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Applying the Urban Resilience Theory to Flooding on Flood-prone settlements along the Pampanga River

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ABSTRACT

By accepting periodic flood as an unavoidable circumstance, urban communities in eastern Pampanga can adapt to flood flows from the Pampanga River better during high-intensity storms by creating a more ecologically-resilient multi-equilibria system of adaptation. A typical solution is to apply engineering solutions to flooding, resulting in a forced state of equilibrium that is ill-adapted to the changing forces of nature. By understanding the dichotomous theory of urban resilience to floods, strategies can be formed to assess and plan a more adaptive flood hazard management framework. To operationalize the theory, an estimation of storm-water and riparian alluvial flow is developed to understand the volumetric capacity of floodwaters natural floodplains need to accommodate flooding. The rational method of computing runoff is applied to the major watershed forming the flood-prone Pampanga River, determining the percentage of floodable area and moving ecological equilibria. This creates a better understanding of the distribution of flood by providing a baseline for the future planning of mitigation and adaptation urban strategies to flooding such as providing vegetated buffer zones, no build zones, and ground to building floor height.

1. Introduction

Due to the Philippines' geographical location, the impact of typhoons increases the country's vulnerabilities to flooding. Classified as a moist tropical climatic region, it experiences high temperatures and large amounts of rain year round. Tropical cyclones often occur in the months of July to November, peaking at around the month of August. With the increasing weather variability, however, the Philippines have also been experiencing storms as early as May. In 2009, the peak of the rainy season moved to September-October. At least five main tropical storm paths can be seen in the Philippines: "one that crosses to the north of Manila; one that traverses south of the capital one that passes east or north-east of the archipelago either disappearing or re-curving in the Pacific; one that forms in the China Sea to the west of the Philippines; and another that re-curves in the China Sea between parallels 10° and 20°." (Bankoff, 2003) As a result, some parts of the Philippines, particularly Luzon, experience more tropical cyclones than other areas.

In the Philippines, the effects of climate change, such as changing weather patterns and intensities, are complicated by existing problems of high poverty incidence, degradation of natural resources, increasing man-made pressures as a result of uncontrolled population growth and very low opportunity costs that ultimately lead to low social consciousness, and governance failure. Coupling these pre-existing problems with weather variability, the Philippines, thus, experiences a bullwhip effect: that for every problem added to weather variability, Filipinos experience more vulnerability to disaster. Just in the recent disaster of the local typhoons such as Ketsana (Ondoy) and Parma (Pepeng) in 2009, to the 2011 and 2012 southwest (Habagat) monsoons, super typhoon Haiyan (Yolanda) in 2013, and destructive tropical storm Fung-wong (Mario) in 2014, many Filipinos have lost not only family members to the flash floods, but also livelihood and homes, reducing the chances of survival for the rest.

Resilience, particularly in urban environments near river basins, thus, becomes important, in land use planning and application as it concerns not only potential loss of biodiversity, but as well as the safety of human lives and the maintenance of a city's identity, consequently providing the ultimate insurance of urban cities against the most socioeconomically disruptive floods (Liao, 2012).

Different interpretations of urban or community resilience can be dissected into two: engineering and ecological resilience. (Table 1) Engineering resilience bases its idea of resilience on resistance to disturbances and recovery back into a single stable state. As an example, common notions of engineering resilience define resilient cities as cities capable of withstanding severe shock without incurring immediate chaos or permanent damage by designing, locating, and operating the built environment in ways that maximize the ability of built assets and their physical and institutional associated support systems to mitigate impacts of hazards (Godschalk, 2003; Bosher, 2008).

Ecological resilience bases its idea on tolerance for disturbances and reorganization into an adjusting equilibrium with minimum socioeconomic damage. (Liao, 2012). The urban resilience theory to flood by Liao (2012), bases itself on two arguments: (1) That forcing a single environmental state erodes resilience as it restricts

Table 1 *Summary of the dichotomy between status quo's notion of urban resilience as engineering resilience and ecological resilience. (Liao, 2012)*

Aspect	Engineering resilience	Ecological resilience
Theoretical construct	Resilience = resistance + recovery	Resilience – tolerance + reorganization
Assumption	One equilibrium (one regime) Predictability	Multiple equilibria (multiple regimes) Unpredictable, uncertain
Concerns	Deviation from ideal level of system functionality or stable state	Regime shift
Focus	Stability/ consistency – returning quickly to equilibrium	Persistence –remaining within current regime
Measurement	The speed of recovery to the previous stable state	The magnitude of disturbance system can undergo before shifting regime
Disturbance role	Disturbance as threat	Disturbances as learning opportunity

environmental dynamics of periodic floods and denies the acknowledgement of inherent uncertainties and variability that result in landscape changes (Folke, 2003; Liao, 2012); and (2) that hazard management should focus on building resilience as opposed to maintaining stability as floods create learning opportunities to realize structural and environmental knowledge, creating better fit resolutions for extreme floods (Folke, 2006; Smit and Wandel, 2006; Liao, 2012).

In theory, ecological resilience advocates a moving natural state with little intervention from built structures brought by urban developments. The understanding, however, of where it is essential to protect moving natural states within areas that are flood-prone such as river settlements, has little exploration. The aim of this paper, therefore, is to apply existing hydrological modelling data in urban areas to understand buffer sizes for ecological resilience. By operationalizing the urban resilience theory to floods, future mitigation and adaptation techniques to hydrological disasters may be better fitted to the settlement.

2.1 *The Pampanga River Basin*

The Pampanga River Basin, with a total area of 10,540 sq. km., is considered the fourth largest basin in the Philippines. (DOST-PAGASA, Pampanga River Basin Flood Forecasting and Warning Center, 2011) The watershed encompasses a total of seven provinces. Small portions of Nueva Vizcaya, Aurora, and Zambales, two-thirds of Bulacan, and the entire provinces of Tarlac, Nueva Ecija, and Pampanga are included in this large watershed. (Manila Observatory, 2009) The river basin has an average annual rainfall of 1900 mm. Major tributaries predominantly come from the north to north-eastern portion of the watershed such as Rio Chico dela Pampanga River (coming from Bamban, Cutcut, and Talavera rivers), Digmala-Tamala River, Coronel River, Peñaranda River (converging from Chico and Sumacbao rivers) and Maasim-San Miguel River, which passes through Candaba, Pampanga. Major tributaries for the Pampanga river basin in the western portion include the Porac-Gumain, Abacan, Portrero, and Angat rivers that converge through the Pasac River (Figure 1).

Though the main sources of drainage come from the Sierra Madre Mountains, only 27% of the watershed is forested (95,694 Has.), equivalent to roughly 10% of the entire basin, much of it with limited old growth on the eastern section (Figure 2) (Manila Observatory, 2009; DILG, 2012). The remaining area of the river basin is predominantly flat.

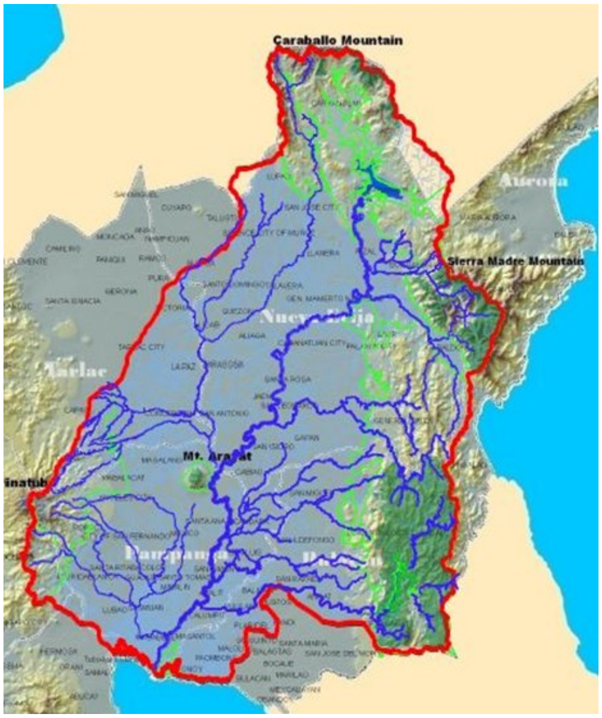

Figure 1 *Major tributaries of the Pampanga River Basin*
(Source: Department of Interior and Local Government, DILG, 2012)

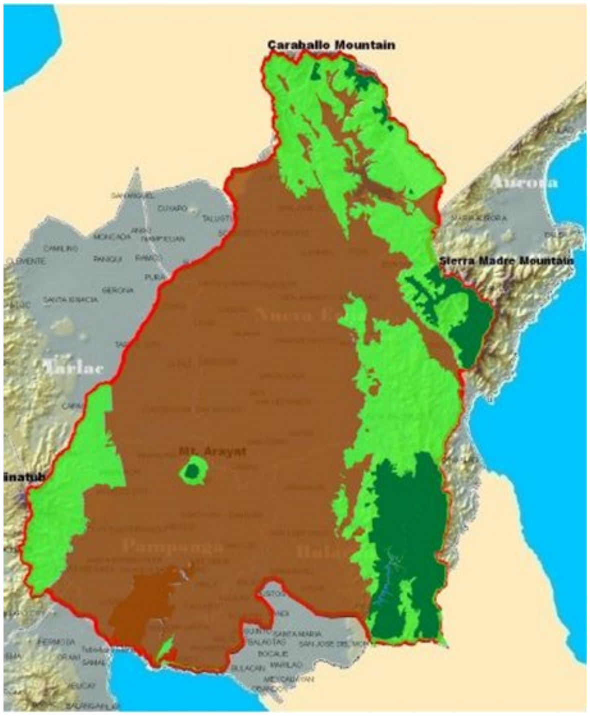

Figure 2: Forest cover within the Pampanga watershed
(Source: DILG, 2012)

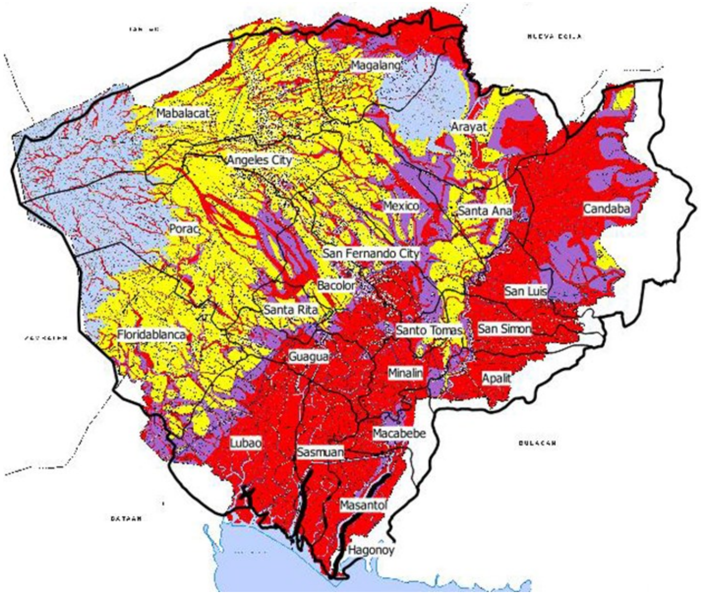

Figure 3 *Flood hazard map of Pampanga. Red, purple, and yellow portions show high (> 1.0m flood depth), moderate (0.51-1.0 m flood depth, and low (0.50m or less flood depth) susceptibility respectively. (After Mines and Geosciences Bureau, 2011; PhilGIS, 2013)*

2.2 *Pampanga River Hazard*

Four out of seven provinces found in the Pampanga River Basin. Pampanga, Nueva Ecija, Tarlac, and Bulacan, are listed in the top ten highly susceptible provinces to flooding in the country, all of which have major tributaries connected from the deforested Sierra Madre Mountains. Pampanga is the most-flood prone with 79.54% of its land susceptible to flooding. (Locsin, 2014) In particular, east of the Pampanga river shows high susceptibility to flooding. Eight towns are highly susceptible to flooding from the Pampanga (Figure 3).

Per return period, the areas vulnerable to flooding increase (Figure 4). The flooding problem along the Pampanga River affects more than a third of its population (Table 2).

Table 2 *Socioeconomic data of Pampanga affected by the Pampanga River flooding*

Socio-economic data	
Total population	2,014,019
Number of households	416,271
% of affected population	36.89%
Affected population east of Pampanga River	
Apalit	101,537
Arayat	121,348
Candaba	102,399
Macabebe	215,610
Masantol	52,407
San Luis	49,311
San Simon	48,353
Santa Ana	52,001
Total affected population	742,966

Source: National Statistics Office, 2013

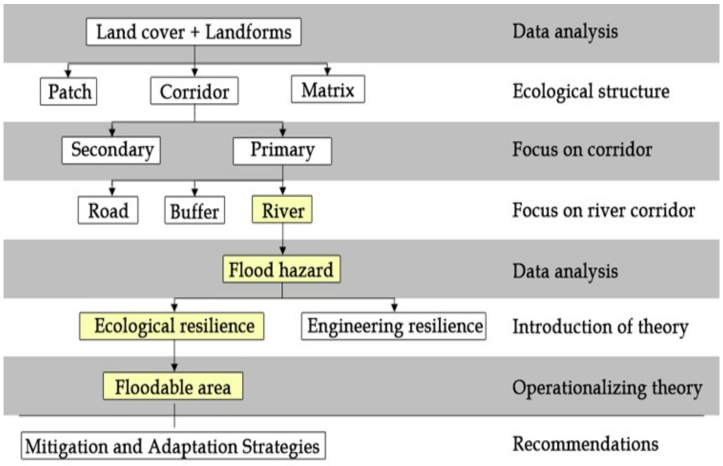

Figure 5 *Research Framework*

3. Methodology

Though there are many works discussing and analyzing in theory ecological resilience (Liao, 2012; Folke, 2003; Smit & Wandel, 2006; Folke, 2006), the application of such urban resilience theory has yet to be developed. Thus, the aim in this methodology is to apply the existing hydrological modelling data gathered from government studies through the Department of Science and Technology's (DOST) Project NOAH (National Operation and Assessment of Hazards), and DREAM (Disaster

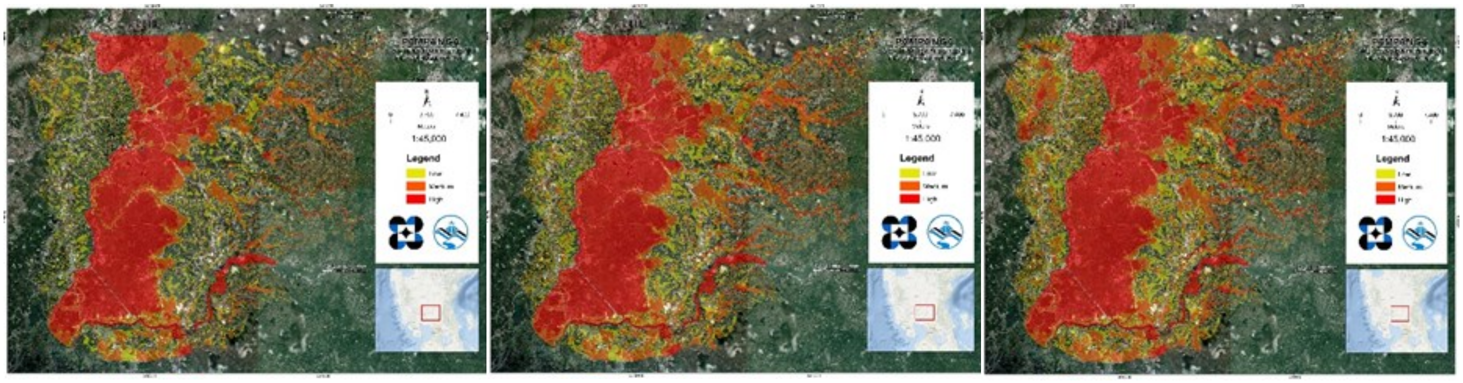

Figure 4 Enhanced flood hazard maps along the Pampanga River for 5-year (left), 25-year (center), and 100-year (right) rainfall return periods.
(Source: Lagmay, Project NOAH, 2012)

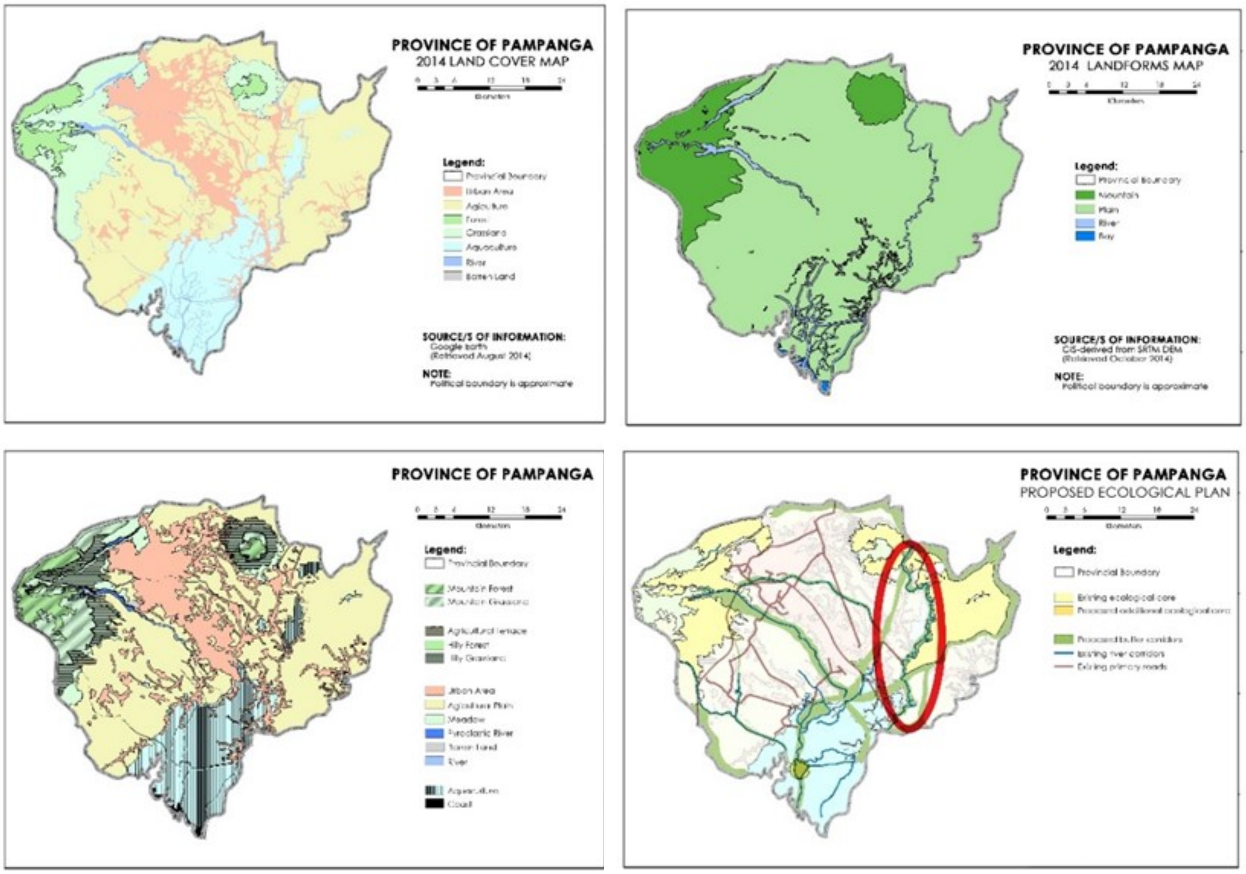

Figure 6 *Proposed ecological plan (bottom right) based on the ecotope map (top left) as derived from the land cover (bottom left) and land forms (top right) maps. The river corridor as study focus is encircled in red.*

Risk Assessment, Exposure and Mitigation) Program and translate it into applicable spatial information for urban community planning.

The basic framework for the research can be seen in Figure 5. Ecological units for the discussion were generated by overlaying its most recent land cover map based on satellite imaging (2014) and land forms to create an ecotope map. Afterwards, the focus of the study was selected from the ecological map of Pampanga by assessing patches, corridors, or matrices under threat of flood hazards. (Figure 6) The urban resilience theory to flooding was then applied to the site by operationalizing the urban resilience theory to flooding's concept of floodable lands as "land capable of storing, or conveying floodwater and sediments without incurring damage locally or otherwise." (Liao, 2012) The percent floodable area will contribute to a city's flood tolerance by assigning areas that should treat periodic floods as unavoidable and benign.

Through Geographic Information System (GIS) processing, enhanced flood hazard maps based on ASTER-DEM images at 10m resolution provided by the Department of Science and Technology (DOST) through the Project NOAH (National Operation and Assessment of Hazards) Program will be used to compute for the floodable areas.

3.1 Theoretical Methodology

The urban resilience theory to flood highlights the importance of identifying floodable lands. The identification of floodable lands and percentage of floodable lands from a hydrological model of the area will enable local government agencies, private developers, and households to apply this information into community planning guidelines.

The theory identifies four properties of floodable lands that will enable the operationalization of the theory: (1) to store or convey floodwater and sediments, (2) to limit local and proximate damage, (3) that it can be of any land use or cover, and (4) contributes to flood tolerance (Liao, 2012).

As such, the functional relationship between flood tolerance and the resilience to socioeconomic change can be expressed through the functional relationships:

$$\textit{Degree of socioeconomic change} = f\,(\textit{flood depth, amount of precipitation})$$

The above relationship shows that the depth of the flood and the quantity of precipitation greatly influence the extent of socio-economic changes. Although the precipitation quantity dictates the magnitude of flood, which can also be expressed with respect to flood depth, still both variables individually or collectively affect the degree of socio-economic changes, at least, in the Philippines' case.

Similarly, the flood magnitude can be expressed as the following relationship:

$$\textit{Flood magnitude} = f\,(\textit{rainfall intensity, duration, frequency})$$

The magnitude of flood is certainly depending on the intensity, duration and frequency of the rainfall. This relationship is statistically proven. The level of flood hazards, in the same line, depends on the flood magnitude, watershed condition and the level of preparedness of the community.

The degree of socioeconomic change can be derived from flood hazard maps, as it is indicative of the hazard level that it brings about to the site. The flood magnitude may be measured through different return periods. As time progresses, the rainfall intensity and frequency should adjust accordingly to the return period to create best fit models.

3.2 *Empirical Methodology*

To operationalize the computations for floodable land, the summation of the area vulnerable to flood hazards based on two different heights, high risk (flood depth above 1.5 meters) and low to moderate risk (flood depth of 1.5 meters and lower) shall be computed for different return periods (5-, 25-, and 100- year storms). The computation can be seen in the following equation.

$$\sum_{i=1}^{6}(a_{iH}+a_{iM}) = (a_{1H}+a_{iM})+(a_{2H}+a_{2M})+\cdots+(a_{6H}+a_{6M})$$

where: i = town affected by Pampanga River (here will be 6 towns)
H = level of risk i.e. high risk
M = level of risk i.e. low to moderate risk

The summation shall be indicative of the affected areas by different degrees of flooding, reflecting potential threats to socioeconomic change due to flooding.

To determine the baseline for mitigation and adaptation strategies, a buffer distance must be computed from the river to determine the general width of land affected by vulnerabilities per rainfall return period. The computation for buffer distances can be expressed by the following Equation.

$$Buffer = \frac{\sum_{i=1}^{6}(a_{iH})+\sum_{i=1}^{6}(a_{iM})+SD}{length_{river}}$$

And , Standard Deviation, SD, can be computed by the following equation:

$$SD = \sqrt{\frac{\sum(a_H - \bar{a})^2}{6}}$$

Table 4 *Computed buffers from east of the Pampanga river per return period*

Flood Return Period	Risk level	Buffer distance (km)
5 year	Above 1.5m	4.01
	1.5m and below	1.86
	Total buffer	5.87
25 year	Above 1.5m	4.45
	1.5m and below	1.99
	Total buffer	6.44
100 year	Above 1.5m	4.93
	1.5m and below	4.16
	Total buffer	9.09

Table 3 *Floodable areas (in square kilometres) along the Pampanga River*

Towns	**Area affected per return period (in sq. km.)**									
		5 year			**25 year**			**100 year**		
	Land area	**Above 1.5m**	**1.5m and below**	**% flooda-ble**	**Above 1.5m**	**1.5m and below**	**% flooda-ble**	**Above 1.5m**	**1.5m and below**	**% flooda-ble**
Apalit	61.47	43.01	4.68	78%	43.01	5.58	79%	44.03	6.71	83%
San Simon	53.37	31.69	2.31	64%	33.29	3.77	69%	33.62	5.59	73%
San Luis	56.83	39.85	7.28	83%	43.61	5.2	86%	44.48	6.99	91%
Sta. Ana	39.84	9.85	6.88	42%	13.13	11.48	62%	13.15	15.34	71%
Candaba	176.4	41.64	59.12	57%	52.58	53.49	60%	55.06	106.89	92%
Arayat	60.51	23.82	7.89	52%	24.88	14.77	66%	30.02	19.09	81%
Floodable area per return pd.	**448.42**	**189.85**	**88.16**	**63%**	**210.5**	**94.3**	**70%**	**220.35**	**160.6**	**82%**
Tot. floodable		**278.01**			**304.8**			**380.95**		
Std. Dev.		11.78	19.96		13.11	17.33		13.29	36.18	
Tot. Std. Dev.		**31.73**			**30.44**			**49.47**		

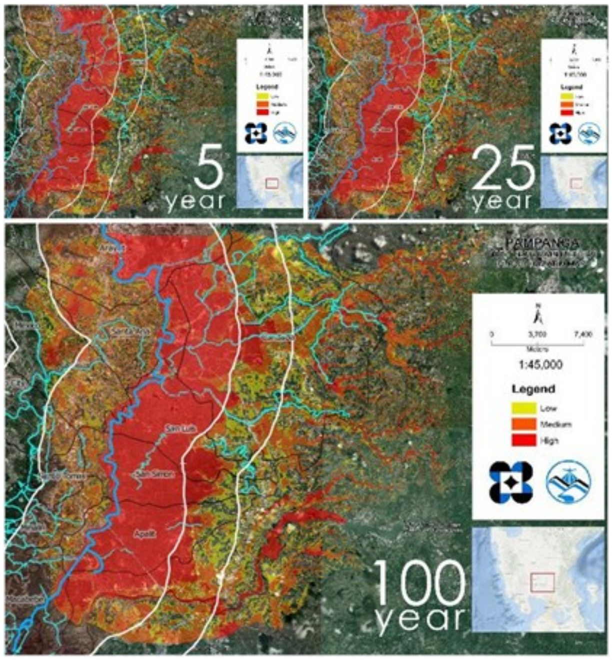

Figure 7 *Maximum buffer zones produced on GIS over enhanced flood maps per 5-, 25-, and 100-year return periods.*

The standard deviation shall be included as this accounts for the outliers in the computation of the areas of flood hazards per return period.

4. Findings and Discussions

The areas affected by flood, separated by town, and computed per flood depth per return period can be found in Table 3. The towns with the highest percent floodable land based on high flood hazards lie on the eastern portion of the Pampanga River, particularly San Luis, Apalit, and San Simon. For a 5-year rainfall return period, 70% of San Luis and Apalit and 59% of San Simon are at risk to floods above 1.50 meters. For a 25-year return period, still 77% of Apalit, 70% of San Luis, and 62% of San Simon are vulnerable to floods above 1.50 meters. At a 100-year rainfall return rate, 77% of San Luis, 72% of Apalit, and 63% of San Simon are vulnerable to inundation above 1.50 meters. This is indicative that most high risk inundation occur east of the Pampanga River, nearest the bay, lying at an elevation of approximately 5 masl (meters above mean sea level).

Areas north of the Pampanga River within the Pampanga province show the highest vulnerability to low to moderate flood hazards. The percentage increase of areas vulnerable to floods 1.50 meters and less are significantly larger in the towns of Arayat and Sta. Ana (north east of the river), and Candaba (north west of the river). For a 5-year rainfall return rate, 13% of Arayat's land area, 17% of Sta. Ana, and 34% of Candaba are vulnerable to floods 1.50 meters and below. For 25-year rainfall return rates, 24% of Arayat, 29% of Sta. Ana, and 30% of Candaba are at risk to low to moderate floods. At a 100-year return period, 32% of Arayat, 39% of Sta. Ana, and a significantly large scale of 61% of Candaba are at risk of inundations up to 1.50 meters.

The buffer distances were computed using the formula identified in the methodology for 5-, 25- and 100- year rainfall return periods (Table 4). The largest buffer distance stands at 4.93 km for high risks, and 4.16 km for low to moderate risks, for a total buffer distance of 9.09 km from the river, at a return rate of 100 years (Figure 7). The significant measure is the buffer for 100-year return rates as it provides as the baseline for mitigation and adaptation policies outlined in the City and Land Use Planning (CLUP) for the Philippines and a revision to the Water Code (Presidential Decree 1067).

5. Conclusion

Areas at risk to floods above 1.50 meters are most vulnerable to socioeconomic changes. As a result, these areas must be reviewed and revised every five years to accommodate the changing rainfall return rates and topography such as land subsidence and soil erosion, to identify the minimum buffer distances for land use planning and disaster prevention. The findings reveal, that the study of flood hazards in the area, have a current minimum buffer distance of 5 km from east of the river, indicative of the buffer for high-risk areas to flooding. The findings also show that areas vulnerable to floods up to 1.50 meters vary across return periods, and that large, infrequent storms have the greatest offset or buffer distance from the main river. A maximum of 9 km from east of the Pampanga river is ideal for the findings of this study. For maximum safety and minimal loss to life and damage to socioeconomic activities, the buffers for 100 year storms are the most ideal to use in mitigating and adaptive policies. Buffer distances for the other return periods also provide as guidelines for planning of land use and regulations depending on the purpose and intention of the planners. The understanding of different buffer distances across different return periods pose as a guideline for tolerability to flooding as it allows to determine land uses that are less vulnerable to socioeconomic changes such as allocating cultivated lands as opposed to urban centres nearer to buffer distances of return periods less than 100 years. The application of such buffer areas and percent floodable areas may be applied to different land use planning policies, private development assessments, and disaster risk management, such as:

- Structural conditions for insurance coverage of settlements and developments within high-risk buffer areas
- Establishment of more appropriate no-build zones within high-risk buffer areas, as opposed to general zoning ordinances on river setbacks
- Incentives for developing urban parks, greenways, and parkways along the identified high-risk buffers near the river area both as a flood mitigation technique and as a greening effort within urban communities
- Establishment of evacuation sites outside of both the low- and high-risk buffer areas that are accessible to different towns affected by the flood
- Sharing knowledge of flood risks and complementing disaster responsiveness before allowing population to settle in flood-prone areas to create self-organizing cities where both the local government and citizen may act immediately and in coordination to avoid damages
- Learning from each flood such as timely behavior, physical adjustments such as debris deposition in unexpected locations, and institutional adjustments

Operationalizing the urban resilience theory to flooding provides as a baseline for mitigation and adaptation policies for areas vulnerable to hydrologic conditions. The application of buffer zones in other flood-prone provinces found in the Pampanga River Basin such as Bulacan, Pangasinan, Tarlac, and Nueva Ecija, and other provinces highly susceptible to floods such as Maguindanao, Mindoro Oriental, Ilocos Norte, and Metro Manila, may prevent loss of human life. The protection and proper hazard planning of these river corridors is important, particularly when urban areas surround it, to limit the fragmented use of spaces through urban growth that intervene with the sustainability of habitats and general biodiversity within the area. The use of such floodable land strategies may also lead to other studies of ideal buffer distances for other hydrologic vulnerabilities that are becoming new areas of interest such as storm surges due to typhoons. Allowing human settlement, through identification of safe and liveable sites along river corridors are important in creating a balanced, symbiotic relationship with the biodiversity and conditions of the land.

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