Engineering and Technology Journal e-ISSN: 2456-3358

Volume 11 Issue 06 June-2026, Page No.- 10360-10369

DOI: 10.47191/etj/v11i06.11, I.F. – 8.595

Flood Susceptibility and Conceptual Drainage Simulation of Barangay Calaba, San Isidro, Nueva Ecija Using HEC-RAS 2D

Christian Joseph O. David[1], Kenneth P. Bauto[2], Mia Czarina C. Padis[3], Mark Ahron Mendoza[4], Jhon Dee B. Batas[5], Stephen Kenji Tandoc[6], Rosel V. Babalcon[7]

[1,2,3,4,5,6,7] Nueva Ecija University of Science and Technology, Sumacab Este, Cabanatuan, Nueva Ecija

ABSTRACT: Flooding is one of the most common natural hazards in the Philippines, especially in low-lying areas where heavy rainfall, flat terrain, and poor drainage cause water accumulation. Barangay Calaba in San Isidro, Nueva Ecija frequently experiences flooding during intense rainfall, yet localized assessments of flood-prone areas remain limited. This study aims to assess rainfall-induced flooding in Barangay Calaba using two-dimensional hydrodynamic simulation and to examine the possible effects of a conceptual drainage system on flood conditions. A quantitative case study approach was applied using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) 2D. Terrain data from the ALOS PALSAR Digital Elevation Model (12.5 m resolution) and rainfall data from PAGASA's Rainfall Intensity Duration Frequency analysis were used to simulate flooding under two scenarios: existing conditions without drainage and conditions with a conceptual drainage system. Simulation outputs were analyzed to identify flood-prone areas and estimate flood depth and inundation extent, while results were compared with the available Project NOAH flood dataset for validation. The study provides insights into localized flood behavior and the possible influence of drainage improvements on flood conditions and supporting local flood mitigation planning

KEYWORDS: Rainfall-Induced Flooding, Two-Dimensional Hydrodynamic Simulation, HEC-RAS 2D, Conceptual Drainage System, Flood Risk Assessment, Barangay Calaba, San Isidro, Nueva Ecija

I. INTRODUCTION

A. Background of the Study

Flooding is a frequent and destructive hazard in the Philippines due to heavy rainfall, low-lying terrain, rapid urbanization, and inadequate drainage systems. Climate change is expected to worsen rainfall extremes, increasing flood risks in regions such as Central Luzon (Acierto et al., 2026). In Nueva Ecija, particularly within the Pampanga River Basin, recurring floods are driven by monsoon rains and typhoons, affecting municipalities like San Isidro (Nagumo & Sawano, 2016; Datu, 2021). Barangay Calaba has also been impacted, prompting government flood control projects such as slope protection along the Pampanga River (Iñigo, 2025), highlighting its vulnerability to flooding.

Hydrodynamic models like HEC-RAS, combined with digital elevation data from sources such as ALOS PALSAR DEM, enable simulation of flood depth, extent, and flow across terrain. However, localized flood studies in smaller communities remain limited. This study aims to assess flood susceptibility in Barangay Calaba to identify high-risk areas and support effective drainage planning and flood mitigation efforts.

B. Statement of the Problem

Flooding commonly occurs when intense rainfall generates surface runoff that exceeds the capacity of natural or artificial drainage systems (Jha et al., 2012). In the Philippines, low-lying and poorly drained areas are particularly vulnerable to rainfall-induced flooding (PAGASA, n.d.). Barangay Calaba in San Isidro, Nueva Ecija experiences localized flooding during heavy rainfall; however, no site-specific assessment currently identifies the area's most susceptible to flooding within the barangay. This limits flood mitigation planning and drainage improvement efforts.

Hydraulic modelling tools such as HEC-RAS can simulate rainfall-induced flooding and estimate flood depth and inundation extent under different terrain conditions (Brunner, 2016). While drainage systems are commonly used to reduce surface runoff accumulation, their potential effect on flooding conditions in Barangay Calaba has not yet been evaluated through localized flood modeling. In addition, comparison with existing flood datasets is necessary to assess general agreement between simulated and available flood-prone areas (Apel et al., 2009).

To address these gaps, this study uses HEC-RAS 2D simulation to assess rainfall-induced flooding in Barangay Calaba, evaluate the influence of a conceptual drainage system, and compare the modeled flood-prone areas with the available Project NOAH flood dataset for validation. Specifically, this study seeks to answer the following questions:

1. Which areas in Barangay Calaba, San Isidro, Nueva Ecija are susceptible to flooding during heavy rainfall based on HEC-RAS 2D rainfall simulation?
2. How does the introduction of a simulated drainage system influence flood depth and inundation extent in the identified flood-prone areas of Barangay Calaba?
3. How do the modeled flood-prone areas compare with the available Project NOAH flood dataset?

C. Significance of the Study

This study assesses flooding behavior in Barangay Calaba using rainfall simulation and digital topographic data. The findings may support flood mitigation and drainage planning in the community. The results may benefit the following:

Local Government Unit (LGU) and Barangay Officials. The study may help identify flood-prone areas for flood mitigation and drainage planning.

Residents of the Barangay. The study may increase flood awareness and preparedness.

Civil Engineers and Urban Planners. The findings may provide insights into flood simulation and drainage assessment.

Future Researchers. The study may serve as a reference for future flood-related studies.

D. Scope and Limitations

This study evaluates flood susceptibility in Barangay Calaba, San Isidro, Nueva Ecija using a two-dimensional HEC-RAS flood simulation. It models rainfall-induced flooding to identify flood-prone areas by estimating flood depth and inundation extent during heavy rainfall events. Terrain data will be sourced from the ALOS PALSAR DEM (12.5 m), while rainfall inputs will be based on PAGASA Rainfall Intensity–Duration–Frequency (IDF) data from the Cabanatuan station. A simplified conceptual drainage system will also be included to assess its potential effect on reducing flood depth and extent. Model outputs will be validated by comparison with historical flood data from the Project NOAH dataset.

The study is limited to rainfall-induced surface flooding and excludes river overflow, dam discharge, and groundwater rise. Accuracy is constrained by the resolution of the DEM, rainfall data quality, and hydraulic assumptions in HEC-RAS, which may not capture fine-scale terrain and drainage features. The drainage system is conceptual and simulation-based only, not a detailed engineering design. Validation using Project NOAH data is limited by the accuracy and resolution of secondary datasets, and the model is not calibrated with field-measured flood depth or discharge data due to data unavailability.

E. Conceptual Framework

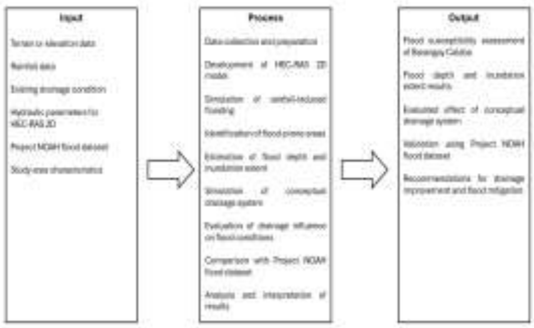

Figure 1.1 Conceptual Framework of the Study.

This study shows the relationship between the data used, the analytical procedures applied, and the resulting flood assessment outcomes through an Input–Process–Output framework. The inputs consist of terrain or elevation data, rainfall information, existing drainage conditions, hydraulic parameters for HEC-RAS 2D modeling, and the Project NOAH flood dataset in Barangay Calaba, San Isidro, Nueva Ecija. These inputs are processed through data preparation, HEC-RAS 2D hydrodynamic simulation of rainfall-induced flooding, identification of flood-prone areas, estimation of flood depth and inundation extent, and simulation of a conceptual drainage system to evaluate its potential influence on flooding conditions. The outputs of the study include the identification of flood-susceptible areas, analysis of flood depth and inundation extent, evaluation of the potential influence of the conceptual drainage system on simulated flooding conditions, and comparison of the simulation results with the Project NOAH dataset to support flood mitigation planning in the barangay.

II. REVIEW OF RELATED LITERATURE

A. Flooding and Rainfall-Induced Flooding

Flooding is widely recognized as a frequent natural hazard caused by rainfall that exceeds drainage capacity, but recent studies show it results from the interaction of rainfall, terrain, land cover, and drainage efficiency (Teng et al., 2017; Cea & Costabile, 2022). These factors influence runoff generation, flow movement, and surface accumulation.

Although rainfall intensity and duration are key drivers, flood extent depends heavily on local conditions. Urban studies show that impervious surfaces increase runoff, while inadequate drainage systems slow water conveyance and cause surface pooling (Agonafir et al., 2023). Global assessments also indicate that flood exposure is rising due to both climate change and land-use alterations that disrupt natural hydrologic processes (Tellman et al., 2021).

In the Philippines, flooding is strongly linked to monsoon rains and tropical cyclones, but local terrain and drainage conditions shape its severity. PAGASA explains that flooding occurs when rainfall exceeds drainage capacity (PAGASA, n.d.). This aligns with Cabrera and Lee (2020), who observed rainfall-driven flooding in Davao Oriental, and Abon et al. (2011), who found that basin characteristics significantly influence flood extent.

At smaller scales, studies emphasize localized flooding in urban and peri-urban areas. Dulawan et al. (2024) found that flood vulnerability in Metro Manila depends not only on exposure but also on infrastructure and drainage capacity, showing that impacts vary even under the same rainfall event. Flooding also has multi-dimensional impacts, including infrastructure damage, transport disruption, livelihood loss, and increased long-term vulnerability, especially in low-capacity communities (Tellman et al., 2021). Overall, literature shows that flooding is a multi-factor system rather than a single-cause event, supporting the need for localized, site-specific flood assessment.

B. Land Use and Surface Characteristics in Flooding

Land use patterns strongly affect rainfall response by controlling runoff and flood susceptibility (Vu et al., 2023). Built-up, agricultural, and bare areas reduce infiltration and increase runoff, leading to faster flow and higher flood peaks, while forested and vegetated areas slow runoff and reduce inundation (Khodaei et al., 2025; Santillan et al., 2019). Thus, land use change significantly alters flood risk over time (Pangilinan, 2014).

Urban and built-up areas consistently show higher flood extent and risk in hydrodynamic models (Farooq et al., 2019; Rangari et al., 2019), including HEC-RAS studies where they flood more than forested zones under similar conditions (Santillan et al., 2019). Agricultural lowlands, especially rice fields, can also increase flood susceptibility due to flat, poorly drained terrain and floodplain location (Santillan et al., 2019). In Philippine basins, conversion of natural land to agriculture or settlements has been linked to increased flooding, though mixed vegetation still offers some mitigation (Boongaling et al., 2017).

Overall, studies highlight that combining land use data with hydrodynamic modeling improves flood risk assessment and planning (Calapini et al., 2025). Preserving vegetation and limiting floodplain development can reduce flood impacts, supporting more resilient barangay-scale planning (Santillan et al., 2019).

C. Terrain and Elevation in Flooding (DEM)

Terrain characteristics strongly influence flood behavior, as elevation and slope control runoff direction and water accumulation, with low-lying and gentle slopes more prone to flooding (Teng et al., 2017). However, their impact also depends on rainfall intensity and drainage pathways.

Digital Elevation Models (DEMs) are commonly used to represent terrain in flood studies, but their resolution and quality can significantly affect results. Jiang et al. (2022) found that DEM resolution influences simulated flood depth and extent, especially in urban areas, while Xing et al. (2022) noted that missing small terrain features like buildings and barriers can alter flood behavior. Although higher-resolution DEMs generally improve accuracy, Uuemaa et al. (2020) showed that improvements depend on landscape type and data quality, meaning higher resolution does not always guarantee better results. Similarly, Parizi et al. (2022) reported that different DEM datasets can produce varying flood extents and depths, highlighting sensitivity to DEM choice.

Overall, studies confirm that terrain is a key driver of flooding and that DEM representation directly affects simulation outcomes. In this study, the ALOS PALSAR DEM (12.5 m) provides relatively detailed terrain information for identifying low-lying flood-prone areas in Barangay Calaba, supporting its use for rainfall-induced flood susceptibility assessment despite some inherent data limitations.

D. Flood Modeling Using HEC-RAS

Hydraulic modeling is widely used in flood studies to simulate water movement and estimate flood extent, with HEC-RAS commonly applied due to its hydraulic representation and spatial output capabilities (Brunner, 2016). Different models serve different purposes; SWMM is used for urban drainage systems, LISFLOOD for large-scale hydrology, while HEC-RAS is suited for detailed floodplain hydraulics (Cea & Costabile, 2022).

The development of HEC-RAS 2D has improved its use for rainfall-induced flooding by simulating overland flow across terrain rather than only channel flow, making it more suitable for surface runoff and accumulation processes (Costabile et al., 2021). Studies show it can reliably estimate flood depth and extent, though accuracy depends on model setup and input data quality. Grid resolution also significantly affects results (David & Schmalz, 2021), and its application in ungauged catchments demonstrates its usefulness even with limited data (Ennouini et al., 2024).

Overall, HEC-RAS 2D is an effective tool for simulating rainfall-driven flooding, especially where surface runoff dominates and river channels are not the main drivers. Its ability to represent spatial water movement makes it suitable for identifying flood-prone areas.

In this study, HEC-RAS 2D is used to simulate rainfall-induced flooding in Barangay Calaba, where flooding is mainly driven by surface runoff and drainage limitations. The rain-on-grid approach helps map spatial water accumulation under simulated rainfall conditions. Although results depend on input data and assumptions, the model provides a reliable basis for assessing flood susceptibility at the local scale.

E. Flood Hazard Mapping and Validation Approaches

Flood hazard mapping is a key tool for disaster risk reduction, helping identify flood-prone areas and guide mitigation strategies. Recent studies commonly use GIS, hydrodynamic models, LiDAR data, and remote sensing to improve map accuracy, which is relevant to this study's use of Project NOAH datasets for validation.

Calapini et al. (2023) showed that integrating LiDAR with HEC-RAS improves flood map reliability in the Cagayan River Basin, supporting the use of NOAH LiDAR data. Puno (2019) validated HEC-HMS and HEC-RAS results using historical floods and community input, similar to NOAH's participatory validation approach. Springer (2021) combined hydrodynamic models with remote sensing and machine learning, validating results using satellite-derived flood extents, while Jiang et al. (2022) emphasized that DEM resolution and building representation significantly affect flood accuracy when compared with observed events.

Remote sensing-based validation is also widely used. Li et al. (2023) used Sentinel-1 SAR imagery to validate urban flood models, and Nguyen et al. (2020) used community observations to validate GIS-based flood maps, similar to NOAH's approach. Ennouini et al. (2024) further showed that even in ungauged areas, HEC-RAS 2D outputs can be validated using publicly available datasets.

Overall, these studies show that flood hazard mapping is most reliable when supported by strong validation methods such as LiDAR, satellite imagery, and field or community data. These align with Project NOAH's approach, strengthening the validity of this study's methodology in a Philippine context.

F. Drainage Systems and Flood Mitigation

Drainage systems manage surface runoff and reduce flooding by improving water conveyance, but their effectiveness depends on capacity, design, and operational conditions. They reduce water accumulation rather than fully preventing flooding.

Studies show that drainage limitations are a major driver of localized flooding. Cea and Costabile (2022) identify drainage capacity as a key factor in urban flood risk, where rainfall exceeding capacity leads to pluvial flooding. Sohn et al. (2020) note that drainage improvements can reduce flood damage, but effectiveness depends on how well the system matches runoff conditions. Similarly, Guo et al. (2024) found that drainage performance can vary under different conditions such as inlet blockage, which can significantly increase flood depth and extent.

Overall, drainage systems influence the magnitude and distribution of flooding rather than eliminating it, and their performance is highly condition-dependent. In this study, these findings support the use of a conceptual drainage scenario in Barangay Calaba to evaluate how improved runoff conveyance may reduce flood depth and inundation extent, providing a preliminary basis for flood mitigation planning without detailed engineering design.

III. METHODOLOGY

A. Research Design

This study uses a quantitative case study design based on hydrodynamic simulation, with Project NOAH flood dataset used for comparative validation. HEC-RAS 6.7 Beta 5 was used to simulate rainfall-induced flooding in Barangay Calaba under two scenarios: (1) existing condition without drainage and (2) condition with a conceptual drainage system. The simulation outputs were used to identify flood-prone areas, flood depth, and inundation extent, while the Project NOAH dataset was summarized to assess general spatial agreement between modeled flood-prone areas and available flood data.

B. Research Locale

The study was conducted in Barangay Calaba, San Isidro, Nueva Ecija. The area consists mainly of agricultural land and relatively flat terrain, which contributes to slow surface runoff and water accumulation during heavy rainfall. The barangay is also located near a river, which coincides with low-lying areas where water accumulation is likely to occur. The locale was selected due to frequent reports of flooding and the absence of a localized flood assessment.

C. Data Collection

Terrain data were obtained from NASA Earthdata using the ALOS PALSAR DEM (12.5 m resolution) and processed in QGIS 3.99.0 by clipping it to Barangay Calaba and aligning the coordinate system. Rainfall data were sourced from PAGASA IDF analysis for the Cabanatuan station (57 years of records), using a 6-hour duration and a 5-year return period as the design storm. The IDF precipitation depth was converted and computed into a constant rainfall intensity of 0.86 in/hr due to the lack of detailed temporal distribution data. This uniform rainfall was applied in HEC-RAS 2D as a constant precipitation input to simulate runoff generation and flooding response across the study area.

D. HEC-RAS 2D Simulation

Flood simulation was conducted using HEC-RAS 6.7 Beta 5 with the ALOS PALSAR DEM (12.5 m resolution) as terrain input. A six-hour precipitation hydrograph was applied as rainfall forcing, and boundary conditions were set using a normal depth condition with a friction slope of 0.010 to represent relatively flat, low-gradient agricultural terrain and stabilize runoff behavior in the model.

A conceptual drainage system was incorporated by modifying the terrain to create simplified channels, not an engineered design. The channels were assigned a 20 ft bottom width, 2H:1V side slopes, and a 20 ft maximum extent width, positioned along existing road alignments to reflect typical barangay drainage pathways and direct flow toward the nearby river. Manning's n was set to 0.06 to represent rough open-channel conditions; however, due to limited field data, no full hydraulic design analysis was performed. The dimensions were assumed for conceptual simulation purposes only and do not represent finalized engineering drainage design specifications. The drainage system is therefore conceptual, and results are interpreted as relative changes in flood behavior rather than exact field conditions.

Flood depth and inundation extent outputs were generated for both scenarios (with and without drainage). The model was rerun after drainage incorporation, and results were exported to QGIS 3.99.0 for spatial analysis. Flood depth rasters were used to identify flood-prone areas and compute total inundated area for comparison between scenarios.

Simulation outputs were also summarized using descriptive statistics to evaluate differences between existing conditions and the conceptual drainage scenario.

TABLE I. FLOOD DEPTH DISTRIBUTION SUMMARY

Flood Depth Category	Depth Range (m)	Existing Condition (Area m²)	With Drainage (Area m²)	Difference (m²)	% Reduction
Low	0–0.50				
Medium	0.51–1.50				
High	>1.50				

To evaluate the effectiveness of the proposed drainage system, a comparative analysis was conducted between the existing condition and the scenario with drainage. Flood conditions were assessed based on depth classification, and the corresponding inundated area for each flood depth category was calculated. The difference in flooded area between the two scenarios was then determined, and the percentage reduction was computed using the following formula:

$$\textit{Percentage Reduction} = [(\textit{Existing Condition} - \textit{With Drainage}) / \textit{Existing Condition}] \times 100$$

This approach allows for a clearer evaluation of how the drainage system influences different levels of flood severity.

TABLE II. VALIDATION OF FLOODED AREA BY DEPTH CATEGORY

Depth Category (m)	Description	Simulated Area (m²)	Project NOAH Area (m²)	Difference (m²)
0–0.50	Low			
0.51–1.50	Medium			
>1.50	High			

The flood extent and depth from the HEC-RAS simulation are validated using flood hazard data from Project NOAH. Both datasets are clipped to the barangay boundary and classified using the same flood depth ranges.

The difference in flooded area is computed by subtracting the Project NOAH flooded area from the HEC-RAS simulated flooded area:

$$\textit{Difference } (m^2) = \textit{HEC-RAS Area} - \textit{Project NOAH Area}$$

A positive value indicates that the simulation produced a larger flooded area than Project NOAH, while a negative value indicates a smaller flooded area.

All statistical results were presented using tables, and thematic maps generated through GIS and simulation outputs to provide a clear and understandable interpretation of the findings.

IV. RESULTS AND DISCUSSION

This chapter presents the results of the study in relation to the research objectives and questions. It includes the analysis and interpretation of data obtained from the HEC-RAS 2D simulation conducted for Barangay Calaba, San Isidro, Nueva Ecija. The findings are organized according to the research questions to show the identified flood-prone areas, the effects of the simulated drainage system on flood depth and inundation extent, and the comparison of the simulation results with the available Project NOAH flood dataset for validation.

A. Flood-Prone Areas Under Existing Condition

This section presents the flood-prone areas in Barangay Calaba, San Isidro, Nueva Ecija under existing conditions based on the HEC-RAS 2D rainfall simulation. The results are illustrated through the simulated flood depth map, which classifies flooding into three categories: low flooding (0.10–0.50 m), medium flooding (0.51–1.50 m), and high flooding (>1.50 m).

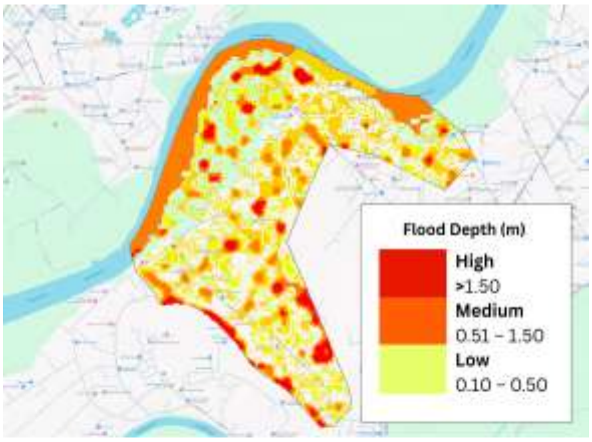

Figure 4.1 Simulated Flood Depth Map Under Existing Condition

As shown in Figure 4.1, simulated flooding in Barangay Calaba is widely distributed with varying severity. Low to medium flooding dominates the interior areas, indicating widespread surface runoff even away from the main river. However, higher flood depths are concentrated near the Pampanga River.

The flood depth map shows that areas along the northern and western riverbanks experience the most severe flooding, forming more continuous high-depth zones compared to the more scattered inland pattern. This reflects the influence of low elevation near the river, which promotes water accumulation.

In contrast, areas farther from the river generally experience lower flood depths, although some localized medium to high flooding still occurs, likely due to surface depressions or limited drainage pathways.

Overall, the results show that flooding in Barangay Calaba is widespread but uneven, with river-adjacent and low-lying areas experiencing the highest flood exposure.

B. Flood Depth and Inundation Extent Under Simulated Rainfall

This section presents the quantitative results of flood depth and inundation extent in Barangay Calaba under simulated rainfall conditions. The distribution of flooded areas is categorized based on depth levels, showing the extent and severity of flooding across the barangay. The summarized values of each flood depth category, including their corresponding area and percentage, are presented in Table III.

TABLE III. FLOOD DEPTH DISTRIBUTION UNDER EXISTING CONDITION

Flood Depth Category	Depth Range (m)	Area (m^2)	Percentage (%)
Low	0–0.50	515,156.25	49.43%
Medium	0.51–1.50	425,937.50	40.87%
High	>1.50	101,093.75	9.70%
Total		1,042,187.50	100%

As shown in Table III, flooding in Barangay Calaba is dominated by low to medium depths. Low flooding (0.10–0.50 m) makes up the largest share at about 49.43%, followed by medium flooding (0.51–1.50 m) at 40.87%, indicating that most inundation is shallow to moderate during rainfall events. High flooding (>1.50 m) accounts for the smallest portion at 9.70%, but it represents the most critical areas due to higher flood risk. Spatially, low and medium flooding are widely distributed across the interior barangay, forming a continuous inundation pattern, while high flooding appears in concentrated patches, mainly along riverbanks and low-lying zones near the Pampanga River, suggesting a link between elevation and flood severity.

Overall, results show widespread but generally shallow flooding, with deeper flood conditions limited to specific high-risk areas, highlighting the need for targeted mitigation in river-adjacent and low-lying zones.

C. Effect of Simulated Drainage System

This section presents the results of the HEC-RAS 2D simulation after the introduction of the conceptual drainage system in Barangay Calaba, San Isidro, Nueva Ecija. The analysis focuses on evaluating the changes in flood depth and inundation extent compared to the existing condition. The simulated results are used to determine whether the proposed drainage system contributes to the reduction of flooding within the barangay.

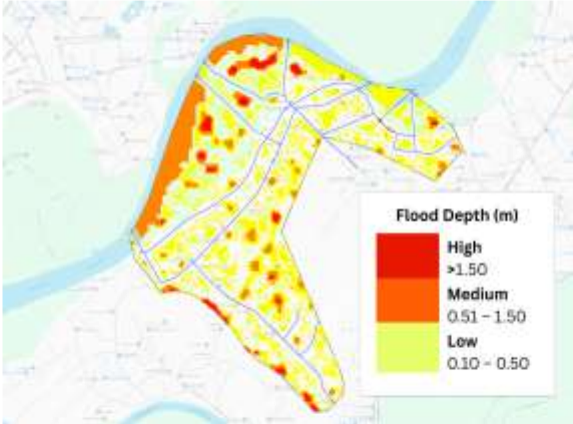

Figure 4.2 Simulated Flood Depth Map with Proposed Drainage System

As shown in Figure 4.2, the simulated flood map with the proposed drainage system shows a clear reduction in flood depth compared to the existing condition in Figure 4.1. High flooding becomes less extensive and more localized, mainly along riverbanks and selected low-lying areas. In contrast, the existing condition shows more continuous high flooding along the northern and western boundaries near the Pampanga River, with additional concentrated areas inside the barangay. With the drainage scenario, high flood zones become more fragmented and reduced, suggesting improved runoff conveyance. Medium flooding also decreases in extent, with several areas shifting to lower depth categories, particularly in the interior portions of the barangay. Low flooding remains widespread but becomes more dispersed, indicating redistribution of surface water rather than concentration in deeper zones.

Overall, the comparison shows that the simulated drainage scenario indicates potential reduction in flood depth and severe flooding extent by directing runoff toward discharge points. However, flooding still persists, especially in river-adjacent and low-lying areas, indicating that while drainage improves conditions, it does not fully eliminate flood risk under the modeled scenario.

D. Quantification of Flood Reduction

This section presents the quantitative assessment of the reduction in flood depth and inundation extent after the introduction of the conceptual drainage system in Barangay Calaba, San Isidro, Nueva Ecija. The comparison between the existing condition and the simulated drainage condition is summarized in Table IV, including the computed area reduction and percentage reduction for each flood depth category.

TABLE IV. COMPARISON OF FLOOD DEPTH AND INUNDATION EXTENT BEFORE AND AFTER DRAINAGE IMPLEMENTATION

Flood Depth Category	Depth Range (m)	Existing Condition (Area m²)	With Drainage (Area m²)	Difference (m²)	% Reduction
Low	0–0.50	515,156.25	394,062.5	121,093.75	23.51%
Medium	0.51–1.50	425,937.50	275,312.5	150,625.00	35.36%
High	>1.50	101,093.75	42,187.5	58,906.25	58.27%

As shown in Table IV, the introduction of the conceptual drainage system reduced flooded areas across all depth categories. Low flooding (0.10–0.50 m) decreased from 515,156.25 m² to 394,062.50 m², a reduction of 121,093.75 m² (23.51%). Medium flooding (0.51–1.50 m) decreased from 425,937.50 m² to 275,312.50 m², a reduction of 150,625.00 m² (35.36%). The largest reduction occurred in high flooding (>1.50 m), which dropped from 101,093.75 m² to 42,187.50 m², a decrease of 58,906.25 m² (58.27%), suggesting greater simulated reduction in deeper flooding under the modeled scenario.

These results suggest that the drainage system improves surface runoff conveyance and reduces water accumulation, with a greater impact on severe flood conditions in low-lying areas. However, the remaining flooded areas indicate that while the system reduces flood extent and depth, it does not fully eliminate flooding, particularly in terrain-influenced and river-adjacent zones.

E. Validation of Simulation Results Using Project NOAH Dataset

This section presents the validation of the HEC-RAS 2D simulation results by comparing the identified flood-prone areas with the available Project NOAH flood dataset. The purpose of this validation is to assess the general spatial agreement of the simulated flood patterns in Barangay Calaba, San Isidro, Nueva Ecija.

TABLE V. VALIDATION OF FLOODED AREA BY DEPTH CATEGORY

Depth Category (m)	Description	Simulated Area (m²)	Project NOAH Area (m²)	Difference (m²)
0–0.50	Low	515,156.25	143,125.00	372,031.25
0.51–1.50	Medium	425,937.50	457,968.75	32,031.25
>1.50	High	101,093.75	624,531.25	523,437.5

As shown in Table V, the simulated results and the Project NOAH dataset show both similarities and notable differences in flood extent across depth categories. For shallow flooding (0–0.5 m), the simulation produces a much larger area (515,156.25 m²) compared to Project NOAH (143,125.00 m²), indicating that the model tends to overestimate shallow inundation. For moderate flooding (0.5–1.5 m), results are relatively comparable, with 425,937.50 m² (simulation) and 457,968.75 m² (Project NOAH), showing partial agreement in mid-range flood conditions. However, a major discrepancy is observed in deep flooding (>1.5 m), where the simulation significantly underestimates flood extent (101,093.75 m²) compared to Project NOAH (624,531.25 m²).

This underestimation suggests important limitations in the modeling approach. First, the use of a 12.5 m DEM (ALOS PALSAR) limits the representation of fine-scale terrain variations that strongly influence ponding and deep water accumulation. Second, the simulation was not calibrated due to the absence of observed flood depth or discharge data, which reduces its ability to reproduce extreme flood conditions accurately. Third, rainfall inputs were simplified into a uniform intensity hydrograph, which may not fully capture storm variability and peak intensities that drive deeper flooding. In addition, the conceptual drainage system assumes idealized runoff conveyance without field-verified parameters, which may further reduce simulated flood depths. Lastly, Project NOAH incorporates LiDAR-based terrain, historical flood records, and multi-source datasets, allowing it to better capture deeper inundation patterns compared to this standalone simulation.

Despite these limitations, both datasets consistently identify similar flood-prone zones, particularly along low-lying areas and near the Pampanga River, indicating agreement in spatial flood distribution. Overall, the HEC-RAS 2D model provides a general representation of general flooding patterns in Barangay Calaba but underestimates deep flooding due to data resolution constraints, simplified assumptions, and lack of calibration.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter summarizes the HEC-RAS 2D simulation results for rainfall-induced flooding in Barangay Calaba, including flood extent, depth, drainage effects, and validation with Project NOAH, followed by conclusions and recommendations for flood mitigation and future studies.

A. Summary of Findings

This study assessed rainfall-induced flooding in Barangay Calaba, San Isidro, Nueva Ecija using HEC-RAS 2D simulation to (1) identify flood-prone areas, (2) evaluate a conceptual drainage system, and (3) compare results with the Project NOAH dataset. The findings are as follows:

1. **Flood-prone areas in Barangay Calaba** Flooding is widespread and mostly low to moderate in depth. Low flooding covers 49.43% of the area, medium flooding 40.87%, and high flooding 9.70%. High flood depths are concentrated in low-lying areas and near the

Pampanga River, showing strong influence of elevation and proximity to the river.

2. **Effect of the simulated drainage system** The conceptual drainage system reduces flood depth and extent across all categories, with the greatest reduction in high flooding (58.27%), followed by medium (35.36%) and low (23.51%). This indicates improved runoff conveyance, especially in severe flood areas, though flooding is not fully eliminated.
3. **Comparison with Project NOAH dataset** The simulation shows similar spatial patterns to Project NOAH, particularly in river-adjacent and low-lying flood-prone zones. However, differences in flood extent per depth category exist, likely due to variations in data resolution and modeling methods. Despite this, overall flood-prone locations are consistent, indicating that the model reasonably represents site conditions.

B. Conclusions

Based on the findings of the study, the following conclusions are drawn:

1) Identification of Flood-Prone Areas: The study identified potential flood-prone areas in Barangay Calaba using HEC-RAS 2D simulation, showing that flooding is widespread and primarily affects low-lying areas and zones near the Pampanga River, confirming the influence of terrain and river proximity on flood susceptibility.
2) Flood Depth and Inundation Characteristics: The simulation results demonstrated that most flooded areas fall under low to medium flood depths, indicating that rainfall-induced flooding in the barangay is generally shallow to moderate, with deeper flooding occurring only in specific high-risk zones.
3) Effectiveness of the Conceptual Drainage System: The introduction of a conceptual drainage system resulted in a noticeable reduction in flood depth and inundation extent, particularly in areas with high flooding, indicating that the simulated drainage scenario suggests improved runoff conveyance under the modeled conditions.
4) Quantified Reduction in Flooding: The analysis showed that the drainage system has the greatest impact on reducing high flood depths, followed by medium and low flood categories, suggesting that drainage interventions are more effective in mitigating severe flooding rather than eliminating all flood occurrences.
5) Validation with Project NOAH Dataset: The comparison between the HEC-RAS simulation and the Project NOAH dataset showed general agreement in identifying flood-prone areas, although differences in flood extent were observed due to variations in data sources and modeling assumptions.
6) Overall Implication for Flood Mitigation *Planning:* The study indicates that HEC-RAS 2D modeling can be a useful tool for localized flood assessment and that drainage improvements may help reduce flooding impacts. It may also serve as a basis for planning flood mitigation measures in Barangay Calaba.

C. Recommendations

Based on the findings of the study, future flood mitigation and drainage planning in the study area may consider improving drainage conveyance systems and implementing continuous flood monitoring and assessment to help reduce potential flooding impacts. Future researchers are also encouraged to conduct calibration-based hydraulic modeling, higher-resolution terrain analysis, and detailed drainage design studies to improve the accuracy and reliability of flood simulation results. Urban drainage and flood simulation studies commonly emphasize the importance of integrated drainage planning and hydrodynamic modeling in flood risk management.

ACKNOWLEDGEMENT

The researchers express their sincere gratitude to Nueva Ecija University of Science and Technology (NEUST), the local government offices that provided secondary data, and all individuals who contributed to the completion of this study. Above all, the researchers thank God Almighty for the guidance, strength, and wisdom throughout the conduct of the research.

REFERENCES

1. Abon, C. C., David, C. P. C., & Pellejera, N. E. B. (2011). Reconstructing the Tropical Storm Ketsana flood event in Marikina River, Philippines. *Hydrology and Earth System Sciences*, *15*(4), 1283–1289. https://doi.org/10.5194/hess-15-1283-2011
2. Acierto, R. a. E., Ushiyama, T., Jaranilla-Sanchez, P. A., & Ohara, M. (2026). Downscaled climate projections for rainfall extremes and drought in Pampanga River and Pasig-Marikina-Laguna-Lake Basin. *Journal of Disaster Research*, *21*(2), 287–298. https://doi.org/10.20965/jdr.2026.p0287
3. Ahmad, I., Farooq, R., Ashraf, M., Waseem, M., & Shangguan, D. (2025). Improving flood hazard susceptibility assessment by integrating hydrodynamic modeling with remote sensing and ensemble machine learning. *Natural Hazards*, *121*(7), 7839–7868. https://doi.org/10.1007/s11069-025-07109-2
4. Apel, H., Aronica, G. T., Kreibich, H., & Thieken, A. H. (2009). Flood risk analyses—how detailed do we need to be? *Natural Hazards*, *49*(1), 79–98. https://doi.org/10.1007/s11069-008-9277-8
5. Banjara, M., Bhusal, A., Ghimire, A. B., & Kalra, A. (2024). Impact of land use and land cover change on hydrological processes in urban watersheds: Analysis and forecasting for flood risk management. *Geosciences*, *14*(2), 40. https://doi.org/10.3390/geosciences14020040
6. Boongaling, C. G. K., Faustino-Eslava, D. V., & Lansigan, F. P. (2017). Modeling land use change

impacts on hydrology and the use of landscape metrics as tools for watershed management: The case of an ungauged catchment in the Philippines. *Land Use Policy*, *72*, 116–128. https://doi.org/10.1016/j.landusepol.2017.12.042

7. Brunner, G. (2016). *HEC-RAS, River Analysis System Hydraulic Reference Manual*. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Reference%20Manual.pdf
8. Cabrera, J. S., & Lee, H. S. (2020). Flood risk assessment for Davao Oriental in the Philippines using geographic information system-based multi-criteria analysis and the maximum entropy model. *Journal of Flood Risk Management*, *13*(2). https://doi.org/10.1111/jfr3.12607
9. Cea, L., & Costabile, P. (2022). Flood risk in urban areas: Modelling, management and adaptation to Climate change. A review. *Hydrology*, *9*(3), 50. https://doi.org/10.3390/hydrology9030050
10. Calapini, W. D., Tan, F. J., Monjardin, C. E. F., & Gacu, J. G. (2025). Geospatial analysis of flood hazard using GIS-Based Hydrologic–Hydraulic modeling: A case of the Cagayan River Basin, Philippines. *Geomatics*, *5*(4), 64. https://doi.org/10.3390/geomatics5040064
11. David, A., & Schmalz, B. (2021). A Systematic Analysis of the Interaction between Rain-on-Grid-Simulations and Spatial Resolution in 2D Hydrodynamic Modeling. *Water*, *13*(17), 2346. https://doi.org/10.3390/W13172346
12. Dulawan, J. M. T., Imamura, Y., Konishi, T., Amaguchi, H., & Ohara, M. (2024). A systematic framework for assessing social vulnerability to flood for integrated flood risk management: A case study in Metro Manila, Philippines. *International Journal of Disaster Risk Reduction*, *112*, 104778. https://doi.org/10.1016/j.ijdrr.2024.104778
13. Ennouini, W., Fenocchi, A., Petaccia, G., Persi, E., & Sibilla, S. (2024). A complete methodology to assess hydraulic risk in small ungauged catchments based on HEC-RAS 2D Rain-On-Grid simulations. *Natural Hazards*, *120*(8), 7381–7409. https://doi.org/10.1007/s11069-024-06515-2
14. Farooq, M., Shafique, M., & Khattak, M. S. (2019). Flood hazard assessment and mapping of River Swat using HEC-RAS 2D model and high-resolution 12-m TanDEM-X DEM (WorldDEM). *Natural Hazards*, *97*(2), 477–492. https://doi.org/10.1007/s11069-019-03638-9
15. Guo, W., Zhai, M., Lei, X., Huang, H., Long, Y., & Li, S. (2024). Two-Dimensional hydrodynamic simulation of the effect of stormwater inlet blockage on urban waterlogging. *Water*, *16*(14), 2029. https://doi.org/10.3390/w16142029
16. Jha, A. K., Bloch, R., & Lamond, J. (2012). Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st century. In *RePEc: Research Papers in Economics*. https://doi.org/10.1596/978-0-8213-8866-2
17. Jiang, W., Yu, J., Wang, Q., & Yue, Q. (2022). Understanding the effects of digital elevation model resolution and building treatment for urban flood modelling. *Journal of Hydrology Regional Studies*, *42*, 101122. https://doi.org/10.1016/j.ejrh.2022.101122
18. Kalakonas, P., Silva, V., Mouyiannou, A., & Rao, A. (2020). Exploring the impact of epistemic uncertainty on a regional probabilistic seismic risk assessment model. *Natural Hazards*, *104*(1), 997–1020. https://doi.org/10.1007/s11069-020-04201-7
19. Khodaei, H., Saleh, F. N., Dalir, A. N., & Zarei, E. (2025). Future flood susceptibility mapping under climate and land use change. *Scientific Reports*, *15*(1), 12394. https://doi.org/10.1038/s41598-025-97008-0
20. NASA Alaska Satellite Facility Distributed Active Archive Center. (2014). *ALOS PALSAR High Resolution Radiometric Terrain Corrected product* [Dataset]. https://doi.org/10.5067/Z97HFCNKR6VA
21. PAGASA. (n.d.). Floods. PAGASA - DOST. https://www.pagasa.dost.gov.ph/learning-tools/floods
22. Pangilinan, M. K. A. S. (2014). An Assessment of the Effects of Urban Flooding on Land-Use Patterns and Policies in Malabon City: Moving toward Integrated Flood Management, 1980–2012. UP-School of Urban and Regional Planning. http://serp-p.pids.gov.ph/publication/public/view?slug=an-assessment-of-the-effects-of-urban-flooding-on-land-use-patterns-and-policies-in-malabon-city-mo.
23. Parizi, E., Khojeh, S., Hosseini, S. M., & Moghadam, Y. J. (2022). Application of Unmanned Aerial Vehicle DEM in flood modeling and comparison with global DEMs: Case study of Atrak River Basin, Iran. *Journal of Environmental Management*, *317*, 115492. https://doi.org/10.1016/j.jenvman.2022.115492
24. Puno, G. R., Talisay, B. a. M., & Paquit, J. C. (2019). *GIS-Based flood hazard mapping in Gingoog River, Mindanao*. https://js.cmu.edu.ph/CMUJS/article/view/20
25. Rangari, V. A., Umamahesh, N. V., & Bhatt, C. M. (2019). Assessment of inundation risk in urban floods using HEC RAS 2D. *Modeling Earth Systems and Environment*, *5*(4), 1839–1851. https://doi.org/10.1007/s40808-019-00641-8
26. Santillan, J. R., Amora, A. M., Makinano-Santillan, M., Gingo, A. L., & Marqueso, J. T. (2019). Analyzing the Impacts of Land Cover Change to the

Hydrologic and Hydraulic Behaviours of the Philippines' Third Largest River Basin. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *IV-3/W1*, 41–48. doi:10.5194/isprs-annals-IV-3-W1-41-2019

27. Sohn, W., Brody, S. D., Kim, J., & Li, M. (2020). How effective are drainage systems in mitigating flood losses? *Cities*, *107*, 102917. https://doi.org/10.1016/j.cities.2020.102917
28. Tellman, B., Sullivan, J. A., Kuhn, C., Kettner, A. J., Doyle, C. S., Brakenridge, G. R., Erickson, T. A., & Slayback, D. A. (2021). Satellite imaging reveals increased proportion of population exposed to floods. *Nature*, *596*(7870), 80–86. https://doi.org/10.1038/s41586-021-03695-w
29. Uuemaa, E., Ahi, S., Montibeller, B., Muru, M., & Kmoch, A. (2020). Vertical accuracy of freely available global digital elevation models (ASTER, AW3D30, MERIT, TANDEM-X, SRTM, and NASADEM). *Remote Sensing*, *12*(21), 3482. https://doi.org/10.3390/rs12213482
30. Vu, V. T., Nguyen, H. D., Vu, P. L., Ha, M. C., Bui, V. D., Nguyen, T. O., Hoang, V. H., & Nguyen, T. K. H. (2023). Predicting land use effects on flood susceptibility using machine learning and remote sensing in coastal Vietnam. *Water Practice & Technology*, *18*(6), 1543–1555. https://doi.org/10.2166/wpt.2023.088
31. Xing, Y., Chen, H., Liang, Q., & Ma, X. (2022). Improving the performance of city-scale hydrodynamic flood modelling through a GIS-based DEM correction method. *Natural Hazards*, *112*(3), 2313–2335. https://doi.org/10.1007/s11069-022-05267-1
32. Yao, Z., Zhao, Y., Wang, H., Li, H., Yuan, X., Ren, T., Yu, L., Liu, Z., Zhang, X., & Li, S. (2023). Comparison and Assessment of Data Sources with Different Spatial and Temporal Resolution for Efficiency Orchard Mapping: Case Studies in Five Grape-Growing Regions. Remote Sensing, 15(3), 655. https://doi.org/10.3390/rs15030655