

An Analysis of Flood Forecasting Parameters in the Bandar Segamat Sub-Basin using HEC-HMS

Nur Ellissa Anis Azli¹, Nor Maizzaty Abdullah^{1*}

¹ Department of Civil Engineering Technology/Faculty of Engineering Technology
Universiti Tun Hussein Onn Malaysia/Jalan Edu Hub Gunasama 1, Pagoh Edu Hub, KM1, Jln Panchor, Pagoh,
84600, Johor, MALAYSIA

*Corresponding Author: maizzaty@uthm.edu.my

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Abstract

Bandar Segamat frequently experiences significant flooding due to heavy monsoon rainfall that leads to rapid runoff and river overflow. From the heavy rain, it created a small island at the Bandar Segamat. The Sungai Segamat Sub-basin, like many other river basins, faces challenges such as water scarcity, floods, and environmental degradation, necessitating effective hydrological modelling techniques to address these issues. This study uses Hydraulic Modelling System (HEC-HMS) to simulate the hydrologic processes of the Segamat River Basin by optimizing 3 main parameters for flood forecasting which are loss, transform and baseflow to improve model accuracy and ensure the most accurate result is achieved. This study also measures the Nash-Sutcliffe Efficiency (NSE) value which is a widely used indicator in hydrological modeling in order to evaluate a model's performance in comparison to observed data. This study uses accessible data and softwares to perform a qualified NSE value and also R² for calibration and validation. Results shows that increment in land use and lag time plays important role for flood forecasting with the NSE value is 0.732 and the R² is 0.75. Comparing the result with previous study, it showed that this current study had increased the result of NSE and R² due to the improvement of the three parameters. The enhanced data shows that it is more suitable for urban areas and long-duration rainfall events. The study concludes that incorporating updated land use data and refining lag time analysis significantly improve hydrologic modeling for flood forecasting in urban settings. It is recommended to integrate real-time data assimilation and explore advanced techniques such as machine learning to further refine predictive accuracy and enhance flood mitigation strategies.

1. Introduction

Bandar Segamat has experienced several notable flood events in the past due to heavy rainfall, particularly during the monsoon seasons that led to rapid runoff, overwhelming the river's capacity and overflowing its banks (Bernama, 2023). The Segamat River Basin is in the southern region of Peninsular Malaysia, a typical tropical, rural, and agricultural river basin (Liew et al., 2021). It is important to identify the land use and the soil characteristics at Bandar Segamat before conducting hydrology model to determine the infiltration and water flow to ensure that the accurate results can be obtained for the flood forecasting (Sulaiman et al., 2012). According to Cea and Costabile (2022), urban development significantly influences flooding risks, primarily due

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to changes in land use and infrastructure. Expanding impervious surfaces like roads, buildings, and pavements decreases the land's natural ability to absorb rainfall (Yount, n.d.). This intensifies surface runoff, overwhelming urban drainage systems and increasing the likelihood of flash floods. This study used HEC-HMS to stimulate the complete hydrologic processes of dendritic watershed systems and to calculate various subbasin and reach characteristics based on the terrain dataset associated with the model and useful to quantify the physical traits of subbasins and reaches. According to Akmal et al. (2024), the HEC-HMS model can provide a hydrological simulation of daily peak flow for calculation of the design flood discharge of a watershed.

By understanding how changes in climate patterns impact hydrological processes, it developed more robust adaptation and resilience-building measures to address water-related challenges in the face of climate change (Azhooni et al., 2018). For this project, the parameters analyzed in HEC-HMS to improve the R^2 and NSE value for model accuracy were loss, transform, and baseflow. Those three parameters are chosen because it plays the most important role for flood forecasting to model how water moves through a subbasin. They were used to calculate runoff and predict future conditions (Chris, 2024). Parameters are adjusted manually and using optimization techniques within HEC-HMS to minimize discrepancies between simulated and observed values. Key parameters typically adjusted include curve number, time of concentration, and baseflow parameters (Gupta et al., 2014). Higher R^2 value, closer to 1, indicates better agreement between the simulated and observed data (Hassan et al., 2023). According to Kolsoumi (n.d.), NSE values range from one to negative infinity. An NSE of one indicates a complete match between the simulated and observed values when the model fits the observed data perfectly. Negative numbers demonstrate that the observed data's mean performs better than the model, while an NSE near to 1 indicates that the model predictions are equally accurate using the mean of the observed data. To achieve this, the model undergoes a calibration process, where the parameters are fine-tuned to optimize the fit of the simulated results to the observed data. Following calibration, validation is performed to test the model's performance on a separate dataset, ensuring the reliability and accuracy of the model's predictions. This systematic approach ensures that the R^2 value remains consistently close to 1, enhancing the robustness of flood forecasting (Patil & Kherde, 2024). The aim of this study is to analyze the impact from the adjustment of flood forecasting parameters at Bandar Segamat due to its land uses, water flow time and infiltration.

1.1 Description of Study Area

Segamat River holds significant importance to the region's landscape. It serves as a central feature for geographical and hydrological studies, reflecting its critical role in the area's natural and environmental dynamics. The catchment area of this river was estimated to be about 2,891 square kilometers and the coordinate is (102°46'34.04"E, 2°28'45.76"N). It flows from Segamat Town and is a tributary of the Muar River with a long path is 37.9 km. The geographical features offer a basic comprehension of the physical dimensions and the spatial context of the river in the area. The hydrological significance of the Segamat River is underscored by its integral role in the regional water network.

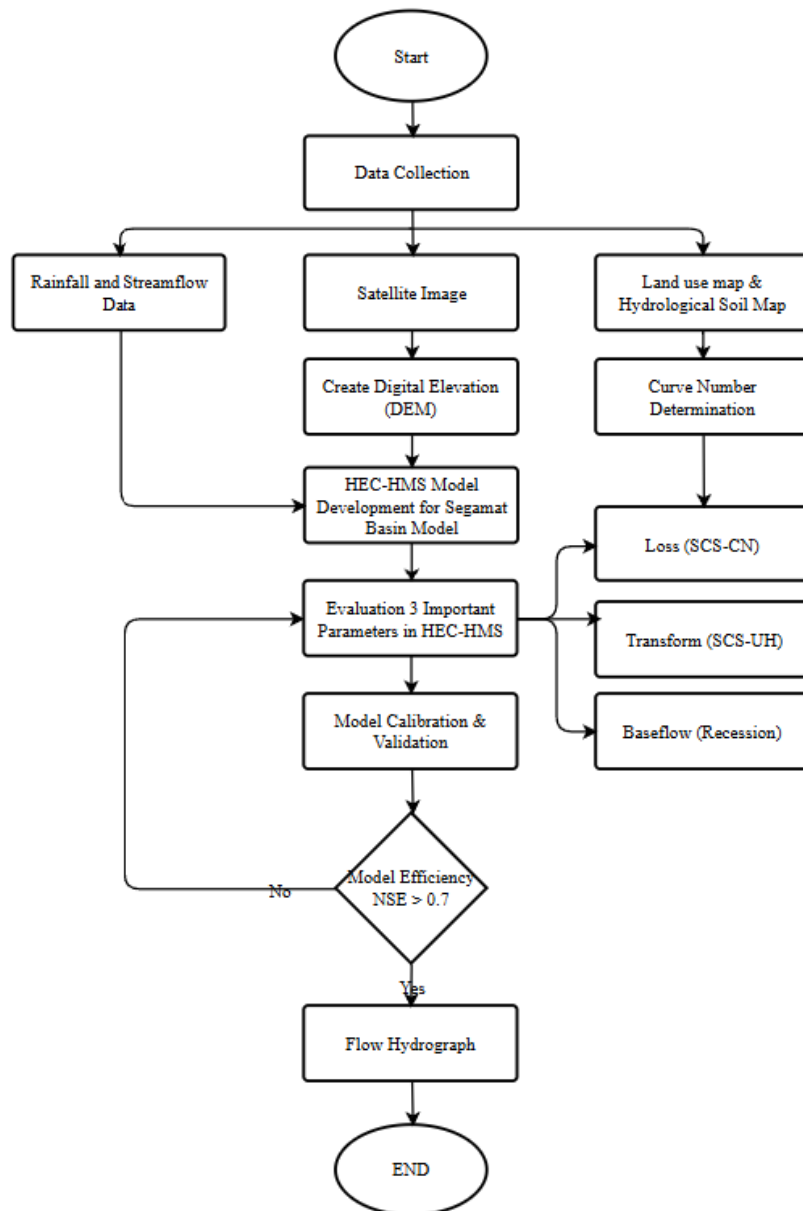
1.2 Problem Statement

According to Bernama (2023), continuous heavy rainfall has led to severe flooding in the Segamat district of Johor, resulting in the inundation of several areas and the formation of small islands. Based on historical flood records, Segamat town was affected the most by the 1969, 1979, 1983, 2007, 2011 and 2023 floods. Therefore, a fundamental problem arises which is the need to identify the key model parameters that significantly influence the accuracy of hydrological simulations in the Sungai Segamat Sub-basin. The purpose is to obtain accuracy for a more accurate flood forecasting. Furthermore, there were a lot of high costs software used to determine the accuracy of flood forecasting such as InfoWorks. This study provides a method to get accurate results but with accessible data and softwares.

2. Methodology

In this chapter, it was explained how to assess the Bandar Segamat Sub-basin's hydrologic model using HEC-HMS, determine the crucial model parameters that greatly affect the sub-basin's hydrological simulations' accuracy, and assess the accuracy and reliability of the hydrological models for the Bandar Segamat Sub-basin by adjusting the model parameters to reduce the discrepancies between simulated and observed hydrological variables. Its catchment area includes diverse terrain, with steep and hilly topography constituting 70% of the basin, while undulating hills and small swamps occupy the remaining 30% (Liew et al., 2021). Such varied landscapes influence the river's hydrological dynamics, including flow patterns, sediment transport, and water quality. Understanding these hydrological processes is essential for effective water resource management and ecosystem preservation in the Johor region. The study's flow and the subbasins of Bandar Segamat are depicted in Figure 1 (a) below.

To start this study, rainfall data was collected from the Department of Irrigation and Drainage. Satellite image was used to define the boundary of Bandar Segamat which the software used was Google Earth Pro. By using polygon tool in Google Earth Pro and references from internet sources, the boundary can be created which also includes the main river which is Sungai Segamat. Then it is saved and exported to kml format to be imported to QGIS software for its topography. The topography can be used to evaluate the outlet of the stream and the flow for the precipitation. Then it was converted to kml file to create the DEM in QGIS software to define the topography. The topography is important to determine the water flow and to define the outlet of Segamat River. It is also vital for analyzing and monitoring land use patterns, helping to address challenges like urban sprawl, deforestation, and land degradation (Machireddy, 2023). For the topography, SRTM downloader has been used to create the DEM at Bandar Segamat and was exported to GeoTiff file to create subbasins in HEC-HMS.



(a)

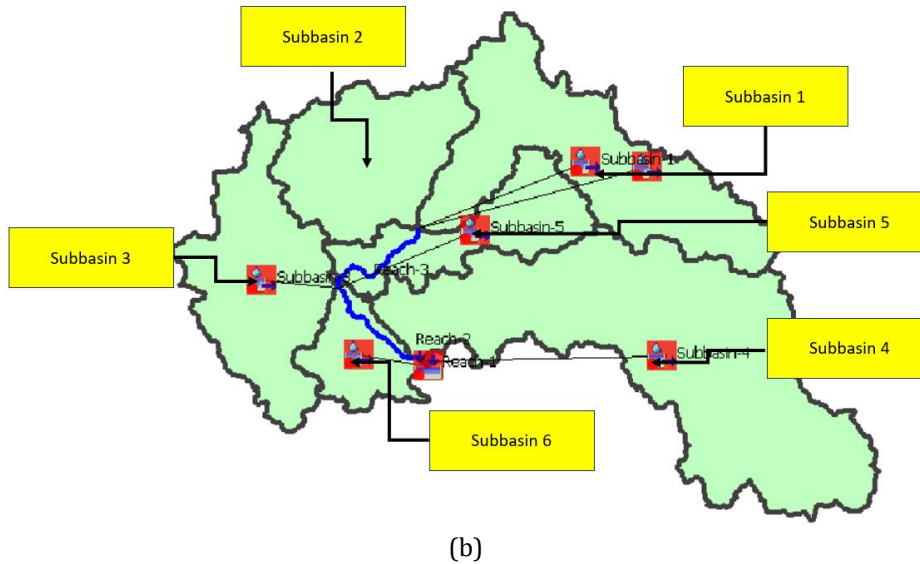


Fig. 1: Method of study using HEC-HMS (a) Flowchart of study (b) Bandar Segamat Sub-basins

2.1 HEC-HMS Model Development for Segamat Basin Model

A hydrological analysis was conducted to develop the model in HEC-HMS, utilizing key input data such as catchment characteristics, catchment area, river length, land use patterns in Bandar Segamat, and rainfall data for the year 2023. The primary parameters incorporated in the model included the loss method using the Soil Conservation Service Curve Number (SCS-CN), the transform method employing the SCS Unit Hydrograph (SCS-UH), and the baseflow method through the Recession approach. This comprehensive process involved determining flow directions and accumulation areas to delineate the boundaries of individual sub-basins.

2.2 Loss Method (SCS-CN)

The SCS-CN method is widely used because it is a practical and cost-effective way to estimate runoff based on land use, soil type, and hydrological conditions, making it suitable for many flood modeling scenarios, especially in regions like Segamat, which are subject to periodic rainfall and flooding (Satheeshkumar et al., 2017). The method required only land use, soil type, and precipitation data, which are generally more accessible than other detailed hydrological modeling methods. The CN value represents the potential runoff-producing characteristics of the watershed and is determined based on soil type, land cover, hydrological soil group, and antecedent moisture conditions (Rama et al., 2024). Table 1 shows the CN value of each subbasins including the percentage impervious used for this study.

Table 1: Curve number value for each subbasins in Bandar Segamat

| Basin Model | Curve Number | Impervious (%) |
|-------------|--------------|----------------|
| Subbasin 1 | 79.62 | 20 |
| Subbasin 2 | 73.01 | 50 |
| Subbasin 3 | 78.01 | 50 |
| Subbasin 4 | 87.88 | 50 |
| Subbasin 5 | 86.50 | 50 |
| Subbasin 6 | 80.16 | 50 |

To improve the CN value, Open Street Map (OSM) Land Use and Earth Engine Apps had been used to identify the specific land use and the area. OSM Land Use plays a crucial role to determine type of land use at Bandar Segamat by providing the area, land use type and also showing the waterbodies. Meanwhile, Earth Engine Apps was used to identify more specific land use and land cover to determine the exact CN number at Bandar Segamat such as the forest and agricultural area. It was because forests have a unique ability to absorb and retain water. Tree canopies intercept rainfall, while the forest floor, often covered with leaf litter, duff, and vegetation, helps increase water infiltration into the soil. This reduces surface runoff, especially during light to moderate rainfall events (Bergstrom & Vieux, 2002). This initiative uses satellite imagery and advanced data processing techniques to monitor and report on changes in forests, agriculture, urbanization, and other land cover types (Lin et al., 2024). Meanwhile agricultural lands typically exhibit a wide range of Curve Number (CN) values due to variations in land use, soil type, and management practices. For example, cropland, which may be plowed and have minimal vegetation cover, often corresponds to higher CN values, typically in the range of 74 to 85,

reflecting increased surface runoff due to reduced infiltration and higher compactness of the soil (Mishra & Singh, 2003).

2.3 Transform Method (SCS-UH)

The SCS and UH methods are used as transform methods to convert rainfall inputs into effective rainfall for hydrological modeling purposes. These methods play crucial roles in simulating the temporal and spatial distribution of rainfall-runoff processes within a watershed. The unit hydrograph is highly advantageous because it simplifies the complex process of hydrological transformation into a manageable and understandable tool. Additionally, it can be used in real-time flood forecasting and water resources management (Rama et al., 2024).

Time of concentration measurements show how long it takes for runoff to go from the watershed's farthest point to its outlet. Depending on the slope, drainage density, and flow pathways of the watershed, T_c values can vary from a few minutes to many hours. Equation 2 is utilized in the computation of Time of concentration (T_c). l is the flow length of the sub-basin. It was obtained right away from HEC-HMS in Subbasin Characteristic. The largest possible retention, S , can be obtained using equation 3. Then, using HEC-HMS, the average watershed land slope, or Y , can be computed as a percentage.

$$\text{Lag} = 0.6 T_c \quad (1)$$

$$T_c = 10.8(S+1)0.71140Y^{0.5} \quad (2)$$

$$S = 1000/CN - 10 \quad (3)$$

Table 2 shows result of the lag time for each subbasins in Bandar Segamat which represent the time for the water flow to the outlet. It was based on the subbasins characteristic that performed in the HEC-HMS which calculated using the Equation 1 and the calculated curve number in Table 1.

Table 2: Lag time for each subbasins in Bandar Segamat

| SCS Unit Hydrograph | | |
|---------------------|--------------------|----------------|
| Subbasin | Graph Type | Lag Time (Min) |
| Subbasin 1 | Standard (PRF 484) | 328.923 |
| Subbasin 2 | Standard (PRF 484) | 98.162 |
| Subbasin 3 | Standard (PRF 484) | 183.738 |
| Subbasin 4 | Standard (PRF 484) | 428.393 |
| Subbasin 5 | Standard (PRF 484) | 89.469 |
| Subbasin 6 | Standard (PRF 484) | 67.703 |

2.4 Baseflow Method (Recession)

The recession method is often used to simulate baseflow. The software utilizes baseflow separation techniques, including the recession method, to estimate baseflow contributions, which is important for simulating streamflow under both normal and flood conditions. Table 3 shows the parameters used for recession method and the input data.

Table 3: Range Used in Recession Method (U.S. Army Corps of Engineers, 2000)

| Parameter | Data |
|---|---------------------|
| Initial Type | Discharge |
| Initial Discharge (m^3/s) | 0.5 |
| Threshold Flow (m^3/s) | 50 |
| Recession Constant | 0.5 |
| Threshold Type | Threshold Discharge |

For this method, the focused parameters are initial discharge, recession constant, threshold type, and threshold flow. Focusing on these parameters allows for the calibration of the model's most sensitive and influential aspects, ensuring better performance and reliability. According to U.S. Army Corps of Engineers (2000), recession constant range for 0.5 is in the range of surface runoff which is 0.3-0.8.

Surface runoff has the lowest recession constant, ranging from 0.3 to 0.8 (U.S. Army Corps of Engineers, 2000). This indicates a rapid decline in flow rate as overland flow quickly dissipates after rainfall events. Surface runoff is heavily influenced by precipitation intensity, land use, and terrain. For example, urban areas with

impervious surfaces typically experience a faster surface runoff response compared to rural or vegetated areas. According to Beven (2012), surface runoff coefficients are influenced by soil type, land cover, and rainfall intensity. Urban areas with impervious surfaces such as concrete and asphalt prevent water from infiltrating, leading to high runoff coefficients typically above 0.7 and lower recession constants. Conversely, natural landscapes with permeable soils and vegetation have lower runoff coefficient which are around 0.1 to 0.3 and higher recession constants.

2.5 Model Calibration and Validation

The rainfall data used is from Department of Irrigation and Drainage, and Ladang Segamat was chosen as the station which the data taken in 2022 and 2023. The rainfall data in 2022 and 2023 was chosen is to compare the NSE for a better accuracy as shown in Table 4 as it has the highest rainfall at Bandar Segamat. Highest data rainfall was chosen as it is crucial for flood forecasting purpose.

Table 4: Time Interval for Calibration and Validation Process

| Process | Time Interval |
|-------------|---|
| Calibration | 29 March 2022 (00:00) – 11 April 2022 (00:00) |
| Validation | 11 January 2023 (00:00) – 24 January 2023 (00:00) |

3. Results and Discussion

The results of the simulated model in Bandar Segamat for the calibration and validation are shown in Table 5. The HEC-HMS model was calibrated using precipitation and discharged data from the Segamat River gauging station, provided by the Department of Irrigation and Drainage, for the period from 29 March 2022 to 11 April 2022. During calibration, the model achieved a coefficient of determination (R^2) of 0.75, indicating that 75% of the variance in observed discharge was explained by the simulated values. This performance suggests a strong correlation between observed and simulated discharge, reflecting the model's ability to replicate hydrological processes accurately. Furthermore, the Nash-Sutcliffe Efficiency (NSE) was 0.732, which is within the acceptable range for hydrological models, as values above 0.5 typically indicate good agreement between observed and simulated data (Rama et al., 2024). These results demonstrate that the calibration process effectively optimized the model parameters to represent the hydrological behavior of the study area which it was in the range of 0.65 – 0.75 that indicates good performance rating.

For validation, the model was tested using precipitation and discharge data from 11 January 2023 to 24 January 2023. Validation results showed an R^2 value of 0.80, indicating that 80% of the variance in observed discharge was explained by the model during this period. This improvement over the calibration phase highlights the robustness of the calibrated parameters when applied to independent data. The NSE value during validation was 0.645, slightly lower than during calibration but still indicating a good level of agreement between observed and simulated discharge.

Despite the satisfactory performance, there are limitations in the study that could be addressed to enhance the model's predictive capability. The relatively short durations of the calibration (13 days) and validation (14 days) periods may limit the generalizability of the results across different hydrological conditions. Extending these periods to include both wet and dry seasons could provide a more comprehensive assessment of the model's reliability.

Table 5: Result for Calibration and Validation for Current Study

| Result | Calibration | Validation |
|--------|-------------|------------|
| R^2 | 0.75 | 0.80 |
| NSE | 0.732 | 0.645 |

The HEC-HMS model was calibrated using the precipitation and discharge data from the Department of Irrigation and Drainage for Segamat River gauging station started from 29 March 2022 to 11 April 2022. For validation process, the precipitation and drainage data were used to validate the HEC-HMS model based on the optimized model parameters which had been adjusted in calibration process. The data used was from 11 January 2023 to 24 January 2023. This timeframe allows the adjustment of model parameters to replicate observed discharge.

The result was compared to the previous study that has been conducted by Muhammad Hamizan Bin Zaidi (2024), student from Faculty of Engineering Technology at Universiti Tun Hussein Onn Malaysia. Table 6 and Table 7 presents the comparison of the CN value and lag time data and the results of each data. This comparison was based on the same date as the calibration and validation as shown in Table 4. It is because, the precipitation and discharge data also affect the result on R^2 and the NSE.

Table 6: Data Comparison Between Previous Study and Current Study

| Subbasin | Previous Study | | Current Study | |
|------------|----------------|----------------|---------------|----------------|
| | CN Value | Lag Time (min) | CN Value | Lag Time (min) |
| Subbasin 1 | 71.33 | 157.99 | 61.34 | 328.92 |
| Subbasin 2 | 78.04 | 77.24 | 82.48 | 98.16 |
| Subbasin 3 | 78.33 | 99.63 | 80.92 | 183.73 |
| Subbasin 4 | 73.80 | 116.00 | 61.66 | 428.39 |
| Subbasin 5 | 76.74 | 203.71 | 81.29 | 89.46 |
| Subbasin 6 | 75.98 | 76.58 | 82.65 | 67.70 |

Table 7: Result Comparison Between Previous and Current Study

| | Previous Study | | Current Study | |
|----------------|----------------|------------|---------------|------------|
| | Calibration | Validation | Calibration | Validation |
| R ² | 0.75 | 0.79 | 0.75 | 0.80 |
| NSE | 0.725 | 0.651 | 0.732 | 0.645 |

The R² values for both calibration and validation are quite similar for both datasets, with 0.75 for calibration and 0.79 for validation in Data 1, and 0.75 for calibration and 0.80 for validation in Data 2. These values indicate that both datasets have a strong correlation between observed and simulated data, suggesting that the model performs reliably in both scenarios. When examining the Nash-Sutcliffe Efficiency (NSE) values, Data 2 slightly outperforms Data 1 during calibration with an NSE of 0.732 compared to 0.725. However, during validation, Data 1 has a slightly higher NSE of 0.651, compared to 0.645 in Data 2. The percent difference for this study is 2.73% for NSE value. This indicates that the model's performance in simulating observed streamflow remains consistent, with both studies achieving comparable accuracy. A minimal difference in NSE also suggests that the changes introduced in the current study, such as modifications in parameters like the curve number or lag time, do not significantly impact the model's overall ability to replicate real-world hydrological processes.

In conclusion, the current study suggests increased runoff potential due to higher curve number and longer lag times, which could result in different accuracy and qualification for each of the parameters. In contrast, the previous study demonstrates lower curve number values and shorter lag times, indicating faster hydrological responses. Despite these differences, both datasets show strong model performance, as reflected by high R² and NSE values, ensuring the reliability of the model calibration and validation process. These findings highlight the importance of refining and adjusting parameters, such as CN values and lag times, to improve the accuracy of hydrological modelling and enhance the representation of watershed behaviour.

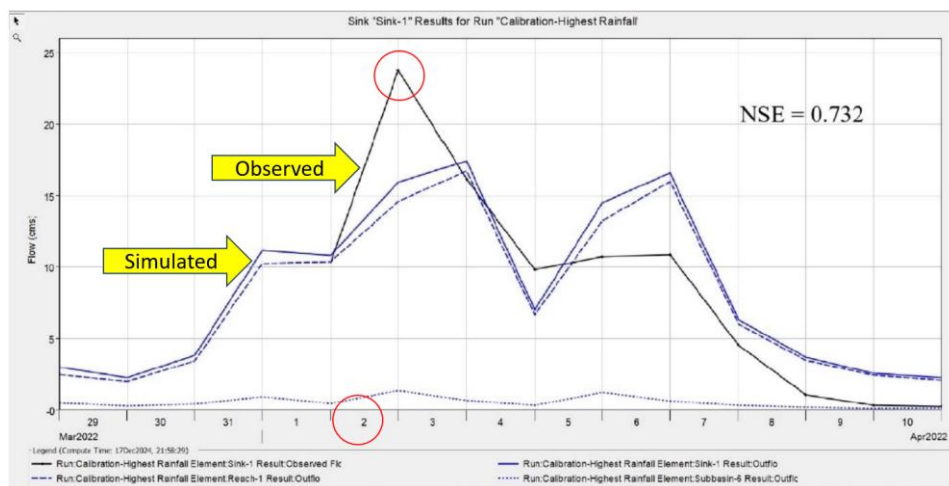


Fig. 2: Flow Hydrograph

The model demonstrates a reasonable level of accuracy in simulating the observed flow trends during the calibration process. While the general timing and recession of flow peaks are well captured, the slight underestimation of peak flow magnitudes, particularly around 2 April 2022, suggests that further refinement of model parameters may be required. Adjustments to Curve Numbers (CN), lag time, or rainfall-runoff

transformation processes could help improve the model's performance and better align the simulated results with observed data. Overall, the calibration results indicate that the model performs well in representing the hydrological behaviour of the watershed.

Additionally, lag time is an important factor in flood events, as it represents the time it takes for runoff to travel from the rainfall point to the outlet. Shorter lag times indicate faster runoff, which can lead to more rapid and potentially severe flooding.

4. Conclusion

This study reflects a more gradual hydrological response, with longer lag times and improved CN values and specific baseflow rate. These characteristics are indicative of reduced infiltration and increased runoff due to impervious surfaces or compacted soils. Current study capturing delayed flow processes where runoff builds up more gradually over time. This makes it particularly useful for areas where slower hydrological responses dominate. Furthermore, its baseflow settings are optimized for conditions involving interflow and surface runoff, with recession constants ranging from 0.8 to 0.9 for interflow and 0.3 to 0.8 for surface runoff. These parameters ensure accuracy in simulating intermediate and rapid flow contributions.

This study suggested that adjustments to curve number, lag time, or rainfall-runoff transformation processes need to be enhanced which could help improve the model's performance and better align the simulated results with observed data. For the result, one of the recommendations is to improve the drainage system to ensure the water flow is smooth and prevent flooding at the basin that has longer lag time.

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