Floodplans: landscape plan for a flood resilient municipality of Marilao, Bulacan, Philippines

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Abstract. According to the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), an average of 20 typhoons a year visits the Philippines; and one of the significant repercussions of typhoons is flooding. Due to worsening and intensifying typhoons, the flooding problem is also getting worse, and two of the main reasons for this are land subsidence and sea-level rise. Marilao, Bulacan, is one of the Philippines' municipalities experiencing worsening flood levels. This study tackles an environmental approach to making the municipality adaptive and resilient to flooding by finding the most appropriate use of the land areas of Marilao to benefit both the environment and its users. The study identified and analyzed the causes of flooding, using relevant maps such as hazard maps, existing land-use plans, and projected land-use plans to draft an effective plan for the municipality. After which, generating projections of the land conditions in the next century was done; to ensure that the proposed plans will accommodate future scenarios within the landscape. These data, along with four possible scenarios on the problems of the site, were analyzed. With this, the study took upon one of the approaches that led to the 2060 Environmental Protection Plan, which primarily focuses on addressing landscape requirements.

Keywords: flooding, landscape projections, land subsidence, sea-level rise

1. Introduction

In the Philippines, flooding has been an increasingly evident and severe problem [1]. One of the leading causes of flooding is the occurrence of typhoons in the country. According to the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), an average of 20 tropical storms enters the Philippine Area of Responsibility per year. Moreover, among those 20 tropical storms, an average of 10 make landfall. The data shows that the Philippines is the most storm-exposed country on earth [2], making the country vulnerable to flooding effects and consequences. With Luzon and Visayas as the most susceptible to typhoon paths traverse the country each year [3].

Marilao, located at the south end of the province of Bulacan, Philippines, is a municipality that is part of the province's 4th district (Figure 1). It stretches in a northeast to southwest direction. Its southwest end is about 10km from Manila Bay's edge, and its northeast
end is part of a pronounced alluvial plain beside the Sierra Madre Mountains. Higher elevations enclose the municipality on its landlocked northeastern side, while its southwestern parts are mostly flatlands of much lower elevations [4]. The water's general flow throughout the municipality is from the northeast end towards the southwest end, in which waters essentially flow toward Manila Bay; this is also how the water flows on the municipality's prominent river: the Marilao River, which traverses the municipality's entirety [5].

The municipality's geophysical characteristics make flooding an inevitable occurrence, mostly when large amounts of rain occur in the area because the municipality serves as a pathway of water coming down from higher elevations to the lower elevations, in which water should ultimately end up in Manila Bay.

As typhoons that hit the country become more robust due to global warming [6], the expectation is that flood levels will worsen, and its damaging effects are then also magnified. With this, specific solutions to flooding that are neither sustainable nor are adaptive to the changing dynamics of the environment may only provide temporary solutions. Reevaluating planning strategies for land-use concerning the current landscape and how it evolves through time ensures that proposed solutions do not resist nor restrain the force of nature but instead adapt to the environment so that communities may flourish despite the changing landscapes.

With this in mind, the study's main guiding question is: how can the municipality of Marilao, Bulacan, be transformed into a flood adapted municipality with regards to the 100-year flood level?

2. Methodology
The methodology follows a landscape planning framework that consists of two parts. Figure 2 [7] shows that the left side focuses on figuring out community considerations that support the study's landscape plan; this is done by first gathering relevant data from the community of Marilao, after which is the application of the two theories related to the community from the theoretical framework. This results in assessing what the community needs regarding flood resiliency and collating it into considerations based on the community.

While the right side of the framework focuses on producing a land-use plan reflected into a landscape plan for the municipality of Marilao, the first step to achieving the landscape plan is extensive data gathering about the current conditions of the landscape of the municipality. After collecting data regarding the landscape, the next step is applying theories regarding the landscape to projection scenarios that may happen in the future. Projection scenarios reveal what would happen with the landscape conditions (relating to flood levels and intensity) if the landscape is left alone. Determining the optimal year for designing a land-use plan and a landscape plan results from knowing the projection scenarios. Finally, in drafting the landscape plan, the chronological execution of the proposed planning strategies regarding management strategies and environmental strategies is essential. The integration of the left and the right sides: the community

![Figure 2 Research methodology](image-url)
considerations with the landscape plan shall result in the study’s goal to design a flood resilient landscape plan.

3. Findings

3.1 Existing Landscape Conditions

Figure 3 [8] is a closer look at the municipality's boundary and how the Marilao River passes through the municipality's entirety. Also highlighted in figure 4 are the major roads that cross the municipality.

![Figure 3 The boundary of Marilao, Bulacan](Source: Google Maps (2020))

![Figure 4 Barangay boundaries overlay in 100-year flood hazard map](Source: Google Maps, DOST-UP DREAM and Phil-LiDAR 1 Program)

Overlaying the municipality's 100-year flood hazard map on the barangay boundaries defines which barangays are most affected by flooding. Findings showed that the majority of barangays in Marilao are severely affected by flooding. From the overlay map [9], the bulk of flood-prone barangays is at the southwestern end of the municipality, which is the lowest elevations of mostly at only 3 meters above sea-level, and the areas nearest Manila Bay [9]. As per areas on the northeastern part, although these areas are of significantly higher elevation peaking at 64 meters above sea-level, flooding still occurs – but only at specific sections that are directly adjacent to the river and its arteries.

3.2 Flooding Causes

Two situations result in flooding in Marilao, Bulacan: first is when the Marilao River overflows due to excess rainwater, and the second is when high tide surges. Typically, during typhoons or when the monsoons bring about large amounts of precipitation, water in the Marilao River's corridor swells until it inundates surrounding areas and then rushes to the lower southwest side of the municipality. Ideally, water drains to Manila Bay. Still, what happens in Marilao, the water gets trapped in the lower-lying areas because of poor drainage, siltation in bodies of water, and overflowing of Manila Bay. Flooding caused by tidal surges happens during high tide, wherein the lowest points of the municipality get flooded even without precipitation.

To effectively plan for flooding adaptability and resiliency of Marilao, it is not enough to look at the landscape's current conditions. Changes in the landscape is a factor impacting flood conditions and levels. Thus, to ensure that proposed strategies will still be relevant in the future, the landscape conditions and how it changes in the next century shall be investigated by this study.

3.3 Land Subsidence and Sea-Level Rise

Currently, Marilao has one of the highest rates of land subsidence in the country [10]. Based on a 2011 study by Kevin Rodolfo and Fernando Siringan, Marilao's land subsidence rate reaches about 55-60mm/year. Compared to the country’s natural land subsidence rate
of around 0.7-2mm/year [10], which means that in less than 17 years, land in Marilao would have subsided by 1 meter already. This data is crucial because solutions applied to problems like flooding usually involve constructed engineering solutions such as building floodwalls, which would be ineffective in the long run because of land subsidence.

As per sea-level rise (SLR), According to PAGASA, sea-level rise in the Philippines is about 5-7mm/year [11], which is on the higher end of SLR globally. RCP 8.5, which is the high-end scenario projection of the sea-level rise in the Philippines made by PAGASA [11], factors in different causes of sea-level rise and is the projection used in this study.

3.4 Landscape Projections
Land subsidence throughout the next century is indicated below in Table 1. For sea-level rise, data from RCP 8.5 is shown below in Table 2.

| Year | Land Subsidence |
|------|----------------|
| 2020 | +0.6 m         |
| 2040 | +1.8 m         |
| 2060 | +3 m           |
| 2080 | +4.2 m         |
| 2100 | +5.4 m         |

| Year | Sea level Rise |
|------|----------------|
| 2020 | +0.1 m         |
| 2040 | +0.2 m         |
| 2060 | +0.4 m         |
| 2080 | +0.8 m         |
| 2100 | +1.1 m         |

3.5 Landscape Projections Cross-Sections
Changes in the landscape concerning the base water level from 2020 up to 2100 are graphically shown in the study's cross-sections [12]. The water level shown in the cross-sections below does not include the flood water level of the 100-year flood scenario but only shows the base tide level.

3.6 Population Projection
The residents of Marilao, Bulacan will be the ones primarily affected by the changes of the landscape in the next century. As the landscape changes, the population changes with it, and as such, the projection for the growth of the population in the next century is also calculated. The population projection is computed with the formula below, and the result is shown in figure 9 [13].
4. Results and Discussions

4.1 Discussion on Planning Strategy and Approach

In dealing with changing dynamics affecting the landscape, such as land subsidence and sea-level rise, choosing a planning strategy and approach is essential because it needs to handle high uncertainty events. Therefore, the planning strategy should be adaptable enough to prepare for more than a single outcome in the future. In designing the appropriate response to uncertainty, the approach should depend on the “degree of uncertainty and the degree to which a system can be controlled” [14].

According to the planning strategy matrix in Figure 10, Scenario Planning is the appropriate response “when control is difficult, and uncertainty is high” [14]. This is the case for this study; factors concerning flooding and its effects on the municipality of Marilao in the next century are highly uncertain and uncontrollable.

4.2 Formulation of Planning Strategy Framework

Adapting Peterson et al.’s Planning Strategy Matrix (Figure 10), Scenario Planning is used in formulating a planning strategy framework for Marilao, Bulacan. Scenario Planning deals with a variety of plausible futures but is not meant to predict the most probable future; instead, it has the objective to generate and examine decisions for each of the plausible futures [14]. With this method, scenario planning essentially aims to prepare for multiple futures, which equips significant actors with the “ability to recognize, adapt to, and take advantage of changes over time” [15]. In creating a variety of plausible futures, the study shall adapt the five-step process indicated in the study by Weeks (Figure 11) [15].

4.2 Generation of Planning Schemes

Following the Planning Strategy Framework, generating the planning schemes begins with step three: Synthesize – wherein a scenario matrix is drafted by using a 2x2 matrix approach with the identified essential variables. The two variables used for the matrix are specifically: population growth for the uncertain variable regarding the community and land subsidence and sea-level rise for the uncontrollable variable regarding the landscape.
The matrix generates four plausible futures A, B, C, and D – of which inferences are made, as shown in Table 3 below.

Table 3 Plausible futures inferences

| Four Plausible Futures’ Inferences: | A | B | C | D |
|------------------------------------|---|---|---|---|
| **High Population Growth** | **Low Population Growth** | **Low Population Growth** | **High Population Growth** |
| Low Land Subsidence, Sea-Level Rise | Low Land Subsidence, Sea-Level Rise | High Land Subsidence, Sea-Level Rise | High Land Subsidence, Sea-Level Rise |
| More usable land area | More usable land area | Less usable land area | Less usable land area |
| More people to be affected by flooding. | The landscape will be able to support its current intended use. | More on engineering solutions to control flooding | The landscape will not be able to support its assigned function. |
| Flood levels will not worsen exponentially. | The problem of flooding will persist if no solutions are applied. | Population affected by flooding could potentially relocate within the municipality. | The population will be exposed to more hazards or threats. |
| The adaptive strategy will be focused on equipping the community to cope with flood conditions. | Flooding solutions will be an immediate-reaction-response type. | Flood adaptive strategy for the community. | Solutions for both the landscape and the community issues are needed. |
| The development will sprawl to accommodate a high population. | The focus will be to control the flooding. | | Flood levels will worsen. |
| The carrying capacity of landscape will be an issue. | | | High risk of overcrowding. |
| Municipality to become a city. | | | |

In forming the four plausible futures' inferences, the guiding question is: What will happen to the municipality, concerning flooding, in the next century given the variables? Plausible futures A, B, C, and D are all given a specific scenario solution name and are assessed for risk and vulnerability, as shown in Table 4 below.

Table 4 Scenario solution name with risk & vulnerability assessment

| Plausible Future | Scenario Solution Name | Risk & Vulnerability Assessment |
|------------------|------------------------|-------------------------------|
| A                | Metropolis Shift Plan  | Medium Risk & Vulnerability   |
| B                | No Alteration Plan     | High Risk & Vulnerability     |
| C                | Hard Engineering Solutions Plan | Medium Risk & Vulnerability |
| D                | Environmental Protection Plan | Low Risk & Vulnerability      |
4.3 Selection of Planning Schemes

The explanation for the four different scenarios and the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis per scenario is below (shown in Figures 12 to 15) [17].

![Metropolis shift plan](image)

**Figure 12** Metropolis shift plan

![No alteration plan](image)

**Figure 13** No alteration plan

![Hard engineering solutions plan](image)

**Figure 14** Hard engineering solutions plan

![Environmental protection plan](image)

**Figure 15** Environmental protection plan

From the evaluation of the four scenarios, an environmental approach is a priority for the solutions of the provisions related to the municipality's landscape conditions. Seeing that *Plausible Future D: Environmental Protection Plan* [17] has more strengths and opportunities with low risks and vulnerability and dealing with the extreme values of the variables considered, this strategy is applied in the study.

4.4 Environmental Analysis

As per the findings on land projections, each municipality's barangay was analyzed if it would be submerged or not in the next century. Table 5 below reflects data from land projections and cross-sections of the municipality. The (X) mark indicates that the barangay is already submerged by the respective year, and the (O) mark indicates that the area is still available for use.

| Barangay     | 2020 | 2040 | 2060 | 2080 | 2100 |
|--------------|------|------|------|------|------|
| Abangan Norte| O    | O    | X    | X    | X    |
| Abangan Sur  | O    | O    | X    | X    | X    |
| Ibayo        | O    | O    | O    | O    | O    |

*Table 5 Land projection assessment from 2020 to 2100*
From the analysis of the landscape projections concerning land subsidence and sea-level rise, and with environmental conditions analysis of the site, the year 2060 is the ideal year to propose a landscape plan for a flood resilient municipality of Marilao, Bulacan. The year 2060 is chosen because it is the year wherein the municipality will experience drastic changes as five barangays are projected to submerge by 2060. Another basis for choosing this year is that there would be time to plan and shift the municipality’s landscape from 2020-2060.

4.5 Land-Use Transition

| Barangay          | 2020 | 2040 | 2060 | 2080 | 2100 |
|-------------------|------|------|------|------|------|
| Lambakin         | O    | O    | O    | O    | O    |
| Lias             | O    | O    | O    | O    | O    |
| Lomas De Gato    | O    | O    | X    | X    | X    |
| Nagbalon         | O    | O    | X    | X    | X    |
| Patubig          | O    | O    | O    | O    | O    |
| Poblacion I      | O    | O    | O    | O    | O    |
| Poblacion II     | O    | O    | X    | X    | X    |
| Prenza I         | O    | O    | O    | O    | O    |
| Prenza II        | O    | O    | O    | O    | O    |
| Sta. Rosa I      | O    | O    | O    | O    | O    |
| Sta. Rosa II     | O    | O    | O    | O    | O    |
| Tabing Ilog      | O    | X    | X    | X    | X    |

**Figure 16** 2020 to 2060 Gantt Chart
Figure 16 above shows a proposed Gantt chart on how the municipality of Marilao will shift from 2020 to 2060 as per the 2060 Environmental Protection Plan [17].

4.7 2060 Site Development Plan
The proposed master plan for Marilao, Bulacan, reflects the 2060 land-use plan [18] and the approach and proposals of the 2060 Environmental Protection Plan (Figure 17). The master plan recommends areas to be developed into green spaces to aid in the municipality's flood resiliency regarding the 100-year flood hazard map and the landscape projections in the next century.

![2060 Master Plan](image)

**Figure 17** 2060 Master Plan

4. Conclusion
The study takes on an environment-centered approach to adaptation and resiliency to flooding. The study is envisioned to serve as a preliminary body of information that approaches the drafting of solutions for flood-related problems by the projection and analysis of future scenarios and developing appropriate planning strategies.

The study's main problem, "How can the municipality of Marilao, Bulacan be transformed into a flood adapted municipality regarding the 100-year flood level?" was answered by creating the 2060 Environmental Protection Plan. The plan drafts actions that the municipality can implement and enforce to improve the municipality's flood resiliency and adaptivity by factoring how the landscape will transform in the next century.

References
[1] Bankoff G 2003 Constructing vulnerability: the historical, natural and social generation of flooding in Metropolitan Manila disasters [Internet] 27(3):224–38. Available from: http://doi.wiley.com/10.1111/1467-7717.00230
[2] Brown S 2013 The Philippines is the most storm-exposed country on earth [Internet] TIME USA Available from: https://world.time.com/2013/11/11/the-philippines-is-the-most-storm-exposed-country-on-earth/
[3] Warren J Typhoons in the Philippines: a historical overview [Internet] ArcGIS Available from: https://www.arcgis.com/apps/MapJournal/index.html?appid=586f9150ae87491a8c7f1b86db7952a9 #detail

[4] Marilao Planning Office 2020 Marilao, Bulacan elevation map and slope map Zenodo doi:10.5281/zenodo.4014926

[5] Google Images 2020 Marilao river flow direction doi:10.5281/zenodo.4014930

[6] Mei W and Xie S P 2016 Intensification of landfalling typhoons over the northwest Pacific since the late 1970s Nat Geosci 9(10):753–7

[7] Aquino G L 2020 Floodplans research methodology chart doi:10.5281/zenodo.4014940

[8] Google Maps, DOST-UP DREAM and Phil-LiDAR 1 Program 2020 100-Year flood hazard map with municipal boundaries overlay Zenodo doi:10.5281/zenodo.4014944

[9] Rodolfo K and Siringan F 2011 Global sea-level rise is recognised, but flooding from anthropogenic land subsidence is ignored around northern Manila Bay, Philippines

[10] Cinco T, Villafuerte M I, Ares E, Manalo J, Agustin W, Aquino K et al 2018 Observed climate trends and projected climate change in the Philippines [Internet] Philippine Atmospheric, Geophysical and Astronomical Services Administration 2–11 p. Available from: https://icsc.ngo/wp-content/uploads/2019/07/PAGASA_Observed_Climate_Trends_Projected_Climate_Change_PH_2018.pdf

[11] Aquino G 2020 Floodplans cross-sections of Marilao, Bulacan doi:10.5281/zenodo.4014955

[12] Aquino G 2020 Marilao, Bulacan population projection from 2020 to 2100 doi:10.5281/zenodo.4014965

[13] Aquino G 2020 Marilao, Bulacan demographic projection from 2020 to 2100 doi:10.5281/zenodo.4014967

[14] Peterson G D, Cumming G S and Carpenter S R 2003 Scenario planning: A tool for conservation in an uncertain world Conserv Biol. 17(2):358–66

[15] Weeks D, Malone P and Welling L 2011 Climate change scenario planning: A tool for managing parks into uncertain futures Park Sci [Internet] 28(1):26–33 Available from: papers3://publication/uuid/8AE42E00-84A9-4E96-A746-F0BDDFODD9ED

[16] Aquino G 2020 Floodplans generating scenario matrix doi:10.5281/zenodo.4014975

[17] Aquino G 2020 Floodplans planning schemes doi:10.5281/zenodo.4014977

[18] Aquino G 2020 Floodplains land-use map doi:10.5281/zenodo.4014981

[19] Buijs J, Boelens L, Bormann H, Restemeyer B, Terpstra T and Der T Van 2018 Adaptive planning for flood resilient areas: dealing with complexity in decision-making about multilayered flood risk management Proc 16th Meet Adapt Plan Spat Transf Groningen, Netherlands 23–5

[20] Chermack T 2011 Scenario Planning in Organizations: How to Create, Use, and Assess Scenarios Berrett-Koehler Publishers

[21] Favato G and Vecchiato R 2017 Embedding real options in scenario planning: A new methodological approach Technol. Forecast. Soc. Change 124:135–49

[22] Hutter G 2007 Strategic planning for long-term flood risk management: Some suggestions for learning how to make strategy at regional and local level Int. Plan Stud. Volume 3(No. 3):273–89

[23] Gunderson L H 2000 Ecological resilience — in theory and application