



# The Effectiveness of Groynes (Flow-Guiding Structures) as An Erosion Control Measure in The Cibeet River, Cipayung, Bekasi Regency

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**Abstract.** Erosion along the Cibeet River, particularly in the Cipayung area of Bekasi Regency, has caused severe riverbank degradation and poses risks to surrounding land use. To address this problem, groynes—structures intended to reduce flow velocity and deflect currents away from vulnerable banks—were assessed for their effectiveness. The study combined field surveys, hydrological modeling with HEC-HMS to estimate design flood discharge, and two-dimensional hydraulic simulations using HEC-RAS. A design discharge corresponding to a 50-year return period (1493.6 m<sup>3</sup>/s) was applied as the primary input. The results indicate that existing groynes provide limited effectiveness, reducing flow velocity by only 3% at the critical cross-section. In contrast, the proposed groyne configuration, designed according to SNI 2400.1:2016, achieved substantial improvements, with velocity reductions of 29% at cross-section CC and 20% and 19% at cross-sections BB and AA, respectively. Overall, the findings demonstrate that technically optimized groyne layouts can significantly enhance flow regulation, mitigate erosion, and contribute to more sustainable river management.

**Keywords:** Groynes, Flow Control, Cibeet River, HEC-RAS, HEC-HMS.

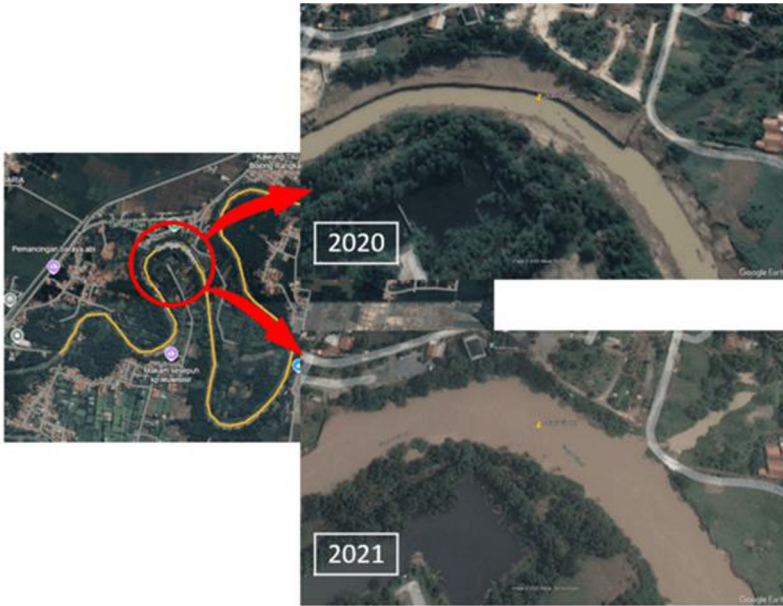
## 1 Introduction

Rivers play a vital role as natural flow systems that distribute water from upstream to downstream, while also supporting various ecological, social, and economic functions [1]. However, the dynamic nature of river flow often leads to changes in channel shape and flow direction, particularly in meandering sections, which are highly susceptible to bank erosion [2].

Scouring is one of the dominant impacts observed in curved river segments, especially on the outer bends, as a result of centrifugal forces and concentrated flow velocity [3]. If left uncontrolled, scour can damage river protection structures, reduce cross-sectional capacity, and pose threats to nearby settlements and infrastructure [4].

The Cibeet River, located in Cipayung District, Bekasi Regency, is a tributary of the Citarum River and exhibits meandering characteristics [5]. In several outer bend areas, severe bank erosion has occurred. Although protective structures such as concrete sheet

pile walls have been constructed, scour continues to occur in the downstream section over a stretch of approximately 200 meters [6] (see Fig. 1).



**Fig. 1.** Comparison of the research location in 2020 and 2021.

One of the physical countermeasures commonly applied to control riverbank erosion is the use of groynes [7], which are structures constructed perpendicular or oblique to the flow direction to deflect currents away from the bank and reduce local velocity near the river wall [8]. According to SNI 2400.1:2016 (BSN, 2016), groynes serve multiple purposes, including directing flow away from the riverbank, decreasing velocity at critical scour points, promoting sediment deposition, and maintaining the stability of the river cross-section [9].

Groynes offer distinct hydraulic effects and can be classified according to their orientation, such as curved, oblique, or perpendicular [9]. Depending on material composition and flow transmission capacity, structures may also be categorized as permeable or impermeable [10]. The effectiveness of groyne structures will vary depending on the river characteristics, such as flow velocity, bend radius, and bank condition. The systematic evaluation of the impacts on flow velocity, current direction, and potential scour is performed using HEC-HMS (estimation of discharge) and HEC-RAS 2D (hydraulic analysis) [8, 2].

The effectiveness of groynes can be evaluated through numerical modeling that integrates hydrologic and hydraulic simulations [11]. Tools such as HEC-HMS (for discharge estimation) and HEC-RAS 2D (for hydraulic analysis) allow for systematic assessment of their impact on flow velocity, current direction, and potential for scour [12]. This study aims to evaluate the effectiveness of the existing groyne structures

constructed along the Cibeeet River as a countermeasure against riverbank scour, using numerical modeling based on field data and existing site conditions [9].

## 2 Method

The study used numerical modeling through computer simulations to assess how groynes affect river flow speed and protect riverbanks from erosion in the Cibeeet River. The research method included two main phases which started with hydrological modeling to find the design flood discharge followed by hydraulic modeling to study flow velocity and direction patterns under various groyne configurations. This design was constructed to directly address the research objectives, namely comparing conditions without groynes, with existing groynes, and with proposed groynes. The overall research framework is illustrated in Fig 2.

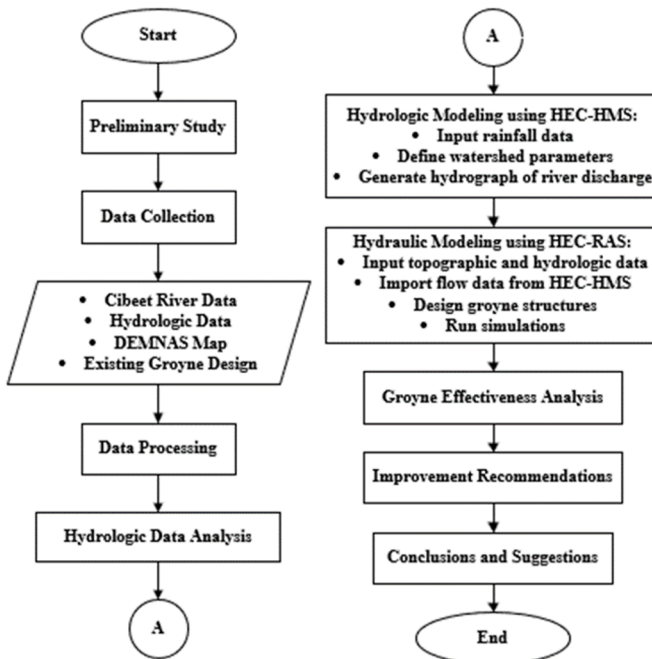


Fig. 2. Research Flowchart.

The study began with the collection of relevant data from the selected research area, located along the Cibeeet River in Cipayung District, Bekasi Regency, West Java. This reach of the river is characterized by meandering patterns and frequent erosion at the outer bends, making it an appropriate case for testing the effectiveness of structural interventions. The data were grouped into three main categories to support each stage of the modelling process:

- Hydrological Data: Annual maximum rainfall records were obtained from rain gauge stations managed by BBWS Citarum. These data were essential for rainfall frequency analysis and flood discharge estimation, which later served as the main input for the hydraulic modelling.
- Topographic and River Geometry Data: Digital elevation data were obtained from DEMNAS (National Digital Elevation Model) and combined with field surveys conducted by BBWS Citarum. These datasets were crucial for accurately constructing the physical representation of the watershed and river channel.
- Groynes Structure Data: Field surveys provided detailed information on the dimensions, orientation, and spacing of existing groynes. These data supported the reconstruction of current groyne layouts as well as the design of alternative proposed configurations.



**Fig. 3.** Cibeet river research location, cipayung, bekasi regency.

Following the data collection stage, hydrological modelling was conducted using HEC-HMS to estimate design flood discharge. This process involved not only rainfall frequency analysis but also the transformation of effective rainfall into discharge using three synthetic unit hydrograph methods: Snyder, SCS, and Nakayasu. The simulated hydrographs were then validated against observed discharge data to ensure reliability and accuracy of the design values used in subsequent hydraulic modelling.

The validated discharge results were subsequently applied as boundary inputs for hydraulic modelling using HEC-RAS 2D. The two-dimensional model was selected due to its ability to realistically visualize flow distribution and direction, especially in meandering bends where erosion typically intensifies. For this purpose, three simulation scenarios were specifically designed to reflect the research objectives, as illustrated in Fig. 3:

- (i). Scenario 1 (Without Groynes): Representing the baseline condition of the river prior to structural intervention.

- (ii). Scenario 2 (Existing Groynes): Replicating the configuration currently installed in the field, providing a measure of the actual effectiveness of the existing design.
- (iii). Scenario 3 (Proposed Groynes): Representing a redesigned configuration based on river engineering principles, aimed at assessing potential improvements in groyne performance.

The hydraulic model was constructed using DEMNAS and field survey data, with boundary conditions set according to validated discharge values. The researchers adjusted Manning's roughness coefficient ( $n$ ) according to the observed channel and bank features. The model simulated unsteady flow to reproduce the time-dependent behaviour of velocity and flow direction during flood events. The analysis produced velocity distribution maps and flow direction vectors which researchers compared between the three different scenarios. The obtained results enabled researchers to determine how groyne structures affect water flow patterns and their ability to protect against erosion.

### 3 Results and Discussion

#### 3.1 Watershed Characteristics

The Cibeeb Watershed is located in Cipayang Subdistrict, Bekasi Regency, and forms part of the Citarum sub-watershed. It has an elongated shape with complex morphological characteristics, including sharply meandering segments that are highly susceptible to erosion, particularly along the outer bends (see Fig. 4).



**Fig. 4.** Cibeeb watershed area indicated by light blue shading.

The Cibeeb Watershed spans 896.71 square kilometers where residential areas and open spaces and agricultural lands make up the majority of land use. The high Curve Number value emerges from the mixture of impervious surfaces and low-infiltration soils which produce excessive surface runoff during heavy rainfall events. The CN

value of 85.22 shows that the area will experience significant surface runoff during heavy rainfall because of its high runoff potential. Based on the obtained CN, the maximum potential retention ( $S$ ) is calculated to be 44.05 mm, with an initial abstraction ( $I_a$ ) of 8.88 mm, representing the volume of water retained before runoff begins. The calculated Imperviousness Percentage (IMP) shows that approximately 7.16% of the total watershed area consists of impervious surfaces. This value affects the amount of rainfall that directly becomes surface runoff without infiltration. All of these parameters are used as inputs in the HEC-HMS model to estimate the design discharge using a synthetic unit hydrograph (HSS) approach.

### 3.2 Rainfall Analysis and Hydrological Modeling Using HEC-HMS

Annual maximum rainfall data from the nearest station were analyzed using Normal, Log-Normal, Gumbel, and Log-Pearson Type III distributions. Distribution testing results indicate that the Gumbel distribution is the most suitable based on the mean and standard deviation values. The Mononobe method was applied to convert daily rainfall into hourly data.

Hydrological modeling was carried out using the HEC-HMS software, employing the Curve Number (CN) method to calculate total surface runoff, and the Synthetic Unit Hydrograph (HSS) methods—SCS, Snyder, and Nakayasu—for rainfall-to-runoff transformation (see Fig. 5).

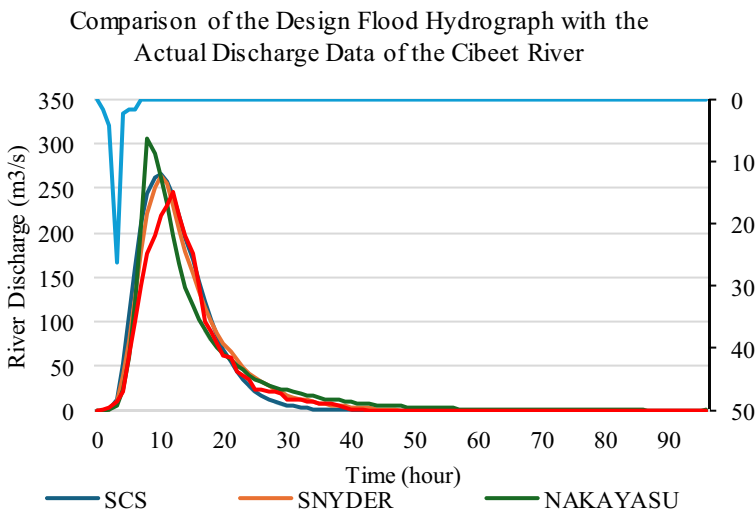


Fig. 5. Modeled flood hydrograph compared with actual discharge of cibebet river.

The simulation results graph indicates that all three methods produce similar hydrograph patterns. However, the Snyder method was selected as it yields discharge values closest to the actual data and is considered the most representative in describing the river's response to daily rainfall events. Therefore, it provides more relevant results for flood planning purposes.

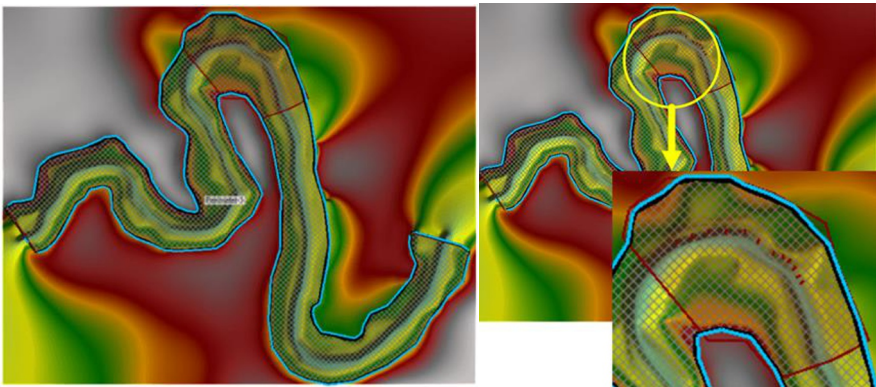
In this study, a design rainfall with a 50-year return period was used to estimate the design flood discharge for hydrological analysis and the planning of the groyne structure. By inputting the rainfall data and the calculated hydrological parameters, the simulation using the Snyder method produced a peak discharge of 1,493.6 m<sup>3</sup>/s.

### 3.3 Hydraulic Modeling and Simulation Using HEC-RAS 2D

Hydraulic modeling was carried out using HEC-RAS 2D software to evaluate river flow behavior under two primary conditions: before and after groyne installation. Simulations were conducted under three different scenarios: without groynes, with existing groynes, and with proposed groynes, considering variations in spacing between the structures.

The model was developed using contour data from DEMNAS, land use maps, and technical data of the groyne structures obtained from field surveys. The simulation was conducted under unsteady flow conditions to dynamically represent changes in discharge and flow velocity during flood events.

It is important to note that in the proposed groyne scenario, the modifications were limited to adjusting the spacing between groynes based on technical design principles. No changes were made to the shape or type of groyne, as the existing structures in the field remain structurally sound and fit for use (see Fig. 6).

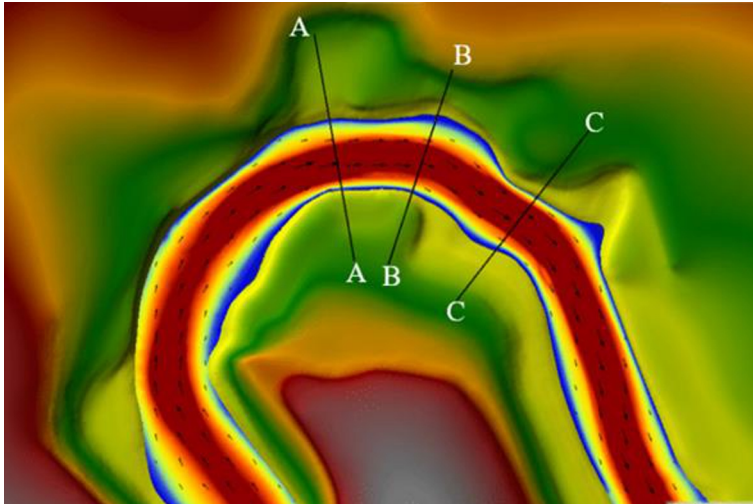


**Fig. 6.** Geometric display and refinement region definition of river model in HEC-RAS 2D.

The geometric model was constructed based on contour data from DEMNAS, land use data, and river cross-section measurements obtained from field surveys. This geometry served as the primary basis in the HEC-RAS 2D modeling to analyze flow behavior under various groyne configurations.

The area displayed represents a critical river segment, specifically the outer bend section with a history of severe erosion. The area delineated by the red line indicates the refinement region, which features a denser grid applied to enhance spatial resolution, thereby producing more detailed and representative hydraulic simulation results.

Scenario 1 – Without Groyne, This scenario simulates river flow conditions in the absence of any guiding structures (groynes). The objective is to obtain a baseline depiction of the velocity distribution pattern and flow direction under natural conditions, which is then used as a reference for comparison with intervention scenarios (see Fig. 7).



**Fig. 7.** Flow direction simulation result after installation of existing groynes and cross section for analytical review.

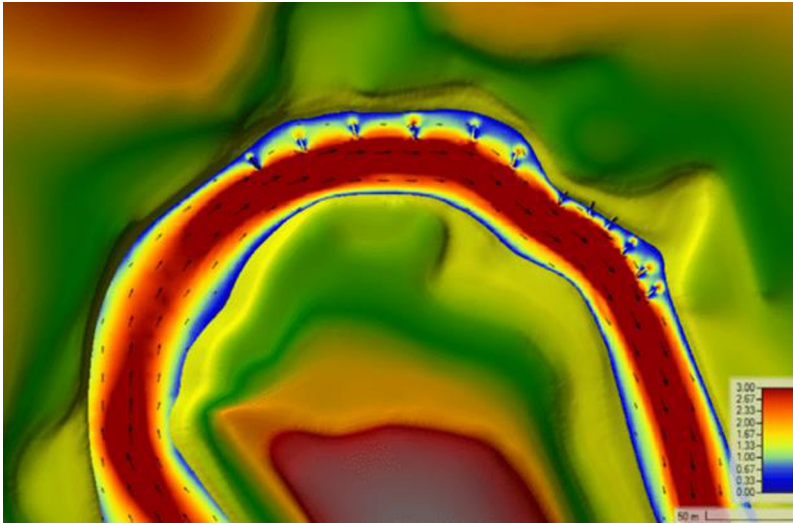
The simulation results indicate that the current flows strongly toward the outer bend, with high flow velocity concentrated in that area. Based on the calculations, the resulting flow velocity is sufficiently high to generate significant shear forces on the riverbank, thereby triggering instability and increasing the potential for bank failure (see Table 1).

**Table 1.** Recapitulation of flow velocities under no-groyne condition at critical river points.

Cross Section	Average River Flow Velocity Without Groynes (m/sec)	Average Flow Velocity with Existing Groynes (m/sec)	Description
AA	1.563	6.227	Potential Erosion
BB	1.486	4.971	Potential Erosion
CC	2.071	6.571	Active Scour Area

Based on previous hydraulic studies [15, 16], flow velocities exceeding 2.0 m/s in non-cohesive riverbed materials are sufficient to initiate scouring. In this scenario, the resulting flow velocity surpasses that threshold, indicating that the hydraulic conditions are capable of causing riverbed erosion and progressive lateral instability.





**Fig. 9.** Flow Direction Simulation Result After Installation of Existing Groynes.

**Table 3.** Comparison of average flow velocities between no-groyne and existing groyne conditions.

Cross Section	A	B	Difference A-B (m/det)
	Average River Flow Velocity Without Groynes Groynes (m/sec)	Average Flow Velocity with Ex- isting Groynes (m/sec)	
AA	1.563	1.559	0.004
BB	1.486	1.489	-0.003
CC	2.071	2.001	0.069

The simulation results demonstrate that the flow velocity at point CC decreased by 0.069 m/s which indicates a decrease in scouring force. The current groyne design fails to distribute water flow evenly throughout the bend segment because the velocity at point BB shows a minimal increase of 0.003 m/s.

Scenario 3 – Proposed Groyne, the third simulation used a modified groyne design which followed technical calculations to enhance flow management capabilities. The groynes maintained their original dimensions and shape but the researchers adjusted their number and placement to match technical standards found in literature. The researchers determined groyne spacing through the following method:

$$D = 1.8 \times L$$

$$D = 1.8 \times 8$$

$$D = 14.4 \quad \approx 14.5m$$

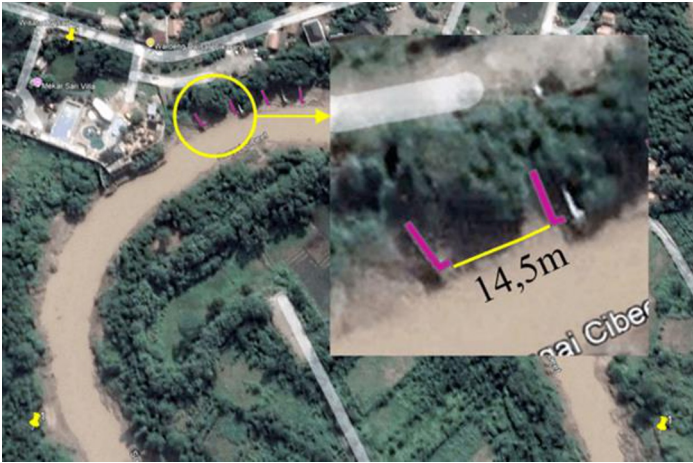
With a groyne length (L) of 8 meters, the optimal spacing between groynes (D) was determined to be 14.4 meters (rounded to 14.5 m). Given the total bend length of 200 meters, the number of proposed groynes was calculated using the following:

$$\begin{aligned} \text{Number of Groynes} &= \frac{\text{length of river with groynes}}{D} \\ \text{Number of Groynes} &= \frac{200m}{14.5m} \\ \text{Number of Groynes} &= 14 \text{ units} \end{aligned}$$

The proposed groyne design appears in Fig. 10 and Fig. 11 which shows 14 evenly spaced groynes at 14.5-meter intervals that follow the Cibeeet River's outer bend curve. The design modification works to create better flow direction and minimize high velocities in dangerous sections.

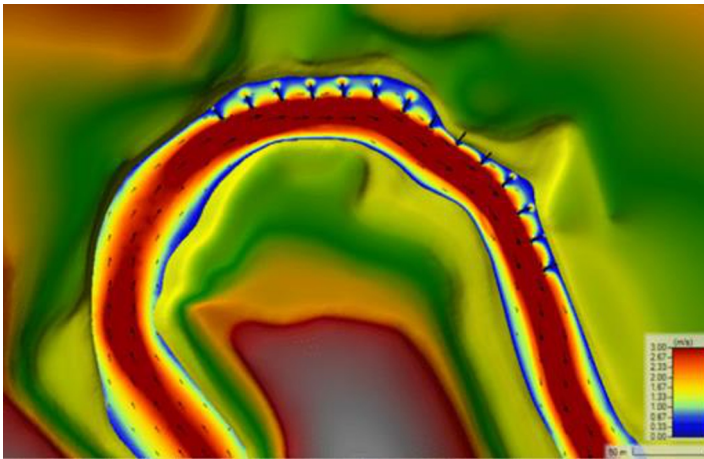


**Fig. 10.** Proposed placement of 14 groynes at the bend of the cibeeet river, marked in pink.



**Fig. 11.** Application of 14.5 m interval between proposed groynes.

The simulation results of the proposed groyne scenario show a more uniform distribution of flow velocity along the river bend. Groynes installed at regular intervals are able to push the flow toward the center of the river cross-section and reduce velocity intensity on the outerbank (see Fig. 12 and Table 4).



**Fig. 12.** Flow direction simulation result after installation of proposed groynes.

**Table 4.** Comparison of average flow velocities between no-groyne and existing groyne conditions.

Cross Section	A	C	Difference A-C (m/det)
	Average River Flow Velocity Without Groynes (m/det)	Average River Flow Velocity with Proposed Groynes (m/det)	
AA	1.563	1.257	<b>0.306</b>
BB	1.486	1.210	<b>0.276</b>
CC	2.071	1.476	<b>0.595</b>

The greatest velocity reduction occurred at cross-section CC, with a decrease of 0.595 m/s. This indicates that the proposed groyne distribution is not only effective in reducing flow velocity but also capable of minimizing erosive forces at critical points. In general, all observation points show a consistent decrease in velocity, indicating that the proposed configuration is more optimal compared to the existing condition.

### 3.4 Groyne Effectiveness Evaluation

The effectiveness evaluation was carried out by comparing the flow velocities across three scenarios at critical cross-sections. The comparison results are presented in Table 5.

**Table 5.** Relative effectiveness of flow velocities based on three modeling scenarios.

Cross Section	Effectiveness of Existing Groyne (%)	Effectiveness of Proposed Groyne (%)
AA	0%	20%
BB	0%	19%
CC	3%	29%

Simulation results show that groynes have an influence in reducing flow velocity, particularly in the outer bend areas of the river. The existing groynes demonstrate limited effectiveness, with velocity reduction occurring at only one point (maximum of 3%). In contrast, the proposed groynes show a more significant reduction in velocity, especially at cross section CC, with an effectiveness of up to 29%.

The proposed groyne system includes 8-meter long arms which are spaced 14.5 meters apart or 1.8 times the groyne length. The SNI 2400-1:2016 technical recommendations for groyne spacing are met by this arrangement [9]. The proposed groynes effectively redirect water flow from the outer bank while creating low-energy areas that allow sediment to settle according to the flow velocity distribution and direction.

The current groynes have proven successful at redirecting river flow from the outer bend according to field observations. The proposed configuration outperforms the existing setup by providing superior support for river channel stability.

## 4 Conclusion

The research shows that hydrological and hydraulic modeling helps determine how groyne structures affect erosion control in the Cibeet River. The Snyder method produced the most accurate results for actual discharge conditions among the three Synthetic Unit Hydrograph approaches (SCS, Snyder and Nakayasu) used in the HEC-HMS Curve Number hydrological analysis. The HEC-RAS 2D hydraulic model showed that river bend velocities reached 2.89 m/s when groynes were absent which would lead to severe erosion. The existing groynes reduced water velocity but their performance remained inconsistent throughout the cross-section with the maximum reduction at 0.069 m/s or 3%. The proposed design achieved better results through technical optimization and 14.5-meter spacing which produced velocity reductions of 0.595 m/s or 29% in essential areas. The research demonstrates that properly designed groyne structures with suitable dimensions and spacing patterns can function as effective references for building flow-control structures in rivers with matching characteristics to reduce erosion effectively.

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