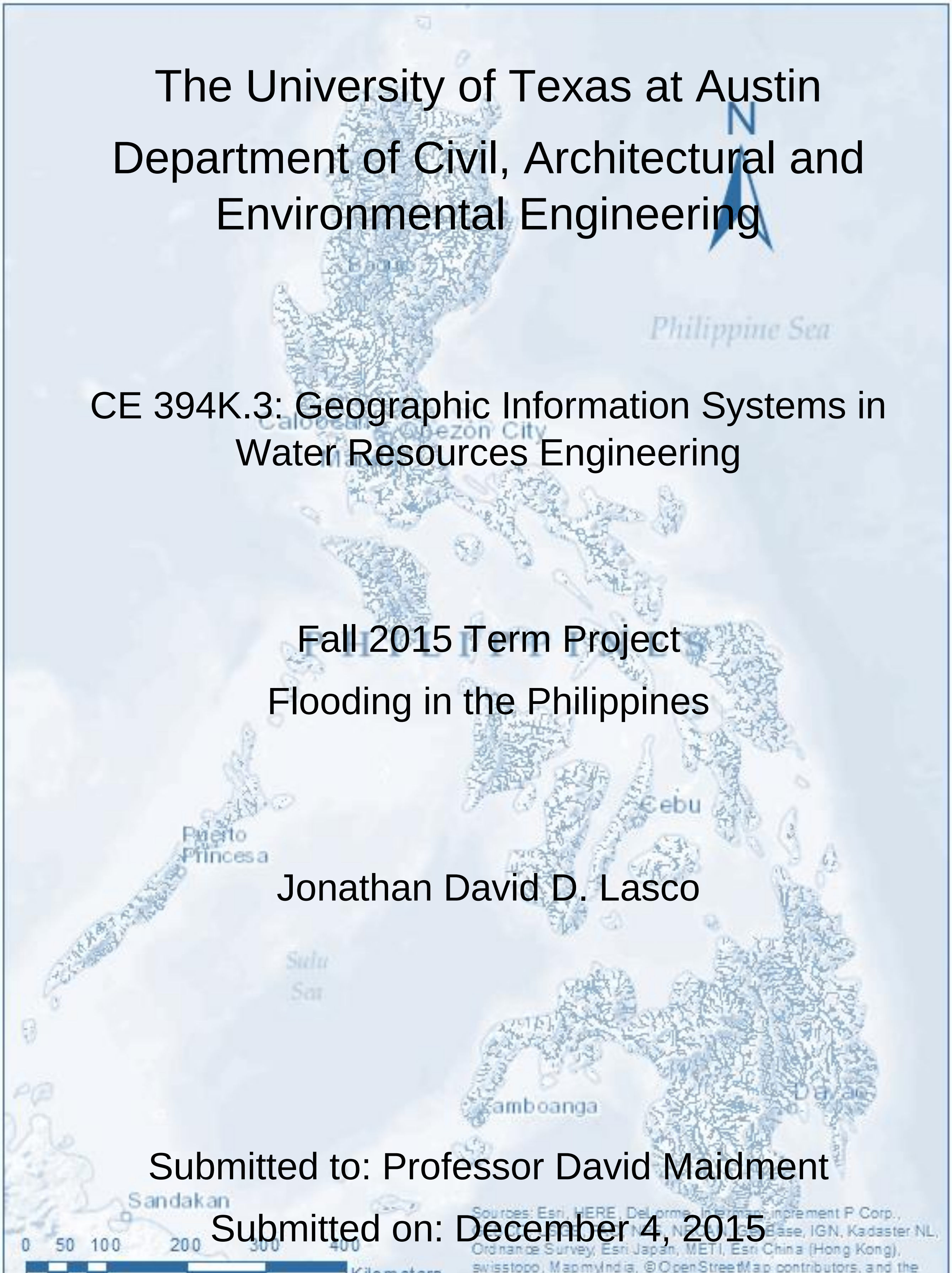

The University of Texas at Austin

Department of Civil, Architectural and Environmental Engineering

CE 394K.3: Geographic Information Systems in Water Resources Engineering

Fall 2015 Term Project

Flooding in the Philippines

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Submitted to: Professor David Maidment

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I. Introduction

Motivation

While blessed with water resources, the Philippines is vulnerable to typhoons. Annually, about 10 typhoons make landfall in the country and most of these typhoons occur during the rainy season. There are many ways to describe a storm event – it may be described as the number of deaths, the damage, or the amount of precipitation that it caused. Shown in Table 1 are the deadliest cyclones in the Philippines.

While there is not much information on Haiphong 1881, there is much that can be implied about the causes of these deaths based on personal experience (the author lived in the Philippines from 1991 to 2015). These causes may be a combination by one or a combination of the following: under-design of buildings, inadequate preparation, resistance of the people to evacuate their homes, underestimation of the magnitude of the cyclones, or simply people being at the wrong place at the wrong time. Under-design of the building may be intentional or unintentional. Intentional under-design may be due to the contractors not following the National Building Code of the Philippines or clients that don't have money to pay for a more resilient home. In fact, a large number of Filipinos only live in nipa huts and shanties making them even more vulnerable to flooding. Unintentional under-design may be due to basing the design on past events. The problem with basing the design on past events is the assumption of hydrologic stationarity (Marriott, 2009) wherein the trend of rainfall events do not change from a cause (e.g. climate change). Inadequate preparation includes poor evacuation plan and negligence of hoarding of the basic necessities, particularly, food. People become resistant to evacuation possibly because of emotional attachment to their belongings – they just don't want to leave their possessions. Moreover, the magnitude of the flood may be underestimate because of the scales of measurement that are used. For example, in 2009, Typhoon Ketsana was measured as a signal no. 1 storm which means that winds ranging from 30-60 kph are expected to occur within 36 hours. Yet despite the slow winds, precipitation was huge and the magnitude of precipitation is what caused the deaths.

Aside from measuring the storm in terms of the number of deaths that it caused, a storm may also be measured by the damage that it caused (Table 2). It may be noticed that a catastrophic death toll does not necessarily make a storm event more destructive (e.g. Haiphong 1881, Haiyan 2013). This is because the amount of damage depends on the area affected by the storm – if it is more developed then it is more likely to suffer more damages compared to, say, a farmland. It may also be noticed that the destructive cyclones are concentrated on the 21st century. This is because there is more development in the 21st century than the 20th century.

A storm may also be described in terms of the amount of precipitation it effects (Table 3). A high amount of precipitation leads to flooding. The most serious case of flooding is when it occurs to an area which is densely populated and highly developed because many people may die and many buildings may collapse leading to the loss of millions of dollars.

Table 1. Deadliest cyclones in the Philippines. (Source: Typhoons in the Philippines, Wikipedia)

Rank	Storm	Deaths
1	Haiphong 1881	> 20,000
2	Haiyan/Yolanda 2013	6,241
3	Thelma/Uring 1991	6,101
4	Bopha/Pablo 2012	1,901
5	Angela 1867	1,800
6	Winnie 2004	1,593
7	October 1897 Typhoon	1,500
8	Ike/Nitang 1984	1,492
9	Fengshen/Frank 2008	1,410
10	Durian/Reming 2006	1,399

Table 2. Most destructive cyclones in the Philippines. (Source: Typhoons in the Philippines, Wikipedia)

Rank	Storm	Damage (million USD)
1	Haiyan/Yolanda 2013	2,020
2	Bopha/Pablo 2012	1,040
3	Rammasun/Glenda 2014	871
4	Parma/Pepeng 2009	608
5	Nesat/Pedring 2011	333
6	Fengshen/ Frank 2008	301
7	Megi/ Juan 2010	255
8	Ketsana/ Ondoy 2009	244
9	Mike/Ruping 1990	241
10	Angela/ Rosing 1995	241

Table 3. Wettest recorded cyclones in the Philippines. (Source: Typhoons in the Philippines, Wikipedia)

Rank	Storm	Precipitation	
		Millimeters	Inches
1	July 1911 cyclone	2210.0	87.01
2	Parma/Pepeng 2009	1854.3	73.00
3	Carla/Trining 1967	1216.0	47.86
4	Zeb/Iliang 1998	1116.0	43.94
5	Utor/Feria 2001	1085.8	42.74
6	Koppu/Lando 2015	1077.8	42.43
7	Mindulle/Igme 2004	1012.7	39.87
8	Kujira/Dante 2009	902.0	35.51
9	September 1929 typhoon	879.9	34.64
10	Dinah/Openg 1977	869.6	34.24

Aside from a quantitative description of storm events, they may also be described qualitatively. Shown in Figure 1 is a mosaic of pictures derived from Yahoo! images that depict the seriousness of typhoons in the Philippines – with a particular theme of flooding. From the quantitative and qualitative measures of typhoons, it may be concluded that flooding – an effect of typhoons – is a serious issue in the Philippines. This term project seeks to address flooding in the Philippines. First, the current flood forecasting system in the Philippines is discussed; second, the land cover variation of the Philippines is mapped and discussed; third, a terrain of analysis of Luzon is conducted; third, attention is focused one river basin in the Philippines – Pampanga River Basin – and hydrologic modeling is performed and compared with actual gage data; finally, recommendations are given of what can be improved to the flood forecasting system in the Philippines.

Objectives

Initially, the author aimed to construct a flood forecasting system for Luzon. However, upon the course of research and data sourcing, the objective was deemed as unreachable due to lack of data sources and lack of access to modeling software. Nevertheless, the ultimate aim of the author is still to create a flood forecasting system for the Philippines similar to the NFIE of the United States of America. This project is a step towards that goal. Henceforth, the final objective of the project is to apply GIS principles in discussing flood forecasting in the Philippines. Specifically, it aims to:

1. Discuss the current flood forecasting system of the Philippines
2. Map the land cover variation of the Philippines
3. Conduct terrain analysis of Luzon
4. Perform watershed delineation of a selected river basin in Luzon
5. Prepare a HEC-HMS model for the selected river basin
6. Validate the HEC-HMS model using historical streamflow data
7. Construct a rating curve for the selected river basin
8. Compare the simulation model of a US agency with the historical streamflow data
9. Recommend future work in the Philippines

In accomplishing these objectives, data was sourced from various sources on the web and from the expertise of other people.

Figure 1. Effects of flooding in the Philippines.

II. Results and Discussion

Flood forecasting in the Philippines (Objective 1)

The Department of Science and Technology (DOST) is the main governmental body that handles typhoons and flooding issues of the country. One of its agencies is the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). As shown in its website, the main mandate of PAGASA is to “provide protection against natural calamities and utilize scientific knowledge as an effective instrument to insure the safety, well-being and economic security of all the people, and for the promotion of national progress” (Section 2, Statement of Policy, Presidential Decree No. 78; December 1972 as amended by Presidential Decree No. 1149; August 1977).

One of the DOST’s project is the Nationwide Operational Assessment of Hazards (Project NOAH), which aims to prevents and mitigate disasters. The project makes use of Geographic Information Systems to disseminate critical information to the audience. This project aims to provide local government units a 6-hour lead time warning to vulnerable communities against imminent floods (Lagmay, 2012). Figure 1 is the user interface of Project NOAH where the left panel are links to flood maps and other natural disaster events. There is also a Twitter news feed about the weather conditions.

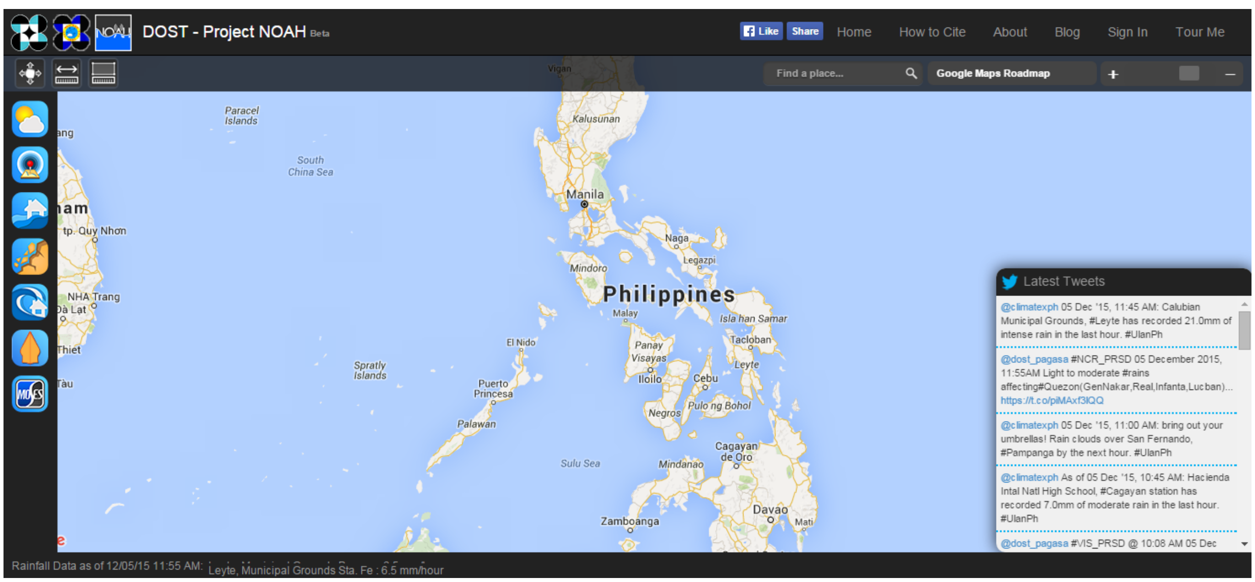


Figure 2. Project NOAH.

Land cover variation of the Philippines (Objective 2)

Determination of the land cover variation is essential in hydrologic modeling because different land covers have different coefficient of permeability. More pervious surfaces are more desirable from the standpoint of flood alleviation because instead of water just rising, a part of it can infiltrate in the ground. Shown in Figure 3 is the land cover variation of the Philippines with the legend defined in Table 4. The dominant land covers are grassland (6), forests (5), and crops (1 and 10). It may also be seen that the developed area only constitutes 2.3% of the total land cover. It may therefore be concluded that the Philippines is still an agricultural country.

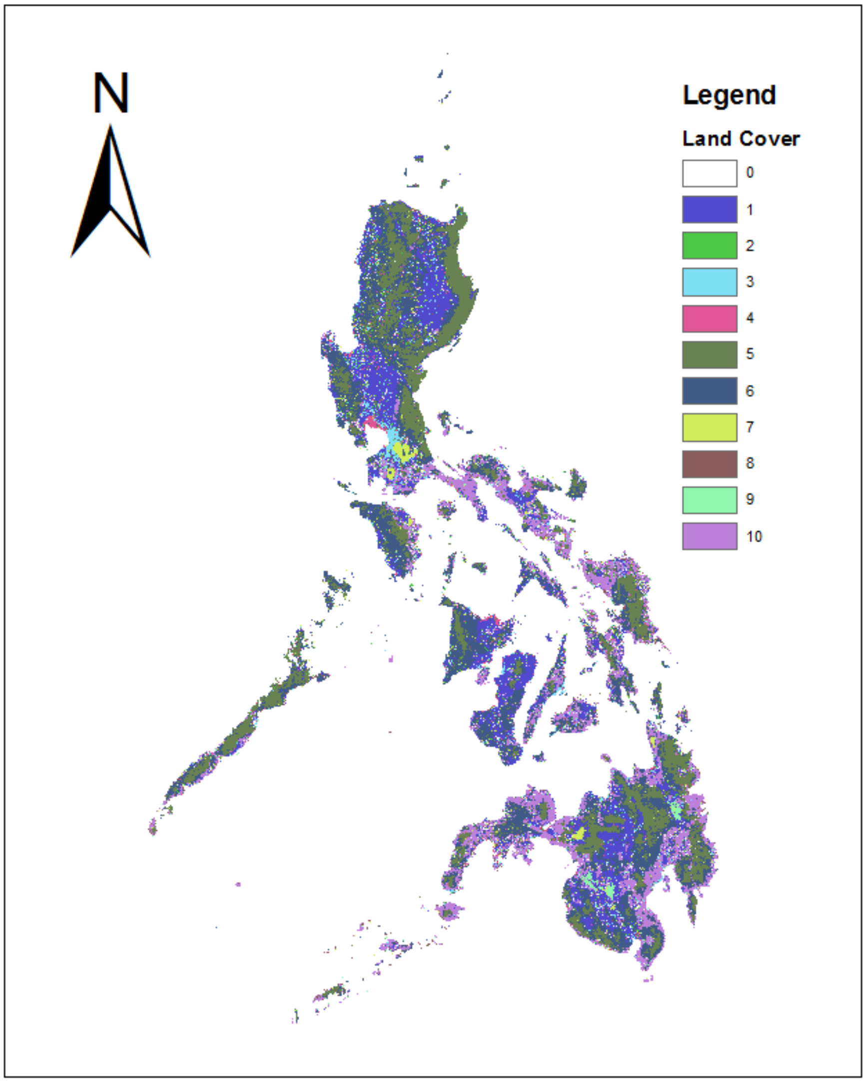


Figure 3. Land use of the Philippines. (Source: NAMRIA)

Table 4. Land use of the Philippines.

Code	Description	Total area (hectares)	%Total
1	Annual crops	6217767.123	21.0%
2	Barren	95694.37854	0.3%
3	Built-up area	694019.4828	2.3%
4	Fishpond	247348.6021	0.8%
5	Forest	6530137.254	22.1%
6	Grassland	8675408.056	29.4%
7	Inland water	482646.1804	1.6%
8	Mangrove	307879.5215	1.0%
9	Marshland	131439.595	0.4%
10	Perennial crops	6167900.41	20.9%
		29550240.6	100.0%

Another important area of research, which is not anymore part of the objective of this project, is determining the land cover change through time. Analysis of the changes in land cover leads to a better understanding of the past which in turn leads to improved understanding of future trajectories (de Sherbinin, 2002).

Terrain analysis of Luzon (Objective 3)

Terrain analysis is a precursor to hydrologic modeling and watershed analysis because water flows from an area of higher elevation (higher head) to an area of lower elevation (lower head). Using ArcMap, the map of Luzon was generated as shown in Figure 4. The highest elevation for Luzon is 2,911 m. This point is Mt. Pulag (Figure 5).

For a more visual representation, it is of interest to represent the topography of an area using contour lines or hillshading. Using ArcMap, a hillshaded map of the area containing highest point is generated (Figure 6). This are is a mountain range and is called the Cordilleras (Figure 7).

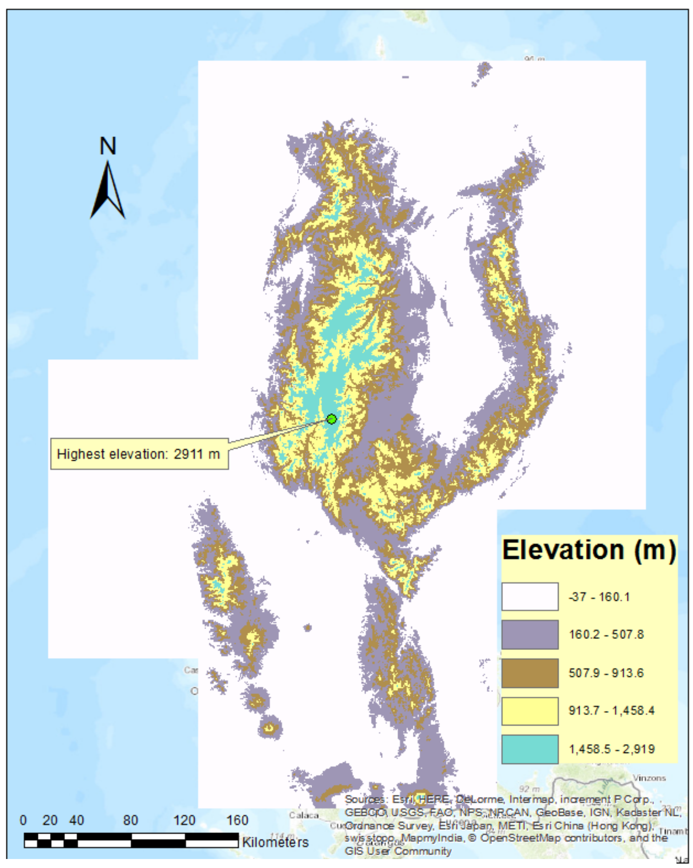


Figure 4. Filled digital elevation model of Luzon.

Figure 5. The summit of Mt. Pulag – the highest mountain in Luzon.

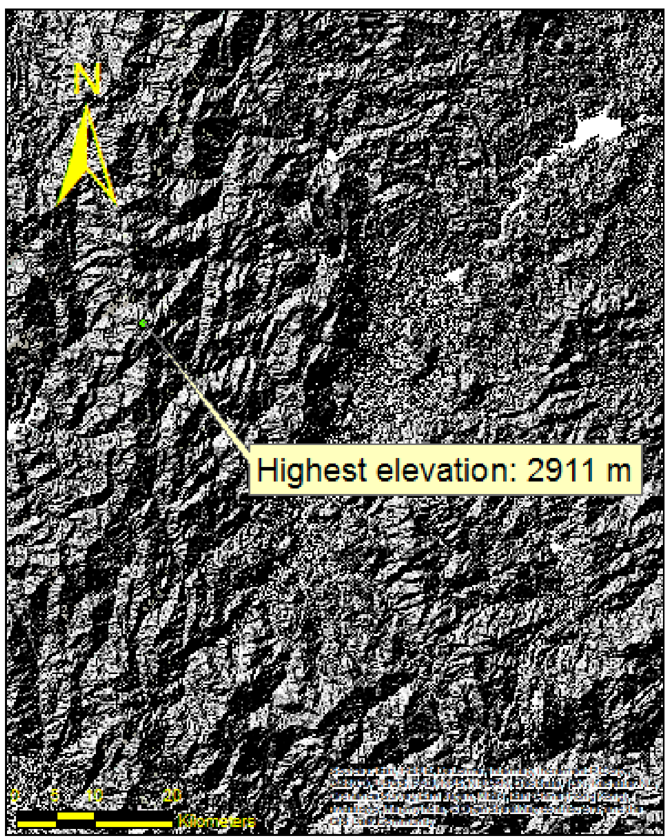


Figure 6. Hillshaded representation of the summit of Mt. Pulag.

Figure 7. The Cordillera mountain range.

Watershed delineation of Pampanga River Basin (Objective 4)

According to the Pampanga River Basin Flood Forecasting & Warning Center (PRBFFWC), the Pampanga River Basin is the 4th largest in the Philippines with an area of about 10,434 km^2. The basin drains through Pampanga River into the Manila Bay. The basin experiences at least one flooding a year, with the wettest months from July to September. In this section, the Pampanga River Basin is delineated using ArcMap. The first step in the delineation process is establishing the DEM. Next, this DEM is filled. Shown in Figure 8 is the filled DEM of the basin. Filling the DEM is necessary so that there are no unnecessary flow accumulations in the delineation process.

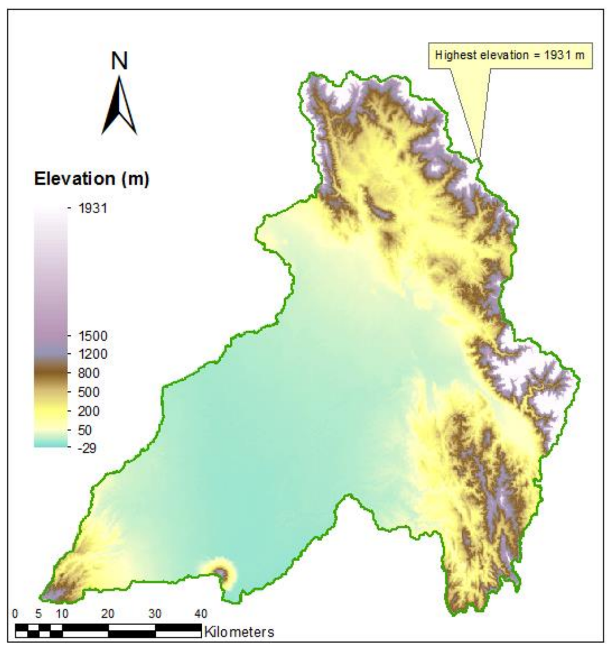


Figure 8. Filled DEM of Pampanga River Basin.

After filling of pits, flow direction and flow accumulation raster is generated (Figure 9 and Figure 10). The interpretation of the flow direction is as follows: 1 = east, 2 = southeast, 4 = south, 8 = southwest, 16 = west, 32 = northwest, 64 = north, 128 = northeast. In the flow accumulation raster, there is a concentration of blue in one area. That area is a reservoir impounded by Pantabangan dam. In the flow accumulation raster, values of high flow accumulation represent the streams. Using the Watershed and Streamlinks tools, Figure 11 is generated. Finally, after conversion to vector, a network is generated (Figure 12).

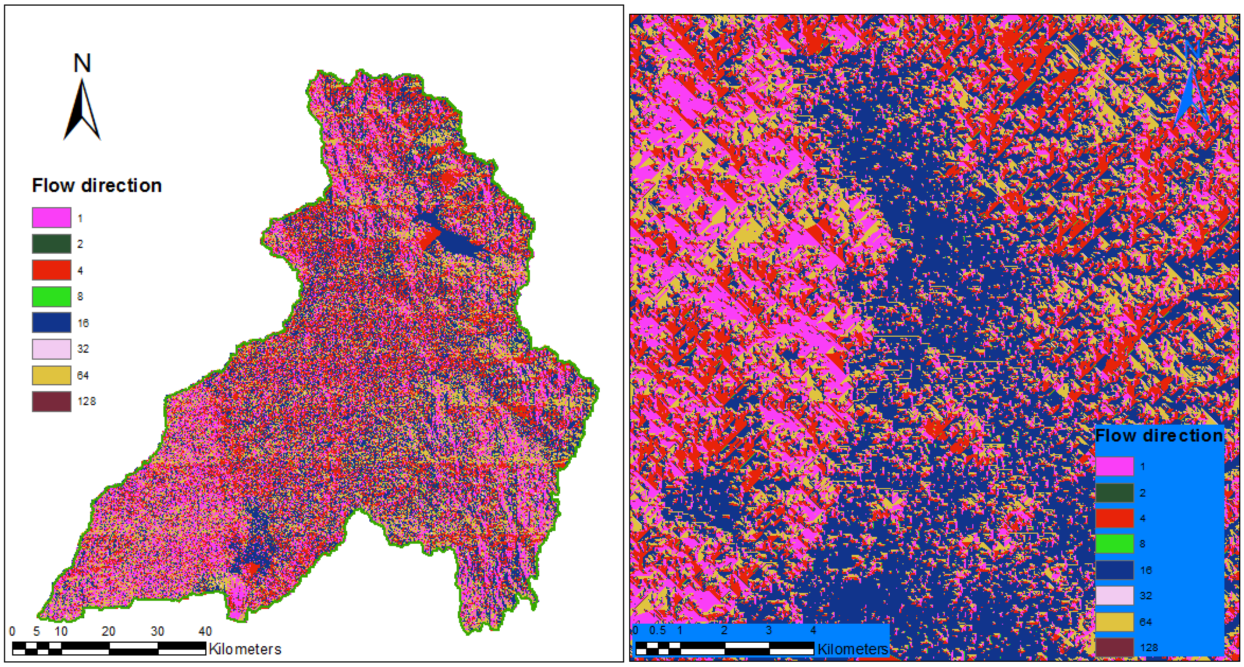


Figure 9. Flow direction in Pampanga River Basin: whole basin (left), concentrated (right).

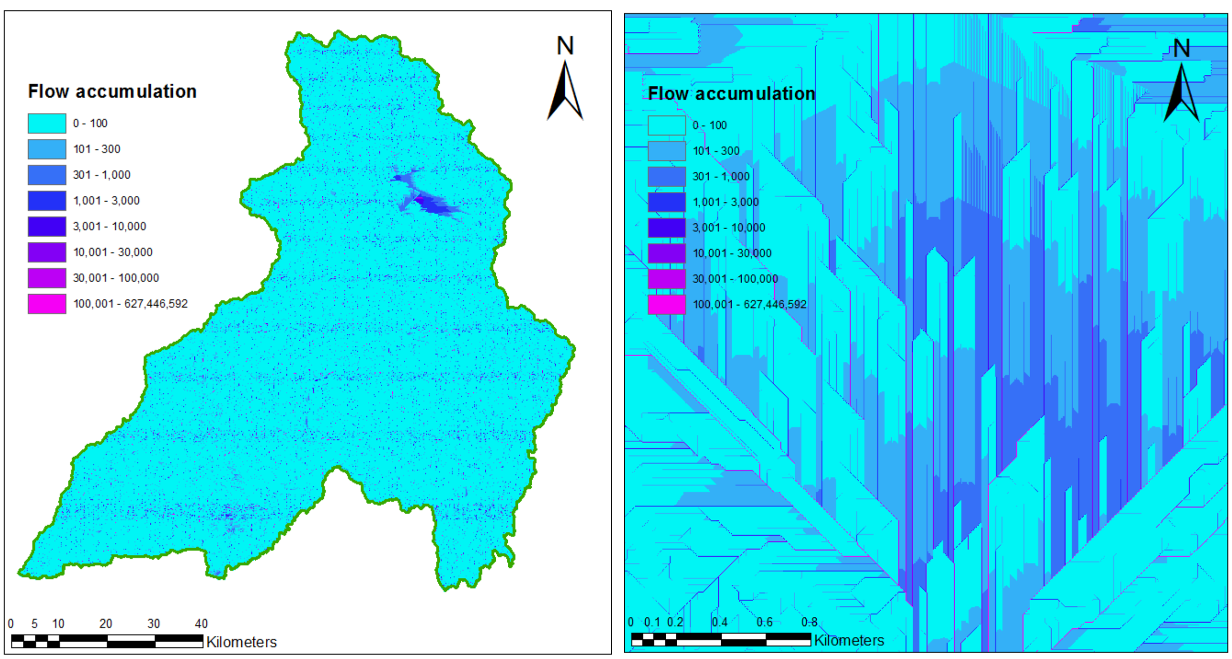


Figure 10. Flow accumulation in Pampanga River Basin: whole basin (left), concentrated (right).

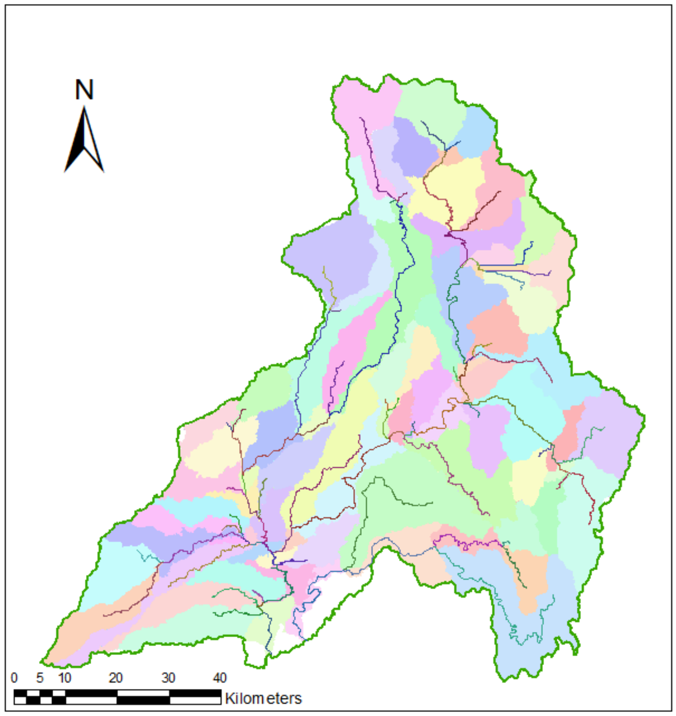


Figure 11. Flowlines and catchments.

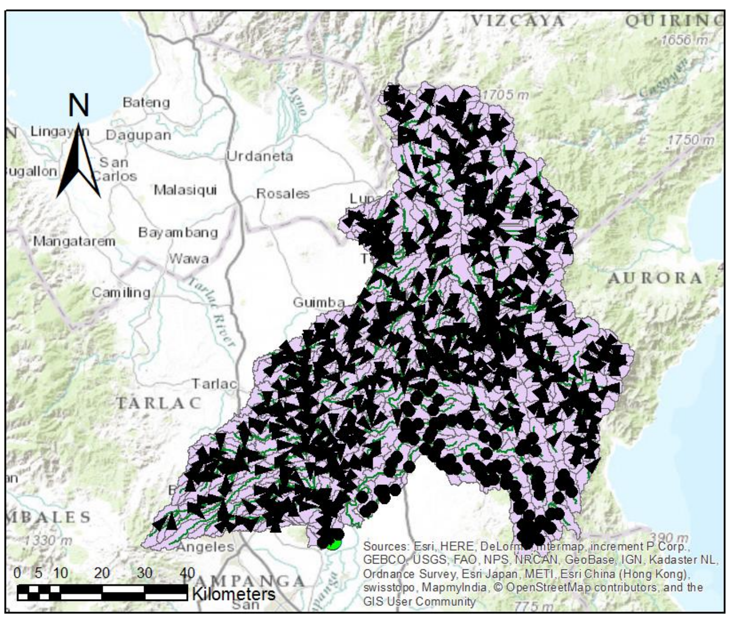


Figure 12. Flow network.

Hydrologic modeling of Pampanga River Basin (Objectives 5-8)

1. Analysis of Gaged River Data

While hydrologic modeling from catchment characteristics is a powerful tool for simulating floods, it is still better to deduce flood events from actual recorded data (Marriott et al, 2009). Twenty (20) years of streamflow data was obtained and analyzed as is discussed in this section. First, the maximum values for each water year are tabulated and ranked in ascending order (denoted by j) and descending order (denoted by i). These values were assumed to have an extreme value distribution type I. From the rankings, each event was assigned by a value of F which is the probability of non-exceedance using the formula:

$$F = \frac{j - a}{N + b}$$

The probability of exceedance may also be obtained using the formula

$$P = \frac{i - a}{N + b}$$

The Gringorten plotting position is preferred for extreme value distributions in which a = 0.44 and b = 0.12 and is used in this analysis. Thus, the probability of non-exceedance is rewritten as

$$F = \frac{j - 0.44}{N + 0.12}$$

And the probability of exceedance,

$$P = \frac{i - 0.44}{N + 0.12}$$

Finally, discharges are plotted against the Gumbel reduced variates, which is an appropriate reduced variate for extreme value type 1 distribution (Marriott et al, 2009):

$$y_G = -\ln(-\ln F)$$

Shown in Table 5 is a tabulated solution discussed thus far. The plot of the discharges against the Gumbel reduced variates are shown in Figure 13. A trend line is then fitted to the graph to relate the discharge to the Gumbel reduced variates and because the Gumbel reduced variates are also related to F, which is just the reciprocal of the return period, an equation relating discharge, Q, and return period, T, is obtained:

$$Q = 399.28(-\ln\left(-\ln\left(1 - \frac{1}{T}\right)\right) + 1332.1$$

Table 5. Analysis of river data.

Water year	Discharge, m^3/s	Rank j	Rank i	Annual non-exceedance probability, F	y_G
1983	523	1	19	0.029288703	-1.26145463
1997	966	2	18	0.081589958	-0.91870744
1996	1109	3	17	0.133891213	-0.69849667
1994	1174	4	16	0.186192469	-0.5193736
1984	1247	5	15	0.238493724	-0.36005781
1989	1258	6	14	0.290794979	-0.21118173
1982	1326	7	13	0.343096234	-0.06741965
1987	1413	8	12	0.395397490	0.074870413
1992	1426	9	11	0.447698745	0.218610445
1991	1535	10	10	0.500000000	0.366512921
1993	1573	11	9	0.552301255	0.521445769
2001	1679	12	8	0.604602510	0.686799282
1985	1717	13	7	0.656903766	0.866982258
1988	1725	14	6	0.709205021	1.068246166
1990	1799	15	5	0.761506276	1.300274972
1995	1874	16	4	0.813807531	1.579726749
1998	2144	17	3	0.866108787	1.939716061
1999	2521	18	2	0.918410042	2.463795239
2000	2521	19	1	0.970711297	3.515727131

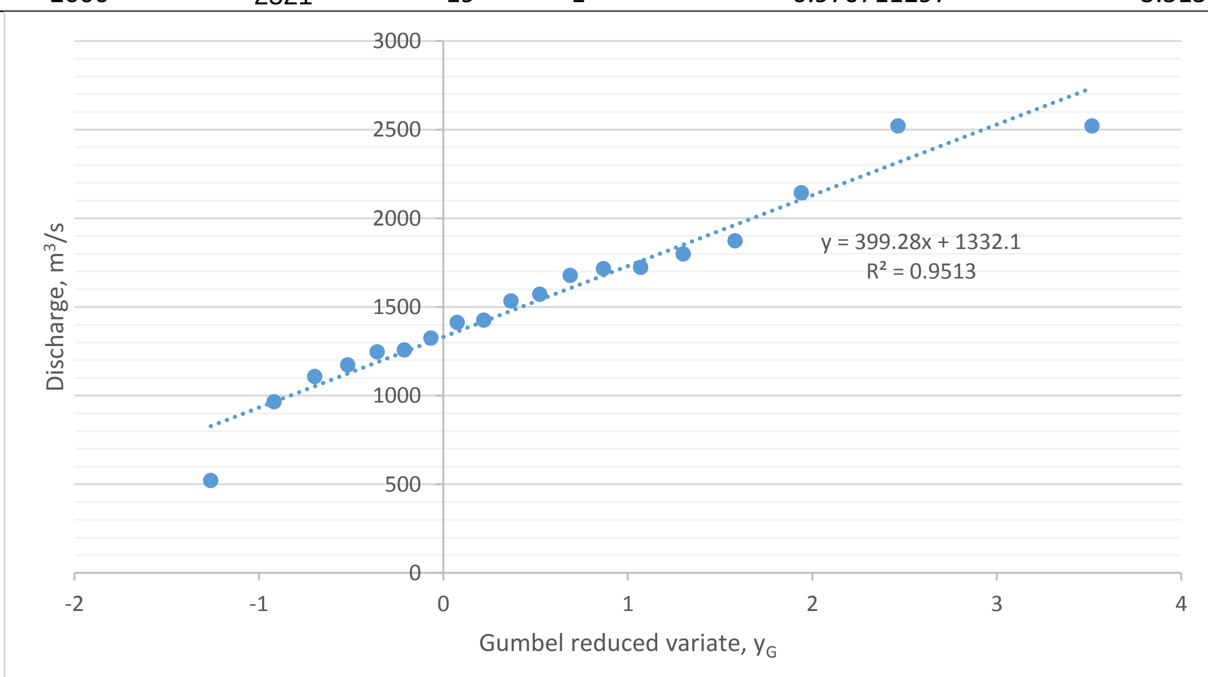


Figure 13. Discharge versus Gumbel reduced variates.

Recorded gage heights are also plotted against the corresponding discharges to construct a rating curve (Figure 14). The equation of the curve is then determined to be:

$$h = 0.2951(Q - 0.0000)^{0.4714}$$

where h is the stage height in meters and Q is the discharge cubic meters per second.

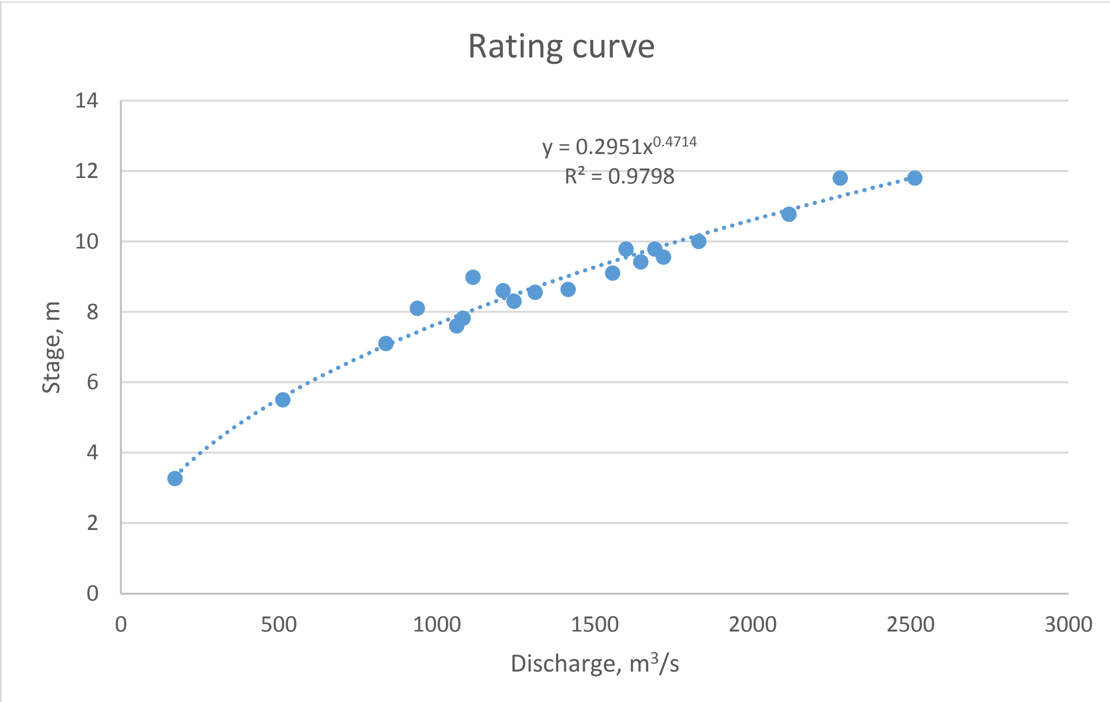


Figure 14. Rating curve for Pampanga River Basin.

Thus, from the gage data, different magnitudes of stages and discharges may be deduced. The values of for 2-yr, 5-yr, 10-yr, and 100-yr events are shown in Table 6.

Table 6. Flood events analyzed from the recorded data.

Return period (yrs)	Discharge, m^3/s	Stage, m
2	1478.441279	9.21
5	1930.996038	10.44
10	2230.626666	11.18
100	3168.847583	13.19

One limitation of this analysis is that there were only twenty usable years obtained; thus, it may not be accurate in predicting 100-yr events. It is therefore recommended to update this analysis (e.g. Bayesian approach) with more years of record.

2. HEC-HMS Modeling

A simple hydrologic model is accomplished through Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). In this method, the curve number data, land use data and soils data are needed (Figure 15). The curve number represents the amount of water that infiltrates to the soil. This is related to the perviousness of the soil. A more pervious soil will have a higher curve number. The curve number is derived from the land use data and the soils data – different kinds of soil have permeability. The HEC-HMS basin model is shown in Figure 16. The loss method used in the model is SCS Curve Number and the Transform Method used is SCS Unit Hydrograph. For the meteorological model the following parameters are used: input type = partial duration, intensity duration = 5 minutes, storm duration = 6 hours, intensity position = 67%. For the frequency analysis, data was obtained from an RIDF Analysis for the Asia Pacific Region conducted by the IHP Regional Steering Committee for South East Asia and the Pacific. The control specifications were set to September 23 – 30, 2009, the dates where typhoon Ketsana hit the basin. Typhoon Ketsana was chosen because of the available data regarding the storm event. Four hydrographs, with 2-yr, 5-yr, 10-yr, and 100-yr return periods were generated and are shown in Figure 17. The resulting data are then compared with actual gage data.

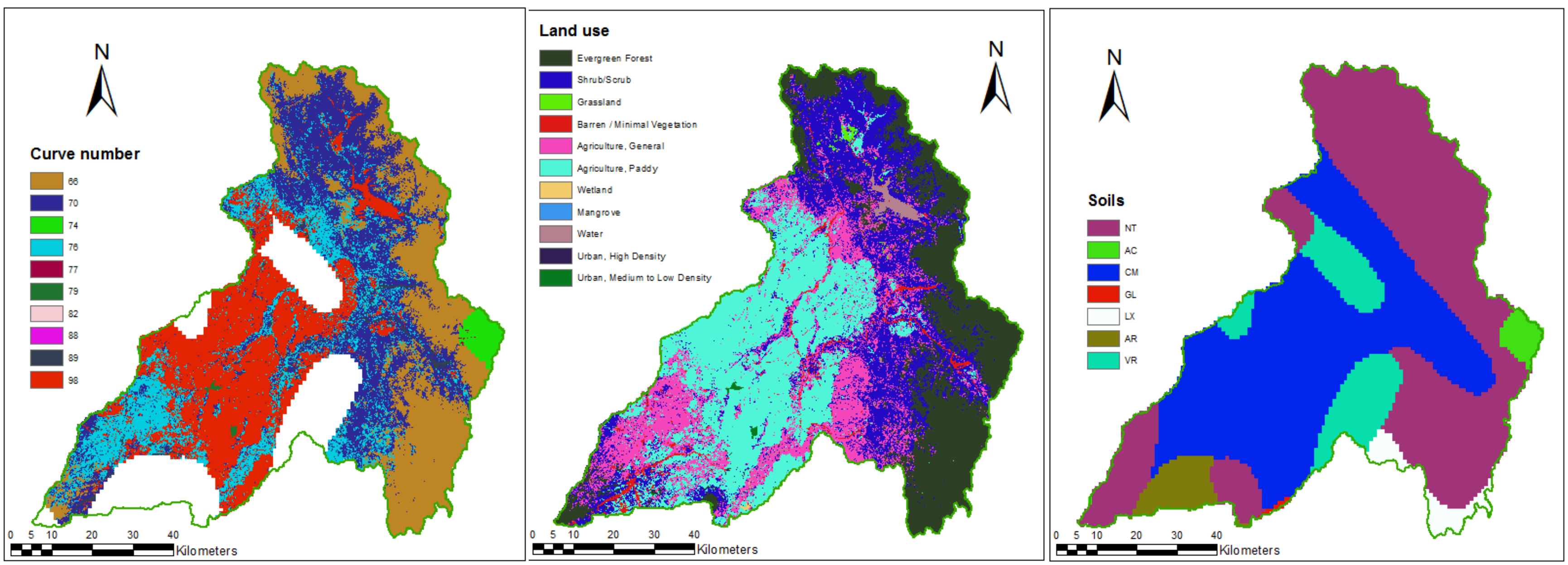


Figure 15. Raster representation of Curve number (left), Land use (center), and Soils (right) of the Pampanga River Basin.

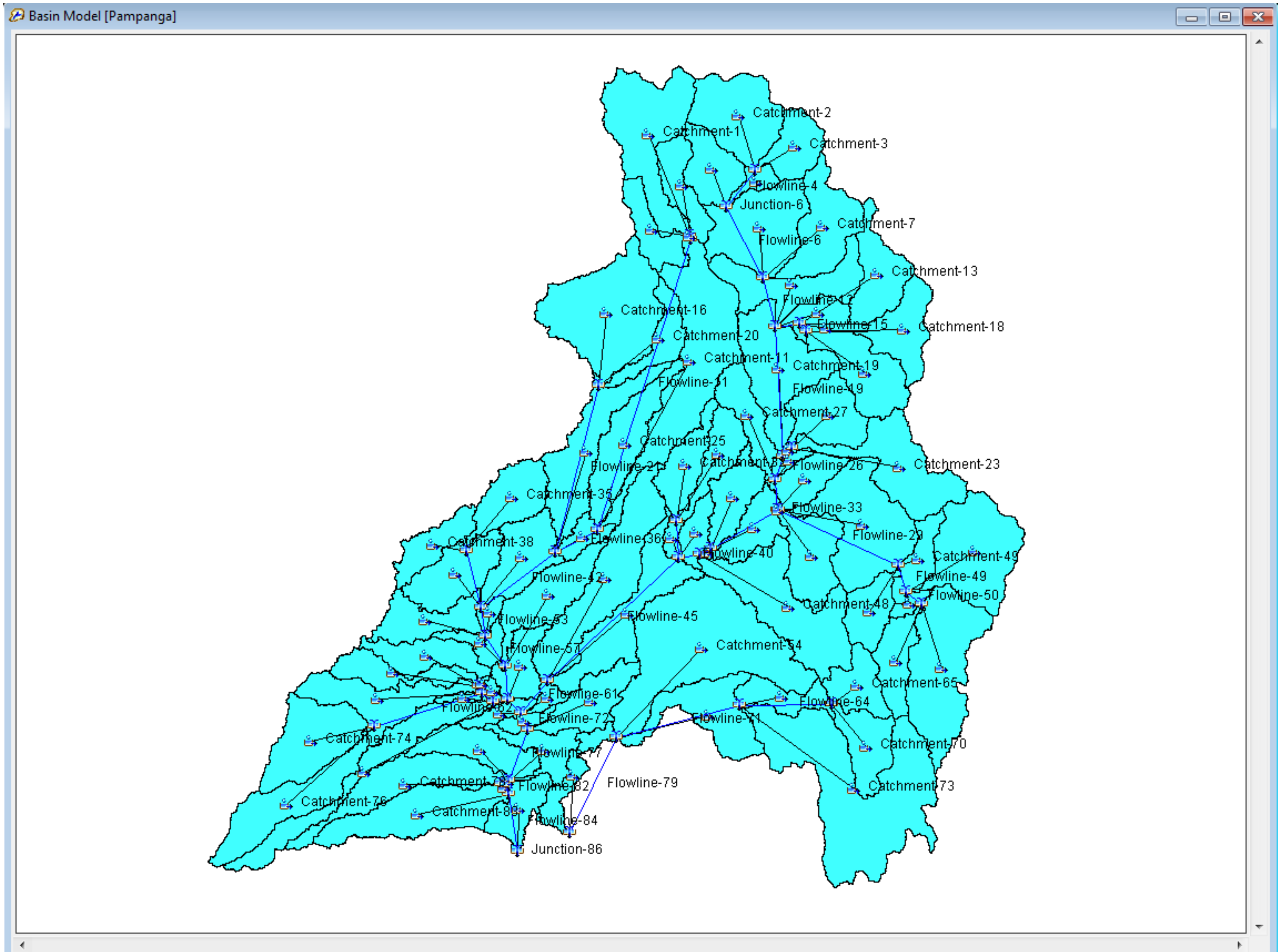


Figure 16. HEC-HMS basin model of the Pampanga River Basin. (Acknowledgment: Cyndi Castro)

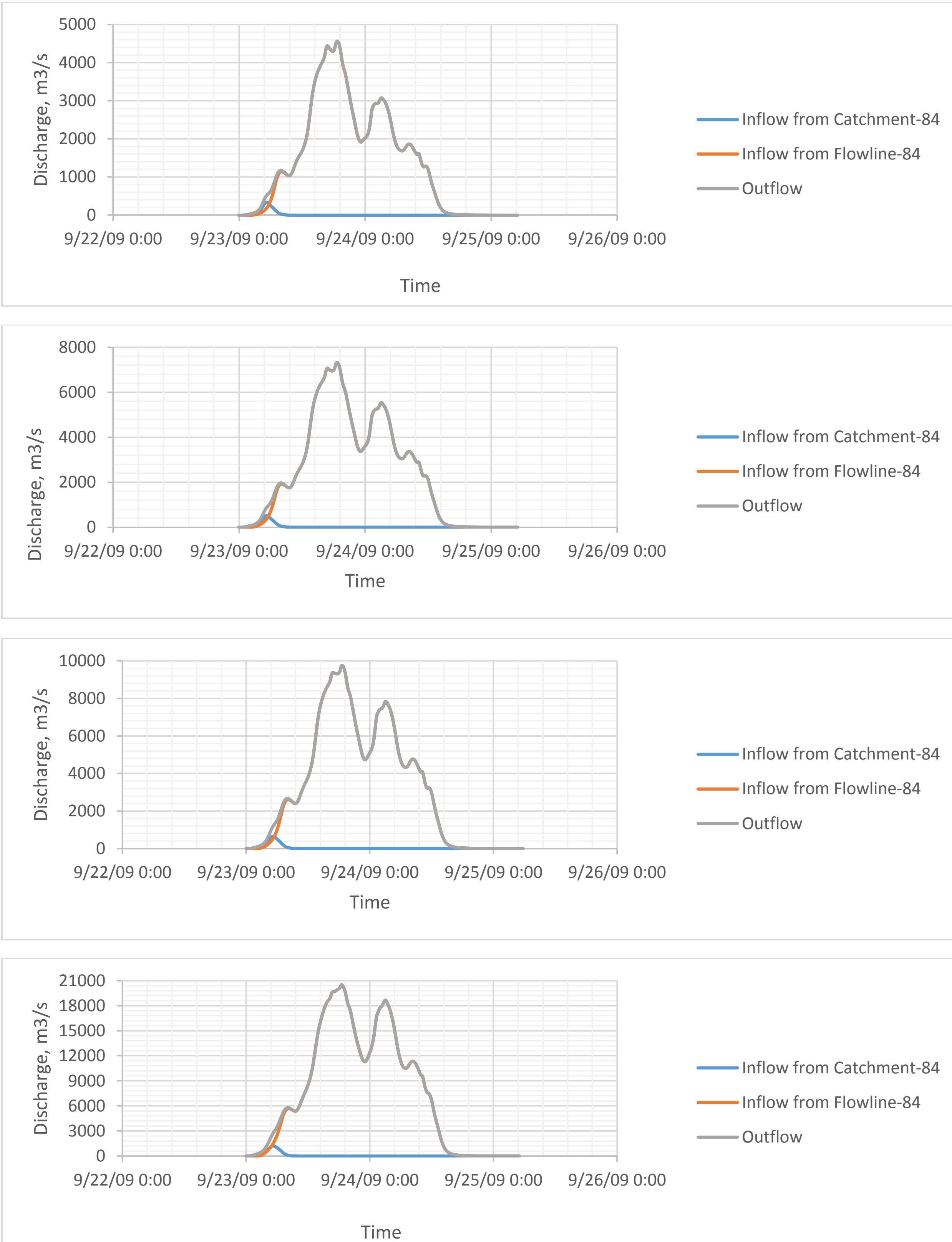


Figure 17. HEC-HMS generated (top to bottom) 2-yr, 5-yr, 10-yr, and 100-yr hydrographs.

Table 7. Comparison of HEC-HMS with mode from actual data.

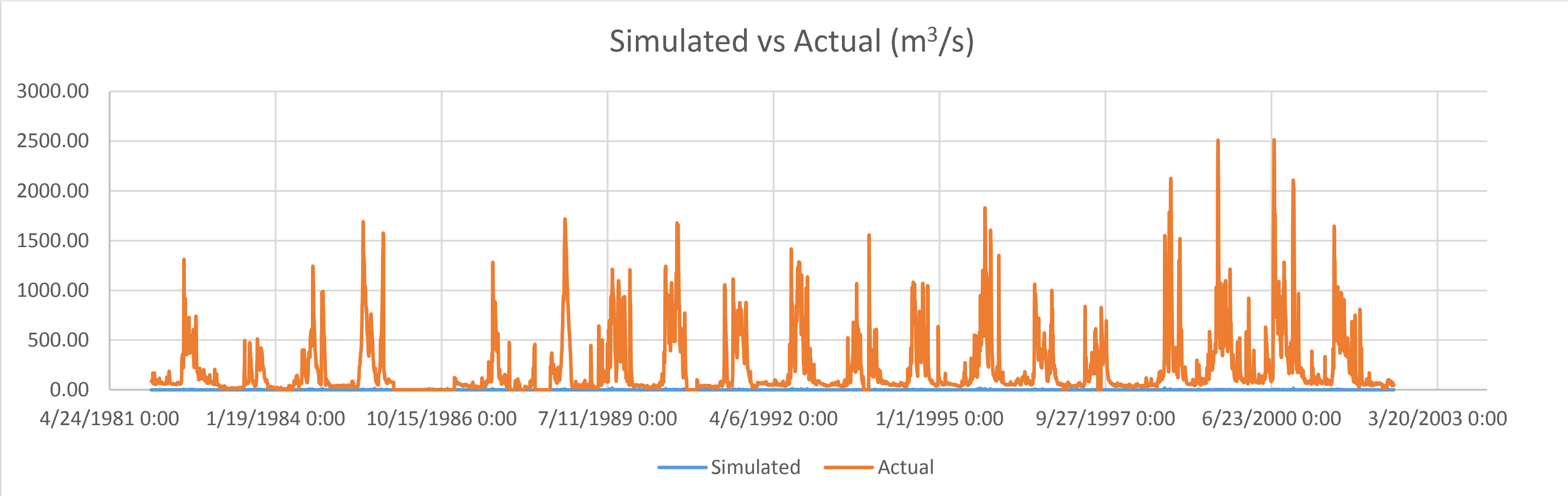
Return period (years)	HEC-HMS Simulated, m^3/s	Extreme Value Modeling, m^3/s
2	4526.1	1478.441279
5	7255.5	1930.996038
10	9700.2	2230.626666
100	20178	3168.847583

It may be noticed that the simulation doesn't agree quite well with the model from actual data. This may be due to the simplification of the HEC-HMS model in which the only inputs in the meteorological model was precipitation data.

3. US Army Simulation Model

USA is one of the most active countries helping the Philippines recover from flood events when beset by flood by either giving financial aid or organizing rescue operations. The US Army Engineering Research Development Center participates in these rescue operations by modeling flood events in the Philippines for their rescue operations. Shown in Figure 17 is the company's simulated data juxtaposed with the actual twenty-year river data discussed earlier. It may be noticed that the simulated data is way off the actual gage measurements. This implies that though satellite images are useful, it is still recommended to obtain local data to avoid missing pertinent information such as location of dams.

Another measure of validating the simulated data is by computing the correlation coefficient of the events, which turned out to be 0.48. This implies that there is positive correlation between the two data sets (simulated and actual). However, a value of 0.48 does not indicate strong correlation, suggesting that the simulation model needs to be improved. Shown also in Figure 17 is a visual representation of correlation.



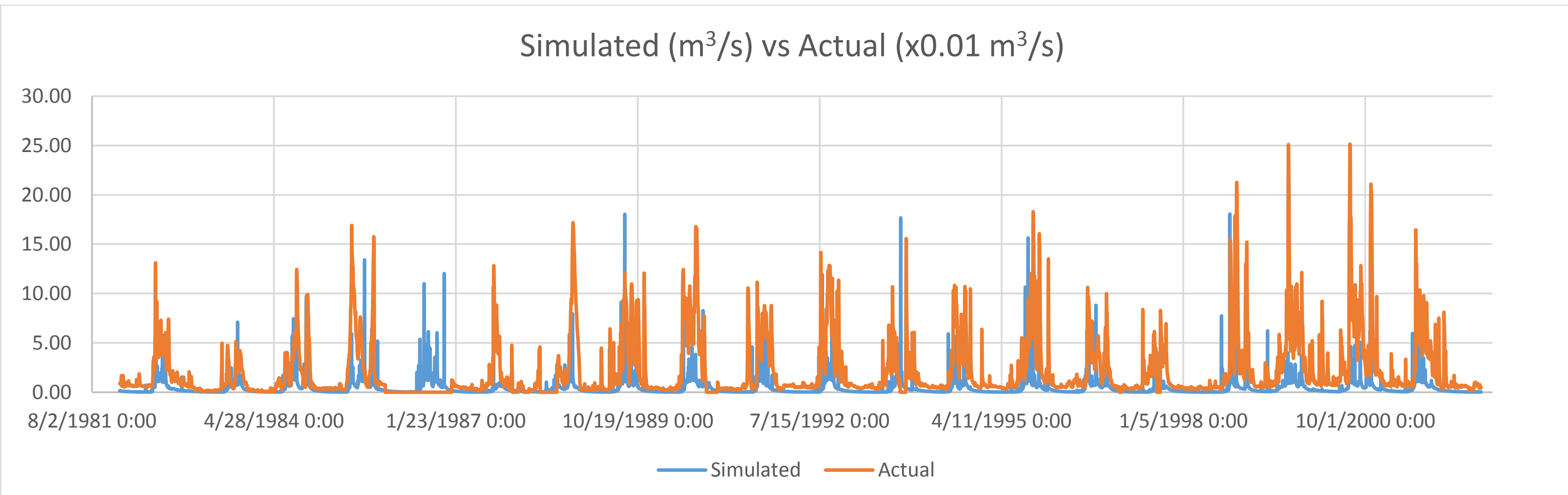


Figure 17. US Army ERDC simulated flows versus actual gaged flows: with magnification (top), with magnification (bottom).

III. Recommendations (Objective 9)

Doubtless, the projects that the Philippine Government (e.g. Project NOAH) are proposing have saved many lives. However, much still needs to be done and the flood forecasting system of the Philippines can be improved in many ways. In this section, the author, leveraging from his overall experience of making this project, recommends that the Philippines adapt the National Flood Interoperability Experiment (NFIE) that is currently being championed in USA. Specifically, it is recommended that:

1. Data sources should be more organized (e.g. NFIE-Services)

One of the hindrances in this project is the sourcing of data. The organization of data in the web in such a way that hydrologists would more easily find the data that they need is one of the steps toward a better flood forecasting system, similar to the NFIE-Services. It is also recommended to promote open-sharing of data like what is being done in HydroShare.

2. Update the geographic coordinate system of the country

There is a local geographic coordinate system, Luzon 1911, available at ArcMap. More than a century has passed and the landscape since 1911 may have already been altered. As such, it is recommended to conduct geodetic surveys to have a geographic coordinate system specifically tailored to the Philippine landscape.

3. Develop a higher-resolution DEM

The DEM model used in this project has a resolution of 30 meters. If LIDAR data would be available in the web, hydrologic models will be more accurate and topography will be more realistically represented.

4. Create a geodatabase for hydrologic elements (e.g. NFIE-Geo and NFIE-River)

Even if data sources that were obtained, it is attribute table doesn't give much information to the hydrologist. Thus, it is recommended that there be a classification system similar to NFIE-Geo and NFIE-River of the USA. Each water body in the Philippines must he codified into unique numbers similar to HUC units and must have unique identifiers that relate them to other feature classes. Moreover, the geodatabase should also include descriptive information of the water bodies such as drainage area of the catchments and length of the flow lines. Hence, the attribute table that will be downloaded is full of information necessary for a hydrologist.

5. Develop a better flood response and flood warning system (e.g. NFIE-Response)

While many Filipinos still don't have access to internet, most families have at least, a cell phone. The Government should find a way of using these communication devices to also communicate looming flood events. Project NOAH can also be further improved by attempting near-real time forecasting system such as what is being aimed by NFIE.

IV. Summary

In this project, the author sought to discuss flooding in the Philippines with the aid of GIS. The first part of the report is general description of the country, including it's current flood forecasting system, the land cover variation of the country, and it's terrain. The second part of the report is the hydrological aspect of the project wherein a basin of interest, Pampanga River Basin, is delineated. Moreover, actual data is also compared with simulated data using HEC-HMS and the simulation models of the US Army ERDC. Finally, the paper ends with some recommendations for the Philippine Government to improve its flood forecasting system.

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Appendix

Ambulong

		1-yr	2-yr	5-yr	10-yr	20-yr	50-yr	100yr
1	5 min	11.32	14.53	19.69	24.44	29.84	39.01	47.39
2	10 min	17.77	22.69	30.01	36.24	42.88	53.29	62.09
3	15 min	23.24	29.32	38.16	45.52	53.21	65.02	74.77
4	20 min	28.35	35.38	45.45	53.69	62.19	75.03	85.46
5	30 min	35.10	43.86	56.65	67.34	78.55	95.82	110.14
6	45 min	40.96	51.51	67.48	81.30	96.24	120.09	140.57
7	60 min	45.53	57.61	75.65	91.05	107.50	133.40	155.35
8	80 min	51.46	64.73	85.17	103.15	122.87	154.88	182.85
9	100 min	55.63	70.44	93.65	114.41	137.50	175.63	209.51
10	120 min	60.03	76.22	101.44	123.88	148.72	189.50	225.54
11	150 min	64.82	82.84	110.96	136.03	163.81	209.50	249.93
12	3 hrs	68.69	87.81	118.19	145.74	176.74	228.63	275.38
13	6 hrs	87.43	113.04	154.01	191.45	233.82	305.27	370.11
14	12 hrs	110.86	144.02	194.78	239.21	287.69	365.94	433.92
15	1-day	132.01	172.29	231.57	281.46	334.11	415.81	484.03
16	2-day	178.10	234.54	319.23	391.88	469.82	593.12	698.09
17	3-day	201.45	264.20	357.17	435.90	519.44	649.92	759.57

Appendix Figure 1. Rainfall data for frequency analysis.

Department of Public Works and Highways BUREAU OF RESEARCH AND STANDARDS EDSA, Diliman, Quezon City	**EXTREME GAGE HEIGHT VALUES**	Station Code No. Date Prepared:

River Creek : ***PAMPANGA RIVER*** @ ***CAMBA, ARAYAT, PAMPANGA***

YEAR/MONTH		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MAX/MIN	OCCURRENCE	
1981	Max															
	Min															
1982	Max	3.29	2.88	2.38	3.42	2.34	2.46	8.56	6.80	6.50	4.00	3.76	3.78	8.56	7/17	
	Min	2.3	2.18	2.13	2.05	2.20	2.21	2.42	4.56	3.60	2.74	2.56	2.26	2.05		
1983	Max	3.76	2.51	2.00	1.62	1.63	1.80	5.48	5.32	4.20	5.50	4.32	2.26	5.50	10/2	
	Min	2.16	1.50	1.60	1.15	1.46	1.41	1.71	2.20	2.12	3.34	2.24	1.31	1.15		
1984	Max	2.2	2.06	1.47	2.18	2.94	4.94	4.88	8.30	8.20	7.64	7.58	2.46	8.30	8/31	
	Min	1.36	1.01	1.01	1.04	1.40	1.47	2.46	2.80	3.60	2.26	2.19	1.75	1.01		
1985	Max	1.9	1.80	1.91	2.40	2.26	9.78	9.36	6.58	4.32	9.38	3.66	2.80	9.78	6/30	
	Min	1.61	1.64	1.56	1.71	1.46	2.30	4.84	4.30	2.24	3.20	2.32	2.40	1.46		
1986	Max															
	Min															
1987	Max	2.87	2.20	2.10	2.68	1.91	2.81	4.36	8.60	6.89	3.39	5.12		8.60	8/20	
	Min	2.16	1.73	1.21	1.38	1.20	1.11	1.64	2.34	2.86	2.00	1.40		1.11		
1988	Max	2.87		1.75	5.00				4.80	3.80	9.56	9.18	4.30	9.56	10/28	
	Min	1.53		1.18	1.70				2.66	2.00	3.40	4.41	1.50	1.18		
1989	Max	2.52	2.24	3.66	4.94	5.93	5.55	6.90	8.10	7.68	7.00	8.10	3.64	8.10	8/6 11/23	
	Min	1.45	1.32	1.35	1.36	1.20	1.80	2.36	3.64	3.20	2.71	1.84	1.08	1.08		
1990	Max	2	1.96	1.86	2.06	2.40	8.11	7.32	7.97	9.78	6.60			9.78	9/6	
	Min	1.7	1.32	1.32	1.38	1.19	1.93	4.22	5.00	4.53	2.48			1.19		
1991	Max	2.76	1.88	1.85	1.83	2.48	7.44	3.53	8.98	6.81	6.78	3.85	1.92	8.98	8/7	
	Min	1.61	1.60	1.40	1.45	1.41	1.73	1.36	1.96	4.25	3.84	1.60	1.39	1.36		
1992	Max	2.12	2.28	2.00	2.37	2.30	2.60	8.64	8.04	8.49	7.60	5.10	3.96	8.64	7/22	
	Min	1.92	1.71	1.66	1.69	1.60	1.45	1.92	3.23	5.28	3.00	2.28	1.97	1.45		
1993	Max	2.52	2.02	2.29	3.08	2.39	5.71	6.10	7.52	5.77		9.10	5.93	9.10	11/3	
	Min	1.98	1.72	1.78	1.80	1.45	1.53	2.26	3.11	2.08		2.90	2.30	1.45		
1994	Max	3.42	2.35	2.43	2.30	2.45	3.70	7.82	7.69	7.56	7.66	2.80	6.24	7.82	7/27	
	Min	2.2	2.11	2.06	1.90	1.75	1.72	2.46	2.90	3.86	2.71	2.02	1.70	1.70		
1995	Max	2.58	3.22	2.23	2.05	3.46	4.05	5.46	5.65	7.97	10.00	9.27	8.45	10.00	10/2	
	Min	2.1	2.06	1.93	1.69	1.64	1.82	2.05	2.86	4.32	3.20	2.72	2.52	1.64		
1996	Max	3.38	2.04	2.53	2.78	3.31	2.99	7.60	7.10	5.58	4.60	7.25	2.87	7.60	7/28	
	Min	2.03	1.90	1.92	1.94	1.90	2.08	2.02	4.02	3.38	2.10	2.89	1.85	1.85		
1997	Max	2.23	2.40	1.92	2.65	7.10	4.45	5.82	5.22	6.72	6.08	2.22	2.28	7.10	5/27	
	Min	1.92	1.75	1.62	1.63	1.64	1.79	3.03	4.20	3.87	2.20	1.73	1.73	1.62		
1998	Max	1.96	2.10	2.05	2.18	2.90	2.79	2.45	3.90	9.05	10.77	7.22	9.10	10.77	10/25	
	Min	1.6	1.54	1.50	1.68	1.61	1.62	1.71	1.30	2.12	3.25	3.29	2.70	1.30		
1999	Max	3.96	2.31	2.71	4.14	3.60	5.77	7.55	11.80	7.91	8.10	4.52	5.46	11.80	8/5,6	
	Min	2.13	2.00	1.78	1.64	2.10	2.40	3.36	4.65	4.30	3.40	2.52	2.49	1.64		
2000	Max	5.74	7.05	4.70	3.15	5.84	4.64	11.80	7.38	8.18	10.21	10.78	7.18	11.80	7/9	
	Min	2.26	2.08	2.27	2.16	2.09	2.36	2.60	4.00	4.05	3.20	3.20	2.84	2.08		
2001	Max	3.16	4.90	3.34	3.12	5.19	5.50	9.42	7.46	7.15	6.21	6.99	6.65	9.42	7/6	
	Min	2.28	2.24	1.88	2.11	1.95	1.37	3.37	4.51	4.38	2.40	1.98	1.57	1.37		
2002	Max	2.8	3.27	2.28	2.22	2.98	2.62							3.27	2/2	
	Min	1.9	1.79	1.88	1.06	1.10	1.62							1.06		
2003																

Maximum Reading **11.80** ***m***
Minimum Reading ***m***

Appendix Figure 2. Extreme gaged heights of the Pampanga River Basin.