Hydrologic and Hydraulic Simulation of Flooding in Areas along Ilugin River and Buli Creek in Pasig, Philippines

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Abstract: The areas surrounding Ilugin-Buli channel are prone to flooding since it is a tributary of a major basin, Pasig-Laguna River, increasing the risk of overflowing along the channel. The study generated flood scenarios in the areas along Ilugin-Buli channel in 2-year, 5-yr, 20-yr, and 25-yr return periods. Flooding in the corresponding periods were simulated by hydrologic and hydraulic models. Hydrologic modeling was done using QGIS and HEC-HMS for delineation and hydrologic conditions. The method used for infiltration is the SCS Curve Number while Clark Unit Hydrograph is used for the transform method. The behavior of the reaches was simulated using the Muskingum-Cunge routing. Physical and hydrological parameters were provided by local agencies for accurate results. Validation of the hydrographs was done using rational method and comparison with the peak discharge of Typhoon Ondoy. For hydraulic modeling, two models were produced using HEC-RAS. Geometric settings were set based on the collected information. Generated hydrographs were used for boundary conditions. One- and two-dimensional hydraulic models showed the flood depth and velocity, and water surface elevations of areas surrounding the Ilugin-Buli channel. Both models indicated depth of 0 to 1 meter in the study area where areas along the channel banks were in 0.05 to 1 meter while other areas are below 0.05 meter. 1D showed how flooding occurred in the upstream section of the channel because its capacity cannot contain the flow rate of the return periods. This was quantified by 2D model with the flood depth and velocity.

Key Words: tributary; hydraulic model; hydrologic model; rational method

1. INTRODUCTION

Flooding is a phenomenon inclined to become a potential hazard influenced by environmental and social characteristics. According to Water Science School in USGS (2018), the stormwater runoff initially flows downhill in small waterways like creeks or *esteros* after which merges into larger streams and eventually river basins. Tributaries of the rivers are used as drainage channels which helps in determining the route of flow discharge. It is important to know and identify the drainage networks like creeks to determine its contribution to flood waters. However, this may face challenges if the channel's capacity cannot handle the flood intensity level. Ilugin-Buli channel bounded by Pinagbuhatan, Pasig City and San Andres, Cainta Rizal, is a tributary of Pasig-Laguna major basin as shown in Figure 1. With this, there is a high possibility of flooding with respect to semi-impermeable urban areas located along Ilugin-Buli channel.

Identification of flood discharges and analysis on the capabilities of drainage systems are done by carrying out hydrological and hydraulic analysis. The most common software used for these simulations are hydrologic engineering center – hydrologic modeling system (HEC-HMS) and hydrologic engineering center river analysis system (HEC-RAS). Firdaus et al. (2022) investigated the drainage channel in the Buah river subsystem to know its capacity, hydrology, and hydraulic flow. Bruno et al. (2022) also used hydrological and hydraulic simulations to investigate a small urban channel in Campo Grande, Mato Grosso do Sul. Generating flood scenarios are beneficial in knowing the effects of land use and coverage in the study area. These shows potential impacts of the associated risks of flooding particularly on extreme scenarios.

Areas along Ilugin-Buli as shown in Figure 2 were recognized to be at high flood risk within years 2020 to 2030 (Pornasdoro et al., 2014). Ondoy in 2009 was reported as the typhoon that caused extensive flooding due to the overflowing of the rivers that drain to the basin (Monjardin et. al, 2019). In a short span of time, the maximum depth of flood in some of these areas have reached up to 7 meters. The discharge of the river channel and tributaries was indicated to be as twice as the normal discharging due to the rainfall intensity (Sato & Nakasu, 2011).

Robas (2014) indicated the need to conduct more comprehensive studies in identifying the risk and hazard on the areas within Pasig City. Likewise, Alfonso et al. (2019) indicated the need for strategic measures specifically designed for a certain municipality to focus more on the heavily inundated key areas. Because of the risk to life, health, property, and natural floodplain resources and functions, knowing the flooding scenarios within the study area is important to identify areas that are prone to flood hazard and quantify the flooding.

The study aims to generate flood scenarios in Ilugin-Buli channel for 2-year, 5-year, 20-year, and 25-year return period flood. The study focused on modelling the hydraulic and hydrological aspects of flooding within Ilugin-Buli in the given return period.

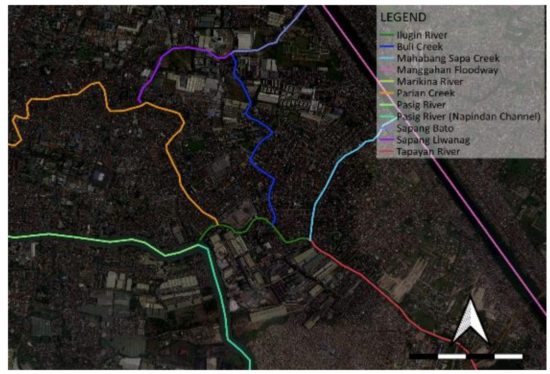

Figure 1. Ilugin-Buli and Other Tributaries of Pasig-Laguna Basin

Figure 2. Map of Areas along Ilugin-Buli

In Metro Manila and nearby provinces, research concerning the understanding of potential hazards through hydrologic and hydraulic modelling are done at large scales. Small-scale models, like in the case of Ilugin-Buli area, can be more specific and provide clearer early warning system and forecasting of urban flooding characteristics. To aid engineers in planning and constructing urban drainages for better water management, the resulting flood generated scenarios can pinpoint vulnerable areas and potential impacts of flooding that needed engineering solutions.

2. METHODOLOGY

Flood scenarios in the study were generated using hydrologic and hydraulic modelling. According to Santos (2021), hydrologic modelling is defined as the study on hydrological cycle which includes precipitation, evaporation, rainfall-runoff, and surface runoff. Concurrently, hydraulic modelling refers to the study of the behavior of flow in a particular water system, such as rivers, stream networks, pipelines, or channels. These models are often integrated to investigate water-related issues particularly flood forecasting and flood scenarios.

Agnihtori et al. (2017) executed a study utilizing GIS, HEC-RAS, and HEC-GeoRAS to model the river flooding in Purna River, Navasari District in India. They utilized ArcGIS with a HEC-RAS extension, to translate the geospatial data to be understood by the HEC-RAS software. The geospatial information was then combined with river cross-sections in HEC-RAS to start its simulation and modelling process. Their integration would illustrate a micro and macro analysis of the area, that could be utilized in further studies and urban planning.

The methodology of the study conducted was broken down into the gathering of necessary data and the processing of acquired information. The geographical, meteorological, and hydrological information were acquired from respective government offices. In the case that such data were not available, field surveys were conducted.

The information gathered was processed utilizing 3 primary software QGIS, HEC-HMS, and HEC-RAS. The delineation of the study area was conducted using QGIS and HEC-HMS with their corresponding geographical information. The delineated area is composed of 6 subbasins, 5 reaches, and 5 joints as illustrated in Figure 3.

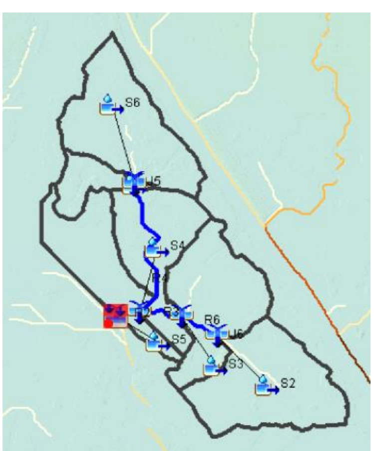

Figure 3. Delineated Catchment

HEC-HMS utilized the delineated basin with the gathered precipitation and hydrological information to simulate the hydrologic cycle and produce hydrographs. The infiltration method used in modeling the basin was the SCS Curve Number loss number, and the Clark unit hydrograph was utilized for the transform method of the hydrologic cycle. Yannopoulos et al., (2006) states that SCS Curve Number loss number and Clark unit hydrograph were deemed the most reliable compared to other methods such as the Snyder method. The time concentration T_c was calculated with equation 1, and the R was calculated with equation 2 for the Clark unit hydrograph. The Muskingum-Cunge routing method was utilized to simulate the behavior of the reaches. Validation utilized the rational method shown in equation 2 to compare peak discharges, Typhoon Ondoy was compared to the produced 50-year return period.

$$T_c = 2.2 * \left(\frac{L * Lc}{\sqrt{Slope_{10-85}}}\right)^{0.3} \qquad \text{(Eq. 1)}$$

where T_c = time of concentration
L = length of the longest watercourse within the drainage area
L_c = stream length to the basin centroid

$$\frac{R}{T_c - R} = 0.65 \qquad \text{(Eq. 2)}$$

where R = storage coefficient

$$Q_p = 0.0028 \times C \times I \times A \qquad \text{(Eq. 3)}$$

where Q_p = peak runoff rate (m^3/s)
C = runoff coefficient
I = rainfall intensity *(mm/hr)*
A = drainage area *(ha)*

Hydraulic models were created utilizing HEC-RAS combined with the delineated study area, hydrographs, and the levels of flooding criteria of the Santos' (2021) flood criteria based on Mines and Geosciences Bureau (MGB) as shown in Table 1. This was divided into two dimensions, 1D and 2D. The 1D focuses on hydraulic conditions such as the river's discharge and cross-section. Centerline was first acquired, and three reaches were identified based on HEC-RAS as shown in Figure 4.

Table 1. Classification of Flood Depth (Santos, 2021)

Flood depth (m)	Classification	Flood Level
0 – 0.1	0	None
0.1 – 0.5	1	Low Flood
0.5 – 1	2	Moderate Flood
1 – 2	3	High Flood
2 and above	4	Very High Flood

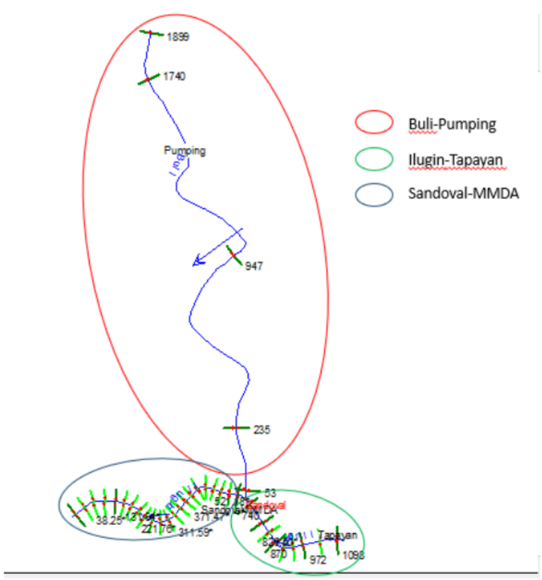

Figure 4. Identification of the Three Reaches

The 2D focuses on flood plain modeling. The 5m raster file were reprojected that contain the right coordinate reference system and was used to visually check the river boundaries and areas of interest. It was used then to trace the perimeter of 2D flow area. The terrain was modified using the Line channel feature due to the raster file did not contain the elevations of creek bed.

Each modeling used parameters such as flow hydrographs, normal depth, and precipitation hydrograph on each boundary conditions to produce the results necessary for the objective of this study.

3. RESULTS AND DISCUSSION

The resulting flow hydrographs of 2-, 5-, 20-, and 25-year return periods were the expected outflow of the catchment at the outlet from the delineated subbasins. Peak discharges for the return periods in the same order were 11.2, 18.4, 28.8, and 30.5 m^3/s. These represented the volume of runoff contributing to the flooding scenarios. Peaks of the hydrographs showed at 21:15. The hydrographs were validated using rational method and RIDF was used to calculate the peak discharge. Validation showed small discrepancies with the simulated peak discharges, having at most 14.23 percent difference. The peak discharge of Ondoy for the basin is 36.5 m^3/s while the generated 50-yr return period is 35.5 m^3/s. This indicated that the modeled hydrologic catchment using HEC-HMS exhibited the hydrologic condition of the catchment.

Typhoon Ondoy was simulated and predicted to be a 50-yr return period, indicating to be larger than the generated flood scenarios. The 2-yr to 25-yr return periods encapsulated the typical design for drainage works and flood protection works which were 10-yr and 25-yr return periods (Gatan, 2009). The basis of the study was Typhoon Ondoy, as MMDA indicated that this was the only typhoon that made the Ilugin-Buli channel overflow. This showed how for an extreme event like Typhoon Ondoy which has a 50-yr return period, higher flood inundation are to be expected. The design for drainage works and flood protection works are only for 10-yr and 25-yr return periods which means that it cannot accommodate the higher return periods of precipitation and discharge.

Results for the hydraulic modelling include the water surface elevation (WSE), velocity, and depth of water for the watershed. The MMDA Floodgate is one of the areas of interest, as this serves as an important hydraulic structure. The channel profile was simplified to an isosceles trapezoid with a 1.25 slope for simplification and modelling speed. DEM used was in reference to the mean sea level (msl), with flood gate at 3.54m above the msl.

The 2-year, 5-year, 20-year, and 25-year return periods were used for the flow hydrograph (inflows from Ilugin Buli-Reach and Ilugin-Tapayan Reach), normal depth (outflow to Ilugin downstream), and rain hydrographs.

For the 2-year return period, the WSE has a distribution of 2.5m to 5.1m above msl, with most of the area on the lower side of the spectrum. The WSE near the floodgate approximately 2.6m. The flow velocity ranges from 0.01-0.33m/s, with most of the area having lower velocities. The flow velocity is not harmful to humans that tread the waters. The area experiences flooding from rain trapped in flat areas, with depths ranging from 0.1m to 0.3m. The flood depths are classified as low flood level; therefore, the area is non-threatening.

The 5-year, 20-year, and 25-year return period flood show similar trends in WSE, velocity, and depth. The channel did not overflow for all return periods, while the velocities and depths of the surrounding areas are safe for humans to travel in. The MMDA Floodgate did not exceed its capacity.

In the survey conducted by Porio (2011) in the low-lying areas near the river systems and tributaries of Metro Manila including Barangay Pinagbuhatan, most of the residents suffer from the inundation of the waterways during typhoons and monsoon seasons. Furthermore, the study indicates that the expansion of urban construction of establishments and temporary structures of informal settlers made flooding more intense since proper drainage and sewerage systems were not implemented. The areas near the Laguna de Bay and Napindan Channel, where Ilugin-Buli Tributaries are located, are also not ideal for habitation and development since these are mostly wetlands. These different factors had contributed to the frequent and increasing intensity of flooding in the area that left communities no choice but to get used to water entering their homes. The DRRMO of the Pasig LGU also reported several flooding incidents in Ilugin, A. Sandaval Ave., and M. H. Del Pilar St. with flood depth up to 6 inches.

The occurrence of challenges in the study were prominent particularly in the fieldwork and site assessment of Ilugin-Buli channel. The obstructions that could affect the results of the study were silt and garbage that are mostly non-biodegradable and growth and proliferation of floating plants, water hyacinths, in specific locations of the river stretch. These were further observed in cross-section profiling for hydraulic modelling, where the undredged creek bed at Ilugin-Tapayan junction obtained from the vicinity map of Metro Manila Development Authority (MMDA) had higher elevation compared to the creek bed at Pumping station near the junction of Ilugin-Buli channel. These can affect the capacity of the channel as well as its flow if certain measures are not done for its removal.

4. CONCLUSIONS

The study generated flood scenarios for 2-year, 5-yr, 20-yr, and 25-yr return periods in areas along Ilugin-Buli channel by hydrologic and hydraulic modeling.

The hydrographs that were simulated using HEC-HMS showed the trend of increasing flow rate as return periods are also increased. 1D hydraulic modeling using HEC-RAS showed the increasing water surface elevations in relation to the simulated hydrographs in every return period. The downstream section in 1D showed little to no inundation depth indicating that the flow from upstream had spread over the riverbanks before reaching the downstream sections. In 2D modeling, flood depth and flood velocity were determined and mapped to describe the extent of inundation of the areas around Ilugin River and Buli Creek. The conditions of the 2-yr exhibits no flooding for both 1D and 2D hydraulic models, minimal locations experienced low floods. The analysis of 5- yr, 10-yr, 15-year, 20-yr, and 25-yr return periods have similar flood patterns and shape, they each resulted with low flooding in the study area.

The study faced limitations due to inadequate information, particularly the scarcity of historical records of flood discharges and the lack of data regarding the morphology of river cross sections. It is recommended to gather these data to conduct flood frequency analysis. Flood frequency analysis will provide a better validation on the hydrologic model generated and thus helps in knowing the magnitude, severity, and frequency of floods in the desired return period for the hydraulic model. Acquisition of measurements during dry and wet season increases the accuracy of simulations. It is also advised to acquire the as-built plans of the cross-sections in Ilugin-Buli channel particularly covered by hydraulic structures to serve as additional boundary conditions for more validation.

As the output would benefit flood response and mitigation (processes and structures), further flood hazard and risk assessment can be done. This includes the area's channel structures (stormwater system and road network), critical buildings, and other factors or hazards that can work in conjunction with floods (earthquakes, soil hazards, vehicular and pedestrian traffic). Other factors may be integrated to the models such as water pollution and quality levels, population density in the area and structures, and distance to closest evacuation center to forecast the vulnerability assessment along the areas around Ilugin-Buli waterway. This information would produce a more in-depth vulnerability flood danger map, which could be utilize in future planning or identification of priority flood management projects.

5. ACKNOWLEDGMENTS

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