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

Fundamental Concepts, Verification, and Development of Simple Synthetic and Natural Unit Hydrographs

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Abstract

All synthetic unit hydrographs can be considered user-defined to some degree, reflecting the inherent influence of user input in their development. This paper constitutes the first part of a two-part series titled *The ITB Unit Hydrograph Method: A Novel Approach to User-Defined Unit Hydrograph Development*. It focuses on foundational concepts, the verification of existing SUH methods, and the creation of simple user-defined Synthetic and Natural Unit Hydrographs. The verification process involves reproducing established hydrographs, including the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva models, by computing their Peak Rate Factor (Kp) and Peak Discharge (Qp) values using ITB-UH formulas. Results demonstrate high accuracy, with discrepancies in Kp values consistently below 1%, confirming the reliability of the ITB-UH Method in replicating existing models. Furthermore, the study highlights the ITB-UH Method's capability to develop user-defined synthetic hydrographs, as exemplified by the Double Triangle Synthetic Unit Hydrograph and the HKR Natural Unit Hydrograph. The Double Triangle model introduces a simple unit hydrograph with distinct geometric properties, while the HKR model effectively represents a natural unit hydrograph derived from rainfall-runoff dynamics in a watershed. Both models were applied to flood discharge simulations in the Pinamula Watershed using consistent steps for effective rainfall excess distribution and convolution. The results demonstrate that all hydrographs, despite differences in shape and peak characteristics, yield consistent total flood volumes. These findings underscore the ITB-UH Method's potential to generate unit hydrographs based on user-defined models—whether defined by equations or tables. It should be noted that the simple user-defined unit hydrographs presented in this paper do not include calibration capabilities, a topic that will be explored in Part II of the series.

Keywords: ITB-UH Method; SCS SUH (Triangle, Curvilinear, Delmarva); ITB Double Triangle Synthetic UH; HKR Natural UH.

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

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1. Introduction

Synthetic Unit Hydrographs, requiring minimal data such as watershed area and slope, are generated using empirical techniques. While applicable to ungauged watersheds, their accuracy may be limited by inherent assumptions and regional parameters, potentially failing to fully capture the unique characteristics of a specific watershed. Accurate flood hydrograph estimation is crucial, especially in data-scarce regions. Synthetic Unit Hydrograph methods, such as Snyder, SCS, Clark, Gray, Nakayasu, and ITB, provide valuable alternatives when direct rainfall-runoff data is limited. These methods were developed with specific assumptions and limitations, reflecting the knowledge and understanding of their respective developers. This underscores the inherent user influence in the development of any unit hydrograph method. All synthetic unit hydrographs inherently involve user input in their development, making them user-defined to some extent**.** This inherent influence stems from the assumptions, limitations, and design choices made by the developers of each specific unit hydrograph method.

This paper explores the evolution and significance of the ITB Unit Hydrograph (ITB-UH) Method, first introduced by Natakusumah (2009) at a national seminar in Bandung, Indonesia [1]. Initially published in the Civil Engineering Journal in 2011 [2] and subsequently 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 at the 7th International Seminar of HATHI in 2021 [5], highlighting the growing interest in the method's wider application. Widely used across Indonesia, the ITB method stands alongside established methods such as Snyder, SCS, and Nakayasu, as demonstrated by numerous national publications from various users [6].

1.1. The Assumptions and Limitations of Synthetic Unit Hydrograph

While Synthetic Unit Hydrographs offer valuable tools for flood estimation and hydrological education, it is crucial to acknowledge their inherent limitations. Before utilizing unit hydrographs for analysis, a thorough understanding of their underlying assumptions and constraints is essential. This awareness ensures informed decision-making regarding the reliability and suitability of the outcomes generated by these methods. Table 1 outlines some of these key assumptions and limitations.

Table 1. The Assumptions and Limitations of Synthetic Unit Hydrographs

Assumption	Description	Limitation
Linearity	The relationship between rainfall and runoff is linear.	This may not hold true in real-world watersheds, where non-linear relationships can occur.
Invariance	The unit hydrograph shape remains constant for all rainfall events.	This neglects potential variations due to factors like soil moisture, antecedent conditions, and infiltration.
Spatial Uniformity	Rainfall is uniformly distributed across the watershed.	This is often an unrealistic assumption, as rainfall can vary significantly across space.
Stream Channel Characteristics	Simplified representation of stream channel characteristics.	This can lead to inaccuracies in peak timing and discharge estimation.
Watershed Homogeneity	The watershed is homogeneous in terms of land use, soil properties, and topography.	Heterogeneity can play a significant role in runoff generation and can lead to errors in peak discharge and timing estimation.
Time Invariance	Watershed characteristics and response remain constant over time.	Land use changes, development, and natural events can alter these characteristics, affecting the applicability of a historical SUH.

1.2. Recent Use of Synthetic Unit Hydrographs

Despite advancements in hydrological modeling, the Synthetic Unit Hydrograph method remains a valuable tool in modern flood prediction, hydraulic structure design, and water resource management. Recent studies demonstrate effectiveness in simulating flood events, estimating peak discharge, and supporting flood control infrastructure.

- Yi et al. (2024) [7] introduced a GIS-based Dynamic Time-Varying Unit Hydrograph (DTDUH) method that considers spatial heterogeneity in runoff generation, improving flood prediction accuracy, particularly in areas with saturation-excess rainfall.
- Rafiee et al. (2024) [8] evaluated the HEC-HMS model using satellite and rain gauge data for flood modeling in the Bashar basin, Iran. The study demonstrated the viability of remote sensing data for flood modeling and highlighted the effectiveness of the SUH method within HEC-HMS.
- Das and Das (2024) [9] compared the performance of SCS-UH, CWC-UH, and Nash-GIUH models in estimating direct surface runoff in the Shilabati River basin. The Nash-GIUH model exhibited superior accuracy, emphasizing the importance of selecting appropriate SUH models for specific regions.
- Qi et al. (2024) [10] applied the SUH method within HEC-HMS to simulate runoff and sediment transport in the Lucky Hills watershed, demonstrating its effectiveness in predicting peak runoff and sediment load in arid regions.

- Marasini & Pokhrel (2024) [11] compared an LSTM deep learning model with the HEC-HMS model for rainfall-runoff simulation in Nepal. The LSTM model outperformed HEC-HMS, highlighting the potential of advanced techniques in data-scarce regions.

1.3. Recent Advancements Related to Synthetic Unit Hydrographs

Synthetic Unit Hydrographs remain a cornerstone of hydrological modeling. Recent advancements in technology, including data-driven machine learning, remote sensing, artificial intelligence (AI), and cloud computing, offer significant potential to enhance their accuracy and applicability.

- **Machine Learning:** Advances in machine learning, driven by the availability of large datasets, offer powerful tools for pattern recognition and generalization. ML algorithms, such as artificial neural networks and support vector machines, can be effectively applied in hydrology, although challenges related to bias-variance tradeoffs in time-correlated datasets persist [12, 13].
- **Remote Sensing:** The use of satellite data, such as from the Global Precipitation Measurement (GPM) mission, provides valuable rainfall estimates in data-scarce regions. Studies by Rafiee et al. (2024) [8] have demonstrated the effectiveness of satellite data in flood modeling, particularly for estimating time of concentration (TC), even in areas with limited ground-based measurements.
- **AI and Cloud Computing:** The integration of AI methods, such as Support Vector Machines (SVM) and **Artificial** Neural Networks (ANN), with cloud computing platforms enables more robust and efficient flood risk assessments, as demonstrated by Nakhaei et al. (2023) [14] in their framework for arid regions.
- **Improved Field Observations:** The development of models like the TS-DUH, which utilizes publicly available datasets and real-time satellite rainfall data, enhances flood prediction accuracy. However, further validation in diverse geographic regions is crucial [15].
- **Open-Source Platforms and Collaboration:** Platforms like HydroShare exemplify the power of collaboration in hydrological research. Building upon the CUAHSI Hydrologic Information System, HydroShare facilitates data sharing and model exchange among researchers. By utilizing social media and employing a Resource Data Model to represent all content, HydroShare fosters open collaboration and supports the advancement of hydrological research [16].

By integrating these advancements, SUHs can be refined to provide more accurate and region-specific flood forecasts, ensuring their continued relevance in hydrological modeling and flood risk management.

1.4. Global Reliance on Synthetic Unit Hydrographs in Flood Management

Despite advancements in hydrological modeling, Synthetic Unit Hydrographs remain a cornerstone of flood management practices worldwide. Established SUH methods are widely incorporated into national flood codes and regulations, highlighting their continued relevance:

- **SNI 2415:2016 is an Indonesian National Standard** (Standar Nasional Indonesia) that provides guidelines and procedures for calculating design flood discharge. Unit hydrograph methods, including synthetic unit hydrograph methods such as Snyder, SCS, Nakayasu, Gama-1, ITB-1, and ITB-2, are widely used and accepted techniques for estimating flood hydrographs [17].
- **UK Flood and Water Management Act 2010:** While not explicitly mandating SUHs, the Act empowers local authorities to use hydrological models, including SUHs, for flood risk assessments, particularly in areas with limited data (UK Government) [18].
- **Australian Rainfall and Runoff (ARR):** ARR guidelines recommend SUH methods like Snyder and SCS for estimating regional flood risks, especially in ungauged basins. These models are essential for flood management practices in Australia (Australian Rainfall and Runoff) [19].
- **Canadian National Flood Risk Assessment Guidelines:** Canada's guidelines incorporate models like HEC-HMS, which utilize SUHs, for flood discharge estimation. This is particularly valuable in urban and rural areas for designing effective water management systems (Canadian Flood Risk Assessment Guidelines) [20].
- **International Commission on Large Dams (ICOLD):** ICOLD guidelines employ SUHs to estimate extreme flood events (Probable Maximum Flood) for dam safety, ensuring dams can withstand severe flood risks (International Commission on Large Dams) [21].
- **Urban Stormwater Management Manual (MSMA) - Malaysia:** MSMA promotes using advanced modeling tools like SWMM and SUHs for designing effective urban drainage systems, safeguarding growing urban areas from flood damage (Malaysia Urban Drainage and Stormwater Management Manual) [22].

- **Australian National Committee on Large Dams (ANCOLD):** ANCOLD's dam safety report recommends SUHs for flood estimation. SUHs are crucial for predicting potential flood discharges and designing spillways that can handle extreme rainfall events (The Australian National Committee on Large Dams) [23].

These examples demonstrate the enduring global reliance on SUHs for flood risk management in design and infrastructure projects. Well-established SUH methods continue to be valuable tools for flood estimation and ensuring community safety.

2. Review of Development of Synthetic Unit Hydrograph

The concept of the Synthetic Unit Hydrograph was pioneered by Sherman (1932) [24], who introduced the concept of 'rainfall excess' through the unit graph method. Snyder further refined this concept, making significant contributions to the development of SUH models [25].

Singh et al. (2014) [26] and Patil & Bhagwat (2019) [27] have categorized SUH models into four primary types: traditional/empirical, conceptual, probabilistic, and geomorphological. Geomorphological models, which utilize topographic data, are particularly valuable for ungauged basins due to their reduced calibration requirements.

- **Traditional Models:** Rely on pre-defined shapes and utilize equations or tables with region-specific constants (e.g., Snyder, Taylor and Schwarz, SCS methods).
- **Conceptual Models:** Simulate the basin using a simplified representation (e.g., linear channel or reservoir) based on the continuity equation and a linear storage-discharge relationship.
- **Probabilistic Models:** Employ parametric approaches utilizing probability distribution functions to derive SUHs.
- **Geomorphological Models:** Leverage basin geomorphology to develop instantaneous unit hydrographs (IUHs) for flood hydrograph modeling in ungauged basins.

These categorizations provide a framework for understanding the diverse approaches employed in SUH modeling and their applicability to different hydrological challenges.

2.1. Overview and Performance Analysis of Traditional Synthetic Unit Hydrograph Models

This review focuses on traditional Synthetic Unit Hydrograph models, including Snyder, Taylor-Schwarz, SCS, Nakayasu, and ITB methods. While these methods provide a foundation for flood estimation, they may have limitations in capturing complex hydrological processes and adapting to modern challenges.

- **Snyder Method (1938, USA):** Developed by Snyder [25], this method establishes empirical relationships between watershed characteristics (area, length, and distance to the outlet) and key UH parameters: time to peak (tp), peak discharge (Qp), and base time (tb). Its simplicity and applicability across diverse catchments have contributed to its widespread use.
- **Taylor and Schwarz Method (1952, USA):** Building upon Snyder's work, the Taylor-Schwarz (TS) model incorporates statistical analysis to refine the relationship between watershed characteristics and UH parameters, improving accuracy, particularly for larger watersheds [28].
- **SCS Method (1957, USA):** Developed by the Soil Conservation Service (USDA) [29, 30], this method employs a dimensionless average UH, simplifying calculations. The SCS method approximates the hydrograph with a triangular shape, making it easy to apply in various contexts.
- **Nakayasu Method (1962, Japan):** Designed for regions with limited data, the Nakayasu method utilizes readily available watershed characteristics and simplified equations for efficient hydrograph calculation. Its applicability in data-scarce regions makes it valuable for hydrological analysis [31].
- **ITB Method (2009, Indonesia):** Introduced by Natakusumah [1], the ITB method employs analytical equations for UH computation. It stands out for its ability to determine the peak rate factor (Kp) and peak discharge (Qp) using both exact and numerical calculations, enhancing accuracy and contributing to its widespread adoption in Indonesia. The latest publication in an Indonesian journal was authored by Natakusumah (2024) [6].

2.2. Five Critical Gaps Address by ITB Unit Hydrograph Method

A review of existing literature on traditional Synthetic Unit Hydrograph models reveals several critical gaps that limit their accuracy and applicability in flood analysis. These gaps include:

- **Unclear Derivation of Peak Discharge Formulas:** Many traditional methods lack transparent derivations for peak discharge formulas, hindering effective teaching, learning, and understanding of the underlying principles.

- **Inflexible Time Steps:** Traditional methods often rely on fixed time steps, limiting their adaptability to modern datasets with varying temporal resolutions.
- **Violation of Mass Conservation Principle:** While theoretically adhering to the principle, many traditional methods, due to their inherent shape definitions, may not always ensure strict adherence to mass conservation in practical applications.
- **Limited Calibration Capabilities:** Many existing SUH methods lack built-in calibration features, hindering their ability to accurately represent the unique hydrological characteristics of specific catchments.
- **Lack of Support for User-Defined UH Customization:** Traditional methods often lack the flexibility to create user-defined unit hydrographs, limiting their adaptability to specific hydrological conditions and research needs.

The ITB Unit Hydrograph Method aims to address these limitations, enhancing the accuracy and applicability of SUH methods in flood analysis.

2.3. The Need for User-Defined Unit Hydrographs: Addressing the Limitations of Traditional Methods

Unit hydrographs, while often presented as standardized tools, reflect the inherent influence of their creators. Methods like Snyder, Taylor-Schwarz, SCS, Nakayasu, and even the initial formulations of the ITB method were developed with specific assumptions and limitations, reflecting the knowledge and understanding of their respective developers. This underscores the inherent user influence in the development of any unit hydrograph method.

The need for user-defined unit hydrographs arises from the diverse and site-specific nature of hydrological processes. Watershed characteristics, including topography, soil type, land use, and climate, exhibit significant spatial variability. Consequently, empirical or statistically derived UH curves, while accurate for their source watersheds, may not effectively represent runoff responses in other locations. This limitation hampers their broader applicability.

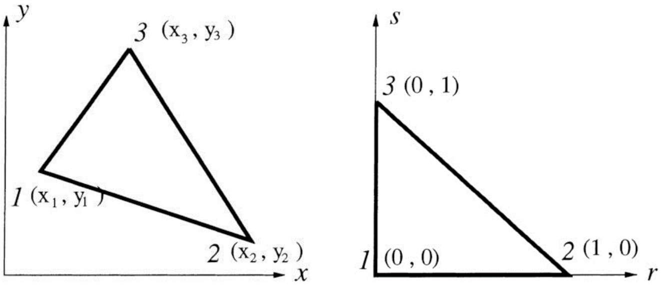
The absence of explicit formulas for key parameters such as Peak Rate Factor (Kp) and Peak Discharge (Qp) in many UH curves pose a significant challenge. These parameters are crucial for adjusting the shape and magnitude of a UH, enabling hydrologists to account for different rainfall intensities, durations, and watershed conditions. Without these scaling factors, the transferability and customization of UH models remain limited, reducing their utility in practical applications.

The ITB Synthetic Unit Hydrograph method addresses these limitations by providing innovative formulas for Kp and Qp, as presented in Equations 7 and 8. Unlike traditional methods, which are often constrained by specific UH shapes or parameters, the ITB method offers a versatile framework that is applicable to any unit hydrograph, regardless of its origin. This universality streamlines the process of developing new hydrographs, accommodating both

3. ITB Unit Hydrograph Method Peak Variables and Their Derivation

The most significant contribution of the ITB Unit Hydrograph method to hydrology is its approach to determining peak variables, specifically the Peak Rate Factor (Kp) and the peak discharge (Qp). These variables are derived from a specified rainfall distribution with a defined unit duration over a catchment area. The peak variables are not only central to the ITB Method but are also applicable to other unit hydrograph methods. The derivation of the formula for Qp is detailed in Natakusumah et al. [2, 3], while the explicit expression for Kp is discussed in Natakusumah et al. [4, 5].

The ITB method introduces a novel derivation process inspired by space transformations, a technique commonly used in the Finite Element Method (FEM). This process involves mapping the hydrograph curve from the physical space into a computational space, enabling easier derivation of the peak variables of unit hydrographs. Figure 1 provides a visual representation of this concept.



a) Physical Space b) Computational Space

Figure 1. Transformation of a triangular element from physical to computational space

The purpose of transforming physical space into a computational space simplifies the process of integration of the area under the UH curve. By performing the integration calculations in the computational space, the results can then be transformed back to the original physical space, resulting in the area under the unit hydrograph curve. Furthermore, by leveraging the definition of Synthetic Unit Hydrograph and the principle of mass conservation, the ITB Method establishes a general formula for the peak rate factor and peak discharge.

3.1. Time Normalization

Time normalization is achieved by dividing the rainfall unit duration by the time to peak (Tn = Tr/Tp). This approach enables flexible adjustments to the time step, allowing for increases or decreases as needed, without the need to rewrite the calculation sheet or modify computer code. This flexibility enhances efficiency and adaptability in various applications.

In real-time flood forecasting, the flexibility in time-step adjustments allows for better alignment with the temporal resolution of the available weather data. A smaller time step can lead to more accurate results by capturing finer details in rainfall and runoff patterns. However, time adjustments will not significantly affect performance in terms of computational delays, as the method is designed to efficiently handle varying time resolutions without introducing substantial inaccuracies or delays**.**

3.2. Transforming a Triangular Hydrograph

Consider a triangular-shaped hydrograph curve resulting from an effective rainfall of R=1 mm on a watershed with an area A, as depicted in Figure 2-a. Integrating the area under the hydrograph curve in physical space yields the volume of the unit hydrograph, which is

$$V = 0.5 \times Qp \times Tp = 0.5 \times 5\ m^3/s \times 8\ s = 20\ m^3 \tag{1}$$

Let Tp represent the abscissa and Qp represent the ordinate of the peak point. The process of transforming a Triangular hydrograph from its physical representation, as depicted in Figure 2-a, into its computational space, involves dividing all values on the time abscissa (t) with respect to Tp and dividing all values on the discharge ordinate (Q) with respect to Qp. This transformation yields a dimensionless hydrograph curve, as presented in Figure 2-b.

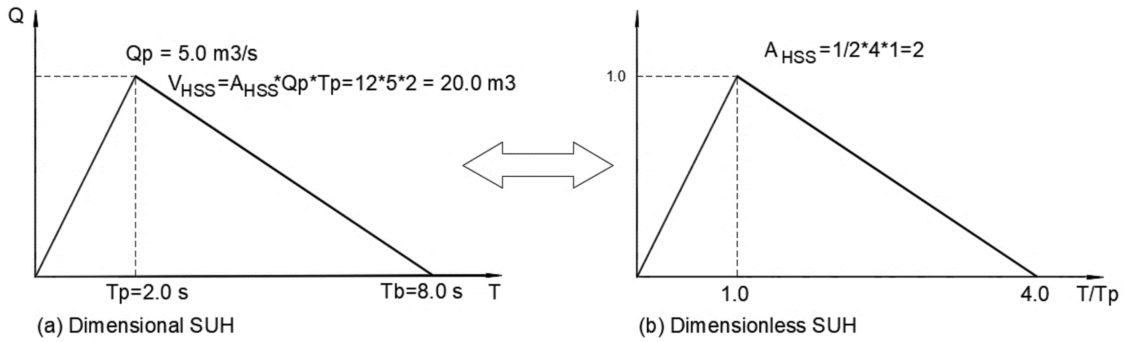


Figure 2. Obtaining volume of triangular dimensional SUH from dimensionless triangular SUH

The area of the dimensionless triangle in computational space (A_{SUH}) is calculated as:

$$\mathrm{A_{SUH}} = 0.5 \times 4 \times 1 = 2\ (\text{dimensionless}) \tag{2}$$

The volume of the unit hydrograph V_{SUH} (with dimensions m3) can be obtained more easily by multiplying A_{SUH} by Qp and Tp, or

$$\mathrm{V_{SUH}} = \mathrm{Qp} \times \mathrm{Tp} \times \mathrm{A_{SUH}} = 5\ \mathrm{m^3/s} \times 8\ \mathrm{s} \times 2 = 20\ \mathrm{m^3} \tag{3}$$

This result is exactly equal to the area calculated entirely in physical space.

3.3. Transforming a Curvilinear Hydrograph

The concept of transformation can be expanded to accommodate more complex forms of the Synthetic Unit Hydrograph, as shown in Figure 3. This figure demonstrates the dimensionless forms of the ITB-1b and ITB-2b SUH, applicable to any catchment area. In Figure 3, a curvilinear-shaped unit hydrograph is illustrated, showing peak discharge (Qp) occurring at peak time (Tp). This approach allows for more flexible applications of the SUH across various hydrological contexts

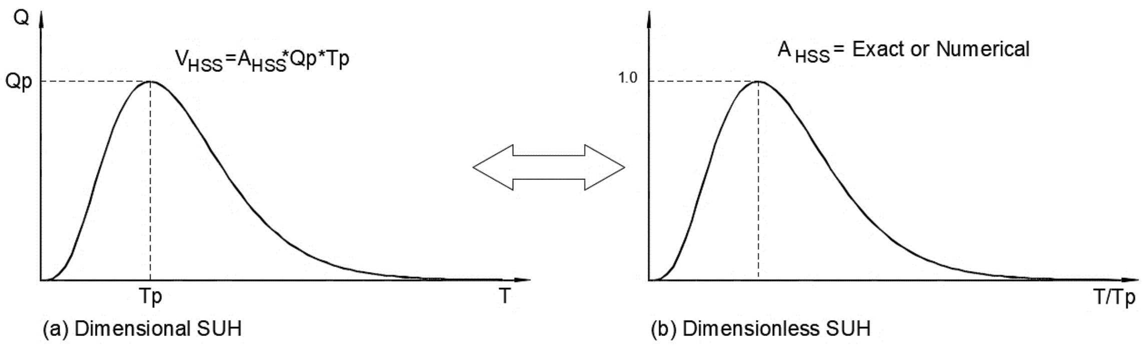


Figure 3. Obtaining volume of curvilinear dimensional SUH from dimensionless curvilinear SUH

If Tp is expressed in hours and then converted to seconds, then:

$$V_{SUH} = A_{SUH} \times Qp \times Tp \times 3600 \quad (m^3)$$

where A_{SUH} is the area of the dimensionless SUH, which can be calculated either exactly or numerically.

3.4. Definition of Synthetic Unit Hydrograph

A unit hydrograph of a catchment represents the direct runoff hydrograph, excluding base flow. It represents the theoretical response of the catchment to a uniform effective rainfall of one unit (e.g., 1 mm) distributed evenly across the entire watershed over a specific unit time (e.g., 1 hour). Unlike a real hydrograph, which is derived from actual rainfall-runoff data, a Synthetic Unit Hydrograph is derived through theoretical or empirical methods. For effective rainfall of R = 1 mm, uniformly distributed over the entire watershed area with an area of A_{CA} (km²), the volume of the effective rainfall (V_{CA}), can be expressed as:

$$V_{CA} = R \times A_{CA} = 1000 \times A_{CA} \ (m^3) \tag{4}$$

3.5. Mass Conservation Principle

The principle of mass conservation states that in a closed system, the total mass remains constant. Applying this principle to the definition of Synthetic Unit Hydrograph, it can be deduced that the volume of effective rainfall for one unit falling uniformly over the entire watershed (V_{CA}) must be equal to the volume of the Synthetic Unit Hydrograph (V_{SUH}) with a peak time Tp.

$$1000 \times A_{CA} = A_{SUH} \times Qp \times Tp \times 3600 \ (m^3) \tag{5}$$

As a result,

$$Qp = \frac{R}{3.6Tp} \times \frac{A_{CA}}{A_{SUH}} \ (m^3/s) \tag{6}$$

Since the unit hydrograph area A_{SUH} is dimensionless, the units remain consistent on both sides of the equations, typically expressed as m^3/s or more generally as volume per unit time. This equation is presented in the first publication of ITB method [1].

3.6. Peak Rate Factor (Kp)

To achieve a standardized form for Equation 6 in determining peak discharge, this paper introduces a key variable: the Peak Rate Factor (Kp), which appeared in the fourth publication of ITB method [4]. This factor represents a unique characteristic to each unit hydrograph and is defined by the following Equation:

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

where A_{SUH} is the area of the dimensionless unit hydrograph, which can be either equation-based or table-based SUH. This area can be calculated exactly, depending on the equation curve used to define the SUH Curve, or numerically using Equation 9. The curve can also be defined in a table format, and its area can be calculated using Equation 9 or its modifications if the time intervals are not uniform.

3.7. Peak Discharge Formula (Qp) and its Significance

Leveraging the Peak Rate Factor (Kp) derived earlier from Equation 8, a standardized peak discharge formula (Qp) for the unit hydrograph can be developed, as expressed in Equation 9. This formula provides a unified method for calculating peak discharge, ensuring consistency and accuracy across different hydrological applications.

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

where Qp is Peak discharge of the unit hydrograph (m^3/s), Kp is Peak Rate Factor (dimensionless), R is Unit rainfall intensity (1 mm), Tp is Time to reach the peak (hours), A_{CA} is Catchment area (km^2).

3.8. Some Remarks on Kp and Qp

This section focuses on key aspects of the Peak Rate Factor (Kp) and Peak Discharge (Qp) within the ITB Unit Hydrograph method.

- **Applicability:** Equations 7 and 8, developed for the ITB 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.
- **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.

3.8.1. 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 4.

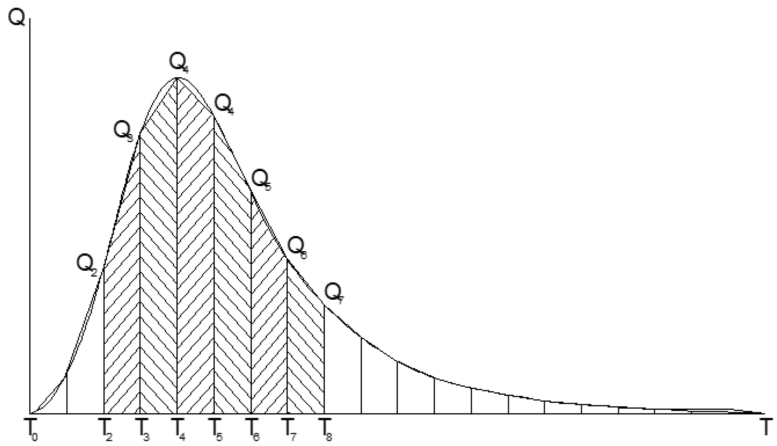


Figure 4. Numerical integration of the hydrograph curve using the trapezoidal method

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 4, is performed using the trapezoidal rule, expressed by the Equation:

$$\mathrm{A_{SUH}} = \frac{1}{2}\sum_{i=1}^{N}(\mathrm{T_{i+1}} - \mathrm{T_i}) \times (\mathrm{Q_{i+1}} + \mathrm{Q_i}) \tag{9}$$

If the intervals are made equal $\Delta\mathrm{T} = (\mathrm{T_{i+1}} - \mathrm{T_i})$ 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:

$$\mathrm{A_{SUH}} = \Delta\mathrm{T}\sum_{i=1}^{N}\mathrm{Q_i} \tag{10}$$

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.

4. Verifying Existing Synthetic Unit Hydrograph

This section explores the capability of the ITB method to verify peak discharge (Qp) and peak rate factor (Kp) values derived from existing analytical equation-based or tabular Synthetic Unit Hydrographs (SUHs). This re-examination serves two purposes. Firstly, it demonstrates the method's potential for validating established SUH definitions. Secondly, it lays the groundwork for subsequent analyses.

To achieve validation, the ITB method can be applied to re-create the Kp and Qp values of well-documented analytical or tabular SUHs, such as the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva methods presented in Figure 5. The SUHs were developed by the former Soil Conservation Service (SCS), now known as the Natural Resources Conservation Service (NRCS) [29, 30].

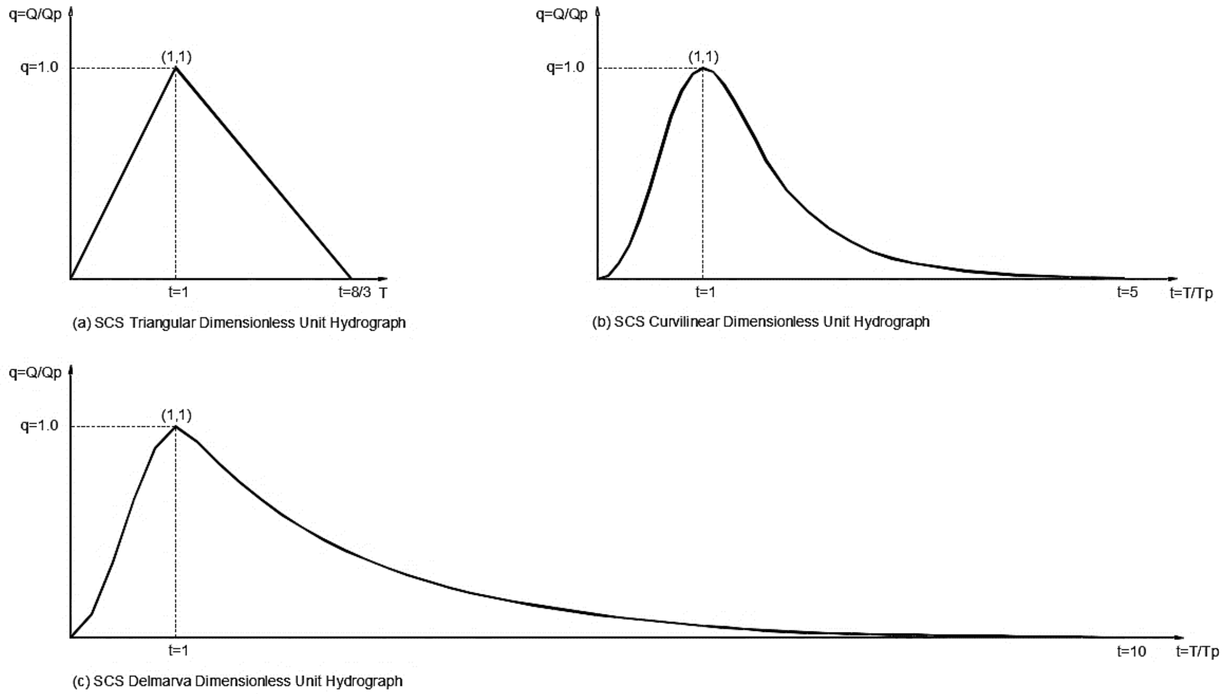


Figure 5. The SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva dimensionless SUH curve

All three dimensionless unit hydrographs (SUHs) are presented on a single graph with identical horizontal and vertical scales. This format allows for direct comparison of their time bases. The graph reveals that the SCS-Triangular SUH has the shortest time base (t = Tb/Tp = 8/3). The SCS-Curvilinear SUH has a slightly longer time base (t = Tb/Tp = 5), while the Delmarva hydrograph has a significantly longer base (t = Tb/Tp = 10)

Building on this concept, the Peak Rate Factor (Kp) and Peak Discharge (Qp) formulas for the ITB SUH method can be used to reproduce the Kp values and Qp formulas for well-documented SUHs like SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva (presented in Figure 5). Comparing the recomputed Kp and Qp values with those published by the Soil Conservation Service (SCS) serves as a validation exercise. If the values coincide, it strengthens the evidence supporting the ITB method's accuracy for various SUHs. This validation establishes a foundation of trust in the ITB method's capabilities, paving the way for its application in user-defined synthetic and natural unit hydrograph development in later sections.

4.1. Verifying the Kp Values and Qp Formulas for SCS-Triangular SUH

The SCS-Triangular Dimensionless Synthetic Unit Hydrograph is a simplified representation of watershed response. It is shaped as an isosceles triangle with a sharp peak at the time of peak discharge (Tp) and linear slopes on both the rising and falling limbs. The hydrograph assumes symmetry, meaning the time from the start of the runoff to the peak (Tp) is equal to the time from the peak to the end of the runoff.

The shape of the hydrograph is defined using the dimensionless time ratio (t/Tp) and the corresponding dimensionless discharge ratio (q/Qp). This allows the hydrograph to be scaled to represent watersheds of varied sizes and rainfall characteristics.

The SCS-Triangular hydrograph is widely used for its simplicity and ease of calculation, making it a practical tool in hydrological studies and flood prediction. Although it does not capture all the complexities of real-world runoff processes, it provides a straightforward approximation suitable for many engineering applications.

The curve of the SCS-Triangular Dimensionless Synthetic Unit Hydrograph, as depicted in Figure 5-a is formed by three points: (0, 0), (1, 1), and $(8/3, 0)$. The area under the SCS-Triangular hydrograph curve can be calculated exactly from area of a dimensionless triangle:

$$A_{SUH}=\frac{1}{2}\times\frac{8}{3}\times 1=\frac{4}{3} \quad (11)$$

The Peak Rate Factor (Kp) is then derived:

$$K_p=\frac{1}{3.6\times\frac{4}{3}}=0.20833333 \text{ (dimensionless)} \quad (12)$$

With this area and by using Equation, the peak rate factor (Kp) for this method is 0.20833333. Therefore, Equation 8 for the peak discharge (Qp) can be expressed as:

$$Qp=0.20833333\,\frac{R\times A_{CA}}{Tp}\ (m^3/s) \quad (13)$$

The formula for the Peak Rate Factor and the Peak Discharge derived above is the same as the formula provided by the SCS

4.2. Verifying the Kp Values and Qp Formulas for SCS-Curvilinear SUH

The SCS-Curvilinear Dimensionless Synthetic Unit Hydrograph curve is a more detailed representation of watershed response compared to the SCS-Triangular unit hydrograph. It is characterized by a smooth, curvilinear shape that represents a gradual rise and fall in discharge. The curve is defined in terms of the dimensionless time ratio (t/Tp) and the corresponding dimensionless discharge ratio (q/Qp).

Unlike the linear slopes of the SCS-Triangular hydrograph, the SCS-Curvilinear hydrograph incorporates a more realistic depiction of the runoff process, with a gradual increase to the peak discharge (Qp) at the peak time (Tp) and a slower recession limb. The curve is typically constructed from tabulated values of t/Tp and q/Qp, which provide a point-by-point description of the hydrograph shape.

The SCS-Curvilinear hydrograph is widely used due to its ability to capture the variability of watershed responses under different conditions while maintaining the simplicity of dimensionless scaling. This makes it a versatile tool in hydrological modelling.

The SCS-Curvilinear Dimensionless Synthetic Unit Hydrograph curve, depicted in Figure 5-b, is characterized by 33 points as defined by the SCS and detailed in Table 2 [33].

Table 2. Coordinates of SCS-Curvilinear dimensionless Synthetic Unit Hydrograph

No.	(t/tp)	(q/qp)	No.	(t/tp)	(q/qp)	No.	(t/tp)	(q/qp)
1	0.000	0.000	12	1.100	0.990	23	2.400	0.147
2	0.100	0.030	13	1.200	0.930	24	2.600	0.107
3	0.200	0.100	14	1.300	0.860	25	2.800	0.077
4	0.300	0.190	15	1.400	0.780	26	3.000	0.055
5	0.400	0.310	16	1.500	0.680	27	3.200	0.040
6	0.500	0.470	17	1.600	0.560	28	3.400	0.029
7	0.600	0.660	18	1.700	0.460	29	3.600	0.021
8	0.700	0.820	19	1.800	0.390	30	3.800	0.015
9	0.800	0.930	20	1.900	0.330	31	4.000	0.011
10	0.900	0.990	21	2.000	0.280	32	4.500	0.005
11	1.000	1.000	22	2.200	0.207	33	5.000	0.000

The SCS-Curvilinear Dimensionless Synthetic Unit Hydrograph is formed by piecewise linear curves; therefore, the exact area must be calculated using the trapezoidal method with non-uniform intervals, as follows.

$$A_{SUH}=\frac{1}{2}\sum_{i=1}^{N}(T_{i+1}-T_i)\times(Q_{i+1}+Q_i) \quad (14)$$

Therefore, the exact area under the SCS-Curvilinear dimensionless SUH curve is;

$$A_{SUH} = \frac{1}{2}[(0.100 - 0.000) \times (0.030 + 0.000) + (0200 - 0.100) \times (0.100 + 0.030) + \cdots + (4.500 - 5.000) \times (0.005 + 0.011) + (5.000 - 4.500) \times (0.000 + 0.005)] \tag{15}$$

$$\rightarrow A_{SUH} = 1.35435$$

The Dimensionless Peak Rate Factor (Kp)

$$K_p = \frac{1}{3.6 \text{ x } 1.35435} = 0.20510043 \text{ (dimensionless)} \tag{16}$$

Therefore, the Peak Discharge (Qp) is:

$$Q_p = 0.20510043 \frac{R \text{ x } A_{CA}}{T_P} \text{ (m}^3\text{/s)} \tag{17}$$

The formula for the peak rate factor and the peak discharge derived above is slightly different from the formula provided by SCS. SCS assigns a Kp value of 0.2083, resulting in a discrepancy of error around 0.1957%. This difference occurs because the SCS equates the Kp value for the SCS-Curvilinear to that SCS-Triangular, an equivalence that is not accurate due to the differing shape of the curves. Consequently, the Kp value for the SCS-Curvilinear calculated using the ITB method is more accurate.

4.3. Verifying the Kp Values and Qp Formulas for SCS-Delmarva SUH

The SCS-Delmarva Dimensionless Synthetic Unit Hydrograph represents a refined approach to modelling watershed response, specifically tailored to the hydrological conditions of the Delmarva Peninsula. This curve features a more gradual rise and fall compared to the SCS-Triangular hydrograph, making it suitable for watersheds with slower response times. The SCS-Delmarva hydrograph is defined using a series of dimensionless time ratios (t/Tp) and corresponding discharge ratios (q/Qp). Unlike the triangular and curvilinear hydrographs, the Delmarva hydrograph has a significantly longer time base (Tb) relative to Tp, reflecting the slower runoff processes typical of certain watershed conditions.

The flexibility of this hydrograph makes it valuable for analysing watersheds where gradual runoff dominates, offering an alternative to the sharper response curves of the triangular or curvilinear models. This is particularly beneficial for flood studies in regions with gentle slopes or extensive infiltration.

The SCS-Delmarva Dimensionless Synthetic Unit Hydrograph curve, depicted in Figure 5.c, is characterized by 51 points defined by SCS in Table 3 [33].

Table 3. Coordinates of SCS-Delmarva dimensionless Synthetic Unit Hydrograph

No.	(t/tp)	(q/qp)	No.	(t/tp)	(q/qp)	No.	(t/tp)	(q/qp)
1	0.000	0.000	18	3.400	0.265	35	6.800	0.027
2	0.200	0.111	19	3.600	0.237	36	7.000	0.024
3	0.400	0.356	20	3.800	0.212	37	7.200	0.021
4	0.600	0.655	21	4.000	0.190	38	7.400	0.018
5	0.800	0.896	22	4.200	0.170	39	7.600	0.015
6	1.000	1.000	23	4.400	0.153	40	7.800	0.013
7	1.200	0.929	24	4.600	0.138	41	8.000	0.012
8	1.400	0.828	25	4.800	0.123	42	8.200	0.011
9	1.600	0.737	26	5.000	0.109	43	8.400	0.009
10	1.800	0.656	27	5.200	0.097	44	8.600	0.008
11	2.000	0.584	28	5.400	0.086	45	8.800	0.008
12	2.200	0.521	29	5.600	0.076	46	9.000	0.006
13	2.400	0.465	30	5.800	0.066	47	9.200	0.006
14	2.600	0.415	31	6.000	0.057	48	9.400	0.005
15	2.800	0.371	32	6.200	0.049	49	9.600	0.005
16	3.000	0.331	33	6.400	0.041	50	9.800	0.000
17	3.200	0.296	34	6.600	0.033	51	10.000	0.000

This SCS-Delmarva dimensionless synthetic unit hydrograph curve is formed by piecewise linear segments; therefore, the exact area must be calculated using trapezoidal rule method with non-uniform intervals, as follows.

$$A_{SUH} = \frac{1}{2}\sum_{i=1}^{N}(T_{i+1} - T_i) \times (Q_{i+1} + Q_i) \tag{18}$$

Therefore, the exact area under the SCS-Delmarva dimensionless synthetic unit hydrograph curve is

$$A_{SUH} = \frac{1}{2}[(0.200 - 0.000) \times (0.111 + 0.000) + (0.400 - 0.200) \times (0.356 + 0.111) + \cdots + (9.800 - 9.600) \times (0.000 + 0.005) + (10.000 - 9.800) \times (0.000 + 0.000)] \tag{19}$$

$$\rightarrow A_{SUH} = 2.28820$$

And the Peak Rate Factor

$$K_p = \frac{1}{3.6 \times 2.28820} = 0.121395760 \text{ (dimensionless)} \tag{20}$$

Therefore, the Peak Discharge is

$$Q_p = 0.121395760 \frac{R \times A_{CA}}{T_P} \text{ (m}^3\text{/s)} \tag{21}$$

The peak rate factor (Kp) for the Delmarva SUH calculated using the ITB method (Kp ITB = 0.1213957) shows a minor deviation from the value provided by the SCS (Kp SCS = 0.12224). This difference translates to a very small percentage discrepancy of $\varepsilon = (\text{Kp ITB} - \text{Kp SCS})/\text{Kp ITB} \times 100\% = -0.6949\%$ while the specific method used by the SCS to determine the Kp value for the Delmarva SUH is unclear, the ITB method's derivation process is transparent. This transparency, along with its results for Triangular and SCS SUHs, suggests the ITB method might potentially yield a more accurate result.

4.4. Validation Summary

Validating Kp values calculated using the ITB-UH formula against SCS values (Table 4) demonstrates close agreement. In particular, the ITB formula is more accurate than the SCS method for SCS-curvilinear SUH, as the SCS incorrectly assigns the same Kp value to both curvilinear and triangular SUHs. This discrepancy arises due to the inherent differences in the shapes of these hydrographs

Table 4. Validation of Kp values computed using ITB-UH formula and SCS Values

No.	SCS Synthetic Unit Hydrograph Type	Kp computed using		Difference (%)
		ITB-UH Formula	SCS Value	
1	SCS-Triangular	0.20833333	0.20833	0%
2	SCS-Curvilinear	0.20510043	0.20833	0.1957%.
3	SCS-Delmarva	0.12139576	0.12224	-0.6949%

These results validate the correctness of the ITB-UH Method and support the claim that it enables the calculation of Kp values and peak discharge (Qp) formulas for user-defined unit hydrographs with unknown Kp and Qp. This capability represents a significant advancement in hydrological modeling, as traditional methods often rely on fixed, predefined Kp values with limited adaptability.

5. Flood Hydrograph from SCS Triangular, SCS Curvilinear and SCS Delmarva SUH

This section illustrates the generation of flood hydrographs for the Pinamula watershed based on the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva SUHs, applying the ITB-UH calculation procedure. Figure 6 depicts the Pinamula River Basin, which drains an area of 49.35 square kilometers (km²) 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) [32].

Figure 6. Pinamula River located in Buol District, Central Sulawesi, as adapted from Tunas (2017) [32]

Assuming a runoff coefficient (C) of 0.60, Table 5 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 5. 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

5.1. Creating Tables of SCS-Triangular, SCS-Curvilinear and SCS-Delmarva Synthetic Unit Hydrographs

The calculation steps, which involve numerous lines of computation, figures, and tables, are best conveyed visually through a table rather than a figure. These steps are meticulously outlined in Table-A.1 for SCS-Triangular SUH, Table-A.2 for SCS-Curvilinear SUH, and Table-A.3 for SCS-Delmarva SUH; all the tables are 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.

5.1.1. The Calculation Steps for the SCS-Triangular SUH

To provide a clear framework for these calculations, the SCS-Triangular SUH is presented in **Table-A1**. 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 modelling.

Part II involves calculating the Time Lag (TL), Time to Peak (TP), and Base Time (TB). The specific equations used vary depending on the chosen variant of the ITB method.

a) Time Lag (TL): Represents the time taken for runoff to reach the catchment outlet. Two formulas are used depending on the chosen variant of the ITB method:

$$\begin{aligned} T_L &= Ct \times 0.81225 \times L^{0.6} \\ &= 1.0 \times 0.81225 \times 15.636^{\,0.6} = 4.2289 \text{ hours} \end{aligned} \tag{22}$$

where Ct is Adjustable time coefficient (by Default Ct=1.0), T_L is Time lag (hours), L is River length (km)

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

$$\begin{aligned} Tp &= T_L + 0.50 \times Tr \\ &= 4.2289 + 0.50 \times 1.0 = 4.7289 \text{ hours} \end{aligned} \tag{23}$$

where Tr = Unit rainfall duration (hours)

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

$$Tb = 5 \times Tp = 5 \times 4.7289 = 23.6447 \text{ Hours} \tag{24}$$

d) Note: Equations 22 to 24 are applicable to the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva methods, as time lag is generally independent of the unit hydrograph shape. Alternatively, these equations can be replaced with corresponding time parameter equations specific to the chosen SUH curve.

Part III calculates Tn (Normalized Unit Rainfall Duration), A_{SUH} (the Synthetic Unit Hydrograph area), Kp (Peak Rate Factor), and Qp (Peak Discharge).

1) Normalized Unit Rainfall Duration

$$Tn = \frac{Tr}{Tp} = \frac{1}{4.72894} = 0.21146 \tag{25}$$

2) Area of SCS Dimensionless Synthetic Unit Hydrograph

$$\begin{aligned} A_{SUH} &= \frac{1}{2} \times \frac{8}{3} \times 1 = \frac{4}{3} = 1.33333 \\ A_{SUH} &= Tn \times (\text{Sum of Column 3 of Part V, in Table A.1}) = 1.32945 \end{aligned} \tag{26}$$

3) Peak Rate Factor (Kp) (Dimensionless Variable)

$$Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.33333 = 0.20833 \qquad \text{(Exact)} \tag{27}$$

$$Kp = \frac{1}{3.6} \times A_{SUH} = \frac{1}{3.6} \times 1.32945 = 0.20894 \qquad \text{(Numerical)} \tag{28}$$

4) Peak Discharge (Qp)

$$Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.20833 \times 1.0 \times 49.350}{4.72894} = 2.17411 \text{ m}^3/\text{s} \qquad \text{(Exact)} \tag{29}$$

$$Qp = \frac{Kp \times R \times A_{CA}}{Tp} = \frac{0.20894 \times 1.0 \times 49.350}{4.72894} = 2.18045 \text{ m}^3/\text{s} \qquad \text{(Numerical)} \tag{30}$$

Part IV, this section verifies the Mass Conservation Principle by calculating the volume of excess rainfall, equivalent to 1 unit (mm), falling over the catchment (V_{CA}) and comparing it to the volume of the unit hydrograph (V_{SUH}). The ratio $R = V_{SUH}/V_{CA}$ is then evaluated to ensure it equals 1, confirming the principle of mass conservation.

Part V, this section provides a detailed calculation of the curve shape for the SCS Triangular SUH. The dimensionless unit hydrograph is represented by the coordinates in Table A1, columns (2) and (3), while the dimensional unit hydrograph is presented in Table A1, columns (4) and (5).

The calculation procedures for the SCS-Curvilinear and SCS-Delmarva SUHs are similarly presented in Table-A2 and Table-A3, respectively. Table 6 presents a comparison of the Kp and Qp values obtained for the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva SUHs, as calculated using the ITB-UH method.

Table 6. Comparison of Kp and Qp Values for Different SCS Synthetic Unit Hydrographs

No.	SCS Synthetic Unit Hydrograph Type	Kp		Qp (m^3/s)	
		Exact	Numerical	Exact	Numerical
1	SCS-Triangular	0.20833333	0.20833	2.17411	2.18045
2	SCS-Curvilinear	0.20510043	0.20833	2.14037	2.13988
3	SCS-Delmarva	0.12139576	0.12224	1.26685	1.26202

5.1.2. Graphing Dimensional Synthetic Unit Hydrograph

The process of generating dimensional and dimensionless coordinates for the SCS-Triangular, SCS-Curvilinear, and SCS-Delmarva SUHs is outlined in Tables A.1, Tables A.2, and Tables A.3, respectively. Each table presents the numerical values for the dimensionless coordinates in Columns 2 and 3, followed by the corresponding dimensional coordinates in Columns 4 and 5. An extract of the dimensional SUH coordinates for each method is provided in Table 7: the first part for SCS-Triangular, the second part for SCS-Curvilinear, and the third part for SCS-Delmarva.

Table 7. Dimensional SCS-Triangular, SCS-Curvilinear and SCS-Delmarva SUH generated numerically

SCS-Triangular			SCS-Curvilinear			SCS-Delmarva		
No	T (hour)	Q(m^3/s)	No	T (hour)	Q(m^3/s)	No	T (hour)	Q(m^3/s)
0	0.000000	0.000000	0	0.000000	0.000000	0	0.000000	0.000000
1	0.211464	0.211464	1	0.211464	0.084744	1	0.211464	0.125043
2	0.422928	0.422928	2	0.422928	0.314391	2	0.422928	0.390277
3	0.634391	0.634391	3	0.634391	0.658465	3	0.634391	0.696442
4	0.845855	0.845855	4	0.845855	0.926684	4	0.845855	0.919845
5	1.057319	0.965609	5	1.057319	0.988536	5	1.057319	0.979652
6	1.268783	0.838730	6	1.268783	0.864974	6	1.268783	0.894265
7	1.480246	0.711852	7	1.480246	0.677778	7	1.480246	0.791488
8	1.691710	0.584974	8	1.691710	0.495803	8	1.691710	0.699857
9	1.903174	0.458096	9	1.903174	0.368413	9	1.903174	0.618857
10	2.114638	0.331217	10	2.114638	0.274145	10	2.114638	0.547889
11	2.326102	0.204339	11	2.326102	0.202170	11	2.326102	0.485692
12	2.537565	0.077461	12	2.537565	0.145609	12	2.537565	0.430609
13	2.749029	0.000000	13	2.749029	0.106155	13	2.749029	0.382214
14	2.960493	0.000000	14	2.960493	0.079543	14	2.960493	0.338901
15	3.171957	0.000000	15	3.171957	0.061587	15	3.171957	0.300908
16	3.383420	0.000000	16	3.383420	0.045093	16	3.383420	0.267570
17	3.594884	0.000000	17	3.594884	0.032584	17	3.594884	0.237716
18	3.806348	0.000000	18	3.806348	0.024971	18	3.806348	0.211302
19	4.017812	0.000000	19	4.017812	0.017679	19	4.017812	0.188219
20	4.229275	0.000000	20	4.229275	0.013873	20	4.229275	0.167512
21	4.440739	0.000000	21	4.440739	0.010067	21	4.440739	0.149945
22	4.652203	0.000000	22	4.652203	0.007478	22	4.652203	0.134085
23	4.863667	0.000000	23	4.863667	0.005363	23	4.863667	0.118543
24	5.075131	0.000000	24	5.075131	0.000000	24	5.075131	0.104492
25	5.286594	0.000000	25	5.286594	0.000000	25	5.286594	0.095250
26	5.498058	0.000000	26	5.498058	0.000000	26	5.498058	0.087562
27	5.709522	0.000000	27	5.709522	0.000000	27	5.709522	0.077486
28	5.920986	0.000000	28	5.920986	0.000000	28	5.920986	0.067377
29	6.132449	0.000000	29	6.132449	0.000000	29	6.132449	0.058258
30	6.343913	0.000000	30	6.343913	0.000000	30	6.343913	0.050137
31	6.555377	0.000000	31	6.555377	0.000000	31	6.555377	0.041995
32	6.766841	0.000000	32	6.766841	0.000000	32	6.766841	0.033834
33	6.978305	0.000000	33	6.978305	0.000000	33	6.978305	0.027708
34	7.189768	0.000000	34	7.189768	0.000000	34	7.189768	0.024651

35	7.401232	0.000000	35	7.401232	0.000000	35	7.401232	0.018003
36	7.612696	0.000000	36	7.612696	0.000000	36	7.612696	0.015025
37	7.824160	0.000000	37	7.824160	0.000000	37	7.824160	0.013040
38	8.035623	0.000000	38	8.035623	0.000000	38	8.035623	0.012053
39	8.247087	0.000000	39	8.247087	0.000000	39	8.247087	0.011063
40	8.458551	0.000000	40	8.458551	0.000000	40	8.458551	0.009063
41	8.670015	0.000000	41	8.670015	0.000000	41	8.670015	0.008065
42	8.881478	0.000000	42	8.881478	0.000000	42	8.881478	0.008074
43	9.092942	0.000000	43	9.092942	0.000000	43	9.092942	0.006062
44	9.304406	0.000000	44	9.304406	0.000000	44	9.304406	0.006068
45	9.515870	0.000000	45	9.515870	0.000000	45	9.515870	0.005062
46	9.727334	0.000000	46	9.727334	0.000000	46	9.727334	0.005066
47	9.938797	0.000000	47	9.938797	0.000000	47	9.938797	0.000000
48	10.150261	0.000000	48	10.150261	0.000000	48	10.150261	0.000000

When plotting the dimensional coordinates for SCS-Triangular, SCS-Curvilinear and SCS-Delmarva SUH alongside their exact dimensional curves, the results closely resemble those shown in Figure 7. 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 all SCS SUHs, 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 all SCS SUHs, except at the true peak point, the numerical and exact curves align closely throughout, showing minimal discrepancy. This indicates that, except at the true peak point, the numerical method effectively captures the key characteristics of the SCS SUH.

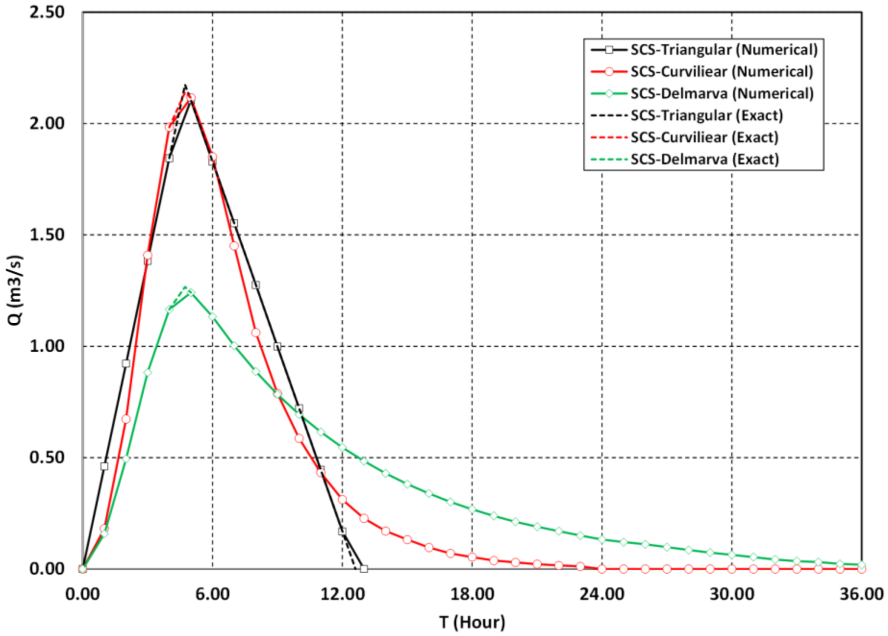


Figure 7. The dimensional exact and numerical SCS-Triangular, Curvilinear and Delmarva SUH for Pinamula River

5.1.3. Convolution numerical SCS-Triangular, Curvilinear and Delmarva SUH Dimensional SUH

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.

The total hydrograph resulting from the convolution of SCS-Triangular, Curvilinear and Delmarva SUH Dimensional SUH hydrographs, as shown in Figure 8 is obtained using a numerically calculated peak discharge value, not an exact peak discharge. Column 1 and Column 9 of Table-A.2 and Table-A.3 contain the time and discharge of the SCS-Triangular, Curvilinear and Delmarva SUH total hydrograph, respectively. When SCS-Triangular, Curvilinear and Delmarva SUH total hydrographs are superimposed on a graph, the resulting curve is displayed in Figure 8. However, despite these variations, the total volume of the hydrographs from both remains the same.

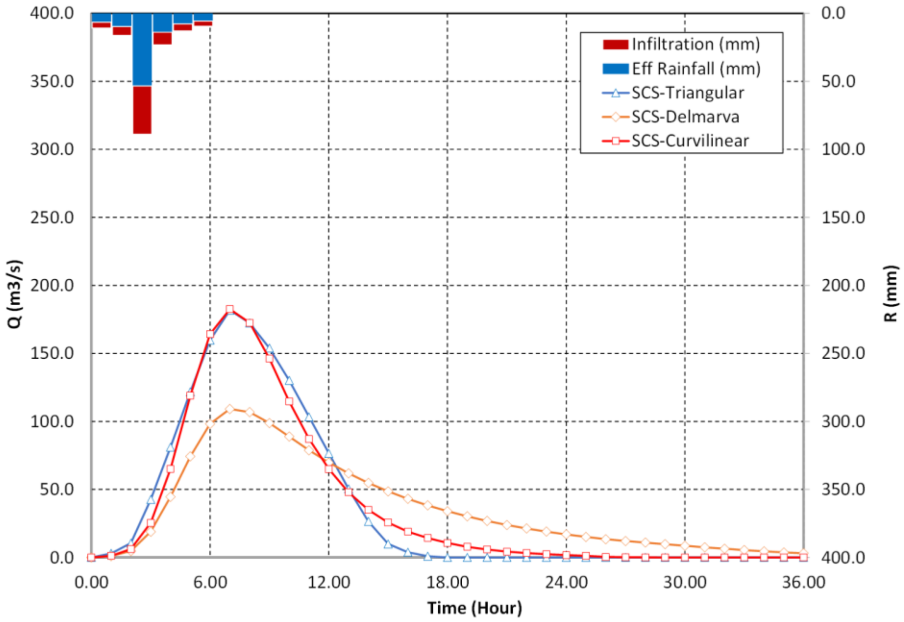


Figure 8. ITB-1b and ITB-2b Hydrograph for Pinamula River with Tr = 1.0 hour

6. Developing User-Defined Synthetic and Natural Unit Hydrograph

The ITB-UH method has been proven to accurately verify Kp and Qp values using SCS Triangular, SCS-Curvilinear, and SCS-Delmarva hydrographs. This section demonstrates the method's ability to determine the unknown Kp and Qp values for the ITB Double Triangle Synthetic Unit Hydrograph (SUH) and the HKR Natural Unit Hydrograph (NUH). These two-unit hydrographs, for which Kp and Qp values were initially undefined, are shown in Figure 9.

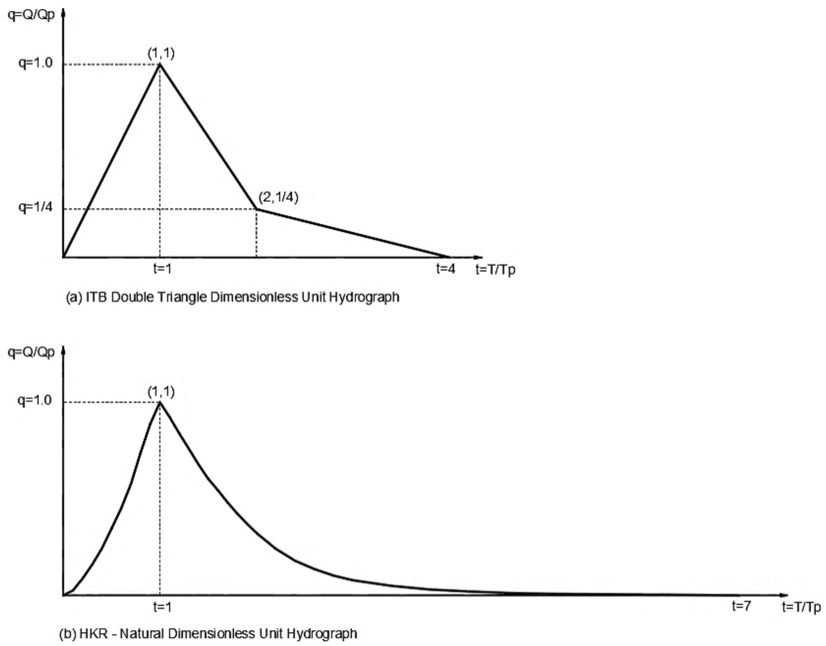


Figure 9. The ITB Double Triangle Synthetic and HKR Natural Dimensionless Unit Hydrographs

The absence of Kp and Qp formulas, as previously discussed, presents significant challenges:

- **Synthetic Unit Hydrographs (SUHs):** User-defined SUHs, such as the ITB Double Triangle SUH (Figure 9-a) and other Double Triangle variations described by Singh [34], lack explicit Kp and Qp formulas. This limits their application in comprehensive flood analysis.
- **Natural Unit Hydrographs (NUHs):** NUHs, derived from observed runoff data, also face limitations. For example, the HKR model for small, semi-arid watersheds (Figure 9-b) lacks Kp and Qp formulas, restricting its adaptability to watersheds with different characteristics.

The ITB method's ability to calculate Kp and Qp values offers a solution for both SUHs and NUHs. By determining these parameters, the ITB method can enhance hydrographs that currently lack them, broadening their applicability across diverse watershed conditions.

6.1. The ITB Double Triangle Synthetic Unit Hydrograph

This section demonstrates an example of creating a new user defined synthetic UH called the ITB Double Triangle Synthetic Unit Hydrograph. This equation-based synthetic unit hydrograph employs a double triangle shape without incorporating peak parameters such as Kp and Qp. The ITB double triangle curve, depicted in Figure 9-a, is defined by four points: (0,0), (1,1), (2,1/4), and (4,0).

The area under the Double Triangular SUH is

$$A_{SUH} = A_1 + A_2 + A_3$$
$$A_{SUH} = \frac{1}{2} \times 1 \times 1 + \frac{1}{2} \times \left(1 + \frac{1}{4}\right) \times 1 + \frac{1}{2} \times 2 \times \frac{1}{4} = \frac{11}{8} \tag{31}$$

The Peak Rate Factor

$$K_p = \frac{1}{3 \times 11/8} = 0.20202020 \text{ (dimensionless)} \tag{32}$$

Therefore, the Peak Discharge is

$$Q_p = 0.20202020 \, \frac{R \times A_{CA}}{T_P} \, (m^3/s) \tag{33}$$

As SUH is new, no Kp values exist for comparison. However, mirroring a linear triangular SUH's Kp determination process suggests the obtained value's accuracy. Since this Synthetic Unit Hydrograph is newly introduced, there are no existing Kp values for comparison. However, considering that the process of determining the Kp value for this Double Triangle Synthetic Unit Hydrograph mirrors that of a linear triangular SUH, it is reasonably safe to conclude the accuracy of the obtained value.

6.2. The Hickok, Keppel, & Rafferty (HKR) Natural Unit Hydrograph

The HKR model (as cited in Hickok et al. [35] & Singh [36]) was tailored for small watersheds, focusing on the runoff characteristics of 14 watersheds ranging from 11 to 790 acres in semi-arid regions like Arizona, Colorado, and New Mexico. It formulated an average dimensionless hydrograph as a natural hydrograph. Unit Hydrograph curve, a tabular-based representation of a natural hydrograph, consists of 32 points detailed in Table 8, with the unit hydrograph shape depicted Figure 9-b.

Table 8. The HKR-Natural Unit Hydrograph

No.	(t/tp)	(q/qp)	No.	(t/tp)	(q/qp)
1	0.000	0.000	17	1.600	0.545
2	0.100	0.025	18	1.700	0.482
3	0.200	0.087	19	1.800	0.424
4	0.300	0.160	20	1.900	0.372
5	0.400	0.243	21	2.000	0.323
6	0.500	0.346	22	2.200	0.241
7	0.600	0.451	23	2.400	0.179
8	0.700	0.576	24	2.600	0.136
9	0.800	0.738	25	2.800	0.102
10	0.900	0.887	26	3.000	0.078
11	1.000	1.000	27	3.400	0.049
12	1.100	0.924	28	3.800	0.030
13	1.200	0.839	29	4.200	0.020
14	1.300	0.759	30	4.600	0.012
15	1.400	0.678	31	5.000	0.008
16	1.500	0.604	32	7.000	0.000

This HKR dimensionless synthetic unit hydrograph curve is formed by piecewise linear segments; therefore, the exact area must be calculated using trapezoidal rule. Therefore, the exact area under the HKR dimensionless synthetic unit hydrograph curve is;

$$\mathrm{A_{SUH}} = \frac{1}{2}[(0.100 - 0.000) \times (0.025 + 0.000) + (0.200 - 0.100) \times (0.087 + 0.025) + \cdots + (5.000 - 4.600) \times (0.008 + 0.012) + (7.000 - 5.000) \times (0.008 + 0.000)] \tag{34}$$

$$\rightarrow \mathrm{A_{SUH}} = 1.27145$$

And the Peak Rate Factor:

$$\mathrm{K_p} = \frac{1}{3.6 \times 1.27145} = 0.2184732 \quad \text{(dimensionless)} \tag{35}$$

Therefore, the Peak Discharge is:

$$\mathrm{Q_p} = 0.2184732 \; \frac{\mathrm{R} \times \mathrm{A_{CA}}}{\mathrm{T_p}} \; (\mathrm{m^3/s}) \tag{36}$$

The HKR Natural Unit Hydrograph (NUH) lacks dedicated Kp and Qp formulas, hindering direct comparison with other methods. However, the process for determining the Kp value in the HKR Natural Unit Hydrograph shares similarities with those used for the SCS Curvilinear and SCS Delmarva SUHs. This resemblance suggests that the Kp value obtained for the HKR Natural Unit Hydrograph is reliable.

6.3. Flood Hydrograph from ITB Double Triangle SUH and HKR-Unit Hydrograph

This section explores the application of the ITB UH method beyond traditional SCS-based models by introducing two alternative approaches: the ITB Double Triangle SUH and the HKR Natural Unit Hydrograph. Building upon the effective rainfall excess distribution (for Tr=1 hour) established in Section 5 (Flood Hydrograph from SCS Triangular, SCS Curvilinear and SCS Delmarva SUH), this section investigates flood hydrograph generation for the Pinamula Catchment using these alternative approaches.

By convolving the ITB Double Triangle Synthetic UH and the HKR Natural UH with the effective rainfall excess and plotting the resulting hydrographs alongside those obtained using the SCS-Curvilinear UH, we gain valuable insights into the comparative behaviour of these models. Figure 10 illustrates this comparison, revealing a close resemblance among the hydrographs generated by the SCS-Curvilinear Synthetic UH, the Double Triangle Synthetic UH, and the HKR Natural UH. This similarity can be attributed to the comparable shapes of their initial dimensionless SUHs, which significantly influence their responses to the same excess rainfall input.

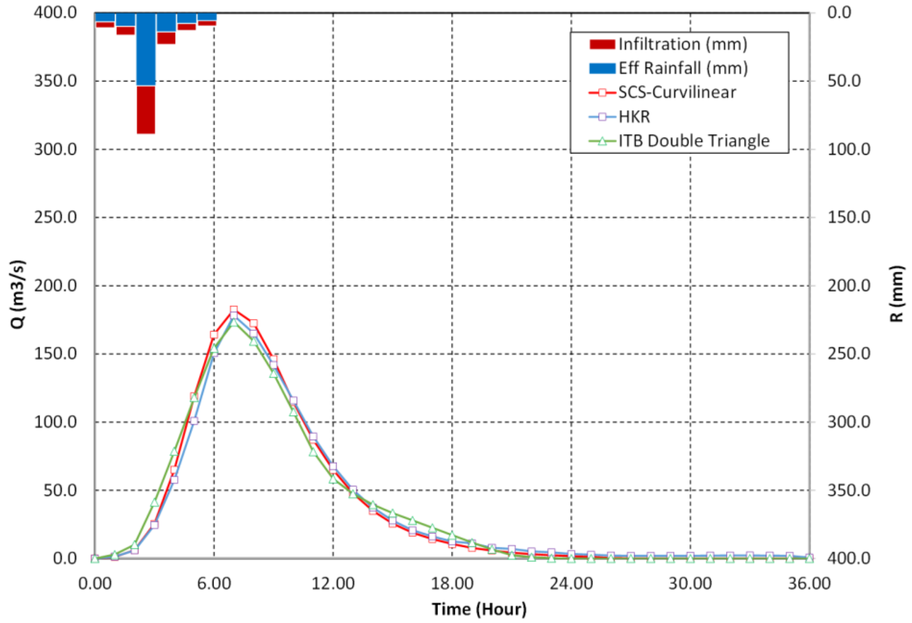


Figure 10. Food Hydrograph Computed Using the SCS-Curvilinear SUH, ITB Double Triangle SUH, and HKR NUH.

7. The Use of the ITB-UH Method in Indonesia

The ITB Unit Hydrograph (ITB-UH) method has emerged as a prominent tool in Indonesian hydrological studies, reflecting its adaptability and perceived reliability across diverse watershed conditions. Its widespread utilization by numerous researchers underscores its significance in addressing various hydrological challenges.

- Mashuri & Kiranaratri (2019) [37] demonstrated the practical application of the ITB-1 method in modeling synthetic unit hydrographs for the Upstream Siak Watershed. This study highlighted the method's ability to represent the complex rainfall-runoff processes within a significant river basin, contributing to improved water resource management.
- Iyan et al. (2022) [38] focused on refining the ITB method's accuracy by optimizing the coefficient parameters of both ITB-1 and ITB-2 within the Bionga Kayubulan Sub-watershed. This research aimed to enhance the method's predictive capabilities by tailoring parameters to specific watershed characteristics, thereby improving the precision of flood estimations.
- Saidah et al. (2022) [39] conducted a comparative analysis to assess the performance of the ITB-UH 2 method against other established techniques, such as the Nakayasu and Limantara methods, specifically within elongated watersheds. This study provided valuable insights into the relative strengths and limitations of different hydrograph methods, aiding researchers in selecting the most appropriate tools for their specific needs.
- Krisnayanti et al. (2020) [40] and Peter (2018) [41], through their undergraduate theses, undertook comparative studies to evaluate the ITB-UH method's performance against widely used methods, including SCS, Melchior, Haspers, and GAMA 1. These studies involved comparing simulated hydrographs with measured data, contributing to a deeper understanding of the ITB-UH method's accuracy and applicability in various hydrological contexts.
- Dewa (2016) [42] conducted an undergraduate thesis exploring the application of the HSS Gama I and HSS ITB-2 methods for synthetic unit hydrograph analysis in the Pam Sub-watershed. This research contributed to the ongoing exploration and refinement of hydrograph modeling techniques, advancing the field of hydrological science.
- Kirana et al. (2023) [43] integrated the ITB-1 and ITB-2 methods as crucial inputs, alongside Nakayasu, Snyder, and SCS methods, for flood risk assessments in the Banyumas and Cilacap Districts of Central Java. This application demonstrated the ITB-UH method's practical utility in supporting flood management strategies and mitigating potential flood impacts.
- Suryadi et al. (2024) [44] applied the ITB-1 method to analyze the high flow frequency of the Cikapundung River in West Java. This study showcased the method's relevance in understanding river flow dynamics and predicting extreme flow events, which are essential for effective water resource planning.
- Christian et al. (2024) [45] utilized the ITB-1 and ITB-2 methods to generate hydrographs for flood routing analysis related to the baffled chute spillway of the Lausimeme Dam. This application emphasizes the ITB-UH method's importance in dam safety assessments and the design of hydraulic structures.

8. 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.

- **Part I Foundations**

  Part I has detailed how the ITB-UH Method enhances flood discharge simulations through transparent derivations, flexible time steps, mass conservation checks, and built-in calibration. This framework not only supports effective flood risk management strategies but also serves as an educational resource, reinforcing crucial hydrograph principles in academic and professional settings.

- **Motivation and Core Improvements**

  The method was developed in response to several limitations of traditional Synthetic Unit Hydrographs, such as limited calibration, rigid time steps, and often opaque derivations of peak discharge formulas. By contrast, the ITB-UH method provides:

  - **Clear Mathematical Foundations:** The SUH curve equations (ITB-1b and ITB-2b) are derived with explicit forms for time-to peak (Tp) and peak discharge (Qp), ensuring ease of teaching, learning, and application.

- **Exact and Numerical Integration:** Exact integrations for dimensionless SUH curves enable a precise determination of the area under the curve, yielding accurate values for the peak rate factor (Kp) and Qp. Numerical integration is used where exact integration is not feasible, and both approaches include a mechanism to verify mass conservation.
- **Flexible Time-Step Normalization:** The ability to normalize time steps Tr by Tp (Tn = Tr / Tp) means users can change the rainfall's temporal resolution without fully recalculating the entire SUH, facilitating quicker sensitivity analyses.
- **Built-In Calibration Capabilities:** Two key parameters, Ct (linked to time to peak) and Cp (linked to peak discharge), can be adjusted to match observed flood hydrographs. This feature addresses the need for site-specific customization, often missing in other SUH methods.

- **Verifying Existing Synthetic Unit Hydrographs (SUHs)**

The ITB-UH Method successfully validated key parameters—Peak Rate Factor (Kp) and Peak Discharge (Qp)—against established SUHs:

- **SCS-Triangular SUH**: Reproduced with exact alignment, demonstrating the method's ability to replicate simple, widely used hydrographs.
- **SCS-Curvilinear SUH**: Achieved more accurate Kp values than the original SCS method, highlighting its superior precision for natural watershed responses.
- **SCS-Delmarva SUH**: Validated with minimal deviation, showcasing its ability to handle complex hydrographs with extended time bases.

These verifications confirm the ITB-UH Method's reliability in replicating traditional SUH models and its potential as a universal analytical tool.

- **Developing User-Defined Synthetic and Natural Unit Hydrographs**

The method's adaptability is exemplified by the creation of:

- **The ITB Double Triangle Synthetic UH**: An innovative Synthetic Unit Hydrographs featuring adjustable peak discharge and time to peak, with derived Kp and Qp values validated through transparent computations.
- **HKR Natural Unit Hydrograph**: An NUH tailored for semi-arid watersheds, enhanced with explicit Kp and Qp values for broader applicability in diverse hydrological contexts.

These advancements enable the ITB-UH Method to bridge gaps in hydrological modelling, allowing for the development of custom hydrographs aligned with specific watershed characteristics.

- **Practical Applications in the Pinamula Watershed**

Applying the method to Pinamula Watershed demonstrated its versatility and consistent computation steps. Simulations using SCS-Triangular, SCS-Curvilinear, SCS-Delmarva, Double Triangle, and HKR hydrographs yielded accurate and comparable flood hydrographs, underscoring its adaptability to real-world scenarios.

9. Declarations

9.1. 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.

9.2. Data Availability Statement

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

9.3. Funding and Acknowledgements

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9.4. Conflicts of Interest

The authors declare no conflict of interest.

10. References

[1] Natakusumah, D. K. (2009). General Procedure for Determining Synthetic Unit Hydrograph for Calculating Design Flood Hydrograph. National Seminar on Water Resources Engineering, The Role of Community, Government and Private Sector as Networks, in Flood Hazard Mitigation, 11 August, Bandung, Indonesia. (In Indonesian).

[2] Natakusumah, D. K., Hatmoko, W., & Harlan, D. (2011). General Procedure for Calculating Synthetic Unit Hydrographs Using the ITB Method and Some Examples of Its Application. Jurnal Teknik Sipil, 18(3), 251. doi:10.5614/jts.2011.18.3.6. (In Indonesian).

[3] Natakusumah, D. K., Harlan, D., & Hatmoko, W. (2013). A new synthetic unit hydrograph computation method based on the mass conservation principle. WIT Transactions on Ecology and the Environment, 172, 27–38. doi:10.2495/RBM130031.

[4] Natakusumah, D. K. (2016). The Use of Synthetic Unit Hydrographs ITB 1 and ITB-2 With Peak Discharge Factor (Kp) Calculated Exactly. PIT HATHI 31, 15 March, 2014, Padang, Indonesia. (In Indonesian).

[5] Natakusumah, D. K., Wicaksana, G. A., & Nathaniel, B. (2021). Towards standardization of design flood calculation using Synthetic Unit Hydrograph methods. 7th International Seminar of HATHI, 30 October, Surabaya, Indonesia. (In Indonesian).

[6] Natakusumah, D. K. (2024). ITB Synthetic Unit Hydrograph Method with Exact and Numerical Peak Discharge Factor (Kp) and Normalized Unit Rainfall Duration (Tr). Media Komunikasi Teknik Sipil, 30(1), 144–156. doi:10.14710/mkts.v30i1.55820.

[7] Yi, B., Chen, L., & Xie, T. (2024). On the Influence of Spatial Heterogeneity of Runoff Generation on the Distributed Unit Hydrograph for Flood Prediction. doi:10.5194/hess-2024-51.

[8] Rafiee, M. R., Rad, S., Mahbod, M., Zolghadr, M., Azamatulla, H. M., & Tripathi, R. P. (2024). Modeling run-off flow hydrographs using remote sensing data: an application to the Bashar basin, Iran. Journal of Water and Climate Change, 15(4), 1490–1506. doi:10.2166/wcc.2024.378.

[9] Das, T., & Das, S. (2024). Event-based flood estimation in un-gauged sub-basins: a comparative assessment of SCS-UH, CWC-UH and Nash-GIUH based rainfall-runoff models in Shilabati River, Eastern India. Natural Hazards. doi:10.1007/s11069-024-06765-0.

[10] Qi, K., Al-Asadi, K., & Duan, J. G. (2024). Modeling Runoff and Sediment Load Using the HEC-HMS Model in an Arid Watershed. Journal of Hydrologic Engineering, 29(3), 05024005. doi:10.1061/jhyeff.heeng-6070.

[11] Marasini, U., & Pokhrel, M. (2024). Comparative analysis of rainfall-runoff simulation using a long short-term memory (LSTM) deep learning model and a conceptual hydrological model, HEC-HMS: a case study of the mountainous river basin of Nepal. Discover Civil Engineering, 1(1), 78. doi:10.1007/s44290-024-00084-w.

[12] Lange, H., & Sippel, S. (2020). Machine Learning Applications in Hydrology. Forest-Water Interactions, 233–257. doi:10.1007/978-3-030-26086-6_10.

[13] Shao, Z., Fu, H., Li, D., Altan, O., & Cheng, T. (2019). Remote sensing monitoring of multi-scale watersheds impermeability for urban hydrological evaluation. Remote Sensing of Environment, 232, 111338. doi:10.1016/j.rse.2019.111338.

[14] Nakhaei, M., Nakhaei, P., Gheibi, M., Chahkandi, B., Wacławek, S., Behzadian, K., Chen, A. S., & Campos, L. C. (2023). Enhancing community resilience in arid regions: A smart framework for flash flood risk assessment. Ecological Indicators, 153, 110457. doi:10.1016/j.ecolind.2023.110457.

[15] Chen, H., Jeanne Huang, J., Li, H., Wei, Y., & Zhu, X. (2023). Revealing the response of urban heat island effect to water body evaporation from main urban and suburb areas. Journal of Hydrology, 623, 129687. doi:10.1016/j.jhydrol.2023.129687.

[16] Hall, C. A., Saia, S. M., Popp, A. L., Dogulu, N., Schymanski, S. J., Drost, N., van Emmerik, T., & Hut, R. (2022). A hydrologist's guide to open science. Hydrology and Earth System Sciences, 26(3), 647–664. doi:10.5194/hess-26-647-2022.

[17] SNI 2415:2016. (2016). Procedures for calculating planned flood discharge (SNI 2415:2016). Procedures for calculating design flood discharge. Badan Standardisasi Nasional, Jakarta, Indonesia. (In Indonesian).

[18] United Kingdom (UK) Government. (2010). Flood and Water Management Act 2010. United Kingdom (UK) Government, London, United Kingdom. Available Online: https://www.legislation.gov.uk/ukpga/2010/29/contents (accessed on March 2025).

[19] Ball, J., Babister, M., Nathan, R., Weinmann, E., Weeks, W., & Retallick, M. (2019). Australian rainfall and runoff: A guide to flood estimation. Commonwealth of Australia, Sydney, Australia.

[20] Public Safety Canada. (2021). National flood risk assessment guidelines. Ottawa, Ontario: Public Safety Canada. Public Safety Canada, Ottawa, Canada. Available online: https://www.publicsafety.gc.ca (accessed on March 2024).

[21] ICOLD. (2020). Guidelines for flood management and dam safety. International Commission on Large Dams (ICOLD), Paris, France.

[22] MSMA. (2021). Urban stormwater management manual for Malaysia (MSMA). Department of Irrigation and Drainage Malaysia, Cyberjaya, Malaysia. Available online: https://www.water.gov.my/jps/resources/PDF/MSMA2ndEdition_august_2012.pdf (accessed on March 2025).

[23] ANCOLD. (2016). Report CL1895: Guidelines on dam safety management. Australian National Committee on Large Dams (ANCOLD), Hobart, Australia. Available online: https://www.ancold.org.au/wp-content/uploads/2016/06/CL1895-Report.pdf (accessed on March 2025).

[24] Sherman, L. K. (1932). Streamflow from rainfall by the unit-graph method. Eng. News Record, 108, 501-505.

[25] Snyder, F. F. (1938). Flood-frequency and drainage-basin characteristics. Transactions of the American Society of Civil Engineers, 103(1), 877–924.

[26] Singh, P. K., Mishra, S. K., & Jain, M. K. (2014). A review of the synthetic unit hydrograph: from the empirical UH to advanced geomorphological methods. Hydrological Sciences Journal, 59(2), 239–261. doi:10.1080/02626667.2013.870664.

[27] Patil, S. K., & Bhagwat, T. N. (2019). A review of synthetic hydrograph method for design storm. International Research Journal of Engineering and Technology, 6(11), 2413-2418.

[28] Taylor, A. B., & Schwarz, H. E. (1952). Unit- hydrograph lag and peak flow related to basin characteristics. Eos, Transactions American Geophysical Union, 33(2), 235–246. doi:10.1029/TR033i002p00235.

[29] Mockus, V. (1957). Use of storm and watershed characteristics in synthetic hydrograph analysis and application. Soil Conservation Service, US Department of Agriculture, Washington, United States.

[30] U.S. Department of Agriculture. (2007). Part 630 Hydrology. Chapter 16: Hydrographs. National Engineering Handbook, US Department of Agriculture, Washington, United States. Available online: https://damtoolbox.org/images/5/5a/NEH16.pdf (accessed on March 2024).

[31] Nakayasu, N. (1962). Runoff characteristics in Japan. Transactions of the Japan Society of Civil Engineers, 77, 1–5.

[32] Tunas, I. G. (2017). Development of synthetic unit hydrograph model based on fractal characteristics of river basin. PhD Thesis, Surabaya, Indonesia. (In Indonesian).

[33] Patel, R. M. (2024). SCS dimensionless unit hydrograph. Available online: http://www.professorpatel.com/scs-dimensionless-unit-hydrograph.html (accessed on March 2025).

[34] Singh, V. P. (1988). The Double Triangle Model. Hydrologic systems: Vol. 1. Rainfall-runoff modeling. Prentice Hall, New Jersey, United States.

[35] Hickok, R. B., Keppel, R. V., & Rafferty, B. R. (1959). Hydrograph synthesis for small arid land watersheds. Agricultural Engineering, 40(10), 608-611.

[36] Singh, V. P. (1988). The Hickok-Keppel-Rafferty (HKR) Model. Hydrologic systems: Vol. 1. Rainfall-runoff modeling. Prentice Hall, New Jersey, United States.

[37] Mashuri, M., & Kiranaratri, A. H. (2019). Study of Modelling Synthetic Unit Hydrograph Using ITB-1 Method (Case Study: Upstream Siak Watershed). Jurnal Kajian Teknik Sipil, 4(2), 99–108. doi:10.52447/jkts.v4i2.1685.

[38] Iyan, E. R., Labdul, B. Y., & Husnan, R. (2022). Optimization of Synthetic Unit Hydrograph Parameter Coefficients Itb-1 and Itb-2 in the Bionga Kayubulan Sub-Das. Composite Journal, 2(1), 21-27. (In Indonesian).

[39] Saidah, H., Setiawan, A., Hanifah, L., Suroso, A., & Supriyadi, A. (2022). Performance of Nakayasu Synthetic Unit Hydrograph, ITB 2 and Limantara for Elongated Watersheds. PADURAKSA: Jurnal Teknik Sipil Universitas Warmadewa, 11(2), 157–165. doi:10.22225/pd.11.2.5013.157-165.

[40] Krisnayanti, D. S., Hunggurami, E., & Heo, R. S. (2020). Comparison of Design Flood Discharge Using Nakayasu, Gama I and Limantara HSS Methods in Raknamo Watershed. Jurnal Teknik Sipil, 9(1), 1-14. (In Indonesian).

[41] Peter, A. D. (2018). Comparison of Several Synthetic Unit Hydrographs (GAMA 1, Nakayasu, ITB 1-2, SCS, and Limantara) with Measured Unit Hydrographs. Bachelor Thesis, Universitas Gadjah Mada, Yogyakarta, Indonesia. (In Indonesian).

[42] Dewa B, A. G. (2016). Synthetic Unit Hydrograph Analysis with HSS Gama I and HSS ITB-2 Methods for Pam Sub-DAS (Final Project). Department of Civil Engineering, Faculty of Engineering, Sriwijaya University, Palembang, Indonesia. (In Indonesian).

[43] Kirana, P. H., Farid, M., Bagus Adityawan, M., Kuntoro, A. A., & Widyaningtyas, W. (2023). Study of Flood Risk Assessment on Banyumas and Cilacap District in Downstream Serayu River Basin, Indonesia. Jurnal Teknik Sipil, 30(2), 149–156. doi:10.5614/jts.2023.30.2.2.

[44] Suryadi, C., Soekarno, I., Kardhana, H., & Kuntoro, A. A. (2024). High Flow and Low Flow Frequency Analysis of Cikapundung River. Bearing: Jurnal Penelitian Dan Kajian Teknik Sipil, 8(2), 52. doi:10.32502/jbearing.v8i2.7840.

[45] Christian, J.D., Harlan, D., Suryadi, Y., Nugroho, E.O. (2024). Effectiveness of Baffled Chute Spillway Utilization at Lau Simeme Dam, Deli Serdang, North Sumatra. Pertemuan Ilmiah Tahunan ke-41 HATHI, 27-29 September, Sorong, Indonesia. (In Indonesian).

Appendix I

Table A.1. Computation of SCS-Triangular 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 (CA)	=	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)	=	1.0000	-	
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	=	4.7289	Hour	
4. Base Time (TB)				
TB = TP	=	5.0000	Defined	
TB	=	23.6447	Hour	

III. Computation of ASUH, Kp, and Tp

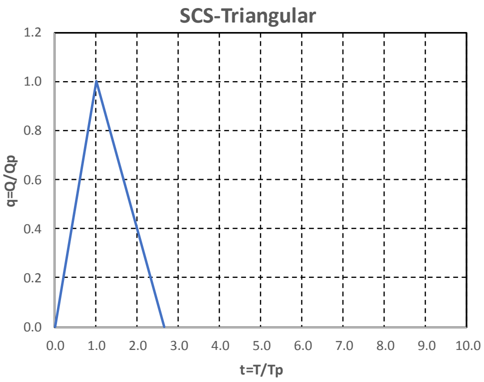
1. Tn = Tr/Tp	=	0.21146	-	Normalize Unit Rainfall Duration
2. A_{SUH} (Numerical, Exact,)	=	1.33333	Exact	
	=	1.32945	Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
3. Kp = 1/(3.6*ASUH)	=	0.20833	Exact	
		0.20894	Numerical	
4. Qp = Kp A_{DAS} R/Tp	=	2.17411	m3/s (Ext)	
	=	2.18045	m3/s (Num)	
	=	0.2917%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * CA)	=	49,350	m3	
2. Dimensional SUH Volume	=	49,350	m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. RD = SUH Vol/CA/1000	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SCS-Triangular

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	0.211464	1.000	0.461087
2	0.422928	0.422928	2.000	0.922174
3	0.634391	0.634391	3.000	1.383261
4	0.845855	0.845855	4.000	1.844348
5	1.057319	0.965609	5.000	2.105466
6	1.268783	0.838730	6.000	1.828813
7	1.480246	0.711852	7.000	1.552161
8	1.691710	0.584974	8.000	1.275509
9	1.903174	0.458096	9.000	0.998857
10	2.114638	0.331217	10.000	0.722204
11	2.326102	0.204339	11.000	0.445552
12	2.537565	0.077461	12.000	0.168900
13	2.749029	0.000000	13.000	0.000000
14	2.960493	0.000000	14.000	0.000000
15	3.171957	0.000000	15.000	0.000000
16	3.383420	0.000000	16.000	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))
  = IF(t<8/3,IF(t<1,t,-0.6*t+1.6),0)
- Column (4) = Column (2) * Tp (Hour)
- Column (3) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A.2. Computation of SCS-Curvilinear 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)	=	1.0000	-	
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	=	4.7289	Hour	
4. Base Time (TB)				
TB = TP	=	5.0000	Defined	
TB	=	23.6447	Hour	

III. Computation of ASUH, Kp, and Tp

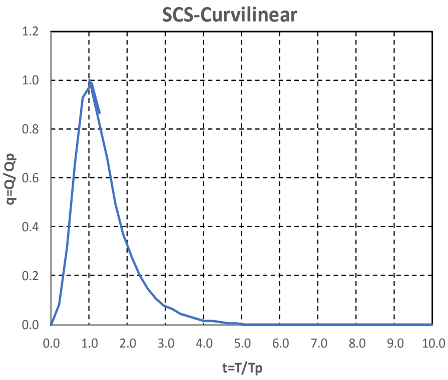
1. Tn = Tr/Tp	=	0.21146	-	Normalize Unit Rainfall Duration
2. A_{SUH} (Numerical, Exact,)	=	1.35435	Exact Eq (8)	Exact (Numerical Integration of the original SCS-Culvilinear Table)
	=	1.35466	Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
3. Kp = 1/(3.6*ASUH)	=	0.20510	Exact	
		0.20505	Numerical	
4. Qp = Kp A_{DAS} R/Tp	=	2.14037	m3/s (Ext)	
	=	2.13988	m3/s (Num)	
	=	-0.0229%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * CA)	=	49,350	m3	
2. Dimensional SUH Volume	=	49,350	m3	(Sum of Column (5) in Section V) x (Tr*3600)
3. RD = SUH Vol/CA/1000	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SCS-Curvilinear

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	0.084744	1.000	0.181343
2	0.422928	0.314391	2.000	0.672761
3	0.634391	0.658465	3.000	1.409040
4	0.845855	0.926684	4.000	1.982997
5	1.057319	0.988536	5.000	2.115354
6	1.268783	0.864974	6.000	1.850945
7	1.480246	0.677778	7.000	1.450367
8	1.691710	0.495803	8.000	1.060961
9	1.903174	0.368413	9.000	0.788361
10	2.114638	0.274145	10.000	0.586639
11	2.326102	0.202170	11.000	0.432620
12	2.537565	0.145609	12.000	0.311586
13	2.749029	0.106155	13.000	0.227160
14	2.960493	0.079543	14.000	0.170214
15	3.171957	0.061587	15.000	0.131790
16	3.383420	0.045093	16.000	0.096494
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))
  Interpolation form SCS-Curvilinear Table
- Column (4) = Column (2) * Tp (Hour)
- Column (3) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A.3. Computation of SCS-Delmarva 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)	=	1.0000	-	
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	=	4.7289	Hour	
4. Base Time (TB)				
TB = TP	=	10.0000	Defined	
TB	=	47.2894	Hour	

III. Computation of ASUH, Kp, and Tp

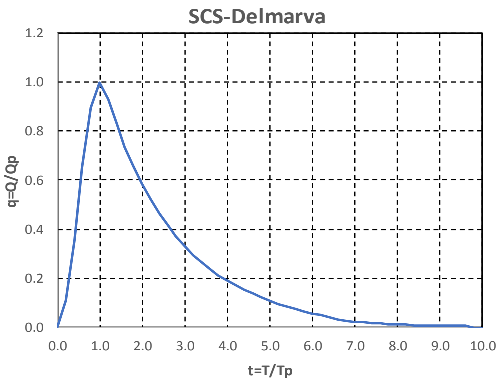
1. Tn = Tr/Tp	=	0.21146	-	Normalize Unit Rainfall Duration
2. A_{SUH} (Numerical, Exact,)	=	2.28820	Exact Eq (8)	(Numerical Integration from the original SCS-Delmarva Table)
	=	2.29697	Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
3. Kp = 1/(3.6*ASUH)	=	0.12140	Exact	
		0.12093	Numerical	
4. Qp = Kp A_{DAS} R/Tp	=	1.26685	m3/s (Ext)	
	=	1.26202	m3/s (Num)	
	=	-0.3817%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * CA)	=	49,350	m3	
2. Dimensional SUH Volume	=	49,350	m3	(Sum of Column (5) in Section V) x (Tr*3600)
3. RD = SUH Vol/CA/1000	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of SCS-Delmarva

No	mensionless 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	0.125043	1.000	0.157807
2	0.422928	0.390277	2.000	0.492537
3	0.634391	0.696442	3.000	0.878922
4	0.845855	0.919845	4.000	1.160861
5	1.057319	0.979652	5.000	1.236339
6	1.268783	0.894265	6.000	1.128579
7	1.480246	0.791488	7.000	0.998873
8	1.691710	0.699857	8.000	0.883233
9	1.903174	0.618857	9.000	0.781010
10	2.114638	0.547889	10.000	0.691447
11	2.326102	0.485692	11.000	0.612952
12	2.537565	0.430609	12.000	0.543436
13	2.749029	0.382214	13.000	0.482361
14	2.960493	0.338901	14.000	0.427700
15	3.171957	0.300908	15.000	0.379751
16	3.383420	0.267570	16.000	0.337678
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))
  Interpolation form SCS-Curvilinear Table
- Column (4) = Column (2) * Tp (Hour)
- Column (3) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A.4. Computation of ITB Double Triangle 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 (CA)	=	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)	=	1.0000	-	
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	=	4.7289	Hour	
4. Base Time (TB)				
TB = TP	=	5.0000	Defined	
TB	=	23.6447	Hour	

III. Computation of ASUH, Kp, and Tp

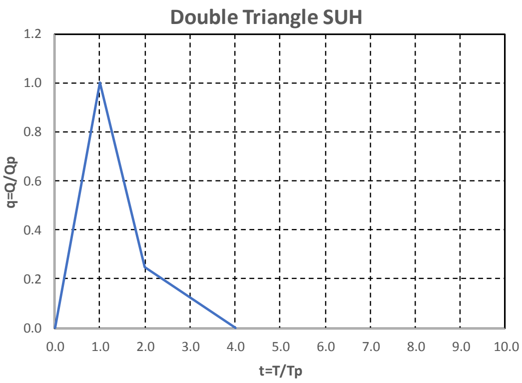
1. Tn = Tr/Tp	=	0.21146	-	Normalize Unit Rainfall Duration
2. A_{SUH} (Numerical, Exact,)	=	1.37500	Exact	
	=	1.37095	Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
3. Kp = 1/(3.6*ASUH)	=	0.20202	Exact	
		0.20262	Numerical	
4. Qp = Kp A_{DAS} R/Tp	=	2.10823	m3/s (Ext)	
	=	2.11445	m3/s (Num)	
	=	0.2952%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * CA)	=	49,350	m3	
2. Dimensional SUH Volume	=	49,350	m3	(Sum of Column (5) in Section IV) x (Tr*3600)
3. RD = SUH Vol/CA/1000	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of Double Triangle SUH

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	0.211464	1.000	0.447130
2	0.422928	0.422928	2.000	0.894260
3	0.634391	0.634391	3.000	1.341390
4	0.845855	0.845855	4.000	1.788521
5	1.057319	0.957011	5.000	2.023554
6	1.268783	0.798413	6.000	1.688207
7	1.480246	0.639815	7.000	1.352859
8	1.691710	0.481217	8.000	1.017511
9	1.903174	0.322620	9.000	0.682164
10	2.114638	0.235670	10.000	0.498314
11	2.326102	0.209237	11.000	0.442422
12	2.537565	0.182804	12.000	0.386531
13	2.749029	0.156371	13.000	0.330640
14	2.960493	0.129938	14.000	0.274749
15	3.171957	0.103505	15.000	0.218857
16	3.383420	0.077072	16.000	0.162966
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))
' = IF(t<1;MIN(1;t);MAX(-0.75*t+1.75;-0.125*t+0.5;0))
- Column (4) = Column (2) * Tp (Hour)
- Column (3) = Column (5) * Qp (m3/s) Use Qp numerical not Exact

Table A.5. Computation of HKR 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)	=	1.0000	-	
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	=	4.7289	Hour	
4. Base Time (TB)				
TB = TP	=	7.0000	Defined	
TB	=	33.1026	Hour	

III. Computation of ASUH, Kp, and Tp

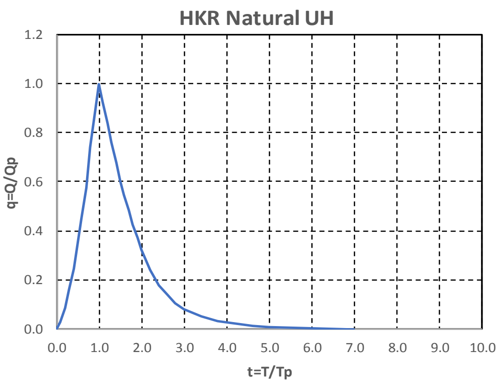
1. Tn = Tr/Tp	=	0.21146	-	Normalize Unit Rainfall Duration
2. A_{SUH} (Numerical, Exact,)	=	1.27145	Exact Eq (8)	(Numerical Integration from the original SCS-Delmarva Table)
	=	1.28815	Numerical	(Sum of Column (3) in Section V) x (Tr/Tp)
3. Kp = 1/(3.6*ASUH)	=	0.21847	Exact	
		0.21564	Numerical	
4. Qp = Kp A_{DAS} R/Tp	=	2.27993	m3/s (Ext)	
	=	2.25037	m3/s (Num)	
	=	-1.2963%	Error	

IV. Conservation Check

1. Rain Vol (1000 * R * CA)	=	49,350	m3	
2. Dimensional SUH Volume	=	49,350	m3	(Sum of Column (5) in Section V) x (Tr*3600)
3. RD = SUH Vol/CA/1000	=	1.00000	Ok≈1.0 mm	
	=			

V. Table for Calculation of HKR-Unit Hydrograph

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	0.095369	1.000	0.214615
2	0.422928	0.266615	2.000	0.599984
3	0.634391	0.493989	3.000	1.111660
4	0.845855	0.806324	4.000	1.814530
5	1.057319	0.956438	5.000	2.152342
6	1.268783	0.783974	6.000	1.764234
7	1.480246	0.618618	7.000	1.392121
8	1.691710	0.487223	8.000	1.096433
9	1.903174	0.370445	9.000	0.833639
10	2.114638	0.275999	10.000	0.621100
11	2.326102	0.201909	11.000	0.454370
12	2.537565	0.149423	12.000	0.336259
13	2.749029	0.110665	13.000	0.249038
14	2.960493	0.082741	14.000	0.186198
15	3.171957	0.065533	15.000	0.147474
16	3.383420	0.050202	16.000	0.112973
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))
  Interpolation form HKR Unit Hydrograph Table
- Column (4) = Column (2) * Tp (Hour)
- Column (3) = Column (5) * Qp (m3/s) Use Qp numerical not Exact