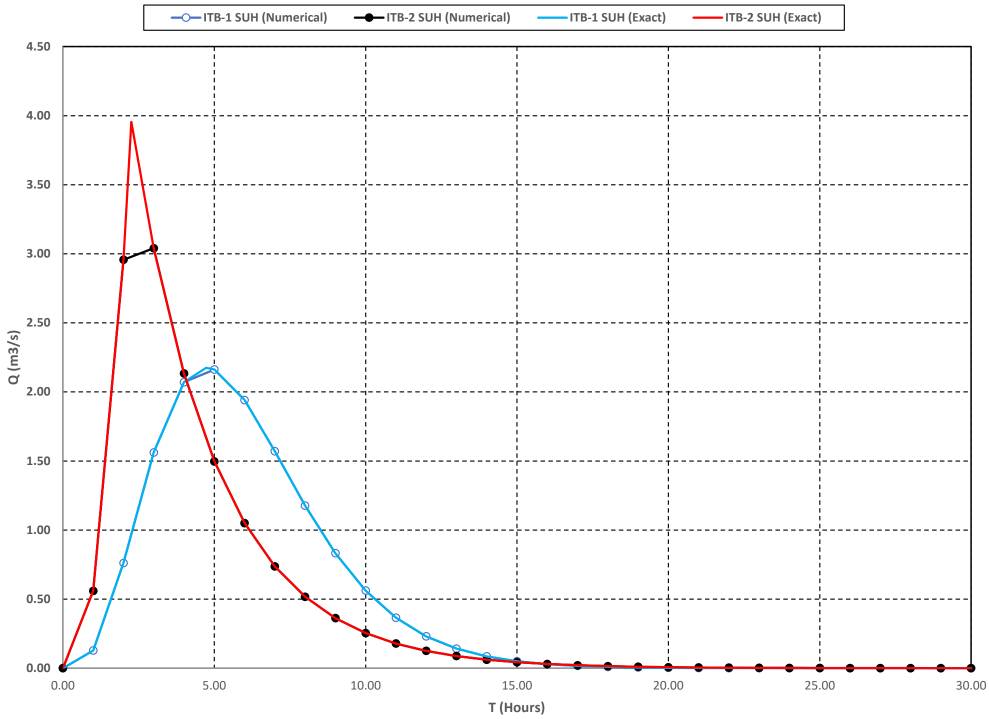


Figure 5. The dimensional exact and numerical ITB-1b and ITB-2b SUH for Pinamula River

4.1.3. Hydrograph Convolution of ITB-1b and ITB-2b Dimensional Synthetic Unit Hydrograph

In hydrology, convolution is a fundamental technique for predicting river flow. It involves combining the effective rainfall distribution with the unit hydrograph, which represents a watershed's unique response to a standardized unit of rainfall excess. This process essentially "mixes" the unit hydrograph's response to each portion of rainfall over time, considering how earlier rain influences later runoff. This convolution process accounts for the time lag and attenuation of the rainfall signal as it travels through the watershed, considering factors such as infiltration, soil moisture, and channel routing. The resulting river flow hydrograph depicts the predicted discharge at different times after a rainfall event, providing crucial insights for flood planning, water resources management, and the design of hydraulic structures.

This calculation can even be done using Excel formulas! Convolution involves summing the product of corresponding rainfall and unit hydrograph values for each time interval. The formula itself (shown mathematically) represents the discharge (Q(t)) at a specific time (t) as the sum, across all previous time steps (τ), of the product between the rainfall (R(τ)) at that time step and the unit hydrograph value (U(t-τ)) shifted by the time difference (t-τ). In Excel, performing convolution for hydrology typically involves setting up a spreadsheet to compute the convolution between the effective rainfall data and the unit hydrograph. Detailed procedures for convolution are extensively covered in many hydrology textbooks.

Following the creation of the ITB-1b and ITB-2b Synthetic Unit Hydrographs in Table 4 and Table 5, convolution is performed using a unit rainfall duration (Tr) of 1.0 hour and the total effective rain distribution specified in Table 1 (also with Tr=1.0). Convolution is typically conducted using tables, as exemplified Table A3 for the ITB-1b and Table A4. for ITB-2b SUHs, respectively. Column (9) of these tables calculates the sum of values in each row from Columns (3) to (8). Notably, Column 10, not commonly found in other literature, employs the trapezoidal method to calculate the flood volume between hours I and I+1 using data from Columns (1) and (9). The formula used is:

$$V_i = 0.5 \times (T_{i+1} - T_i) \times (Q_{i+1} - Q_i). \tag{16}$$

4.1.4. Plotting Convolution Results of Synthetic Unit Hydrograph

The total hydrograph resulting from the convolution of ITB-1b and ITB-2b hydrographs, as shown in Figure 6 is obtained using a numerically calculated peak discharge value, not an exact peak discharge. Column 1 and Column 9 of Table A2 and Table A3 contain the time and discharge of the ITB-1b and ITB-2b total hydrograph, respectively. When both the ITB-1b and ITB-2b total hydrographs are superimposed on a graph, the resulting curve is displayed in Figure 6. From the analysis of both curves, it is apparent that the hydrograph produced by ITB-2b features a greater peak flow and reaches its peak more quickly. On the other hand, the hydrograph from ITB-1b demonstrates a lower peak flow and a more delayed peak time. However, despite these variations, the total volume of the hydrographs from both remains the same.

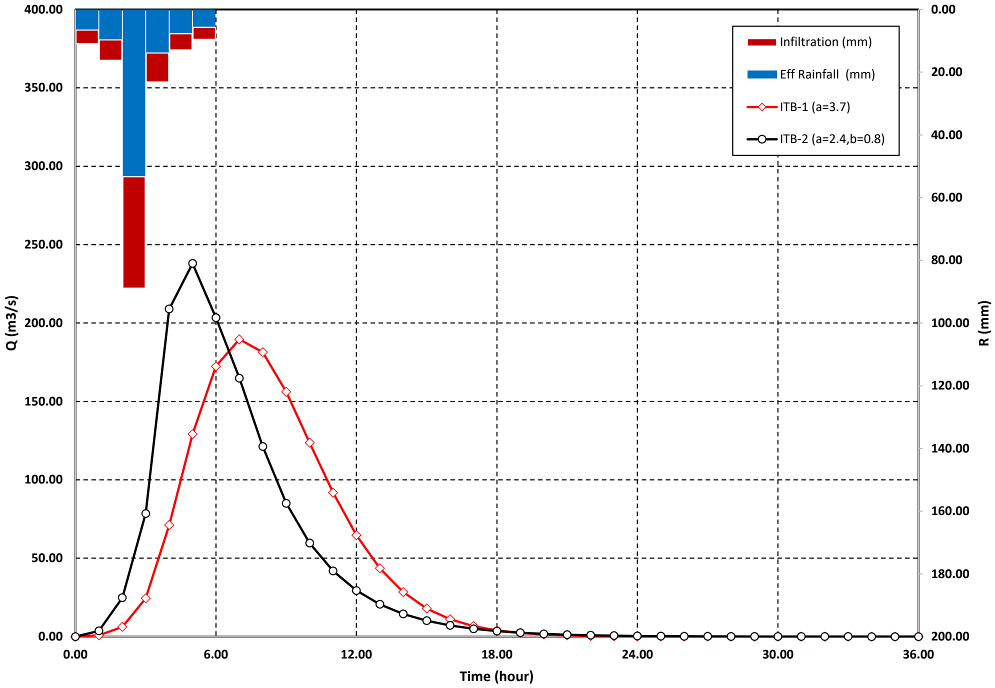


Figure 6. ITB-1b and ITB-2b Hydrograph for Pinamula River with Tr = 1.0 hour

4.2. Analysis of Flood Hydrographs at Pinamula River with Tr = 0.5 hour

The ITB Method allows for Flexible Time Step Adjustments by introducing unit duration normalization, enabling flexible adjustments to the time step. This capability, embedded in the calculation, is not commonly found in other methods, allowing for adjustments to the time step without requiring significant recalculations.

To assess the impact of altering the normalized unit hydrograph duration (Tn = Tr/Tp), we reduced Tr from 1.0 hour to 0.5 hour. Consequently, when the unit rainfall duration is halved from 1.0 hour to 0.5 hour with a coefficient C = 0.6, the original rainfall distribution shown in Table 1 is transformed into the one presented in Table 6. As a result, the rainfall amount for each half-hour interval becomes half of what it was for a one-hour interval.

Table 6. Total rainfall, infiltration, and effective rainfall for Tr = 0.5 hour

Tr=0.5 hour			
Hour	**R (mm)**	**Infil (mm)**	**Reff (mm)**
0.00	0.000	0.000	0.000
0.50	5.448	2.179	3.269
1.00	5.448	2.179	3.269
1.50	8.104	3.241	4.862
2.00	8.104	3.241	4.862
2.50	44.445	17.778	26.667
3.00	44.445	17.778	26.667
3.50	11.552	4.621	6.931
4.00	11.552	4.621	6.931
4.50	6.451	2.581	3.871
5.00	6.451	2.581	3.871
5.50	4.762	1.905	2.857
6.00	4.762	1.905	2.857
6.50	0.000	0.000	0.000

4.2.1. Creating Tables for the ITB-1b and ITB-2b Synthetic Unit Hydrographs

By utilizing the same Pinamula River characteristics, as detailed in Section 4.1 (Analysis of Flood Hydrographs at Pinamula Catchment with Tr = 1.0 hour), the flood hydrograph for a unit rainfall duration (Tr) of 0.5 hours was determined. This involved a series of complex calculations, including the generation of figures and tables. These calculations are meticulously outlined in Table A5 for the ITB-1b SUH and Table A6 for the ITB-2b SUH, each comprising multiple sections. Given the alterations in Tn values (Tn = Tr/Tp) and the adjustments made to rainfall and infiltration distributions, it was necessary to recompute the ITB-1b and ITB-2b Synthetic Unit Hydrographs. Subsequently, with the updated Tn values set to 0.5, the revised tables are presented in Table A5 and Table A6.

4.2.2. Hydrograph Convolution

Following the finalization of the ITB-1b and ITB-2b Synthetic Unit Hydrographs (in Table A5 and Table A6), the next step involves performing convolution. Convolution is a mathematical operation that essentially combines the ITB-1b/ITB-2b unit hydrographs with the effective rainfall distribution (Table 6) to generate the flood hydrograph for a specific rainfall event. This flood hydrograph represents the discharge of water over time at the outlet of the watershed.

Tables typically carry out convolutions for the ITB method, as demonstrated in Table A7 for the ITB-1b SUH and Table A8. for the ITB-2b SUH., respectively. Column (15) in these tables calculates the sum of each row's values from Columns (3) to (14), representing the flood hydrograph for a unit rainfall event with a duration of Tr = 0.5 hours. A unique feature of the ITB method is the inclusion of a small table in the bottom right corner of Table A7 and Table A8. This table verifies adherence to the mass conservation principle, ensuring that the total volume of water entering the watershed equals the total volume discharged. This minor addition is a feature not commonly found in other methods.

4.2.3. Results Comparison: Time Step Sensitivity

A crucial aspect of the ITB method is its ability to adapt to different time steps for rainfall excess. Comparing the SUH for Pinamula River generated using Tr = 1.0 hour and Tr = 0.5 hour, as shown in Figure 7, is essential for understanding the influence of rainfall duration on flood characteristics. The results clearly demonstrate that a finer time step (Tr = 0.5 hour) leads to significant improvements in the hydrograph shape. This is evident in the smoother profile of the hydrograph, which more accurately reflects the real-world rise and fall of flood discharge. Notably, the use of Tr = 0.5 hour can lead to a slightly higher in peak discharge and a more precise representation of the initial rise in the hydrograph. This highlights the importance of considering rainfall duration with appropriate granularity for effective flood modeling and prediction.

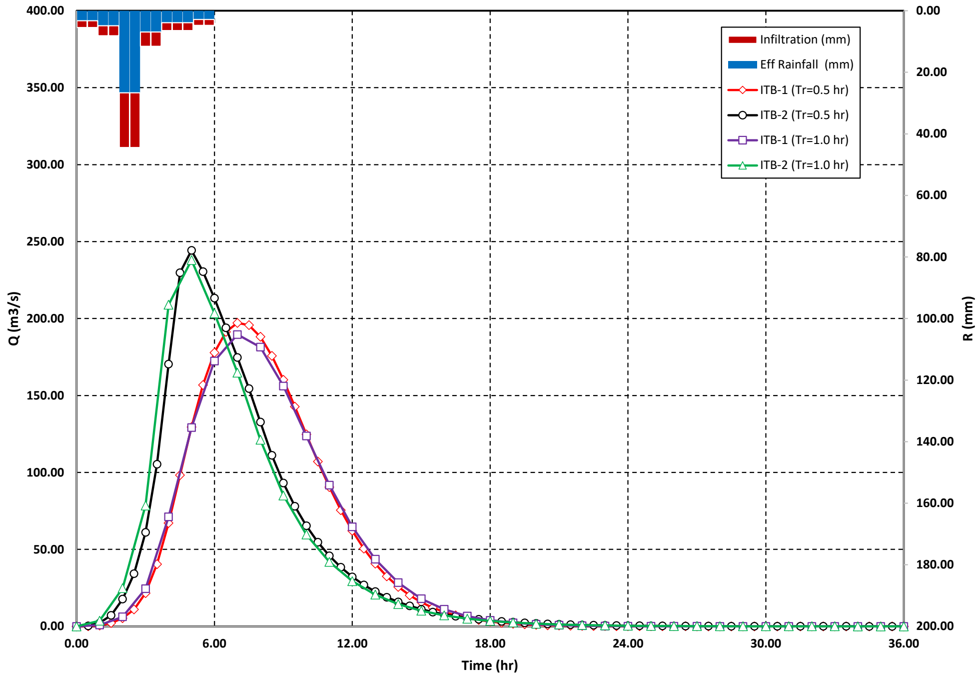


Figure 7. Flood hydrograph of ITB-1b and ITB-2b SUH for Pinamula River with Tr=1.0 and Tr=0.5 hour

4.3. Calibration of Flood Hydrographs at Pinamula Catchment with Measured Data

Calibration is crucial because no two catchments are exactly alike; each has unique physical and hydrological characteristics—such as varying land use, soil types, slopes, and rainfall patterns—that can significantly affect how rainfall translates into runoff. When a model is calibrated, its parameters (for instance, time to peak and peak discharge) are adjusted to match observed data from the specific watershed under study. This process ensures that the simulated hydrograph more closely reflects the real behavior of that catchment.

In the context of SUH, many traditional methods (e.g., certain forms of SCS or Nakayasu) have fixed or limited parameter sets. These methods cannot easily be recalibrated to account for local conditions, which can lead to misaligned peak flows and timings, especially in catchments that deviate from the assumptions on which those methods were originally based. By contrast, the ITB method incorporates inherent calibration features, allowing parameters like time to peak (Tp) and peak discharge (Qp) to be fine-tuned based on measured rainfall and runoff.

4.3.1. Calibration Dataset

The calibration process uses rainfall and flood discharge data provided by Tunas (2017) [12] to fine-tune the ITB method for greater accuracy. Table 7 outlines the relationship between total rainfall (R_{total}), infiltration (Infil), and direct runoff (QDRO), crucial for improving model performance [13]. Key variables include effective rainfall (Reff), total discharge (Q_{total}), base flow (Q_{Base}), and direct runoff (QDRO), all of which play a vital role in calibrating the ITB method. The table helps compare observed rainfall and discharge values, offering insights into the rainfall-runoff relationship that enhance the model's accuracy across varying hydrological conditions.

Table 7. Effective Rainfall, Infiltration, and Direct Runoff

Hour	R_{total} (mm)	Infiltration (mm)	Reffe (mm)	Q_{total} (m^3/s)	Q_{Base} (m^3/s)	QDRO (m^3/s)
0	4.400	5.310	0.000	0.930	0.930	0.000
1	16.700	5.310	11.390	10.120	1.150	8.970
2	5.300	5.310	0.000	20.080	1.370	18.710
3	5.000	5.310	0.000	24.370	1.600	22.770
4	2.200	5.310	0.000	23.410	1.820	21.590
5				22.590	2.040	20.550
6				18.630	2.260	16.370
7				15.310	2.490	12.820
8				13.280	2.710	10.570
9				9.620	2.930	6.690
10				8.470	3.150	5.320
11				6.420	3.380	3.040
12				5.750	3.600	2.150
13				5.450	3.820	1.630
14				5.440	4.040	1.400
15				5.430	4.270	1.160
16				5.420	4.490	0.930
17				5.410	4.710	0.700
18				5.400	4.930	0.470
19				5.390	5.150	0.240
20				5.380	5.380	0.000

Figure 8 visually complements the table, depicting the hydrograph and illustrating the relationship between rainfall and discharge over time. By clearly mapping the rainfall data to observed discharge, the hydrograph highlights key hydrological responses, such as peak flow and the timing of runoff events. Such detail is crucial for fine-tuning the ITB method, as it helps to identify potential discrepancies between simulated and observed data.

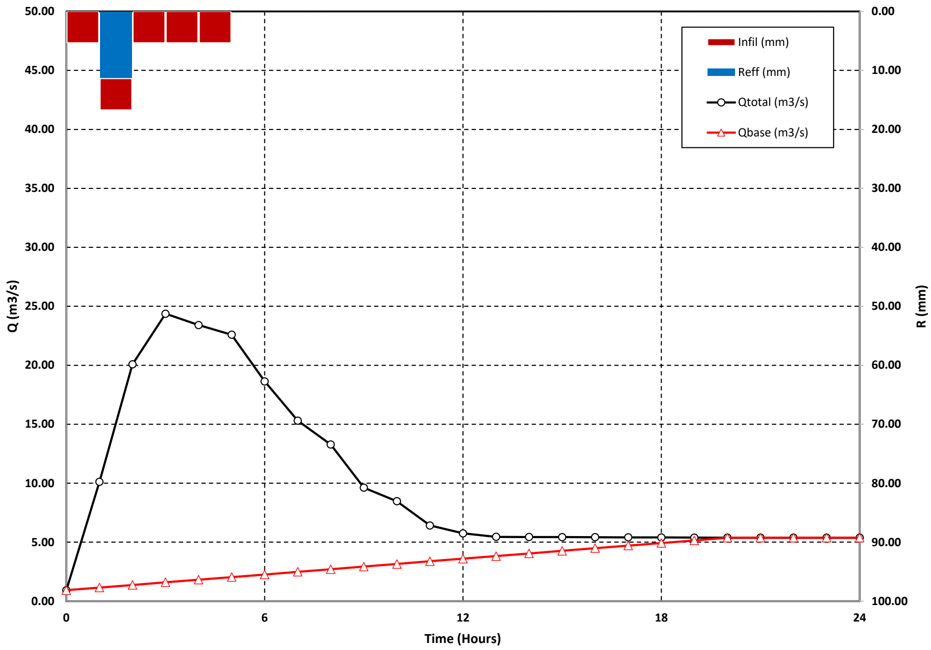


Figure 8. Effective rainfall, infiltration, total discharge, and base flow SUH for Pinamula River

4.3.2. UnCalibrated Hydrograph Comparison

This study improves flood discharge calculations for the Pinamula River by integrating effective rainfall data from Table 7 and initial parameter values prior to calibration from Table 8. The initial hydrographs, produced using uncalibrated ITB-1b and ITB-2b SUH variables as shown in Figure 9, exhibit significant discrepancies in peak discharge compared to observed data. These differences are reflected in the suboptimal performance metrics, such as NSE, PBIAS, and IA. Therefore, calibration is essential to improve the accuracy and reliability of flood discharge simulations for this watershed.

Table 8. Initial parameter values before calibration

SUH	α	β	Ct	Cp
ITB-1b	3.7	-	1	1
ITB-2b	2.4	0.8	1	1

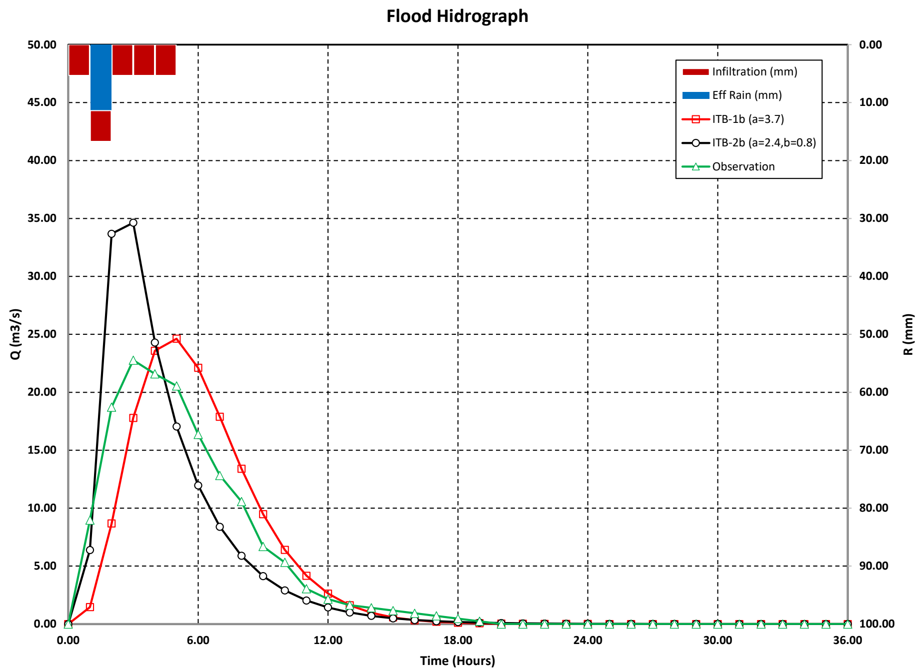


Figure 9. ITB-1b and ITB-2b hydrographs for Pinamula River before calibration, compared with the observed hydrograph

4.3.3. Calibrated Hydrograph Comparison

An iterative calibration process was applied, beginning with uncalibrated hydrographs (Figure 9). The adjustments primarily targeted the Ct values to refine the timing of the peak discharge: Ct values below 1.0 advanced the peak, while values above 1.0 delayed it. Specifically, the Ct value for ITB-1b was decreased, and for ITB-2b, it was increased, ensuring that the calculated peak times aligned with the observed data. Following this, Cp values were systematically refined to achieve closer matches in peak discharges. Underestimated peaks were corrected by increasing Cp values, while overestimated peaks were addressed by reducing them. Once the peak timing was satisfactorily adjusted, further fine-tuning of Cp values for both ITB-1b and ITB-2b was conducted to ensure a more accurate alignment between the calculated and observed peak discharges, resulting in improved calibration accuracy.

The final calibrated parameters, shown in Table 9, reflect this iterative process, with constants α and β kept unchanged. This allowed the calibration improvements to focus solely on Ct and Cp, ensuring clearer insights into their impact. To assess the accuracy of the calibrated hydrographs, metrics like Nash-Sutcliffe Efficiency (NSE), Index of Agreement (IA), and Percent Bias (PBIAS) were used, providing a solid measure of the model's performance in simulating flood discharges.

Table 9. Final parameter values after calibration

SUH	α	β	Ct	Cp	NSE	PBIAS	IA
ITB-1b	3.700	-	0.880	1.050	0.8783	2.6984	0.9456
ITB-2b	2.400	0.800	1.500	1.250	0.8364	5.3468	0.9216

Figure 10 displays the hydrographs for Pinamula River generated using the calibrated parameter values from Table 9. Visual inspection reveals a significant improvement in the agreement between the simulated and observed hydrographs. Calibration led to a closer match between the simulated and observed peak discharge. ITB-1b demonstrates beter performance visually in matching the observed data. The performance metrics, such as NSE, PBIAS, and IA, reinforce this observation, indicating that ITB-1b is the more effective model for flood discharge predictions at the Pinamula catchment. Given that ITB-1b visually aligns more closely with the observed values and the metrics confirm this, ITB-1b provides a more accurate representation of the hydrological behavior at Pinamula river.

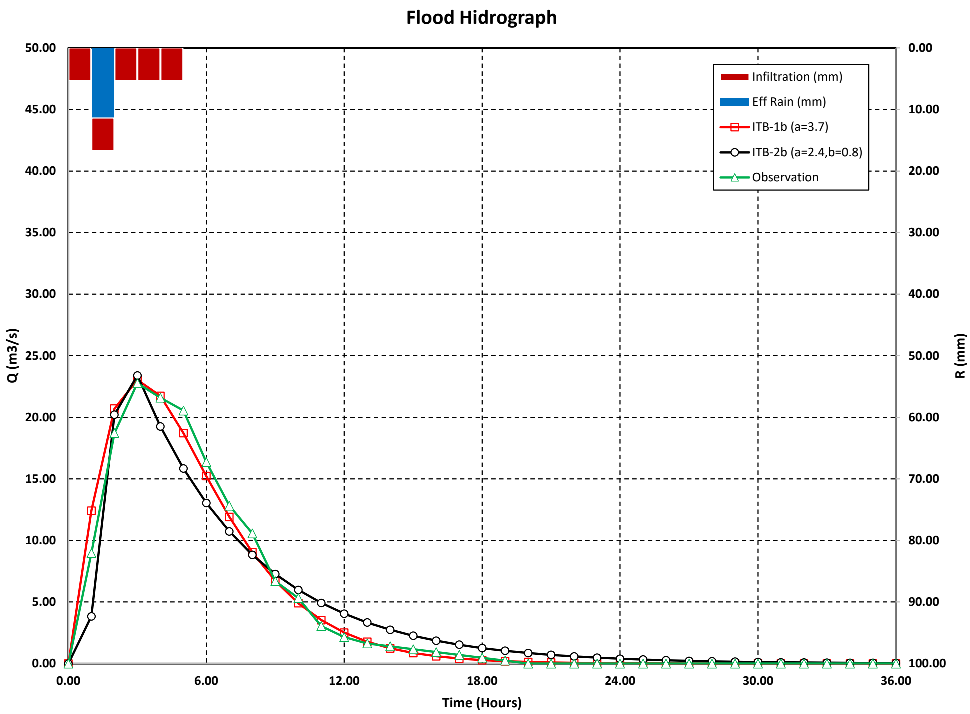


Figure 10. The ITB-1b and ITB-2b hydrographs for Pinamula River after calibration with observed hydrograph

5. Conclusions

Flooding remains a pressing concern for communities and infrastructure, necessitating robust and accurate methods for flood discharge estimation. In *Part I* of this two-part series, the ITB Unit Hydrograph (ITB-UH) Method is introduced as a direct response to the limitations of traditional SUHs—offering a clearer derivation of peak discharge, flexible time steps, and built-in calibration. This foundation enhances both the theoretical robustness and the practical adaptability of flood modeling, providing crucial benefits for engineers, hydrologists, and decision-makers.

- **Practical Applications and Findings**
  - *Pinamula River Case Study*

    Demonstrations at Pinamula River highlight the method's versatility. Whether using a 1-hour or 0.5-hour rainfall duration, the ITB-UH Method proved adaptable, producing realistic hydrographs comparable to SCS-Curvilinear and Nakayasu.

  - *Calibration with Observed Data*

    By adjusting Ct and Cp, the model can be fine-tuned to match observed peak flows and timing. Metrics like NSE, PBIAS, and IA confirm the method's reliability.

  - *Visual and Statistical Evaluation*

    In some scenarios, ITB-1b produced higher NSE, whereas ITB-2b more closely mirrored observed hydrograph shapes (especially on the falling limb), indicating that the "best" model might depend on priorities (statistical fit vs. visual alignment).

- **Overall Significance of the ITB-UH Method**

The ITB-UH Method represents a significant step forward in hydrological modeling by addressing many of the limitations associated with traditional SUH approaches. Its key contributions include:

  - *Improved Accuracy*

    Precise derivations for Kp and Qp, combined with calibration options, enhance the theoretical basis and reliability of flood predictions.

  - *Versatility and Flexibility*

    Flexible time-step normalization allows seamless adjustments to various rainfall resolutions, and custom UDUHs can be developed for diverse catchment conditions.

  - *Enhanced Understanding of Catchments*

    Calibration refines local parameters, providing deeper insights into how water moves through a watershed, while explicit mass conservation checks help maintain modeling integrity.

  - *Advancement in Hydrological Modeling*

    Robust mathematical derivations and calibration steps establish a new standard for Synthetic Unit Hydrograph development, ensuring consistent, transparent flood analyses across a wide range of contexts.

Collectively, these features position the ITB-UH Method as a powerful and comprehensive tool for flood risk assessment, water resource management, and the design of flood mitigation infrastructure. By overcoming the limitations of older SUH methods—such as limited calibration, rigid time steps, and opaque derivations, the ITB-UH Method ensures both theoretical soundness and practical adaptability in modern hydrological practice.

6. Declarations

6.1. Author Contributions

Conceptualization: D.K.N.; methodology: D.K.N.; software: J.J. and F.A.; validation: W.H., D.H., and E.O.N.; formal analysis: W.H. and D.H.; investigation: E.O.N. and A.A.K.; resources: A.A.K. and M.F.; data curation: M.F. and J.J.; writing—original draft preparation: D.K.N.; writing—review and editing: D.K.N., W.H., and J.J.; visualization: J.J. and F.A.; supervision: A.A.K. and E.O.N.; project administration: M.H. and D.H.; funding acquisition: D.K.N. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding and Acknowledgements

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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Appendix I

Table A1. Computation of ITB-1b SUH for Pinamula River for Tr = 1.0 hour

I. Characteristics of Watershed and Rainfall

1. River Name	=	Pinamula	
2. Station	=	Pinamula	
3. Watershed Area (A)	=	49.350 Km^2	
4. Main River Length (L)	=	15.640 km	
5. Rainfall Depth (R)	=	1.000 mm	
6. Unit Rainfall Duration (Tr)	=	1.000 Hour	

II. Calculation of Time Lag, Time to Peak, and Time Base

1. Time Coefficient (Ct)	=	1.00000 -	
2. Time Lag (TL)			
TL = Ct*0.81225*L^0.6	=	4.22894 Hour	ITB-1 Time lag formula
3. Peak Time (TP)			
TP = TL + 0.5 * Tr	=	4.72894 Hour	
4. Base Time (TB)			
TB = TP	=	10.00000 Defined	
TB	=	47.28942 Hour	

III. Computation of ASUH, Kp, and Tp

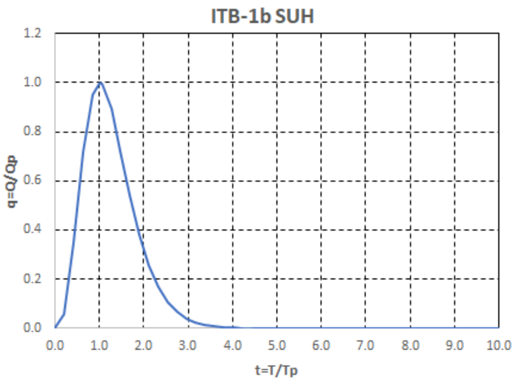
1. Tn = Tr/Tp	=	0.21146 -	Normalize Unit Rainfall Duration
2. Peak Coefficient (Cp)	=	1.00000 -	
3. Alpha	=	3.70000 -	
4. A_{SUH} (Numerik, Exact,)	=	1.33275 Exact	$A_{SUH} = \frac{e^m \Gamma(m+1.0)}{m^{m+1}}$
	=	1.33287 Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
5. Kp = 1/(3.6*ASUH)	=	0.20843 Exact	
		0.20840 Numerical	
6. Qp = Kp A_{DAS} R/Tp	=	2.17507 m3/s (Ext)	
	=	2.17486 m3/s (Num)	
	=	-0.0097% Error	

IV. Conservation Check

1. Rain Vol (1000 * R * ADAS)	=	49,350 m3	
2. Hydrograph Volume	=	49,350 m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. Runoff Depth	=	1.00000 Ok≈1.0 mm	
	=		

V. Table for Calculation of SUH ITB-1b:

No	Dimensionless SUH		Dimensional SUH	
	t=T/Tp	q=Q/Qp	T (hour)	Q=q×Qp
(1)	(2)	(3)	(4)	(5)
0	0.000000	0.000000	0.000	0.000000
1	0.211464	0.058947	1.000	0.128202
2	0.422928	0.350329	2.000	0.761916
3	0.634391	0.718149	3.000	1.561873
4	0.845855	0.952114	4.000	2.070714
5	1.057319	0.994162	5.000	2.162162
6	1.268783	0.892542	6.000	1.941154
7	1.480246	0.721993	7.000	1.570233
8	1.691710	0.541133	8.000	1.176889
9	1.903174	0.382622	9.000	0.832148
10	2.114638	0.258389	10.000	0.561959
11	2.326102	0.168123	11.000	0.365644
12	2.537565	0.106083	12.000	0.230716
13	2.749029	0.065233	13.000	0.141872
14	2.960493	0.039242	14.000	0.085346
15	3.171957	0.023164	15.000	0.050379
16	3.383420	0.013450	16.000	0.029252
117	24.741261	0.000000	117.000	0.000000
118	24.952725	0.000000	118.000	0.000000
119	25.164189	0.000000	119.000	0.000000
120	25.375653	0.000000	120.000	0.000000



Note:

- Column (1) = Integer numbers from 0 to as needed
- Column (2) = Column (1) * Tn (Section III No. 1)
- Column (3) = SUH Curve Shape it is Function(Column (2))
  q(t) = (t * EXP(1 - t))^(a * Cp)
- Column (4) = Column (2) * Tp (Hour)
- Column (5) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A2. Computation of ITB-2b SUH for Pinamula River for Tr=1.0 hour

I. Characteristics of Watershed and Rainfall

1. River Name	=	Pinamula	
2. Station	=	Pinamula	
3. Watershed Area (A)	=	49.350	Km^2
4. Main River Length (L)	=	15.640	mm
5. Rainfall Depth (R)	=	1.000	mm
6. Unit Rainfall Duration (Tr)	=	1.000	Hour

II. Calculation of Time Lag, Time to Peak, and Time Base

1. Time Coefficient (Ct)	=	1.00000	
2. Time Lag (TL)			
TL = Ct*0.81225*L^0.6	=	1.41112	Hour
3. Peak Time (TP)			
TP = TL + 0.5 * Tr	=	2.25779	Hour
4. Base Time (TB)			
TB = TP	=	20.00000	Defined
TB	=	45.15583	Hour

III. Computation of ASUH, Kp, and Tp

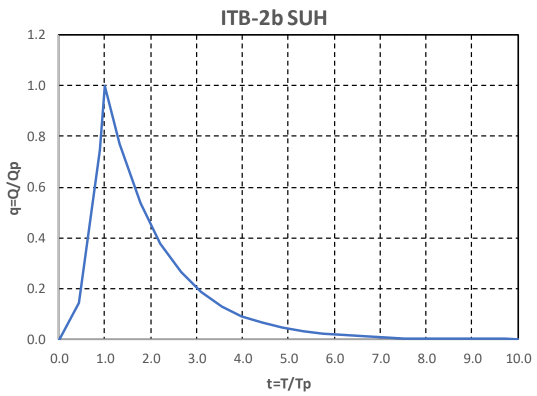
1. Tn = Tr/Tp	=	0.44291	-	
2. Peak Coefficient (Cp)	=	1.00000	-	
3. Alpha	=	2.40000	-	
	=	0.80000	-	$A_{SUH} = \frac{1}{m+1} + \frac{1}{(n \cdot Cp)} - \frac{\exp(-(b-1)*(n \cdot Cp))}{(n \cdot Cp)}$
4. A_{SUH} (Numerik, Exact,)	=	1.54412	Exact	
	=	1.53504	Numerik	(Sum of Column (3) in Section V) x (Tr/Tp)
5. Kp = 1/(3.6*ASUH)	=	0.17989	Exact	
		0.18096	Numerik	
6. Qp = Kp A_{DAS} R/Tp	=	3.93206	m3/s (Ext)	
	=	3.95532	m3/s (Num)	
	=	0.5914%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * ADAS)	=	49,350	m3	
2. Hydrograph Volume	=	49,350	m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. Runoff Depth	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SUH ITB-2b:

No	HSS Tak berdimensi		HSS berdimensi	
	t=T/Tp	q=Q/Qp	T (jam)	Q=q×Qp
(1)	(2)	(3)	(4)	(5)
0	0.000000	0.000000	0.000	0.000000
1	0.442911	0.141631	1.000	0.560197
2	0.885821	0.747534	2.000	2.956735
3	1.328732	0.768753	3.000	3.040663
4	1.771643	0.539391	4.000	2.133464
5	2.214554	0.378461	5.000	1.496933
6	2.657464	0.265545	6.000	1.050315
7	3.100375	0.186318	7.000	0.736947
8	3.543286	0.130729	8.000	0.517075
9	3.986197	0.091725	9.000	0.362803
10	4.429107	0.064359	10.000	0.254558
11	4.872018	0.045157	11.000	0.178610
12	5.314929	0.031684	12.000	0.125320
13	5.757840	0.022231	13.000	0.087930
14	6.200750	0.015598	14.000	0.061696
15	6.643661	0.010944	15.000	0.043289
16	7.086572	0.007679	16.000	0.030373
118	52.263467	0.000000	118.000	0.000000
119	52.706378	0.000000	119.000	0.000000
120	53.149289	0.000000	120.000	0.000000



Catatan :

- Column (1) = Integer numbers from 0 to as needed
- Column (2) = Column (1) * Tn (Section III No. 1)
- Column (3) = SUH Curve Shape it is Function(Column (2))
  q(t) =MIN(1,t^α,MIN(1,EXP((1-t)*(β*Cp))))
- Column (4) = Column (2) * Tp (Hour)
- Column (5) = Column (5) * Qp (m3/s)

Use Qp numerical not Exact

Table A3. Convolution of ITB-1b SUH for Pinamula River for Tr=1.0 hour

Time (Hour)	ITB-1b SUH	Rainfall Depth (mm)						Hydrograph	
		1	2	3	4	5	6	7	8
		6.537	9.724	53.334	13.863	7.742	5.714	Q (m3/s)	Vol (m3)
0.00	0.000	0.000						0.000	0.000
1.00	0.128	0.838	0.000					0.838	1508.602
2.00	0.762	4.981	1.247	0.000				6.228	12718.375
3.00	1.562	10.211	7.409	6.838	0.000			24.457	55232.941
4.00	2.071	13.537	15.188	40.636	1.777	0.000		71.139	172072.841
5.00	2.162	14.135	20.136	83.301	10.562	0.992	0.000	129.127	360478.611
6.00	1.941	12.690	21.026	110.440	21.652	5.898	0.733	172.438	542817.901
7.00	1.570	10.265	18.876	115.317	28.706	12.091	4.354	189.610	651686.459
8.00	1.177	7.694	15.269	103.530	29.973	16.031	8.925	181.422	667857.558
9.00	0.832	5.440	11.444	83.747	26.910	16.738	11.833	156.113	607562.957
10.00	0.562	3.674	8.092	62.768	21.768	15.028	12.356	123.685	503635.873
11.00	0.366	2.390	5.465	44.382	16.315	12.156	11.093	91.800	387873.875
12.00	0.231	1.508	3.556	29.972	11.536	9.111	8.973	64.655	281620.478
13.00	0.142	0.927	2.244	19.501	7.790	6.442	6.725	43.630	194913.615
14.00	0.085	0.558	1.380	12.305	5.069	4.350	4.755	28.417	129684.831
15.00	0.050	0.329	0.830	7.567	3.198	2.831	3.211	17.966	83489.981
16.00	0.029	0.191	0.490	4.552	1.967	1.786	2.089	11.075	52274.674
17.00	0.017	0.109	0.284	2.687	1.183	1.098	1.318	6.681	31960.676
18.00	0.009	0.062	0.163	1.560	0.698	0.661	0.811	3.955	19143.417
19.00	0.005	0.035	0.092	0.893	0.406	0.390	0.488	2.303	11262.899
20.00	0.003	0.019	0.051	0.504	0.232	0.226	0.288	1.321	6523.088
21.00	0.002	0.010	0.028	0.282	0.131	0.130	0.167	0.749	3725.760
22.00	0.001	0.006	0.016	0.156	0.073	0.073	0.096	0.419	2101.818
23.00	0.000	0.003	0.008	0.085	0.040	0.041	0.054	0.232	1172.609
24.00	0.000	0.002	0.005	0.046	0.022	0.023	0.030	0.128	647.690
25.00	0.000	0.001	0.002	0.025	0.012	0.012	0.017	0.069	354.525
26.00	0.000	0.000	0.001	0.013	0.006	0.007	0.009	0.037	192.464
27.00	0.000	0.000	0.001	0.007	0.003	0.004	0.005	0.020	103.701
28.00	0.000	0.000	0.000	0.004	0.002	0.002	0.003	0.011	55.491
29.00	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.006	29.506
30.00	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.003	15.597
31.00	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	8.200
32.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	4.290
33.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.234
34.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.158
35.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.598
36.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.307
37.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.158
38.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080
39.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041
40.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021
41.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011
42.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
43.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
44.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
45.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
46.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
59.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				VT = Hydrograph Volume = ∑ Column 8				m3	4782735.9
				ADAS = Watershed Area = As per Input				km2	49.350
				RE = Effective Rainfall = As per Input				mm	96.915
				DRO = Runoff = VT/ADAS/1000				mm	96.915
				RRR = Rainfall Runoff Ratio = DRO/RT				%	100.00%

Table A4. Convolution of ITB-2b SUH for Pinamula River for Tr=1.0 hour

Time (Hour)	ITB-2b SUH	Rainfall Depth (mm)						Hydrograph	
		1	2	3	4	5	6	7	8
		6.537	9.724	53.334	13.863	7.742	5.714	Q (m3/s)	Vol (m3)
0.00	0.000	0.000						0.000	0.000
1.00	0.560	3.662	0.000					3.662	6592.042
2.00	2.957	19.329	5.448	0.000				24.777	51190.622
3.00	3.041	19.878	28.752	29.878	0.000			78.508	185913.032
4.00	2.133	13.947	29.568	157.695	7.766	0.000		208.977	517472.376
5.00	1.497	9.786	20.747	162.171	40.988	4.337	0.000	238.029	804609.866
6.00	1.050	6.866	14.557	113.787	42.152	22.890	3.201	203.452	794665.822
7.00	0.737	4.818	10.214	79.838	29.576	23.539	16.896	164.880	662998.061
8.00	0.517	3.380	7.166	56.018	20.751	16.516	17.376	121.208	514958.339
9.00	0.363	2.372	5.028	39.304	14.560	11.589	12.192	85.045	371254.829
10.00	0.255	1.664	3.528	27.578	10.216	8.131	8.554	59.671	260488.863
11.00	0.179	1.168	2.475	19.350	7.168	5.705	6.002	41.868	182770.545
12.00	0.125	0.819	1.737	13.577	5.029	4.003	4.211	29.376	128239.925
13.00	0.088	0.575	1.219	9.526	3.529	2.809	2.955	20.612	89978.822
14.00	0.062	0.403	0.855	6.684	2.476	1.971	2.073	14.462	63133.134
15.00	0.043	0.283	0.600	4.690	1.737	1.383	1.455	10.147	44297.009
16.00	0.030	0.199	0.421	3.290	1.219	0.970	1.021	7.120	31080.747
17.00	0.021	0.139	0.295	2.309	0.855	0.681	0.716	4.996	21807.631
18.00	0.015	0.098	0.207	1.620	0.600	0.478	0.502	3.505	15301.202
19.00	0.010	0.069	0.145	1.137	0.421	0.335	0.353	2.459	10736.002
20.00	0.007	0.048	0.102	0.797	0.295	0.235	0.247	1.726	7532.856
21.00	0.005	0.034	0.072	0.560	0.207	0.165	0.174	1.211	5285.386
22.00	0.004	0.024	0.050	0.393	0.145	0.116	0.122	0.850	3708.461
23.00	0.003	0.017	0.035	0.275	0.102	0.081	0.085	0.596	2602.021
24.00	0.002	0.012	0.025	0.193	0.072	0.057	0.060	0.418	1825.693
25.00	0.001	0.008	0.017	0.136	0.050	0.040	0.042	0.293	1280.987
26.00	0.001	0.006	0.012	0.095	0.035	0.028	0.030	0.206	898.798
27.00	0.001	0.004	0.009	0.067	0.025	0.020	0.021	0.144	630.636
28.00	0.000	0.003	0.006	0.047	0.017	0.014	0.015	0.101	442.482
29.00	0.000	0.002	0.004	0.033	0.012	0.010	0.010	0.071	310.465
30.00	0.000	0.001	0.003	0.023	0.009	0.007	0.007	0.050	217.836
31.00	0.000	0.001	0.002	0.016	0.006	0.005	0.005	0.035	152.844
32.00	0.000	0.001	0.001	0.011	0.004	0.003	0.004	0.025	107.242
33.00	0.000	0.000	0.001	0.008	0.003	0.002	0.002	0.017	75.246
34.00	0.000	0.000	0.001	0.006	0.002	0.002	0.002	0.012	52.796
35.00	0.000	0.000	0.001	0.004	0.001	0.001	0.001	0.008	37.044
36.00	0.000	0.000	0.000	0.003	0.001	0.001	0.001	0.006	25.992
37.00	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.004	18.237
38.00	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.003	12.796
39.00	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	8.978
40.00	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	6.299
41.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	4.420
42.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	3.101
43.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.176
44.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.527
45.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.071
46.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.743
47.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500
48.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.267
58.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
59.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				VT = Hydrograph Volume = ∑ Column 8				m3	4782735.9
				ADAS = Watershed Area = As per Input				km2	49.350
				RE = Effective Rainfall = As per Input				mm	96.915
				DRO = Runoff = VT/ADAS/1000				mm	96.915
				RRR = Rainfall Runoff Ratio = DRO/RT				%	100.00%

Table A5. Computation of ITB-1b SUH for Pinamula River for Tr=0.5 hour

I. Characteristics of Watershed and Rainfall

1. River Name	=	Pinamula		
2. Station	=	Pinamula		
3. Watershed Area (A)	=	49.350	Km^2	
4. Main River Length (L)	=	15.640	km	
5. Rainfall Depth (R)	=	1.000	mm	
6. Unit Rainfall Duration (Tr)	=	0.500	Hour	

II. Calculation of Time Lag, Time to Peak, and Time Base

1. Time Coefficient (Ct)	=	1.0000	-	
2. Time Lag (TL)				
TL = Ct*0.81225*L^0.6	=	4.2289	Hour	ITB-1 Time lag formula
3. Peak Time (TP)				
TP = TL + 0.5 * Tr	=	4.4789	Hour	
4. Base Time (TB)				
TB = TP	=	10.0000	Defined	
TB	=	44.7894	Hour	

III. Computation of ASUH, Kp, and Tp

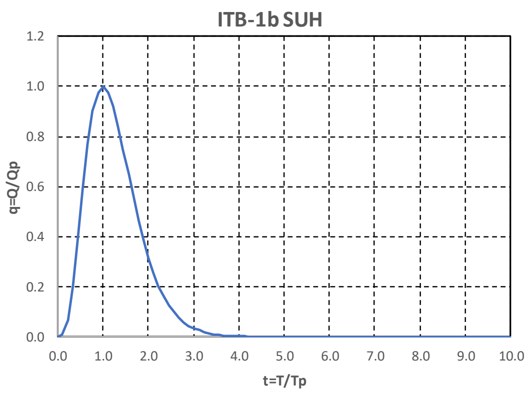
1. Tn = Tr/Tp	=	0.11163	-	Normalize Unit Rainfall Duration
2. Peak Coefficient (Cp)	=	1.00000	-	
3. Alpha	=	3.70000	-	
4. A_{SUH} (Numerik, Exact,)	=	1.33275	Exact	$A_{SUH} = \frac{e^m \Gamma(m+1,0)}{m^{m+1}}$
	=	1.33275	Numerik	(Sum of Column (3) in Section V) x (Tr/Tp)
5. Kp = 1/(3.6*ASUH)	=	0.20843	Exact	
		0.20842	Numerik	
6. Qp = Kp A_{DAS} R/Tp	=	2.29648	m3/s (Ext)	
	=	2.29647	m3/s (Num)	
	=	-0.0004%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * ADAS)	=	49,350	m3	
2. Hydrograph Volume	=	49,350	m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. Runoff Depth	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SUH ITB-1b:

No	Dimensionless SUH		Dimensional SUH	
	t=T/Tp	q=Q/Qp	T (hour)	Q=q×Qp
(1)	(2)	(3)	(4)	(5)
0	0.000000	0.000000	0.000	0.000000
1	0.111633	0.008023	0.500	0.018425
2	0.223267	0.068988	1.000	0.158429
3	0.334900	0.204611	1.500	0.469883
4	0.446534	0.392483	2.000	0.901324
5	0.558167	0.592932	2.500	1.361649
6	0.669801	0.770181	3.000	1.768695
7	0.781434	0.901391	3.500	2.070015
8	0.893068	0.977464	4.000	2.244714
9	1.004701	0.999959	4.500	2.296374
10	1.116335	0.977017	5.000	2.243689
11	1.227968	0.919756	5.500	2.112189
12	1.339602	0.839668	6.000	1.928270
13	1.451235	0.747041	6.500	1.715556
14	1.562869	0.650197	7.000	1.493157
15	1.674502	0.555298	7.500	1.275225
16	1.786136	0.466498	8.000	1.071298
118	13.172753	0.000000	59.000	0.000000
119	13.284386	0.000000	59.500	0.000000
120	13.396020	0.000000	60.000	0.000000



Note:

- Column (1) = Integer numbers from 0 to as needed
- Column (2) = Column (1) * Tn (Section III No. 1)
- Column (3) = SUH Curve Shape it is Function(Column (2))
  q(t) = (t * EXP(1 - t))^(a * Cp)
- Column (4) = Column (2) * Tp (Hour)
- Column (5) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A6. Computation of ITB-1b SUH for Pinamula River for Tr=0.5 hour

I. Characteristics of Watershed and Rainfall

1. River Name	=	Pinamula	
2. Station	=	Pinamula	
3. Watershed Area (A)	=	49.350	Km^2
4. Main River Length (L)	=	15.640	mm
5. Rainfall Depth (R)	=	1.000	mm
6. Unit Rainfall Duration (Tr)	=	0.500	Hour

II. Calculation of Time Lag, Time to Peak, and Time Base

1. Time Coefficient (Ct)	=	1.0000	
2. Time Lag (TL)			
TL = Ct*0.81225*L^0.6	=	1.4111	Hour
3. Peak Time (TP)			
TP = TL + 0.5 * Tr	=	2.2578	Hour
4. Base Time (TB)			
TB = TP	=	20.0000	Defined
TB	=	45.1558	Hour

III. Computation of ASUH, Kp, and Tp

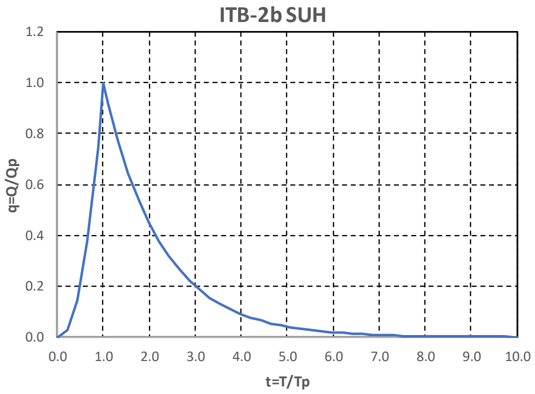
1. Tn = Tr/Tp	=	0.2215	-	
2. Peak Coefficient (Cp)	=	1.0000	-	
3. Alpha	=	2.4000	-	
	=	0.8000	-	$A_{SUH} = \frac{1}{m+1} + \frac{1}{(n \cdot Cp)} - \frac{\exp(-(b-1)*(n \cdot Cp))}{(n \cdot Cp)}$
4. A_{SUH} (Numerik, Exact,)	=	1.5441	Exact	
	=	1.5377	Numerik	(Sum of Column (3) in Section V) x (Tr/Tp)
5. Kp = 1/(3.6*ASUH)	=	0.1799	Exact	
		0.1806	Numerik	
6. Qp = Kp A_{DAS} R/Tp	=	3.9321	m3/s (Ext)	
	=	3.9486	m3/s (Num)	
	=	0.419%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * ADAS)	=	49,350	m3	
2. Hydrograph Volume	=	49,350	m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. Runoff Depth	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SUH ITB-2b:

No	HSS Tak berdimensi		HSS berdimensi	
	t=T/Tp	q=Q/Qp	T (jam)	Q=q×Qp
(1)	(2)	(3)	(4)	(5)
0	0.000000	0.000000	0.000	0.000000
1	0.221455	0.026834	0.500	0.105956
2	0.442911	0.141631	1.000	0.559239
3	0.664366	0.374781	1.500	1.479845
4	0.885821	0.747534	2.000	2.951680
5	1.107277	0.917758	2.500	3.623819
6	1.328732	0.768753	3.000	3.035464
7	1.550188	0.643940	3.500	2.542633
8	1.771643	0.539391	4.000	2.129816
9	1.993098	0.451817	4.500	1.784024
10	2.214554	0.378461	5.000	1.494374
11	2.436009	0.317015	5.500	1.251750
12	2.657464	0.265545	6.000	1.048519
13	2.878920	0.222432	6.500	0.878284
14	3.100375	0.186318	7.000	0.735687
15	3.321831	0.156068	7.500	0.616243
16	3.543286	0.130729	8.000	0.516191
118	26.131734	0.000000	59.000	0.000000
119	26.353189	0.000000	59.500	0.000000
120	26.574644	0.000000	60.000	0.000000



Catatan :

- Column (1) = Integer numbers from 0 to as needed
- Column (2) = Column (1) * Tn (Section III No. 1)
- Column (3) = SUH Curve Shape it is Function(Column (2))
  q(t) =MIN(1,t^α,MIN(1,EXP((1-t)*(β*Cp))))
- Column (4) = Column (2) * Tp (Hour)
- Column (5) = Column (5) * Qp (m3/s)

Use Qp numerical not Exact

Table A7. Convolution of ITB-2b SUH for Pinamula River for Tr=0.5 hour

Time (Hour)	ITB-1b SUH	Rainfall Depth (mm)							Hydrograph	
		1	2		9	10	11	12	7	8
		3.269	3.269		3.871	3.871	2.857	2.857	Q (m3/s)	Vol (m3)
0.00	0.000	0.000							0.000	0.000
0.50	0.018	0.060	0.000						0.060	54.203
1.00	0.158	0.518	0.060						0.578	574.481
1.50	0.470	1.536	0.518						2.143	2449.301
2.00	0.901	2.946	1.536						5.342	6736.806
2.50	1.362	4.451	2.946						10.943	14656.766
3.00	1.769	5.781	4.451						21.615	29302.870
3.50	2.070	6.766	5.781		0.000				40.434	55844.109
4.00	2.245	7.337	6.766		0.000	0.000			67.116	96794.454
4.50	2.296	7.506	7.337		0.071	0.000	0.000		98.281	148857.331
5.00	2.244	7.334	7.506		0.613	0.071	0.000	0.000	129.485	204989.707
5.50	2.112	6.904	7.334		1.819	0.613	0.053	0.000	156.855	257706.092
6.00	1.928	6.303	6.904		3.489	1.819	0.453	0.053	177.853	301237.446
6.50	1.716	5.608	6.303		5.271	3.489	1.343	0.453	191.349	332282.303
7.00	1.493	4.881	5.608		6.846	5.271	2.575	1.343	197.146	349645.305
7.50	1.275	4.168	4.881		8.013	6.846	3.891	2.575	195.725	353583.382
8.00	1.071	3.502	4.168		8.689	8.013	5.054	3.891	188.133	345471.951
8.50	0.887	2.899	3.502		8.889	8.689	5.915	5.054	175.769	327512.036
9.00	0.725	2.370	2.899		8.685	8.889	6.414	5.915	160.153	302330.568
9.50	0.586	1.916	2.370		8.176	8.685	6.561	6.414	142.724	272589.929
10.00	0.469	1.532	1.916		7.464	8.176	6.411	6.561	124.714	240694.130
10.50	0.372	1.214	1.532		6.641	7.464	6.035	6.411	107.084	208617.425
11.00	0.292	0.954	1.214		5.780	6.641	5.510	6.035	90.518	177841.428
11.50	0.228	0.744	0.954		4.936	5.780	4.902	5.510	75.449	149370.505
12.00	0.176	0.576	0.744		4.147	4.936	4.266	4.902	62.100	123793.865
12.50	0.136	0.444	0.576		3.434	4.147	3.644	4.266	50.532	101368.586
13.00	0.104	0.339	0.444		2.807	3.434	3.061	3.644	40.696	82105.552
13.50	0.079	0.258	0.339		2.268	2.807	2.534	3.061	32.468	65847.504
14.00	0.060	0.195	0.258		1.814	2.268	2.072	2.534	25.681	52333.951
14.50	0.045	0.147	0.195		1.438	1.814	1.674	2.072	20.154	41251.485
15.00	0.034	0.110	0.147		1.130	1.438	1.339	1.674	15.702	32270.302
15.50	0.025	0.082	0.110		0.881	1.130	1.061	1.339	12.152	25068.943
16.00	0.019	0.061	0.082		0.683	0.881	0.834	1.061	9.347	19349.593
16.50	0.014	0.046	0.061		0.525	0.683	0.651	0.834	7.149	14846.321
17.00	0.010	0.034	0.046		0.402	0.525	0.504	0.651	5.438	11328.276
17.50	0.008	0.025	0.034		0.306	0.402	0.388	0.504	4.117	8599.527
18.00	0.006	0.018	0.025		0.231	0.306	0.297	0.388	3.102	6496.844
18.50	0.004	0.013	0.018		0.174	0.231	0.226	0.297	2.327	4886.348
19.00	0.003	0.010	0.013		0.131	0.174	0.171	0.226	1.739	3659.692
19.50	0.002	0.007	0.010		0.098	0.131	0.129	0.171	1.295	2730.209
20.00	0.002	0.005	0.007		0.073	0.098	0.097	0.129	0.960	2029.277
20.50	0.001	0.004	0.005		0.054	0.073	0.072	0.097	0.710	1503.055
21.00	0.001	0.003	0.004		0.040	0.054	0.054	0.072	0.523	1109.642
21.50	0.001	0.002	0.003		0.029	0.040	0.040	0.054	0.384	816.667
22.00	0.000	0.001	0.002		0.022	0.029	0.029	0.040	0.282	599.285
22.50	0.000	0.001	0.001		0.016	0.022	0.022	0.029	0.206	438.546
23.00	0.000	0.001	0.001		0.012	0.016	0.016	0.022	0.150	320.076
23.50	0.000	0.001	0.001		0.008	0.012	0.012	0.016	0.109	233.026
24.00	0.000	0.000	0.001		0.006	0.008	0.008	0.012	0.079	169.248
59.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
59.50	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
60.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
					VT = Hydrograph Volume = ∑ Column 8				m3	4782735.9
					ADAS = Watershed Area = As per Input				km2	49.350
					RE = Effective Rainfall = As per Input				mm	96.915
					DRO = Runoff = VT/ADAS/1000				mm	96.915
					RRR = Rainfall Runoff Ratio = DRO/RT				%	100.00%