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DETERMINATION OF FLOOD MITIGATION PLANNING PARAMETERS IN AN UNGAUGED RIVER BASIN: HYDROLOGIC AND HYDRAULIC ASPECTS

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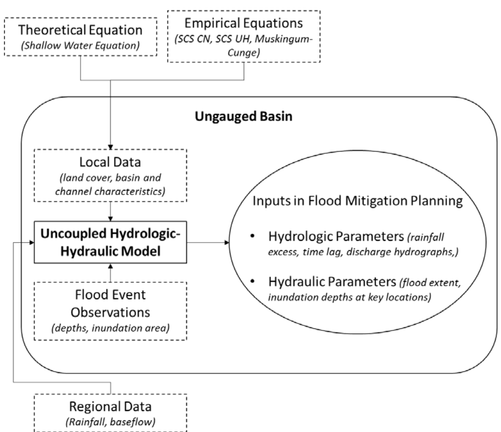
Graphical abstract



Abstract

Flood mitigation planning involves the development of a comprehensive set of structural and non-structural measures to minimize the adverse effects of flooding. Implementing this process in ungauged locations poses particular challenges due to the lack of relevant hydrologic and hydraulic parameters necessary for making informed decisions. This paper presents a methodology for determining such parameters using a hydrologic-hydraulic model in a pilot site, specifically the Mapatos River Basin in Camarines Sur, Philippines. The model applied a combination of well-established theoretical and empirical equations, including the shallow-water equations, SCS Curve Number Method, SCS Unit Hydrograph Method, Convolution Equation, and Muskingum-Cunge Equation. To extract the physical characteristics of the study area, high-resolution topographic data was utilized, with a horizontal resolution of 1 meter in the river and immediate floodplains and 5-m resolution for the rest of the basin. The validity of the model was assessed using data from a recent flood event, resulting in a Nash-Sutcliffe Efficiency value of 0.54, indicating satisfactory results. It should be noted that the simulated flood depths tended to be higher than the observed values, which is appropriate for design studies as a margin of safety must always be incorporated into planning and design. For the design consideration of 25-year, 50-year, and 100-year average storms in the basin, the hydrologic design parameters, such as rainfall excess, time lag, peak discharge, and total hydrograph, were quantified. Similarly, the hydraulic aspects, such as flood extent and flood depths at critical locations in the downstream floodplains, were determined. This methodology can be readily applied to other ungauged locations, provided that similar or more sophisticated model validations are conducted.

Keywords: flood mitigation, flood risk assessment, hydrologic analysis, HEC-HMS, HEC-RAS

1.0 INTRODUCTION

Among the 193 countries recognized by the United Nations, the Philippines ranked first in terms of having the highest disaster risk in the year 2023 [1]. The most frequent disaster experienced in the country is flooding, which, along with typhoons, also causes the most extensive economic damage [2]. Consequently, the national government is actively investing in long-term solutions to address the issue in various flood-prone communities nationwide.

Effective planning plays a crucial role in developing an organized, comprehensive, and efficient solution to this complex problem. Flood mitigation planning involves the formulation of a range of structural and non-structural measures aimed at minimizing the adverse impacts of flooding. The initial planning process requires thorough data collection, including the gathering of relevant characteristics pertaining to the occurrence of riverine flooding within a given river basin.

Ideally, a basin should possess a long-term record of hydrologic and hydraulic parameters, such as rainfall, streamflow, and water levels, among others. These data allow for the convenient inference or processing of design conditions. Regrettably, many flood-prone basins in the country remain ungauged, yet they require mitigation plans due to their high vulnerability to flooding.

The conventional method of determining hydrological parameters in ungauged basins is typically through the use of empirical equations. These equations estimate design discharges by directly correlating them to prominent basin characteristics such as drainage area, basin slope, and stream length [3]. However, with the advancements in computing technology over the past two decades, it has become commonplace to employ numerical models as tools for gathering baseline information in water resources projects, particularly in flood-related studies [4]. Furthermore, it has been proven that the results obtained from modeling are superior to widely used empirical methods like flow regression analyses and transposition methods, as evidenced by performance evaluation standards such as the coefficient of determination, mean absolute error, percentage volume bias, Nash-Sutcliffe Efficiency (NSE), and Global Performance Index (GPI) [5].

Various hydrologic and hydraulic modeling tools exist, differing in their algorithms (empirical, conceptual, or physically-based), computational approaches (deterministic or stochastic), and spatial representations (lumped or distributed in basins, 1-dimensional or 2-dimensional or a combination of both in rivers and floodplains) [6]. Some modeling tools are particularly adept at handling ungauged cases due to a balance between data requirements and the relative accuracy of the results [7]. The United States Army Corps of Engineer's (USACE) Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) and HEC-River Analysis System (HEC-RAS) are among the frequently utilized tools in the ASEAN Region, consistently delivering satisfactory results for ungauged basins [7,8,9,10,11,12]. In the utilization of hydrologic and hydraulic models, calibration and validation are essential steps to establish the credibility of the models, ensuring that simulation results can be accurately applied to real-life events. For basins without available data, either uncalibrated models are used or alternative methods of model calibration and/or validation are employed. Uncalibrated hydrologic models can be used in a semi-quantitative manner, comparing the results from different scenario simulations in terms of relative increase or decrease of values from the baseline scenario [13]. In a recent study [14], it was suggested that uncalibrated HEC-HMS models produce reasonable and typically conservative (high) results for extreme flood events. Alternative calibration methods for hydrologic models include steady-state assumption in the long-term water balance of a natural basin [15], area-weighted transposition of streamflow values in gaged watersheds [11], or regionalization of hydrologic parameters [12,16]. Similarly, hydraulic models applied to ungauged streams undergo a calibration-validation procedure typically based on flood extent extracted from satellite images [17,18] or water levels reported from recent flooding incidents [19]. Notably, there are studies that analyze uncalibrated hydraulic models [20,21,22]. Costabile et al. [20] demonstrated that the practical use of uncalibrated HEC-RAS 2-dimensional model for runoff simulation produced reasonable results when compared to observed flows. Natarahan & Radhakrishnan [21] explained that accurate geoprocessing of stream and floodplain geometry can serve as a replacement for the calibration procedure. However, Tscheikner-Gratl et al. [22] cautions that uncalibrated hydrodynamic models tend to overestimate flood volumes.

Due to data scarcity in ungauged sites, uncoupled hydrologic-hydraulic models are employed in certain applications [19,23,24,25,26]. First, a numerical hydrologic analysis is conducted, and then the results are utilized as inputs for the hydraulic model. Based on the available literature, it is sufficient to perform calibration-validation on only one aspect, either the hydrology or the stream hydraulics component. According to Siqueira et al. [23], as long as channel geometry and floodplain topography are accurately represented in the model, such as using high-resolution Digital Elevation Models (DEMs), simulated discharges of uncalibrated hydrologic models can be readily adopted in hydrodynamic modeling. A similar recommendation was made by Trinh [24] in proposing a methodological framework for future flood risk assessment in ungauged catchments in Southeast Asia.

The primary objective of this study is to ascertain the hydrologic and hydraulic design parameters of an ungauged river basin, which will serve as crucial inputs for flood mitigation planning. The study delves into the efficacy of the present state-of-the-art in uncoupled hydrologic-hydraulic modeling within the ASEAN region, specifically assessing its applicability in practical design and planning scenarios.

2.0 METHODOLOGY

2.1 Study Area and Local Data

The study area, as depicted in Figure 1, is located in Pasacao, Camarines Sur, Philippines. Mapatos River Basin (left figure), which is the subject of hydrologic analysis, has an area of 46.31 km^2 and an average basin slope of 6.05%. Adjacent to the basin is the port of Pasacao, which serves as a vital economic center in the region. The coastal area of the basin has experienced substantial development for residential, commercial, and institutional purposes. However, this location is also susceptible to both inland and coastal flooding. In response to these challenges, ongoing government initiatives are being undertaken to develop an effective flood mitigation strategy. Figure 1 (right) shows the 1,970.4-m downstream reach of Mapatos River, which is the current focus of government's flood mitigation planning activity, and also the subject of hydraulic analysis of this study. Regrettably, there is a lack of hydrologic records within the basin and the river, necessitating the use of alternative methodology to characterize the hydrologic conditions of the basin and the hydraulic properties of the river for flood mitigation planning purposes. Given the limited means available to calibrate and validate the results of hydrologic and hydraulic analyses in an ungauged basin, it is crucial to utilize the most up-to-date and accurate data to derive the river and basin characteristics [27]. To accomplish this goal, primary data gathering was conducted using LiDAR (Light Detection and Ranging) Technology, which facilitated the development of a 1-m resolution DEM for the downstream river reach and floodplains. Additionally, a 5-m resolution Interferometric Synthetic Aperture Radar (IFSAR) DEM from the National Mapping and Resource Information Authority (NAMRIA) was utilized to supplement the primary dataset for the remaining

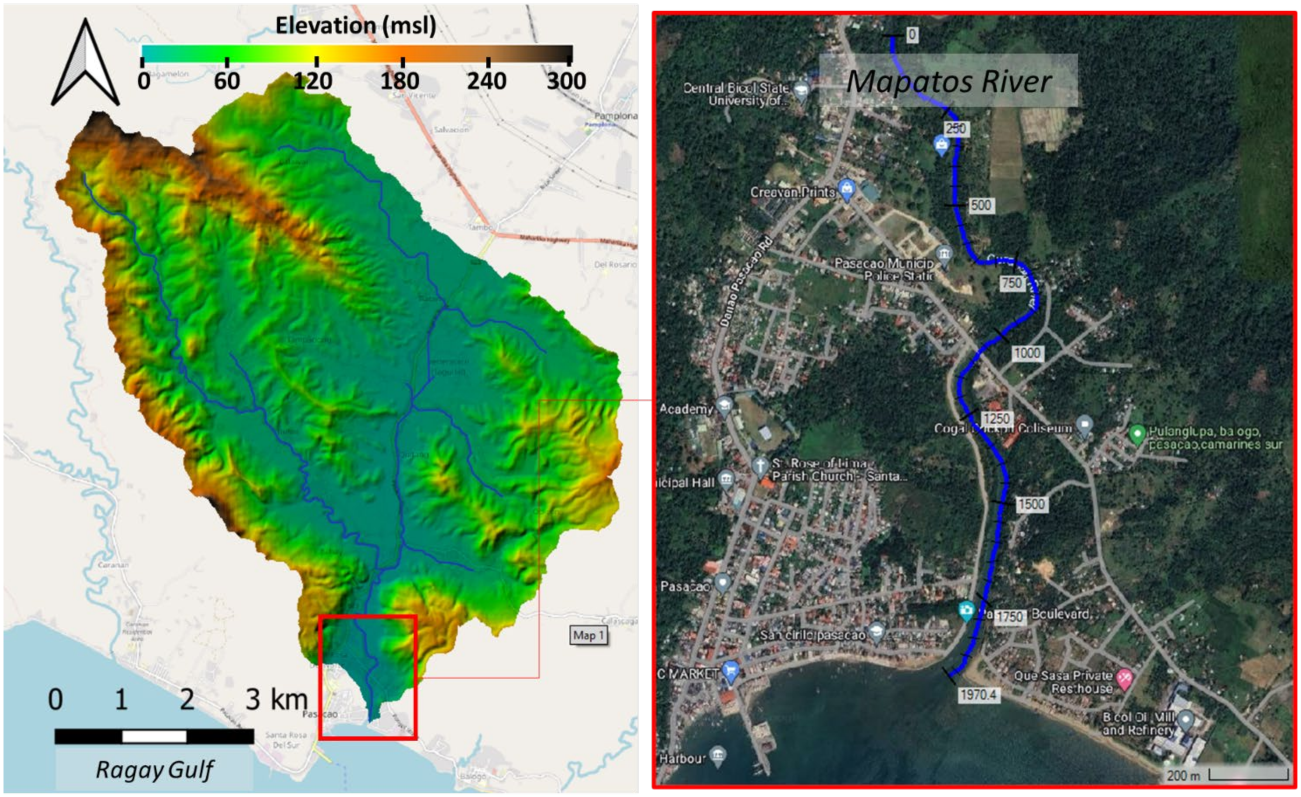


Figure 1 Study area – Mapatos River Basin (left) and downstream reach of Mapatos River (right)

portion of the basin. The land cover map of the basin, with a resolution of 10 m, was also obtained from NAMRIA.

2.2 Study Approach

Figure 2 presents an overview of the methodology employed in the study. Initially, HEC-HMS was utilized to represent the hydrological characteristics of the basin. Subsequently, the flood response of the downstream river reach was simulated using HEC-RAS. The analysis involved a combination of both theoretical and empirical equations, with an emphasis on utilizing local data whenever possible. Regional data was incorporated as necessary to supplement the local data. In cases where historical streamflow and water level records were unavailable, anecdotal accounts and evidences of maximum water stages from a recent flood event were used as an alternative data source for model validation. The outputs of the study consist of quantitative hydrologic and hydraulic parameters, which are crucial inputs for the planning and design of various flood mitigation strategies. It should be noted, however, that this study exclusively focuses on riverine flooding. Although the analysis incorporates the influence of seawater levels by utilizing the gulf's stage hydrograph as a boundary condition in the hydraulic model, it does not account for the effects of coastal waves and direct coastal flooding.

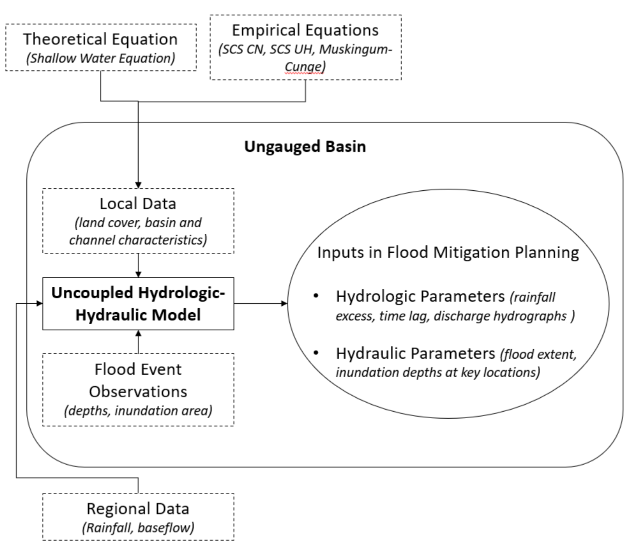


Figure 2 General study approach

2.3 Hydrologic Model

Table 1 presents the methodologies and data utilized for each hydrologic process in model development. Rainfall data was sourced from PAGASA Daet Station, the closest weather station in the study area, approximately 50 km away. For historical event simulation, a 6-hourly rainfall hyetograph from Nov. 9-11, 2020, corresponding to the rainfall associated with Typhoon Vamco, was employed. Average storm simulations, on the other hand, considered return periods of 25, 50, and 100 years, which are standard in drainage and flood control design considerations. The rainfall intensity-duration-frequency (RIDF) relationship based on frequency analysis of 58 years of historical data was directly obtained from the weather station. Given that Vamco and other historical extreme rainfall events passing through the project site featured concentrated rainfall intensity over a day, the model imposed a 24-hour design rainfall duration, distributed according to the Alternating Block Method. This method assigns a non-uniform rainfall distribution over the duration, resembling a discrete pseudo-normal distribution based on the cumulative rainfall depth [28].

Table 1 Description of methods and data in hydrologic modeling

Hydrologic Process	Estimation Method	Required Parameters	Data Source
Precipitation	Direct use of data	historical rainfall hyetograph of a flood event	rain gauge data from nearest PAGASA* weather station
		Rainfall Intensity-Duration-Frequency Relationship	processed historical rainfall records of nearest PAGASA* weather station
Hydrologic Losses	SCS CN Method	Curve Number (CN)	CN Map
Rainfall-Runoff Transformation	SCS Unit Hydrograph Method	Curve Number (CN)	CN Map
		Longest flow path of each subbasin Subbasin Slope	extracted from IFSAR** Digital Elevation Model (5mx5m resolution)
Baseflow	Constant	Flow Rate	derived from recorded regional baseflow rate per unit basin area [29]
Channel Routing	Muskingum-Cunge	Reach Length Channel Slope Channel Width Index Celerity Channel Roughness	derived from IFSAR** Digital Elevation Model (5mx5m resolution) and satellite images

**PAGASA - Philippine Atmospheric, Geophysical and Astronomical Services Administration*

***IFSAR - Interferometric Synthetic Aperture Radar*

To estimate hydrologic losses and to perform rainfall-runoff transformation, the SCS Curve Number Method and SCS Synthetic Unit Hydrograph were utilized, respectively. The Curve Number (CN), a crucial parameter in these equations, was obtained from the nationwide Curve Number Map developed by Alcober & Macuha [30], which has a horizontal resolution of 25 m. The soil type within the basin is a mixture of Hydrologic Soil Groups C and D, hence CN's of subbasins are in the high range, i.e., between 76 to 84. As Mapatos River is perennial, baseflow needed to be quantified in the model. A constant value of 8.28 l/s/km^2 of catchment area was adopted, based on gaged rivers in the Bicol Region [29]. Lastly, channel routing employed the Muskingum-Cunge method, an improvement over the widely used Muskingum Model. Unlike its purely empirical predecessor, the Muskingum-Cunge equation incorporates physically-based parameters, integrating channel flow hydraulics in its formulation. The Muskingum-Cunge Model is based on the convective diffusion equation resulting from the combination of the continuity equation and the diffusion form of the momentum equation. Further details about the method can be found in the HEC-HMS Technical Reference Manual [28].

Version 4.12 of HEC-HMS was used to develop an event-based, spatially distributed hydrologic model. The 46.31-km^2 basin was divided into twenty-eight (28) subbasins, properties of which are summarized in Table 2. For the initial model setup, a historical extreme rainfall event was utilized, while the final hydrologic design parameters were based on average storms.

Table 2 Physical characteristics of subbasins of Mapatos River Basin

Subbasin	Area (ha)	Curve Number	Longest Flow Path (km)	Basin Slope (%)	Lag Time (min)
1	175.22	76.46	2.61	9.61	34
2	146.61	77.38	2.57	2.56	60
3	225.41	80.97	3.11	2.38	83
4	215.91	81.30	2.48	7.58	37
5	168.9	82.72	2.84	6.16	49
6	112.47	81.96	2.31	3.81	48
7	157.09	79.49	2.58	6.64	38
8	256.18	81.48	2.87	5.67	43
9	193.18	81.06	2.89	7.24	45
10	121.73	83.35	2.50	0.44	137
11	105.63	82.53	2.51	4.65	43
12	107.96	80.42	2.32	8.11	34
13	160.64	82.94	3.44	3.68	62
14	210.38	83.53	3.78	5.10	63
15	147.65	80.04	3.28	5.19	54
16	131.98	81.10	1.91	7.96	27
17	211.9	82.62	1.86	1.71	54
18	144.63	84.22	2.60	7.00	41
19	244.04	82.78	1.97	15.05	21
20	199.31	78.63	2.93	2.66	69
21	191.63	79.79	3.52	7.79	54
22	172.2	77.68	3.06	5.58	46
23	204.61	80.53	1.64	10.01	21
24	105.24	82.58	2.58	9.28	37
25	132.22	83.71	3.13	6.94	45
26	59.95	80.28	3.78	2.34	90
27	181.22	78.15	2.09	3.40	44
28	147.18	83.82	2.52	5.31	42

In order to establish a relationship between the observed flood levels and the outcomes of the hydrologic model, as well as to determine the hydraulic design parameters, a hydraulic model was created for the downstream portion of the river. This model utilized a two-dimensional unsteady-state hydraulic modeling approach, employing HEC-RAS version 6.4. The core of the hydraulic model relied on the shallow water equations. The finite-volume method was utilized for the continuity equation,

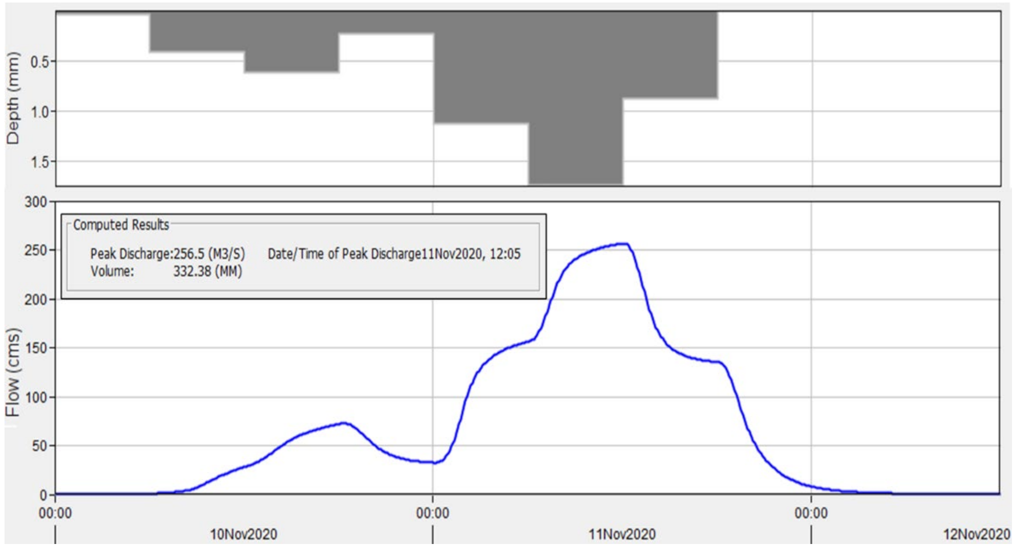


Figure 3 Simulated flow hydrograph during Typhoon Vamco

while the momentum equation took on a finite-difference form. The numerical solvers employed were semi-implicit: explicitly solving acceleration and diffusion terms, semi-implicitly representing friction and flow divergence terms, and implicitly representing the pressure gradient term. A comprehensive explanation of the hydraulic equations and numerical solutions can be found in the Hydraulic Reference Manual [31].

2.4 Hydraulic Model

The hydraulic model encompassed a full two-dimensional representation of approximately 2 km of river reach and its associated floodplains. An unstructured mesh was employed, utilizing cell sizes ranging from 1 m^2 within the river and banks, up to 400 m^2 near the basin divide. Surface roughness parameters were determined based on land cover data, with initial estimates sourced from the HEC-RAS manual [31] and subsequently refined through calibration, taking into account the anecdotal water levels observed during flooding caused by Typhoon Vamco. Upstream boundary conditions incorporated flows from subbasins and channels not accounted for in the hydraulic model, while internal boundary conditions considered flows from subbasins partially encompassed by the model, placed at their respective subbasin outlets. For historical flood event simulations, the downstream boundary conditions were determined using the stage hydrograph resulting from coastal hydrodynamic modeling [32]. As for average storm scenarios, which are regarded as the design conditions and therefore require a conservative approach, the downstream boundary was set at a constant stage equivalent to the highest astronomical tide (HAT) recorded in Ragay Gulf, where the river outfall is situated.

3.0 RESULTS AND DISCUSSION

3.1 Hydrologic and Hydraulic Modeling of Vamco Flood Event

The flood and severe wind caused by Typhoon Vamco was one of the most significant disasters that occurred in the Philippines in 2020. It affected 1.27 million families, resulting in 101 casualties, and causing damages amounting to more than PhP 20.22 billion (408.44 million USD) in infrastructure and agriculture [33]. In the study area, the typhoon brought about a total rainfall of 380.1 mm, with 331.9 mm (87%) of it occurring within a 24-hour period. The hydrologic model generated a flow hydrograph, depicted in Figure 3, illustrating a peak discharge of 256.5 m^3/s. Due to the absence of gaging stations throughout the entire river basin, historical discharge values cannot be verified. This is a common challenge faced in ungauged basins where limited or no historical data is available to directly quantify past hydrologic conditions.

An alternative method for validating the results involves the direct utilization of calculated hydrologic parameters within a hydraulic model. The hydraulic model results can then be compared to physically observed conditions such as flood extent [17,18,24] or inundation depths [19,27]. Flood extent can be inferred from satellite images or aerial photographs, if accessible. Inundation depths, on the other hand, can be acquired through on-site interviews and the identification of flood marks. In this study, flood depth was utilized to validate the model. The hydraulic model employed an unstructured grid and incorporated subgrid technology to represent terrain data. Unlike conventional hydraulic modeling algorithms that average physical properties (e.g., hydraulic radius, elevation, etc.) within a single computational cell, HEC-RAS captures specific details by creating detailed hydraulic property tables within each cell. Each cell possesses a volume-elevation curve that allows for partial flooding within the grid. This approach significantly enhances computational efficiency as cell sizes do not need to be as small as the terrain data, while still accurately capturing terrain characteristics.

Figure 4 showcases the locations where anecdotal accounts and evidences of peak flood depths during Typhoon Vamco were observed. Data was obtained through semi-structured interviews with locals, with the objective of pinpointing flood heights during the event. The elevations of identified flood marks and key points were subsequently measured using a total station. Figure 5 presents a comparison between the observed maximum flood depths and the results generated by the hydraulic model. In this validation process, the Nash-Sutcliffe efficiency (NSe) was computed as 0.54, indicating a satisfactory

Figure 4 Locations within the floodplain near the riverbanks where there were observed maximum flood levels during Typhoon Vamco

model performance. Furthermore, the simulated depths consistently exceeded the observed depths by an average of 0.22 m (43%). This alignment with other studies [14, 20, 23] suggests that the simulation results produced by the HEC-RAS full 2D model are reasonable and typically conservative. In design studies, the inclusion of a factor of safety is paramount, thus accepting conservative estimates, as indicated by the trend shown in the hydrologic-hydraulic model, is appropriate.

3.2 Hydrologic Design Parameters

Hydrologic and hydraulic parameters are essential for the planning, design, and management of structural and non-structural measures against flooding. When it comes to the hydrologic aspect, rainfall-runoff analysis or flood-flow frequency analysis is typically employed. In the case of an ungauged basin, frequency analysis is not possible, so rainfall-runoff analysis, often done with hydrologic numerical modeling tools like HEC-HMS, is preferred. In the Mapatos River Basin, determining rainfall excess, time lag, peak discharge, and full hydrographs is necessary for future flood mitigation planning.

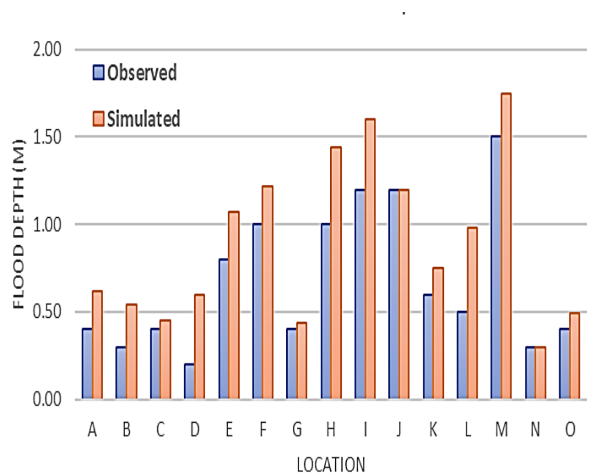


Figure 5 Observed vs. simulated maximum flood levels during Typhoon Vamco

Figure 6 displays the gross rainfall values for different average storms and how they are divided into excess rainfall and hydrologic loss based on model results. It is evident that the basin as a whole has a high runoff turnout, with over 80% of rainfall directly becoming runoff. Upon examining the input data, this result can be attributed to the soil type. According to SCS classification, hydrologic soil groups from A to D are arranged according to decreasing infiltration rates. The study area has predominantly sandy clay loams and silty clays as identified by the Bureau of Soils and Water Management (BSWM), and as reflected in the study of Alcober and Macuha [30]. These types correspond to Hydrologic Soil Groups C and D, which have moderately high and high runoff potentials, respectively. This fact could play a significant role in the planning of non-structural measures, such as in the development of future land use plans.

In the Philippines, the concept of lag time is used as an input in the formulation of early warning systems, as well as in evacuation and rescue operations. For the study area, the lag time, which is the delay between the design rainfall event's center of mass and the peak discharge at the basin outlet, was estimated at 70 minutes. The average basin slope is steep, i.e., greater than 20%, hence the resulting lag time is expected to be relatively fast.

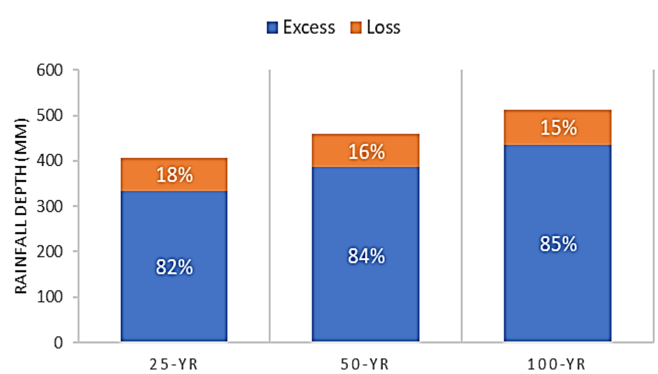


Figure 6 Rainfall excess and losses of average storms with different return periods

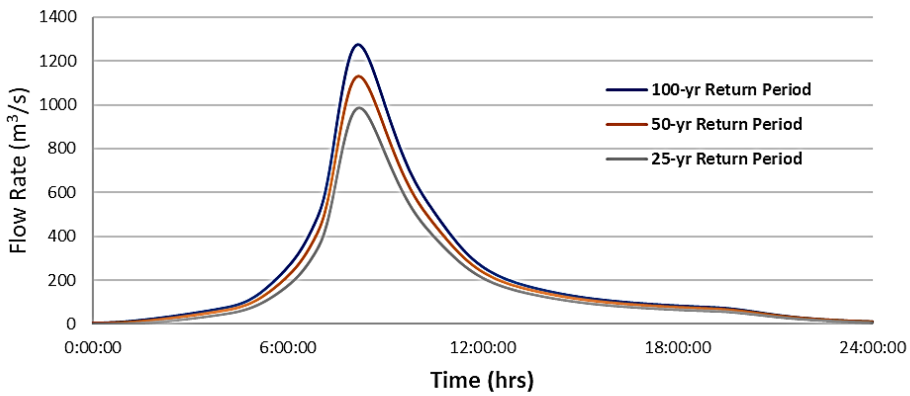


Figure 7 Simulated flow hydrographs of average storms with different return periods

Arguably, the most crucial hydrologic parameter needed in the planning and design of flood structural measures is the peak discharge. Peak discharges are necessary for sizing hydraulic structures such as canals, culverts, pump stations, dams, and weirs. The simulated peak discharges for 25-year, 50-year, and 100-year average storms are 983.6 m^3/s, 1130.4 m^3/s, and 1275.2 m^3/s, respectively. For a detailed analysis of flood events and the planning of other flood mitigating measures like reservoirs and detention basins, the peak discharge needs to be supplemented by the full hydrograph. The flood hydrograph provides a comprehensive description of a historical flood event or a hypothetical design flood condition. Figure 7 illustrates the flood hydrographs generated in the Mapatos River Basin. The same timing parameters can be deduced for different return periods, while the flow magnitudes are directly proportional to the differences in rainfall excess. Another important use of the hydrograph is that it connects the hydrology aspect to other basin processes, such as river hydraulics, watershed sediment yield, and stream sediment transport. In this study, the hydrographs were used as an upstream boundary condition for the hydraulic modeling exercise, the results of which are presented and discussed in the next subsection.

3.3 Hydraulic Design Parameters

The validated hydraulic model depicts the time-dependent water surface elevations in both the river and floodplains. It provides a clear representation of the flood progression relative to the input flow and/or stage hydrographs at the model boundaries. The maximum flood extent and levels are typically utilized as design parameters, often presented through flood hazard maps. Flood maps are important in land use planning, insurance rate determination, property valuation, and flood emergency response planning. Particularly crucial is the role of flood maps in guiding the development of both structural and non-structural measures to combat flooding. Flood heights are essential information for the hydraulic design of floodwalls, dikes, levees, and similar structures. Additionally, early warning systems, evacuation plans, and public awareness programs rely on the information and visual representation of flood hazards. Figure 8 displays the flood maps for the project site's design conditions. Generally, there are subtle differences in terms of flood extents among the 25-year, 50-year, and 100-year rainfall events, which is characteristic of flat coastal areas. In the case of the downstream Mapatos River, i.e., sub-basins 26-28 from

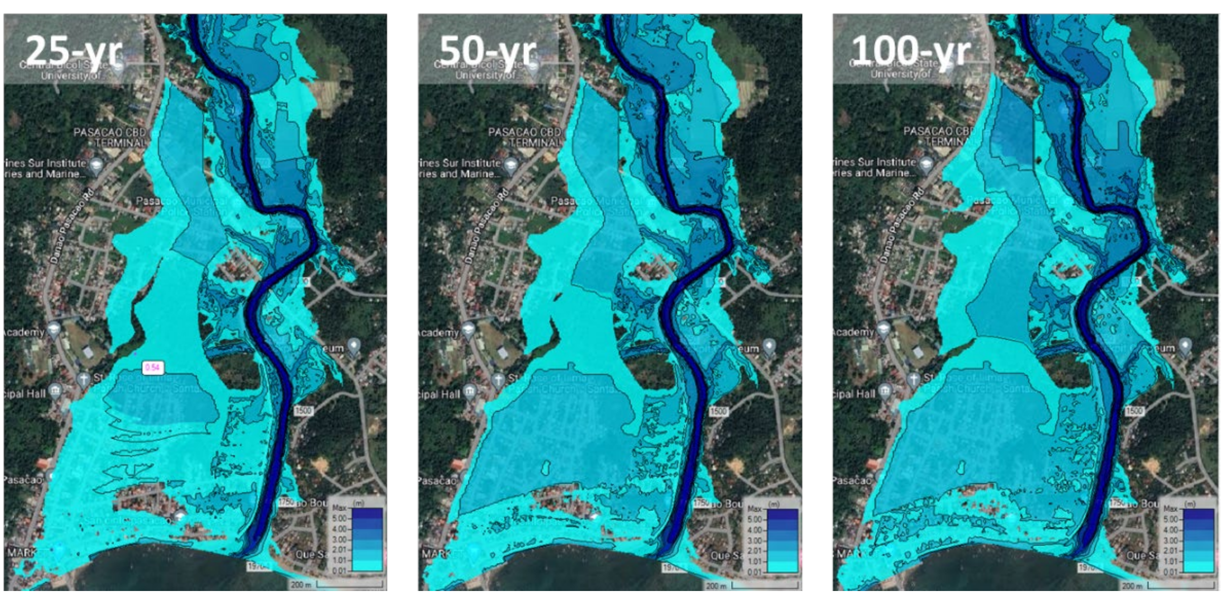


Figure 8 Flood inundations maps for different return periods

Table 2, average catchment slope is around 2-5%. Once the river breaches, floodwater rapidly spreads across a wide floodplain area. Referring to Figure 8, contour lines (at 1-meter intervals) indicate the differences between different return periods. As expected, higher return periods correspond to increased water levels. To further examine flood depths and their impacts, key locations were identified, as demonstrated in Figure 9. In relation to the hydraulic model's scope, the upstream area primarily consists of commercial establishments, while residential blocks are located downstream in the western floodplain. It is also important to evaluate the proximity of public schools, which serve as evacuation areas during disasters. Notably, the municipal police station, serving as the central hub for emergency deployment and response personnel during calamities, is situated near the river and therefore included in the assessment.

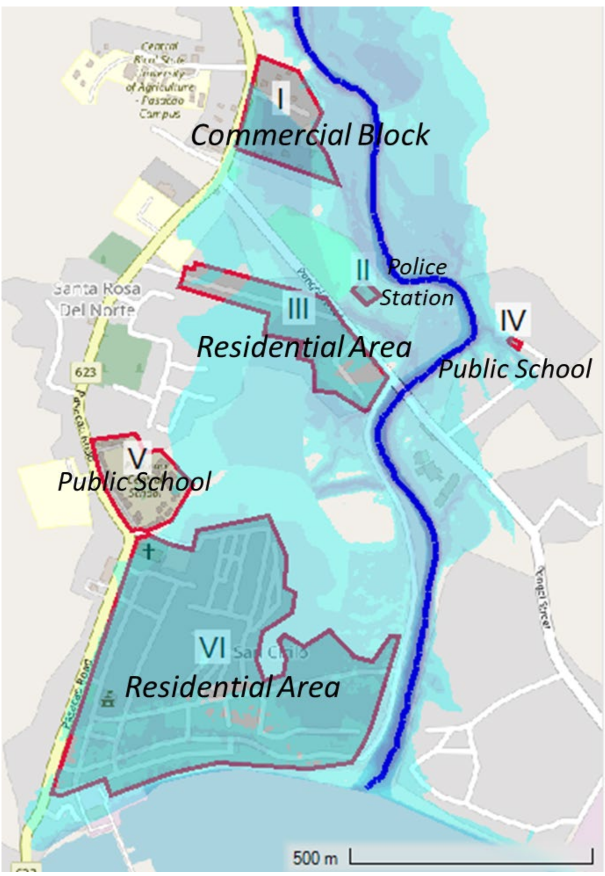


Figure 9 Important locations within the floodplains superimposed in the 100-yr flood map

Table 3 presents the maximum and average flood depths in specified locations for different design conditions. The flood vulnerability of each location can be assessed based on the table values. Both schools exhibit significantly lower average flood depths compared to other areas. Pasacao Central School (Location V) in the western floodplain, although partially flooded, experiences an average inundation depth of 1 cm or ankle-level during a 100-year rainfall event. Considering that the DEM reflects natural ground elevations, it can be inferred that the buildings on the property remain flood-free and therefore provide a safe evacuation location. Conversely, Tilnac Elementary School (Location IV) in the eastern floodplain has relatively higher depths and is located at the flood extent boundary of a 100-year design period. The site may serve as a suitable evacuation area for periodic, low-return period flooding but carries some risk for high-return periods. On the other hand, the commercial and residential blocks, as well as the police station, exhibit high maximum and average flood depths. Depending on the specific criterion used in the design process, whether maximum or average-based flood depth reduction, the information in the table serves as important parameters in the development of effective flood mitigation strategies.

Table 3 Flood depths in important locations within the floodplain area

Location ID	Description	Flood Depths (m)					
		25-yr		50-yr		100-yr	
		Max	Ave	Max	Ave	Max	Ave
I	Commercial Block	2.46	0.71	2.64	0.83	2.82	0.94
II	Police Station	1.25	0.45	1.45	0.65	1.64	0.84
III	Residential Area 1	3.34	0.56	3.53	0.69	3.7	0.82
IV	Public School 1	1.95	0.07	2.14	0.1	2.33	0.14
V	Public School 2	0.12	0.01	0.15	0.01	0.15	0.01
VI	Residential Area II	1.9	0.71	2.1	0.93	2.27	1.11

4.0 CONCLUSION

One of the challenges in flood mitigation planning in an ungauged location is the limited availability of hydrologic and hydraulic data required for the development of effective mitigating measures. This paper presents a methodology for estimating crucial hydrologic design parameters, such as rainfall excess, lag time, peak discharge, and total hydrograph, as well as hydraulic parameters like flood extent and inundation depth. The significance of each parameter is also briefly discussed to provide a comprehensive understanding of the planning process. The developed hydrologic-hydraulic model generates conservative estimates of flood levels, which is essential for design studies as a safety margin must always be included in the planning and design phase. The methodology can be applied to other ungauged locations, provided that similar or more advanced model validations are conducted.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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