Hydrologic Modeling and Delineation of Calumpang River Watershed using GIS and Hydrologic Model System

R.R.Santoalla[1], J.T.Cortes[1], K.P.Generos[1], V.A.Monta[1], F.J.Tan[1], F.A.Uy[1] and Lai Siang Leng[2]
[1]*School of Civil, Geological and Environmental Engineering,*
Mapúa University Intramuros 658 Muralla St., Intramuros, Manila 1002, Philippines.
[2]*School of Microelectronic Engineering, Universiti Malaysia Perlis,*
Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
rodmarsantoalla10@gmail.com

***Abstract*—The Calumpang Bridge in CALABARZON Region, Southern Luzon Philippines did not withstand the river current brought by Super Typhoon Glenda (Rammasun) on July 2014, causing the destruction of one-third of the bridge, thus resulting to traffic congestion and economic distress for the residents and businessmen. This paper aims to create a calibrated hydrological model. Specifically, it focuses on delineating watershed, simulation based on observed flow data and validation that will be the basis for flood risk map for the river. The watershed has been delineated and it is calibrated, the basin was modeled using Hydrologic Model System and GIS Applications to determine hydrologic parameters which have spatial characteristic and to compute the peak Discharge and loss infiltration. The model delineated by the use of GIS software has been hydrologically corrected. The model describes the correlation of the rainfall, losses, time of concentration, Storage factor and amount of discharge. It shows that the amount of Rainfall at a given time dictates the amount of discharge the watershed generates. The higher the rainfall amount, the higher the discharge. The model was validated using Percentage Error and Rational Method, and due to the accuracy of the validated model, it provides a promising approach to Bridge Structural Design and Flood Risk Map Generation.**

***Index Terms*—HEC-HMS; GIS; Calumpang Bridge; Rammasun.**

I. INTRODUCTION

Fossil Batangas province is bounded to the north by Cavite province, on the northeast and east by the provinces of Laguna and Quezon, respectively, on the south by the Verde Island passages and the west by the West Philippine Sea [1]. It has a land area of 3,165.81 square kilometers. Its land percentage to CALABARZON land area is 18.8%. In Batangas, the average monthly rainfall is less than 50 mm per month from January to April. For June, July, August, and September when southwest monsoon flow, maximum rain period occurs in Batangas, the average monthly rainfall is 275 mm per month [2]

Batangas' major river system is the Calumpang River which flows into the Batangas Bay. It has a catchment area of approximately 472.00 square kilometers. It has an approximate length of eight kilometers and an average width of 90 meters. When Typhoon Glenda hit the city in 2014, it resulted in flooding of the areas around the river and destruction of Calumpang Bridge [1].

Calumpang river watershed area is quite urbanized along the riverbanks inland, but the area near the coast along the river is not quite urbanized, meaning it does not house any significant structure. For the last eight years, since 2006, there has been a significant development inland around the watershed but again there is still no significant urbanization along the river near the coast (As based on 2006-2014 satellite image of the watershed).

In July 2014, Super Typhoon Glenda hit the province of Batangas which caused flooding in the area around Calumpang River resulting to the destruction of the 22-year-old Calumpang Bridge and the Calumpang Dike [7]. As of February 2015, the rehabilitation of the bridge is at its planning stage. These events have occurred in the study area due to non-established risks and hazards that are possible to generate.

The researchers aim to create a hydrological model that can be used as a basis to assess the risk involved in the watershed based on certain amount of rainfall and how it will affect the livelihood and properties of the residents. The researchers' aim is to create a hydrological model using two computer programs called ArcGIS and HEC-HMS. ArcGIS will be used to process the geographical information that has been gathered and digitalized to create a hydrological model. On the other hand, the Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes of watershed systems. This software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing.

The two software are commonly used in watershed and flood studies. Based on past studies [4-6], these software are known for their reliability. Additionally, the researchers are knowledgeable about the said software. The researchers' ArcGIS were provided by the Institute for a year. HEC-HMS is a freeware and downloadable from the Hydrologic Engineering Center (HEC) website. Lastly, the data from ArcGIS can be exported to HEC-HMS through a toolbar and vice versa.

The study was conducted using two computer software, ArcGIS and HEC-HMS, to create a hydrological model of Calumpang river watershed. This research is not a design of infrastructures to prevent flooding and risk analysis of the watershed. The scope area only covers the Calumpang River watershed. The model can be a basis for the flood risk map that authorities can use. The output is in the form of data model and there is no prototype

II. MATERIAL AND METHODS

This work was conducted based on the framework shown in Figure 1. The data about rainfall was based on the data coming from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

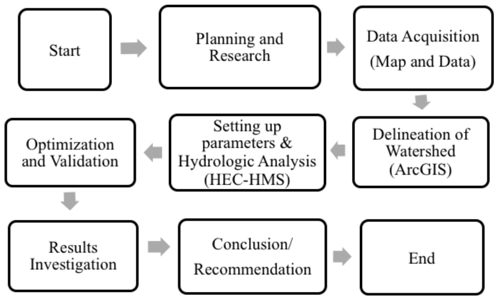

Figure 1: Research Framework

The researchers have gathered the following data to help in their study:

- SAR-DEM (Sound and Ranging – Digital Elevation Model) from Phil-Lidar I (Mapua Chapter)
- CN Values as initial Parameters
- Rain gauge station and Rainfall values: Rain Gauge Station located at Brgy, Kumintang, Batangas City, Rainfall Values from DOST-PAG ASA

Figure 2 shows the satellite image of the Calumpang River watershed area and Figure 3 shows SAR-DEM of Region 4-A Raw Map Data.

Figure 2: Satellite Image of Calumpang River Watershed (2015)

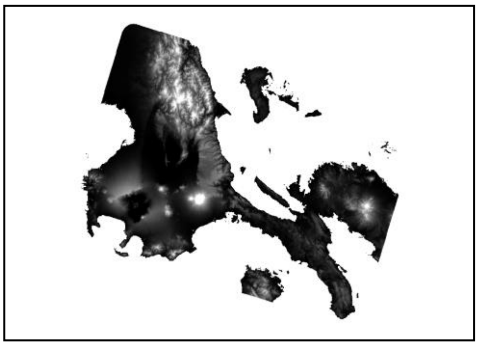

Figure 3: SAR-DEM of Region 4-A Raw Map Data

A hydrologic analysis was performed to estimate the flood discharge at a location along the flooding source. The hydrologic modeling tool in the ArcGIS which is the HEC-GeoHMS is a toolbox that provides methods for describing the physical components of a surface. These hydrologic tools hydrologically corrected and delineated watersheds create stream networks and set some hydrologic parameters. HEC-HMS preformed hydrologic analysis of the watershed using the hydrologically corrected DEM from ArcGIS. One parameter included was the sub-basins area express in KM^2. These areas were acquired in the ArcGIS. Curve Number Loss Method determined the amount of rainfall that infiltrated and amount of rainfall that became a part of runoff. The parameter that this method includes the curve number (CN) which is a hydrological parameter that projects the value of direct runoff infiltration.

The Clark Transform Method is processes of translation and reduction that dictates the movement of flow through a watershed. Time of concentration (TC) and Storage Coefficient, both in hours, generated in the ArcGIS was set to be the parameter.

The recession method was used because the volume and timing of the base flow are strongly influenced by the precipitation event itself. The inputted parameters were the initial discharge using 37 m^3/s outflow from the outlet) wherein the computed total area of the sub basin was 373.3005$km^{2,}$ Recession Constant which describing the rate of base flow decay and the Threshold flow which is specified as the ratio of the peak flow. As an initial parameter, the researcher assigned Recession Constant to 1 and Ratio to Peak to be 0.5: l. Muskingum-cunge method of using channel characteristic is used to obtain the routing coefficient of the channel. Parameters include channel length, slope, and Manning's n, width and side slope. Length of the channel and slope of the channel was computed in the HEC-GeoHMS toolbox in ArcGIS. Manning's n coefficient was said to be 0.04 in accordance with the usual practice in a hydrologic study. The width shape varies with the average width of the reach using the Google Earth application.

The researchers based the model calibration and validation on the standard of American Society of Agricultural and Biological Engineers Standard/Engineering Practice.

III. RESULTS AND DISCUSSIONS

Hydrologic analysis of the Calumpang River watershed was prepared through the use of HEC-HMS. A new project was created in HEC-HMS by importing the Calumpang River Watershed Model from the ArcGIS. The control specification and time data series used the following data from DOST – PAGASA and PHIL – LIDAR I (Mapua Chapter). The initial parameter was optimized in HEC-HMS. It was based on the previous simulated run. The optimized results for the base flow and storage coefficient are shown in Table 1.

The optimized results for Clark Time of concentration and curve number are shown in Table 2. The optimized results for initial abstraction and threshold ratio are shown in Table 3.

Table 1
Base Flow and Clark Storage optimized values

Base Flow Initial Flow (m^3/s)			Clark Storage Coefficient (Hour)		
Element	Initial	Optimized Value	Element	Initial	Optimized Value
W1000	0.3505	0.34349	W1000	4.5368	4.5592
W1010	0.17376	0.17028	W1010	1.9787	2.968
W1020	0.038905	0.038127	W1020	0.66668	0.44445
W1030	0.750644	0.73563	W1030	3.7057	5.5586
W1040	0.0185	0.01813	W1040	0.47009	0.46069
W1050	1.7887	1.7529	W1050	4.9906	5.0138
W1060	0.10783	0.10567	W1060	1.5569	1.0379
W1070	0.11107	0.10885	W1070	1.8693	1.2462
W1080	0.23088	0.22626	W1080	3.0308	3.0376
W1090	0.56772	0.55637	W1090	4.5288	4.5512
W1100	2.0195	1.9791	W1100	4.5837	6.8756
W1110	0.084465	0.082776	W1110	1.8279	1.7913
W1120	0.49878	0.4888	W1120	5.0559	5.0806
W1130	0.38937	0.38158	W1130	3.3454	3.2785
W1140	0.2541	0.24902	W1140	3.0151	2.9168
W580	1.1091	1.0869	W580	7.9149	7.9509
W590	0.80156	0.78553	W590	7.7145	11.572
W600	0.61097	0.59875	W600	5.5141	5.5404
W610	1.9043	1.8662	W610	9.5866	9.6261
W620	1.8184	1.782	W620	11.74567	11.785
W630	0.4604	0.45119	W630	6.8947	6.9131
W640	1.9137	1.2758	W640	11.5	11.535
W650	0.837	0.82026	W650	8.001	12.002
W670	0.23613	0.23141	W670	3.6628	5.4942
W680	0.83039	0.81378	W680	7.7066	7.7415
W690	0.41151	0.40328	W690	5.5126	5.5387
W700	0.16363	0.10909	W700	2.8693	2.8119
W710	0.45344	0.44437	W710	4.1969	4.2167

Table 2
Clark Time of Concentration and Curve Number optimized values

Clark Time of Concentration (Hour)			Curve Number		
Element	Initial	Optimized Value	Element	Initial	Optimized Value
W1000	2.7799	4.1698	W1000	88.847	87.07
W1010	1.2124	1.2183	W1010	89	87.22
W1020	0.40851	0.27234	W1020	83.89	55.927
W1030	2.2707	3.4061	W1030	86.99	85.25
W1040	0.28805	0.28229	W1040	83.528	81.857
W1050	3.058	3.0703	W1050	87.159	85.416
W1060	0.95399	0.63599	W1060	76.502	51.001
W1070	1.1454	0.7636	W1070	76.217	74.693
W1080	1.8571	1.8571	W1080	76.477	74.947
W1090	2.775	4.1625	W1090	88.254	86.489
W1100	2.8086	4.2129	W1100	83.409	81.741
W1110	1.12	0.74667	W1110	75.909	74.391
W1120	3.098	3.1134	W1120	84.051	82.37
W1130	2.0499	1.3666	W1130	80.317	78.711
W1140	1.8475	1.2317	W1140	78.5	52.333
W580	4.8498	4.874	W580	79.465	77.876
W590	4.727	4.7504	W590	79.118	77.536
W600	3.3787	3.3955	W600	80.166	78.563
W610	5.8741	5.9034	W610	64.993	65.253
W620	7.1971	7.2325	W620	85.313	85.459
W630	4.2247	4.2456	W630	76.65	68.985
W640	7.0467	7.0815	W640	86.348	86.562
W650	4.9026	4.927	W650	73.903	73.903
W670	2.2444	3.3666	W670	78	76.44
W680	4.7222	7.0833	W680	77.498	75.948
W690	3.3778	3.3946	W690	78	76.44
W700	1.7581	1.7669	W700	89	87.22
W710	2.5717	3.8576	W710	83.976	82.296

Table 3
Initial Abstraction and Threshold Ratio optimized values

Initial Abstraction (mm)			Threshold Ratio		
Element	Initial	Optimized Value	Element	Initial	Optimized Value
W1000	1.5943	1.6023	W1000	0.5	0.75
W1010	1.5697	2.3546	W1010	0.5	0.5024
W1020	2.4389	3.6583	W1020	0.5	0.5025
W1030	1.8994	1.9089	W1030	0.5	0.50249
W1040	2.5046	3.7569	W1040	0.5	0.5025
W1050	1.871	1.8803	W1050	0.5	0.50249
W1060	3.9009	5.8514	W1060	0.5	0.5025
W1070	3.963	5.9445	W1070	0.5	0.5025
W1080	3.9062	5.8593	W1080	0.5	0.5025
W1090	1.6903	2.5354	W1090	0.5	0.75
W1100	2.5262	2.5388	W1100	0.5	0.75
W1110	4.0306	6.0459	W1110	0.5	0.5025
W1120	2.4099	2.4219	W1120	0.5	0.75
W1130	3.1124	4.6686	W1130	0.5	0.50249
W1140	3.4784	5.2176	W1140	0.5	0.50161
W580	3.2819	3.2983	W580	0.5	0.5
W590	3.352	3.3687	W590	0.5	0.5
W600	3.1422	3.1579	W600	0.5	0.75
W610	6.8406	6.8747	W610	0.5	0.5
W620	2.1864	2.1973	W620	0.5	0.5
W630	3.8687	3.888	W630	0.5	0.5
W640	2.0079	2.0179	W640	0.5	0.5
W650	4.4846	4.507	W650	0.5	0.5
W670	3.5821	3.6	W670	0.5	0.5025
W680	3.6875	3.7059	W680	0.5	0.5
W690	3.5821	3.6	W690	0.5	0.75
W700	1.5697	2.3546	W700	0.5	0.50249
W710	2.4234	2.4355	W710	0.5	0.75

HEC-HMS lessened the difference in the value between the simulated run to the observed value. In this way, simulation run for a different rainfall will have a little difference to the observed value.

To validate the result, the researchers compared the Simulated Peak Discharge with its corresponding Observe Discharge.

To validate the result, the researchers compare the Simulated Peak Discharge with its corresponding Observe Discharge.

- Simulated Peak Discharge = 751.5 m^3/s
- Corresponding Observe Discharge to the Simulated Peak Discharge = 693.4 m^3/s.

Thus, the % difference between these two is 8.04% which is classified as very good based on American Society of Agricultural and Biological Engineers Standard/Engineering Practice for model calibration and validation. In addition, by using Rational Method for Validation,

$$Q = CIA/3.6 \tag{1}$$

where C = Run-off Coefficient
I = Rainfall Intensity during Time of Concentration (mm/hr)
A = Area (KM^2)

Thus, Q= 728.13 m3/s. Hence, the % of difference between the simulated peak discharge and Q is 4.16% which is classified as very good based on American Society of Agricultural and Biological Engineers Standard/Engineering Practice for model calibration and validation.

IV. Conclusion

The main goal of this study was to create a hydrological model for Calumpang River Watershed in Batangas. After the acquisition and establishment of hydrologic datasets, the study goal was fulfilled. As a result, the Calumpang basin was modeled using HEC-HMS through ArcGIS, and HEC-GeoHMS to determine Hydrologic parameters which have spatial characteristic and to compute the peak Discharge and loss infiltration using the SCS-CN method. The model created by the researchers has been delineated using Arc – GIS; therefore, it has been hydrologically corrected. The model describes the correlation between the rainfall amount and discharge. It shows that the amount of Rainfall dictates the amount of discharge the watershed generates. The higher the rainfall amount, the higher the discharge.

The American Society of Agricultural and Biological Engineers Standard/Engineering Practice was used for model calibration and validation. The model was categorized as a very good model when it comes to the validation of Hydrology/flow. Therefore, the researchers were able to create a hydrological model within the standards, in which it can be further improved for further study.

References

[1] Miall, Andrew D. "Fluvial Sediments." *AccessScience*, McGraw-Hill Education, 2014.

[2] Batangas City Government, City Planning and Development Office (2013) "Socio – Economic, Physical and Political Profile".

[3] David, Resito D. and Templo, Linda M. (2003). "MANUAL ON FLOOD CONTROL PLANNING". In JICA website.

[4] Donigian, A.S., Duda, P.B., Hummel, P.R., and Imhoff, J.C. (2012) "Basins/HSPF: Model Use, Calibration, and Validation.

[5] Feldmen, Arlen D. (2000). "Hydrologic Modeling System HEC – HMS Technical Reference Manual" Hydrologic Engineering Center, U.S.Army Corps of Engineers.

[6] Otieno, Jennifer A. (2004). "Scenario study for Flood Hazard Assessment in the lower Bicol Floodplain Philippine using A 2D Flood model" International Institute for Geo-Information Science and Earth Observation.

[7] Pama, Alexander R.,(2014). "Final Report re Effects of Typhoon Glenda (Rammasun)". In NDRRMC website.