Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area

Summary Report

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Contents

Executive Summary

The Greater Metro Manila Area (GMMA) is a global megacity that experiences some of the world's worst natural disasters, as a result of geological (e.g. earthquakes, volcanic eruptions and tsunamis) and hydrometeorological hazards (e.g. tropical cyclones and floods). As an affirmative step to implement the Hyogo Framework for Action, The Philippine Government has undertaken a program of hazard and risk analysis capacity building through a collaborative partnership among the National Disaster Risk Reduction & Management Council (NDRRMC) Collective Strengthening of Community Awareness for Natural Disasters (CSCAND), the Australian Government Department of Foreign Affairs and Trade (DFAT) and Geoscience Australia (GA). The activity was the Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area, Philippines (GMMA RAP), and was part of the Metro Manila Post-Ketsana Recovery and Reconstruction Program.

Through the GMMA RAP collaboration, CSCAND and GA successfully:

- Acquired 1,311 km^2 of high resolution digital elevation data acquired with LiDAR covering GMMA, including the Pasig-Marikina river basin and the shoreline of Manila Bay extending from Bulacan to Cavite;
- Developed an exposure database, which describes the 'elements at risk' from natural hazards, including buildings and population;
- Assessed the risk and impacts from flood, severe wind and earthquake in GMMA through undertaking the first multi-hazard risk assessment for megacity.

Flood modelling scenarios in the Pasig-Marikina River Basin highlighted that flooding can have very serious impacts on GMMA, beyond what has been experienced in recent disasters such as Tropical Storm Ondoy (Ketsana). In a hypothetical 1/200 AEP scenario, the deepest inundation (3+m) occurs along the Upper Marikina and San Juan Rivers, with almost 60 billion pesos in physical damage and over 2 million people with inundated homes.

Tropical cyclone severe wind modelling indicates that GMMA may suffer costly wind damages due to damaged structures (residential, commercial, industrial and critical facilities and other structures), with total costs in Greater Metro Manila of approximately PHP 77.61 Million/km^2 for the 0.2% AEP. The City of Mandaluyong has the highest expected economic loss amounting to PHP 163.87 Million/km^2, as it is densely built-up and has high proportions of vulnerable building types (makeshift (N), wood one-storey (W1), and concrete (C1) and pre-1972 building stocks).

Earthquake modelling in GMMA highlights the risk to the region from the Marikina Valley Fault System, and the West Valley Fault in particular, which runs directly beneath Manila. Two scenario earthquakes were modelled on the WVF, a M7.2 event (the estimated maximum size to could occur on this fault) and a M6.5 event (the most probable earthquake size). The modelled total number of casualties within GMMA from the Magnitude 7.2 scenario is over 37,000 fatalities and 605,000 injuries and the modelled total economic losses for GMMA from the Magnitude 7.2 scenario is almost 2.5 trillion pesos.

These outcomes together represent a significant leap forward in our understanding of natural disaster hazard and risk in GMMA, and will form a scientific basis that will influence policies and disaster mitigation measures in the region such as planning guidelines, land use planning, and risk insurance.

1 Introduction

The Greater Metro Manila Area (GMMA), comprising 16 cities and one municipality of Metro Manila, and the provinces of Laguna, Rizal, Cavite, and Bulacan, is a global megacity with an estimated population of up to 20 million. It is the major centre of economic activities and the most densely populated region in The Philippines with approximately 19,137 people per square kilometre (2010, National Statistics Office). It is estimated that as many as 35% of the population within the GMMA live in informal settlements (2009, Asia Development Bank), many of whom live below the poverty line. This makes the city and its people vulnerable to the impacts of natural disasters.

Due to its geographical location, the Philippines is highly prone to natural disasters resulting from earthquakes, volcanic eruptions, tsunamis and tropical cyclones. Metro Manila lies along the flat alluvial and deltaic land extending from the mouth of the Pasig River in the west and the high rugged lands of the Marikina valley and the Sierra Madre Mountains in the east. Due to its geographical location and urban setting, Metro Manila suffers greatly from the impacts of hydrometeorological (e.g. tropical cyclones and floods) and geological hazards.

There is an international and national policy context that is increasingly focused on reducing the risks from natural disasters. The international and national policies focused on disaster risk reduction, such as the Hyogo Framework for Action (HFA) adopted by The Philippines, place considerable importance on identifying and understanding the risk from natural hazards. One of the five priorities for action in the HFA outlines a requirement to invest in scientific and institutional capabilities to "identify, assess and monitor disaster risks and enhance early warning" including multi-risk assessment and mapping. The Philippine Government has undertaken affirmative actions to implement the HFA[9].

A scoping mission to the Philippines after Tropical Storm Ketsana (Ondoy) in September 2009[10], undertaken by DFAT and Geoscience Australia revealed a huge need for multi-hazard risks analysis, particularly for flood and earthquake, in GMMA, with an activity that could build upon significant progress already made in natural hazard mapping and assessment[11].

A program of hazard and risk analysis capacity building was defined through a partnership among DFAT, Geoscience Australia and NDRRMC-CSCAND; the Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area, Philippines (GMMA RAP). This partnership would play a key role in the proposed Metro Manila Post-Ketsana Recovery and Reconstruction Program, particularly the component on Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake in GMMA. The mode of delivery and implementation arrangements were conceptually similar to a twinning program via an equal partnership arrangement among DFAT, Geoscience Australia and NDRRMC-CSCAND with a focus

[9] The Government recently enacted the Disaster Risk Reduction and Management Act, and approved the Strategic National Action Plan (SNAP) on Disaster Risk Reduction (DRR). Last year, the Philippines passed the Climate Change Act and created the Climate Change Commission. The Commission recently approved the National Framework Strategy on Climate Change (NFSCC) and is now working on the National Action Plan on Climate Change. Both Disaster Risk Reduction and Management Act and Climate Change Act, as well as SNAP and NFSCC recognise the importance of building scientific and institutional knowledge on disaster and climate risks.

[10] Schneider, Scott and Orquiza (December 2009). Scoping Mission Report on Disaster Risk Management Requirements of Metro Manila.

[11] DFAT currently supports the READY (Hazards mapping and assessment for effective community-based disaster risk management) Project being implemented by NDRRMC-CSCAND with the United Nations Development Programme (UNDP) since 2006, and the activity on Strengthening Natural Hazard Risk Assessment Capacity in the Philippines implemented by Geoscience Australia since 2008.

placed on developing new, and strengthening existing partnerships that ultimately supported the development of new natural hazard risk information. This activity followed the successful completion of an earlier GA-DFAT project on enhancing risk assessment capacity in the Philippines which concluded in 2011[12].

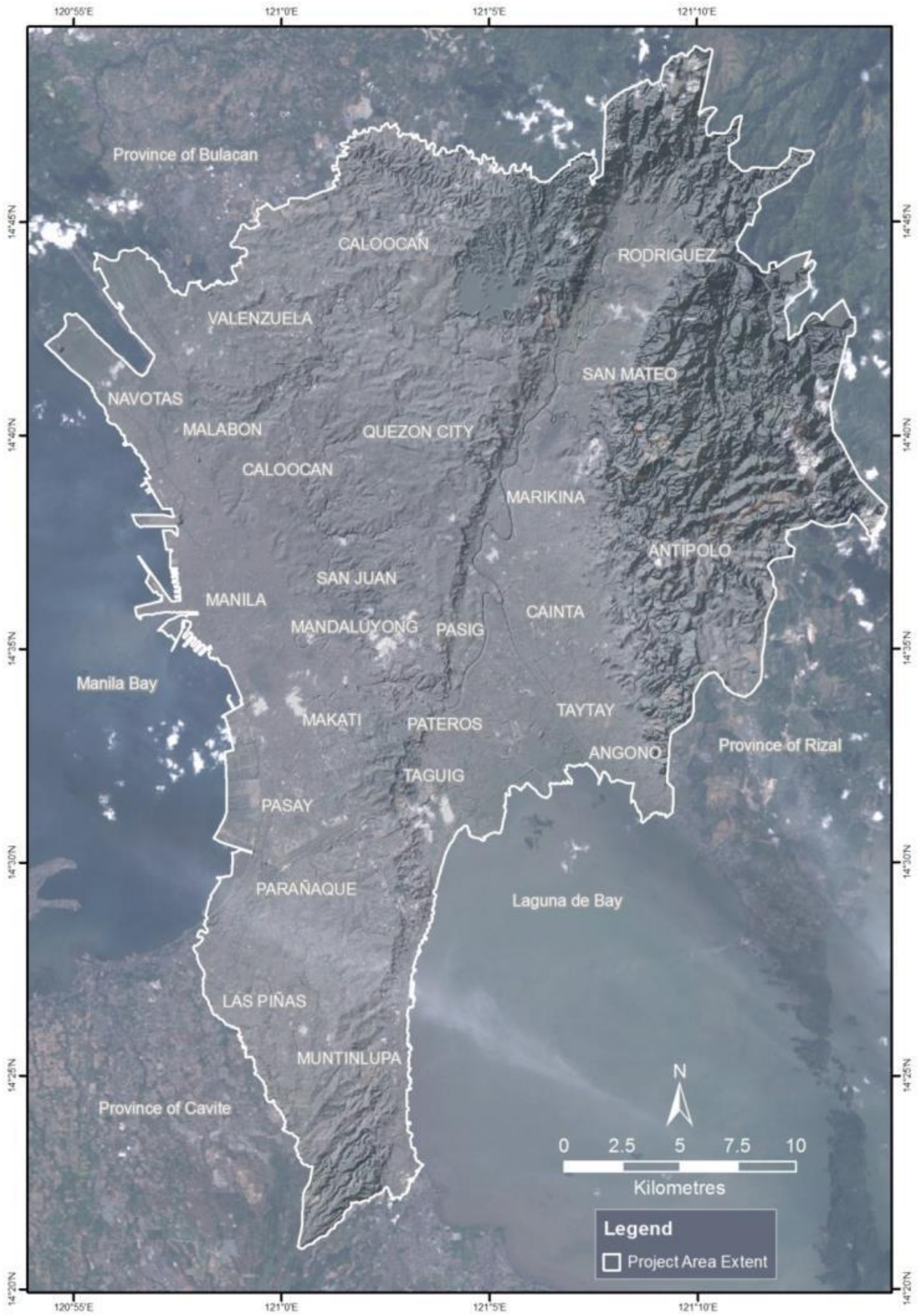

Figure 1.1. Map of the study area – Greater Metro Manila Area.

[12] Simpson and Allen (2012) Enhancing natural hazard risk assessment capacity in the Philippines – Completion Report. Geoscience Australia Professional Opinion 2012/02

The primary objective of the GMMA RAP was to analyse the risk from flood, severe wind and earthquake in the Greater Metro Manila Area through the development of fundamental datasets and information on hazard, exposure and vulnerability, with the anticipated outcomes of this activity including:

- Base datasets fundamental to natural hazard risk analysis, such as high-resolution digital elevation models, are available in GMMA for the analysis of natural hazard risk and climate change impacts.
- Technical specialists have an improved understanding and capability to produce exposure databases, and exposure information is available in the GMMA for the analysis of natural hazard risk and climate change impacts.
- Scientists within PAGASA and MGB are able to better assess the risk and impacts from flood in the Pasig-Marikina River Basin and have an improved understanding of these risks.
- Scientists within PAGASA are able to better assess the risk and impacts of tropical cyclone severe wind and have an improved understanding of these risks in the Greater Metro Manila Area.
- Scientists within PHIVOLCS have an improved understanding of earthquake risk in the Greater Metro Manila Area.

This report summarises the technical outputs from the capacity building interactions between CSCAND and GA, which together represent the first multi-hazard risk assessment for megacity, and form the scientific underpinning for future policy and disaster mitigation measures in GMMA.

2 High Resolution Digital Elevation Data and Imagery

An essential input to the hazard and risk modelling in GMMA RAP is a high resolution Digital Elevation Model (DEM), a highly detailed representation of the earth's surface. Without a high-resolution DEM it would not have been possible to develop a flood risk model in the densely urbanized areas of Metro Manila. Acquisition of airborne LiDAR and imagery also provided other benefits to the Government of the Philippines including detection and mapping of active fault lines, improved ability to develop accurate exposure information for GMMA, and in the future will underpin the ability to accurately determine the impact of different sea level rise scenarios in the Manila area.

Light Detection and Ranging (LiDAR) technology is now widely accepted for the collection of terrain data to generate high resolution DEMs (vertical accuracy of <15 cm). It offers fast acquisition and processing of data with minimum human dependence since most of the processing is done automatically and is capable of day and night data collection. Therefore a LiDAR mission was carried out to develop a seamless high resolution elevation dataset for Greater Metro Manila Area (GMMA). The acquisition was carried out by Fugro Spatial Solutions (FSS) from Australia from March to April 2011. A comprehensive QA/QC process was then conducted by Geoscience Australia (GA) and National Mapping and Resource Information Authority (NAMRIA). Aerial photographs complimented the LiDAR in the classification of points, 3D visualization and 3D modelling.

The deliverables included an orthoimage from digital aerial photographs, unclassified and classified point cloud, LiDAR derived products such as intensity, DEM comprising of Digital Terrain Model (DTM), Digital Surface Model (DSM), Canopy Elevation Model (CEM) and Foliage Cover Model (FCM). The extent of these outputs is the cities and municipalities of Metro Manila, along with parts of Bulacan, Rizal, Laguna and Cavite provinces.

The LiDAR and aerial photography mission in GMMA successfully acquired high resolution DEM and imagery, covering GMMA including the Pasig-Marikina river basin and the shoreline of Manila Bay extending from Bulacan to Cavite. A total of 1,291 km^2 for digital aerial photography and 1,311 km^2 for LiDAR were captured within a period of 16 and 15 days respectively. The extents of the LiDAR and aerial photography are detailed in Figure 2.1.

Some issues encountered during the implementation of this project include the late delivery of primary and validation Ground Control Points that resulted in significant delays in the data processing. Another factor was the limited flying time allowed by Civil Aviation Authority of the Philippines due to air traffic within the project area. Less than ideal weather conditions were also a problem as not all the project areas (the northern end part following West Valley Fault) were captured by aerial photography.

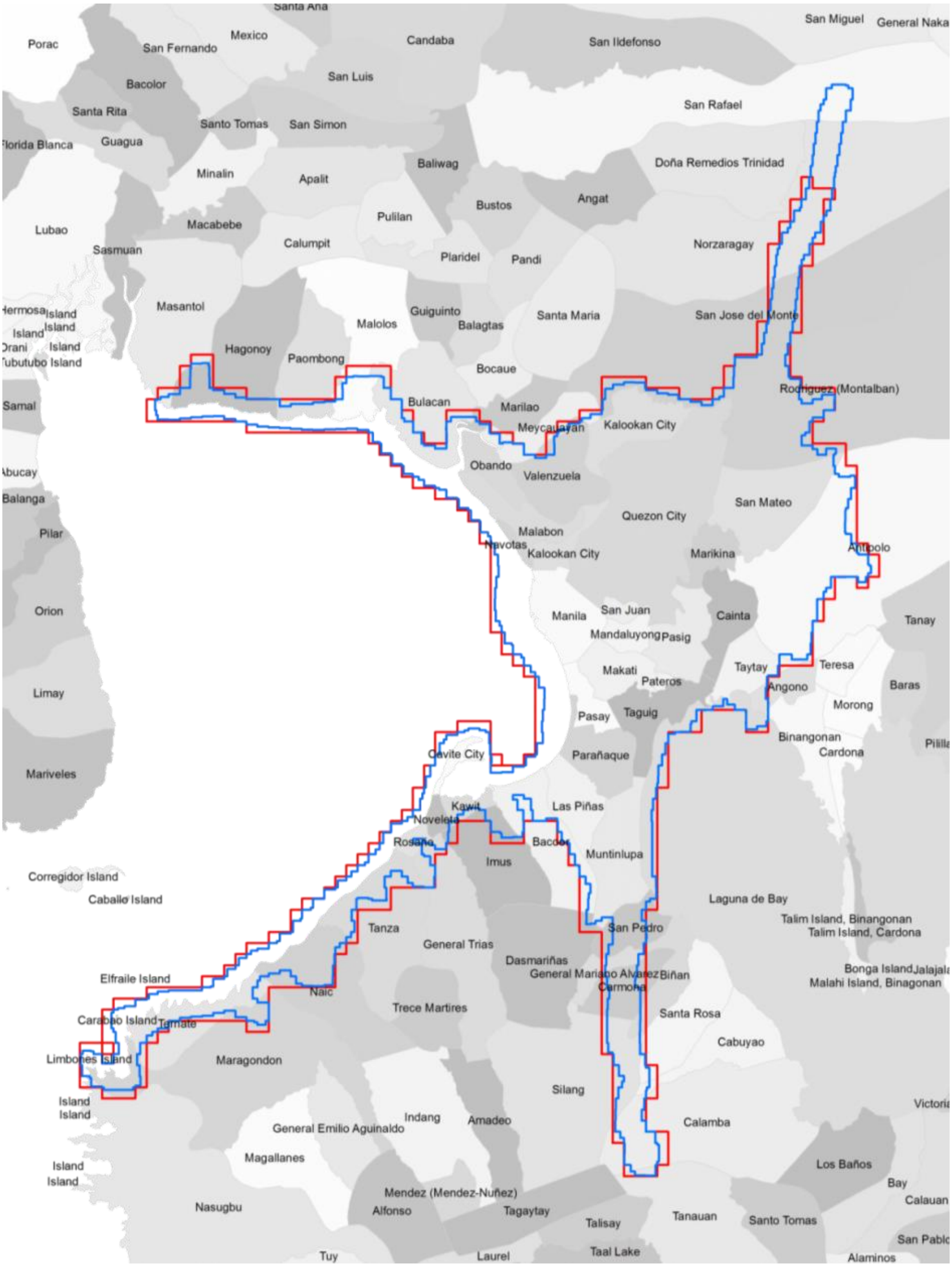

Figure 2.1. LiDAR data collection extent (shown in blue) and aerial photography coverage (shown in red).

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3 Exposure Information Development

In the context of natural hazard risk analysis, exposure relates to the 'elements at risk' from natural hazards. The elements at risk that are usually of most interest in a risk analysis are those that are part of the human geography that are of value and are critical for the functioning of society, such as buildings, structures, facilities, network infrastructure and utilities, people and communities, primary sources of food and potable water, and natural resources. Exposure information provides a single source of information that risk analysts can use to calculate the quantity of physical damage, economic loss and potential casualties caused by one or more hazard events. It enables the analysis by storing information in a single dataset with a well-defined schema, which ensures that information is consistent, topologically correct and compatible with models of vulnerability.

In previous work under MMEIRS, themes of exposure information were developed as separate datasets. In order to meet risk analysis requirements, these need to be harmonised into a single dataset containing all the required exposure attributes. In the Iloilo earthquake pilot impact study, exposure information was generated at the barangay-level. The introduction of flood risk analysis in the GMMA RAP required a more detailed expression of exposure, as barangay level exposure is incompatible with the horizontal extent of inundation.

The aim of the exposure database development project was to establish relationships and access to existing spatial datasets managed by data custodians. Numerous spatial datasets were made available by National Government agencies, Regional/ provincial government, Local Government Units and donor projects including MMEIRS, Resilience Project and READY Project. The data made available was not necessarily usable in its existing form; datasets had to be assessed to determine their utility in the exposure database development.

The Area-Based Approach was selected for development of exposure information of buildings and population in GMMA. The Area-Based Approach to exposure information development involves summarising the essential exposure characteristics for a defined polygonal area. Each polygon would be defined by the spatial extent of its land use classification and the typical mix of buildings for that land use would be quantified using either a count of the buildings or the floor area of the buildings. Information on the mix of building types may come from a number of sources, depending on the availability of input data on buildings for that land use. This approach is suitable for areas where there are many exposed elements within a well-defined area (e.g. buildings) for which an aggregated expression of exposure can be recorded.

Reliable and consistent information on buildings is critical for the development of exposure information. In an exposure database, attributes of buildings that are needed to support risk analysis include:

- Building location, expressed as either points or polygons;
- Horizontal extent (footprint shape and area expressed in m^2); and
- Vertical extent (number of storeys and floor area expressed in m^2).

Building footprint datasets, usually developed and maintained as polygon datasets, immediately provide two of the three components described above (location and horizontal extent). The Building Geometry Model (http://www.ga.gov.au/metadata-gateway/metadata/record/75459/), which is a series of spatial analysis processes that estimate building footprint and floor area information from LiDAR and aerial imagery data, was developed by staff at Geoscience Australia in order to derive the third component (vertical extent). The top surface of buildings was isolated from the LiDAR data, then this data was combined with other spatial data (such as land use) and knowledge about the vertical separation between floors to calculate important attributes that added value to exposure information.

The development of exposure information was performed for all areas in the activity using the process described in the flowchart in Figure 3.1.

The Exposure component of the project produced two primary datasets:

1. Exposure of buildings and population, which records key exposure attributes needed to undertake natural hazard risk analysis for flood, tropical cyclone severe wind and earthquake across Metro Manila and western parts of Rizal Province adjacent to Metro Manila; and
2. Exposure of billboards, which records the location and geometric properties of major billboard structures across Metro Manila and western parts of Rizal Province adjacent to Metro Manila. These structures are included in a larger group of Potentially Wind Sensitive Structures, which may be of interest in the conduct of severe wind risk analysis.

The component also produced documentation to assist with the development of exposure information:

- Metadata for final datasets;
- Exposure Database Development Framework;
- Exposure Database Development Manual; and
- Options for a File and Data Management Structure.

A number of issues were encountered throughout the development of exposure information. One of the key issues was the uncertainty in LGU and barangay extents. The project was provided LGU boundary information from several sources, including the LGUs themselves, regional government agencies, national government agencies and related projects completed in the previous decade. In many instances there were differences in the alignment of boundaries when each dataset was compared to the others. These location differences had implications for:

- Preparation of base mapping layers for LGUs of interest and ensuring relevant areas are accounted for;
- Distribution of population estimates at the polygon level; and
- Merging of compiled exposure information for each LGU into a single spatial data layer.

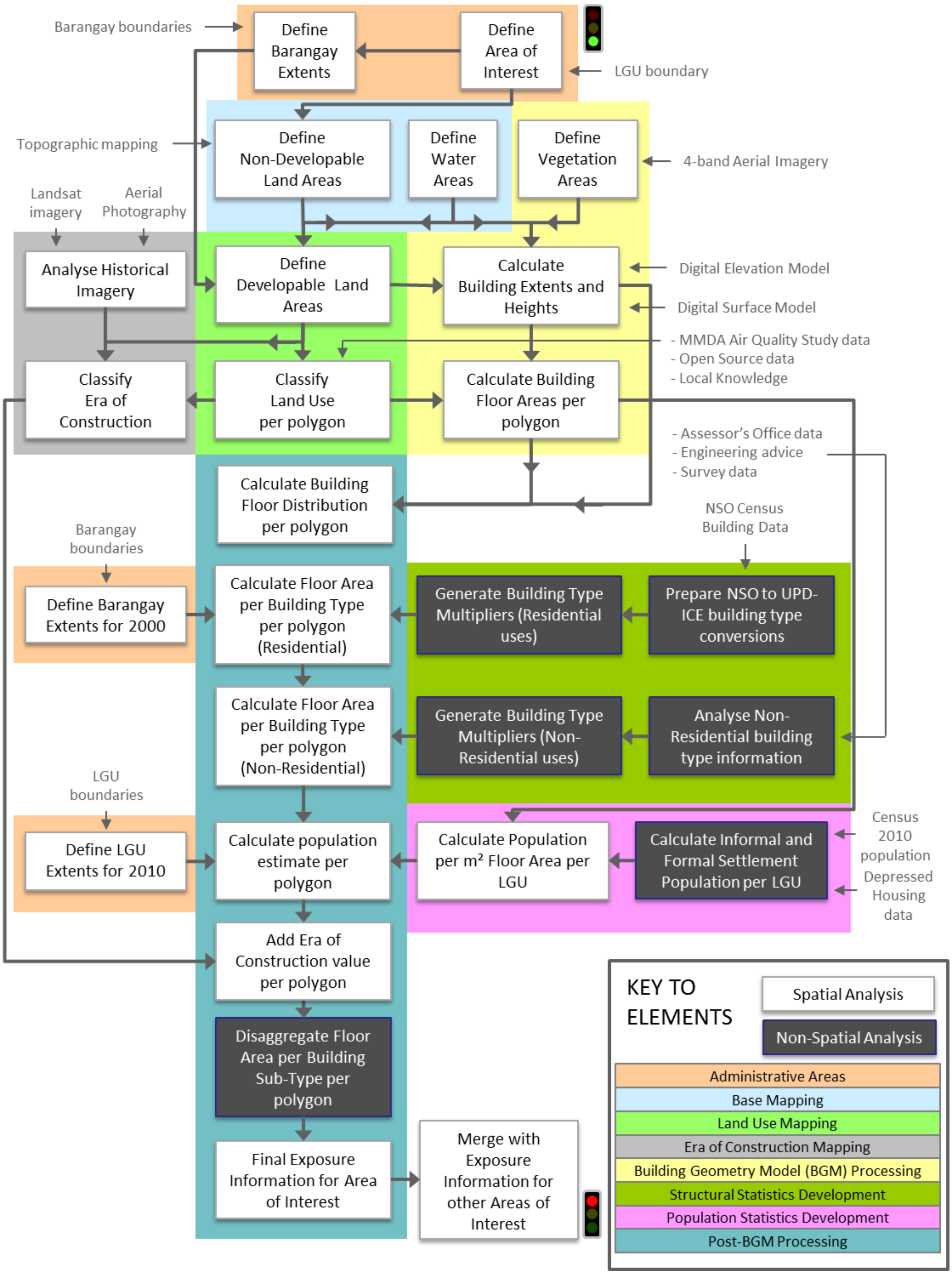

Figure 3.1. The workflow for exposure information development in the Area-Based Approach.

4 Flood Risk Analysis

The Philippines is one of the most flood-prone countries in the world. For the last ten years, there have been over 60 reported major floods in the Philippines. Nearly 14 million people have been affected and the death toll has reached more than 700 people with damages estimating over $400 million (EM-DAT International Disaster Database).Metropolitan Manila, the economic centre of the Philippines, is considered the most susceptible city to flooding. Owing to its geographical location, low elevations, high density of population and infrastructure, Metropolitan Manila has greater exposure to flooding impacts than most other parts of the Philippines. This was illustrated during the passage of Tropical Storm Ondoy (Ketsana) in Greater Metro Manila Area on 26 September 2009 which brought 455 mm of rainfall for 24-hr to its catchments. This event caused severe flooding, resulting in many casualties (464 dead, 529 injured and 37 missing), with direct impacts on around 5 million people; and damages to infrastructure and agriculture of 11 billion Pesos[13].

These factors resulted in flood hazard and risk assessments being a key aspect of the GMMA RAP. The flood risk analysis technical working group included representatives from PAGASA, MGB, MMDA, LLDA, DPWH, and GA. It focussed on the flood risks in the Pasig Marikina River Basin, which covers much of the Greater Metro Manila Area, including the relatively large Marikina, Pasig and San Juan River systems. Key outputs from the flood work include the statistical estimates of: a) Extreme rainfall frequencies at a number of sites in the Pasig-Marikina River Basin; b) Catchment-averaged extreme rainfall frequencies; and c) Frequency of high lake levels in Laguna Lake.

The team chose to use HEC-HMS as a rainfall-runoff modelling tool in the GMMA RAP. This was because it can be used to implement a wide range of event-based semi-distributed rainfall runoff models; is freely available, and extremely widely used. As such, it was considered a useful tool for the team to learn to use, both in the present study, and potentially for future work. The team chose to use the HEC-RAS 1D+ hydraulic model, because it is widely used for flood inundation studies (including previous studies in Metro Manila); is not too computationally demanding in an area the size of Metro Manila; can interact well with HEC-HMS for rainfall runoff work; supports a wide variety of hydraulic structures; includes storage-areas for increased flexibility in floodplain modelling; is freely available; and has a good graphical interface. While some preliminary exploration of both ANUGA and Delft3D for detailed 2D modelling of small areas was undertaken, there were technical challenges in applying both, and ultimately insufficient time to develop these models in addition to the HEC-RAS model. However, the 1D+ model provides reasonable estimates of peak flood depths in the channels and floodplains, and is thus appropriate for risk estimation in the GMMA RAP.

Statistical estimates were used to simulate design flood scenarios in the Pasig-Marikina River Basin using the combined capabilities of HEC-HMS and HEC-RAS models. The model was shown to perform reasonably well in simulating the flood depths associated with Tropical Storm Ondoy (Ketsana). The calibrated model was compared with the observed data both in the river and from the floodplain (Figure 4.1). The result of the model calibration agrees well with the observed water level

[13] NDRMMC., 2009. Final Report on Tropical Storm Ondoy (Ketsana) and Typhoon Pepeng (Parma). National Disaster Coordinating Council.

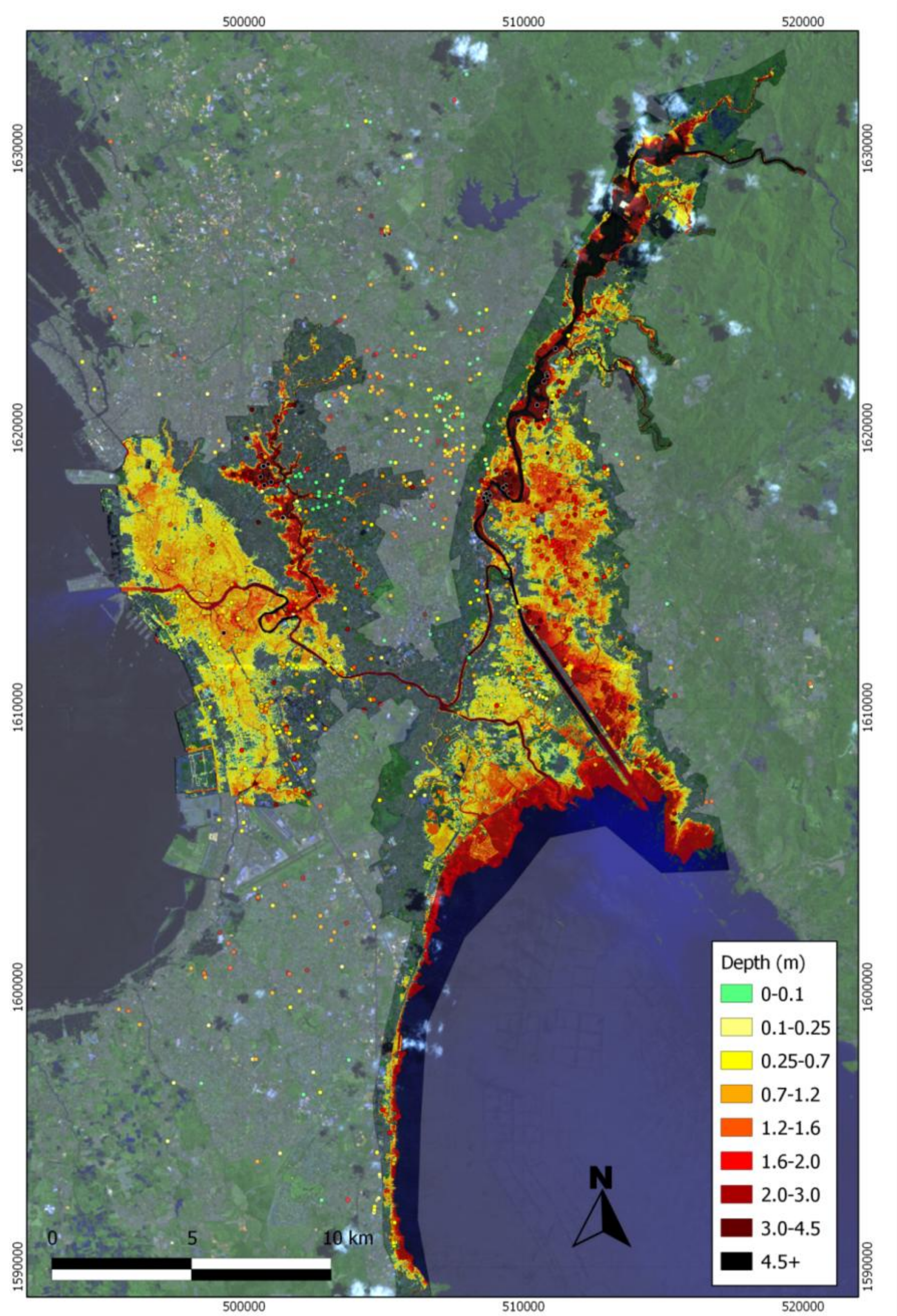

Figure 4.1. Modelled and observed (points) depths during Tropical Storm Ondoy. Areas outside the model region are shaded semi-transparently.

data from the Effective Flood Control Operation System. The model results also typically agreed with the reported spot-depth data collected by nababaha.com except for areas outside the model domain. With these observations, it can be concluded that this study was able to simulate the TS Ondoy event and the resulting hazard and risk maps with different AEPs can provide useful inputs to support contingency planning of the local government units and other applications relating to flood risk mitigation.

The calibrated model was then used to simulate the range of design flood events with AEPs of 1/5 to 1/200 years[14]. As an example, Figure 4.2 shows the simulated 1/200 AEP peak flood depths. The damages associated with events were estimated using the recently developed exposure database for Metropolitan Manila and the building vulnerability models. Damage estimates were based on the 'damaged floor area equivalent', the 'building damage cost' and the 'number of people with inundated homes'. For each AEP scenario, we computed the damaged floor area equivalent, building damage cost, and number of people with inundated homes (Figure 4.3). For reference, computed values for Tropical Storm Ondoy are also shown.

Large areas of Metro Manila are vulnerable to severe flood inundation, with depths of one to several metres being widespread during large events (Figures 4.1 & 4.2). Fundamentally this is because much of Manila is built on naturally flood prone lands, including floodplains along the Marikina, Pasig and San Juan Rivers, tidal flats along Manila Bay, and various lakeshore and deltaic landforms around Laguna Lake. The land surface in these areas was originally built by sediments deposited during flooding, and would always have been flood prone. Significant efforts to reduce this flooding have been made, such as the construction of the Mangahan Floodway, numerous pumping stations, flood gates, drains and dykes. However, Manila remains very flood prone, and urban development has also contributed to flooding by constricting or obstructing overland and river drainage pathways, reducing soil infiltration capacity, and accelerating land subsidence in some areas.

In the hypothetical 1/200 AEP scenario, the patterns of flooding are qualitatively similar to those observed during Tropical Storm Ondoy, but with greater flood depths and extents (Figure 4.2). The deepest inundation (3+m) occurs along the Upper Marikina and San Juan Rivers. Widespread inundation of ~ 0.5-2 m depth also occurs east of the Marikina River and Mangahan Floodway. This is caused by a mixture of inflows from the local catchment, overflow from the Marikina River, and high river levels in the Mangahan Floodway which inhibit drainage due to backwater effects. Flooding occurs in the Lakeshore and Taguig-Pateros regions, due to high water levels in Laguna Lake. In the areas west of the San Juan River, north and south of the Pasig River, flooding is widespread but typically shallower than in other regions (~0.2 – 1.2m), and is driven by a mixture of local rainfall, inflow from rivers and Manila Bay, and the flat topography which promotes relatively slow drainage.

[14] The AEP for the flood scenario is usually assigned based on a statistical analysis of hydrological records at the site, such as the peak river discharge, the rainfall intensity and duration, and/or the peak water levels somewhere within the flooded region. The flood scenario would then be created by inputting the hydrological information into a flood inundation model. As a simple example, a 1/100 AEP flood scenario may be developed by estimating the river discharge which is exceeded in only 1% of all years (based on statistical analysis of historical discharge records), and then running a hydraulic model with this discharge to estimate the resulting flood extents.

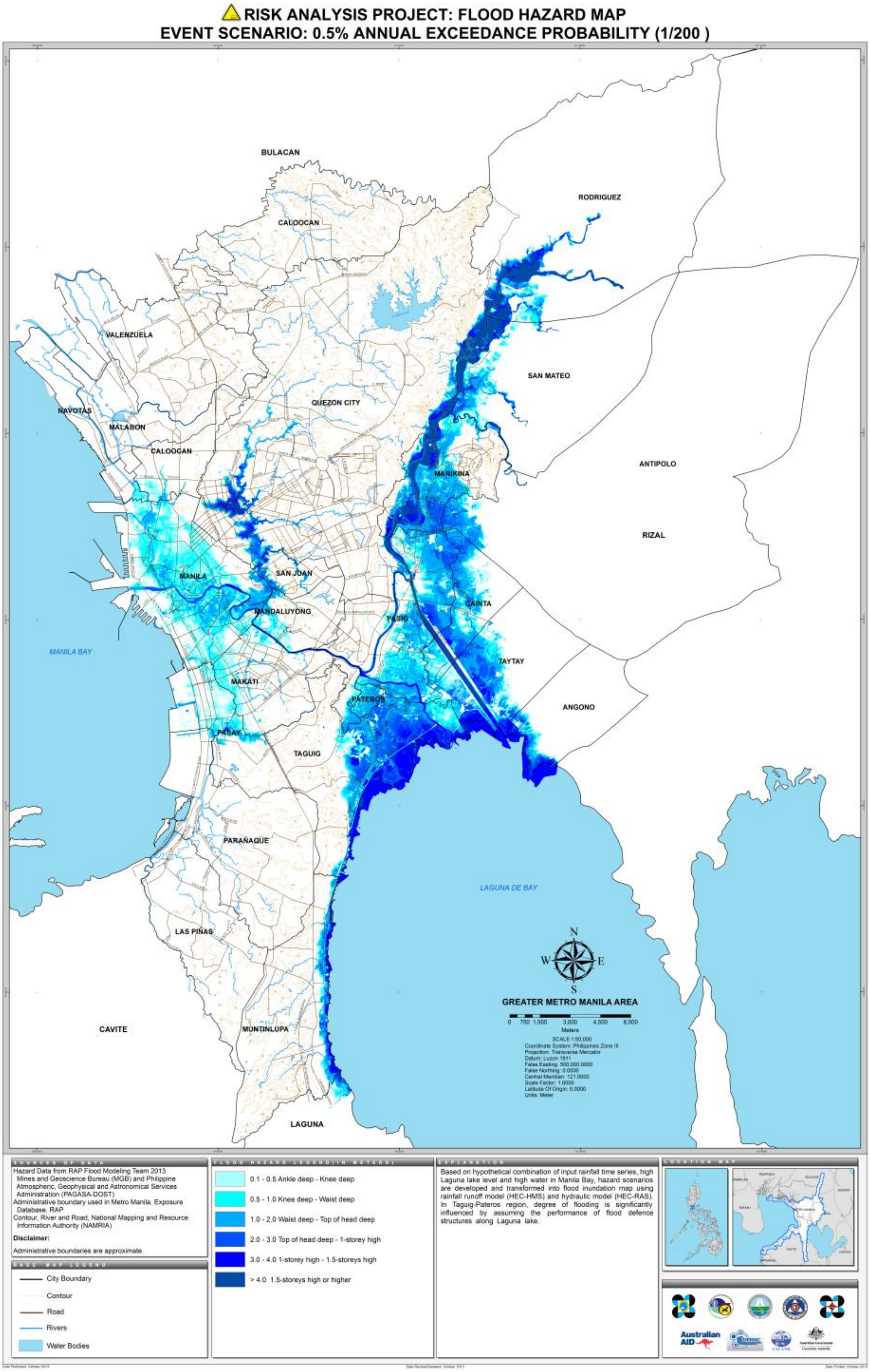

Figure 4.2. Modelled peak depths for an AEP 1/200 flood event.

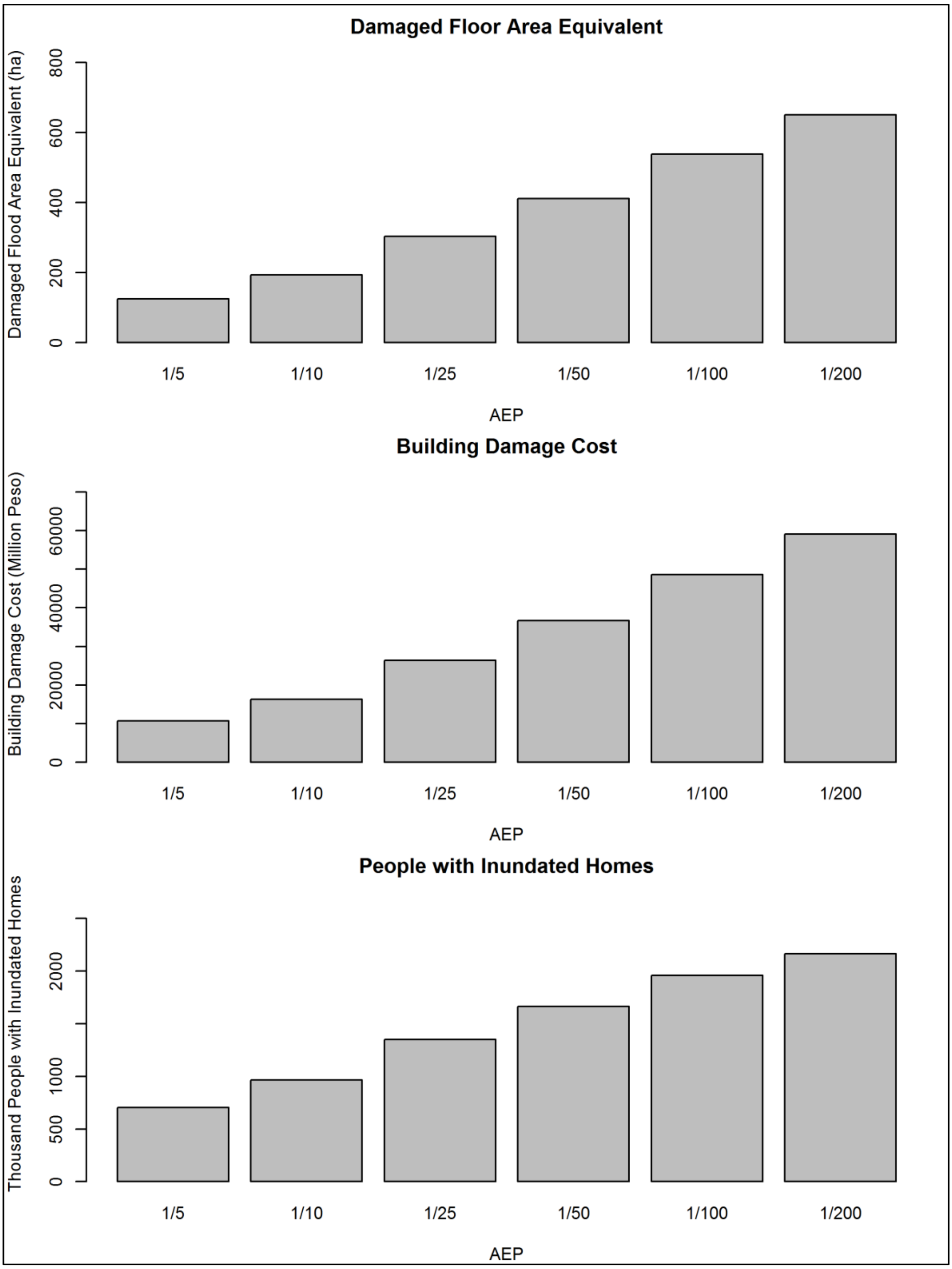

Figure 4.3. Damage estimates for each AEP flood scenario.

Regarding flood damages, there is a clear difference in the spatial patterns when measured in terms of the damaged floor area equivalent, the cost of building damages, and the population with inundated homes. For large flood events (e.g. AEP 1/200), the damaged floor area equivalent shows patches of particularly intense damage around the Marikina River near Tumana, along the banks of the Mangahan Floodway and the San Juan River, and at various locations along the Lakeshore and Taguig-Pateros regions. Highly damaged areas are characterised by the simultaneous occurrence of deep flooding, dense settlement, and a large proportion of 'Makeshift' and 'Wooden' buildings. The latter are more intensely damaged by deep flooding than are other building types. However, they are also less expensive to replace, and so the building damage costs are comparatively more evenly spread out within zones that experience deep flooding. In terms of the number of people with inundated homes, large parts of the city have around 10-50 thousand people per square kilometre, with the most intense patches occurring at sites of with high population density in predominantly low rise housing.

In less extreme events (e.g. 1/10 AEP), deep flooding is concentrated along the margins of the Upper Marikina and San Juan Rivers, and floodplain flows are much less extensive. Moderate flooding occurs along lakeshore areas and low-lying parts of Taguig, and along drainage paths east of the Upper Marikina and Mangahan rivers. The damaged floor area is still intense around Tumana, and remains significant in many areas bordering the Marikina and San Juan Rivers, and the Mangahan Floodway. Many of these areas also have dense populations with inundated homes. The damaged building costs are relatively more evenly distributed, due to the lower replacement cost of the most vulnerable building types.

All damages increase strongly with increasing AEP (Figure 4.3). Tropical Storm Ondoy falls between the 1/50 and 1/100 AEP for every damage measure used herein. For the 1/200 AEP scenario, the building damages are around 40% greater than Tropical Storm Ondoy, and the population with inundated homes is around 20% greater. While these damages are substantially larger than those experienced during Ondoy, latter can serve as a reasonable 'mental picture' for the patterns of inundation and damages expected from large flood events in the Pasig Marikina Basin.

Broadly, it is suggested that basin-scale work such as that undertaken in the GMMA RAP can be usefully supplemented with smaller scale flood studies to support local flood management decisions. Smaller scale studies have a greater capacity to ground-truth input data, and to develop and test detailed hazard and vulnerability models, whilst still drawing on inputs from larger scale work such as the present. Such studies are the most appropriate to support robust local-scale flood management decisions, especially if discrepancies are found between observational data and the results of larger scale studies, or between multiple large scale studies.

5 Tropical Cyclone Severe Wind Risk Analysis

The Philippines is situated in a geographical location often visited by tropical cyclones – the most frequently occurring natural hazard. Tropical cyclone formation is mostly developed in the eastern part of the Philippines (7.5°N to 15°N and 128°E to 138°E) or in the Western North Pacific Ocean. About 50.2% of the TC developed inside the Philippine Area of Responsibility (PAR), 49.8% outside the PAR and 7.2% developed in the West Philippine Sea[15]. Annually, about 19 to 20 tropical cyclones enter the Philippine Area of Responsibility (PAR) and about five to seven tropical cyclones cross the islands and are destructive. According to the Office of the Civil Defense (OCD) of the National Disaster Risk Reduction and Management Council (NDRRMC), ninety-one (91) of the one hundred seventy five (175) destructive tropical cyclones that hit the country from 2004 to 2011 brought billions of pesos in damages and a number of casualties. Some tropical cyclones are very strong with maximum winds of more than 185 km/h near the centre, which could damage houses and buildings and topple down power lines over a wide area. A mature cyclone may have a diameter of about 1000 km which can cover the whole archipelago of the Philippines.

Severe wind hazard describes the likelihood of extreme wind speeds occurring over a long period of time. For tropical cyclones, the record of observed typhoon events in the Philippines contains only 60 years of events. During this time, it is unlikely that all areas of the Philippines have experienced extreme winds, and certainly not the most extreme possible in each area. For assessing risk, it is necessary to estimate the wind speeds associated with much rarer events (e.g. events that may occur only once in 100 or 250 years). To overcome the lack of observations of extreme winds, the Tropical Cyclone Risk Model[16] (TCRM) developed by Geoscience Australia (GA), is used in the study to generate the regional level wind speed across the entire Philippine Area of Responsibility (PAR) based on historical TC record from 1951-2011.

Wind hazard is represented as a return period wind speed – the likely wind speed to be exceeded, on average, once within a given period in time. For example, the wind hazard is described as a 1-in-100 year wind speed. This does not mean that the corresponding wind speed will be exceeded only once in any 100-year period. There is about a 63% chance of the 100-year wind speed being exceeded once or more, and a 37% chance of that wind speed will not be exceeded over a 100-year period. Regional Severe Wind Hazard Maps can be used to update the wind zoning map of the Philippines and can be considered in building design and as a guide for emergency managers and planners for evacuation planning. Local hazard maps can assist in site selection for evacuation centres to ensure they are in the safest location, but remain accessible to those in the community expected to utilise the centres.

The regional severe wind hazard maps were developed using TCRM, and represent a 3 second gust wind speed at 10 meter height above open, flat terrain. As expected, the highest wind speeds are in the northern and eastern sections of the country, corresponding to those regions most often impacted by tropical cyclones which initially developed in the Western North Pacific (WNP) area and moved

[15] Cinco, T. A., F. Hilario, *et al*., 2011: Updating Tropical Cyclone Climatology in the Philippines. Climate Data Section, Climatology and Agrometeorology Branch. PAGASA-DOST.

[16] http://github.com/GeoscienceAustralia/tcrm

westerly to northwest direction. 1% AEP gust wind speeds exceed 250 km/h over Catanduanes. Gust wind speeds are lowest over southern and western parts of Mindanao, where tropical cyclones are infrequent and less intense.

The impact of severe wind varies considerably between structures at various locations, due to the geographic terrain, the height of the structure concerned, the surrounding structures and topographic factors. In order to accurately estimate damage to buildings from severe winds, an understanding of wind speeds at the site of the building is required. The wind speeds described in the previous section are still indicative at a regional resolution only. There are a number of factors that need to be considered to determine the local wind speed within the area. The regional wind speed needs to be modified to reflect the effects of local land cover (e.g. forests, high-rise buildings or water bodies), the shielding effect due to upwind structures and topographic effects. This is done using so-called site-exposure multipliers[17]. These site-exposure multipliers are developed using the high-resolution digital elevation and digital surface models in conjunction with multispectral aerial photography captured as part of the project.

Figure 5.1 presents the local wind speed hazard (0.2% AEP) for GMMA. There are isolated pockets in Manila LGU where wind speeds are in the range 60-100 km/h. Angono, Antipolo, Rodriguez, San Mateo and Taytay are potentially threatened with 161 to 202 km/h mean wind speed for 0.2% AEP (500-year return period) because these are mountainous areas and are located in higher elevated areas in the north-eastern part of GMMA. Most of the urban areas of GMMA are in the range of 100-140 km/h gust wind speed. Slightly higher wind hazard is present along the shoreline of Laguna de Bay in Muntinlupa, Taguig and Angono, due to the low roughness of the water body to the south and east of these areas. Areas along the Pasig and Marikina Rivers, and the Manggahan Floodway experience higher wind hazard, as do areas neighbouring the Ninoy Aquino International Airport.

The wind risk assessment is a function of the interaction of the wind hazard, building exposure and the vulnerability of the building structures that will be impacted by the wind hazard. The wind risk assessment can be used to determine what might be the expected losses in terms of property damage and the corresponding damage cost due to wind hazard. In assessing the risk, the western and the central sections of GMMA are subject to severe wind impact and have a higher risk than the other areas in GMMA. These areas are densely built-up with high proportion of vulnerable building types (makeshift, wood-type), old structures or “high rise” buildings, and that are located in high hazard areas. On the other hand, the expected cost of wind damage depends on the proportion of wind damaged buildings and the cost of the building.

The Greater Metro Manila Area may suffer costly wind damages due to damaged structures (residential, commercial, industrial and critical facilities and other structures) and the total cost in the Greater Metro Manila is approximately PHP 77.61 Million/km^2 for the 0.2% AEP. The City of Mandaluyong has the highest expected economic loss amounting to PHP 163.87 Million/km^2, being densely built-up and due to more vulnerable building types (makeshift (N), wood one-storey (W1), and concrete (C1) and pre-1972 building stocks. There is a significant spatial variation of the risk in highly dense built-up area as a result of exposure as shown in Figure 5.2. The expected cost of damage depends on the high proportion of wind damaged buildings as well as where the building cost is high.

[17] Lin, X.G. and Nadimpalli, K. (2005). Natural Hazard Risk in Perth: Chapter 3: Severe Wind Hazard Assessment in Metropolitan Perth, Geoscience Australia Report, GeoCat No. 63527.

For those areas identified as high risk to wind damage, building codes/regulations must be strictly implemented to mitigate severe wind risks. For already developed areas, retrofitting is encouraged – the methods applied in this study can be used to set out a cost-benefit study for retrofitting older, more vulnerable building types to increase their resilience to severe winds.

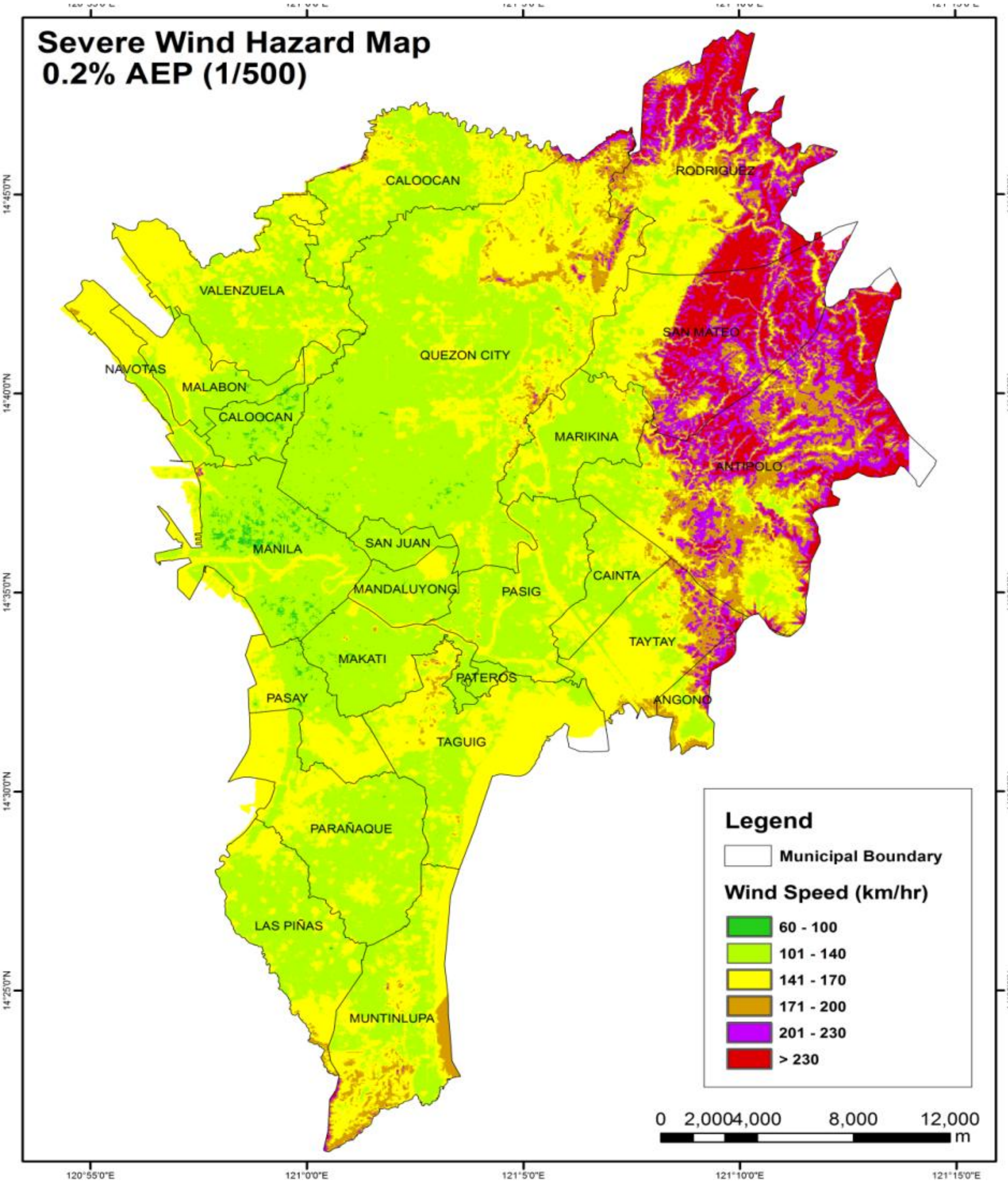

Figure 5.1. 0.2% AEP local gust wind speed for GMMA.

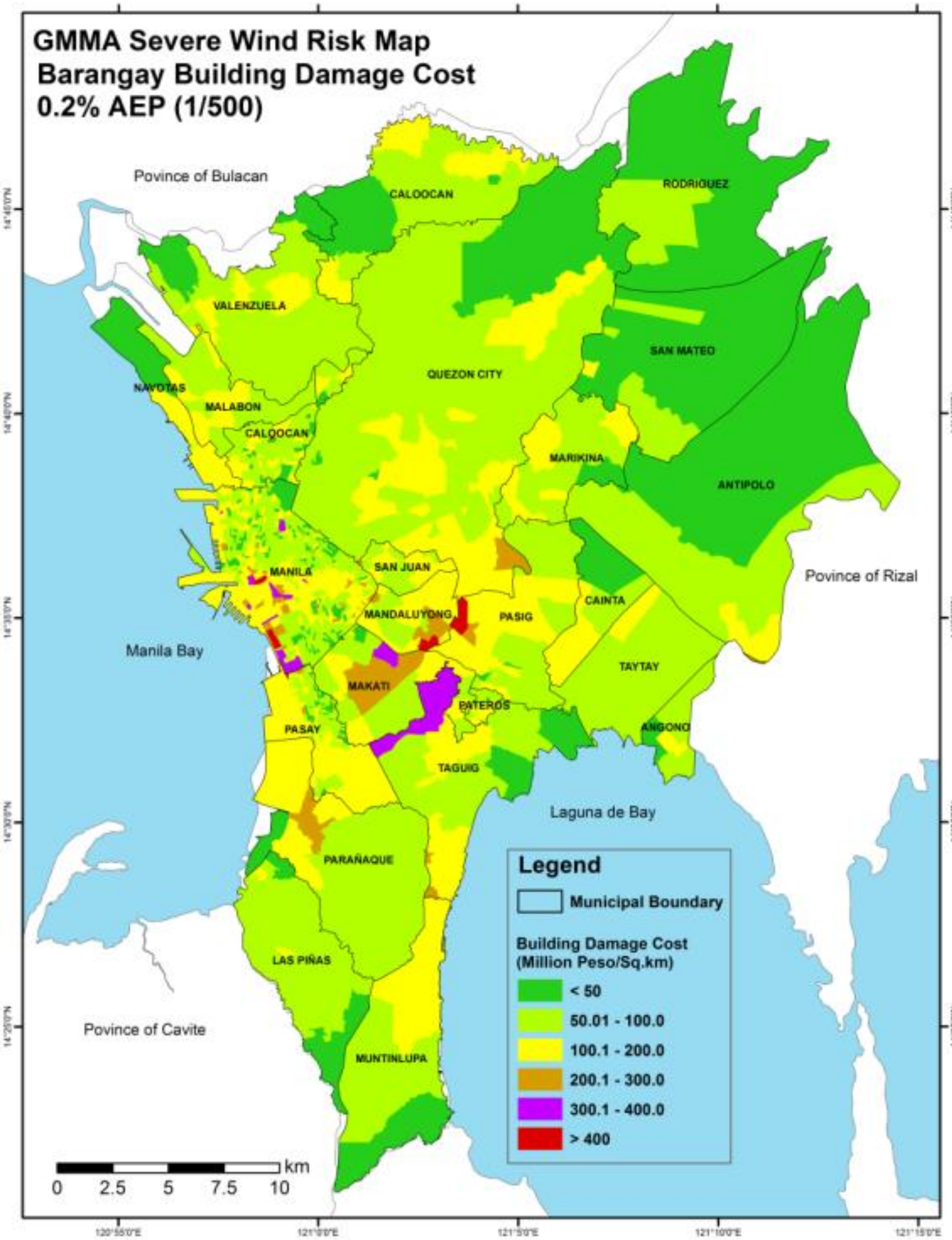

Figure 5.2. Building Damage Cost (Replacement Value) for the 0.2% AEP (1/500) event in GMMA

6 Earthquake Risk Analysis

The Philippine archipelago represents a complex system of microplates that are being compressed between two convergent plate margins that bound the nation: the Philippine Sea to the east and Eurasian plates to the west. Between the convergent subduction zones, oblique tectonic motion is accommodated by numerous crustal faults that traverse the archipelago; in particular, the 1,600 km-long Philippine Fault Zone, which runs from northern Luzon in the north through to the island of Mindanao in the southern Philippines[18]. Because of its tectonic setting, the Philippines experiences frequent damaging earthquakes[19].

The 90–135 km-long Marikina Valley Fault System (MVFS)[20][21] belongs to the aforementioned system of faults that accommodate oblique convergence. The MVFS is comprised of the East and West Valley Faults (EVF and WVF, respectively). The WVF transects the eastern part of Metro Manila and posed the most significant earthquake threat to Metro Manila and nearby provinces (Figure 1.2). Understanding the frequency of large earthquakes on the WVF and the potential magnitudes are of critical importance to emergency managers to prepare for and mitigate against the impact of these infrequent, high consequence events. The recurrence of large earthquakes on the WVF has previously been estimated at between 400 to 600 years, with considerable uncertainty (Nelson et al., 2000). Given the length of the fault, it is believed that it could accommodate an earthquake of up to moment magnitude MW 7.5 base on published fault-scaling relationships (Wells and Coppersmith, 1994).

The GMMA RAP earthquake risk analysis extends upon methodologies developed through the Quick Unified Inventory of Vulnerability and Exposure for REDAS (QuiveR) Project through functions such as improved site class models based upon a combination of geotechnical measurements and topographic slope, and the review of ground-motion prediction equations (GMPEs) based on measured strong ground motions from the Philippines.

In addition to the provision of earthquake impact information from improved ground-shaking, exposure and vulnerability models, this project included a paleoseismic trenching activity to attempt to better constrain both the potential frequency and magnitude of large earthquakes on the WVF. Improved knowledge of earthquake recurrence on the WVF can vastly improve the accuracy of probabilistic seismic hazard and risk assessments (PSHA and PSRA, respectively). However, inconclusive data from the paleosiesmological study revealed only that:

- a conservative range of magnitude 6.4 to 7.3 might be in order for WVF, and;

[18] Barrier, E., P. Hunchon, and M. A. Aurelio, 1991. Philippine fault: a key to Philippine kinematics. Geology, 19, 32–35.

[19] Bautista, M. L. P., and K. Oike, 2000. Estimation of the magnitudes and epicenters of Philippine historical earthquakes. Tectonophys. 317, 137–169

[20] Daligdig, J. A., R. S. Punongbayan, G. M. Besana, and N. Tun˜gol, 1997. The Marikina Valley Fault System: Active Faulting in Eastern Metro Manila. PHIVOLCS Professional Paper

[21] Rimando, R. E., and P. L. K. Knuepfer, 2006. Neotectonics of the Marikina Valley fault system (MVFS) and tectonic framework of structures in northern and central Luzon, Philippines. Tectonophys. 415, 17–38.

- one and possibly the most recent surface rupturing event from one trench was inferred before year 1450 AD, while in another trench it is only possible to estimate that three to ten surface rupturing events post-date 5000 years.

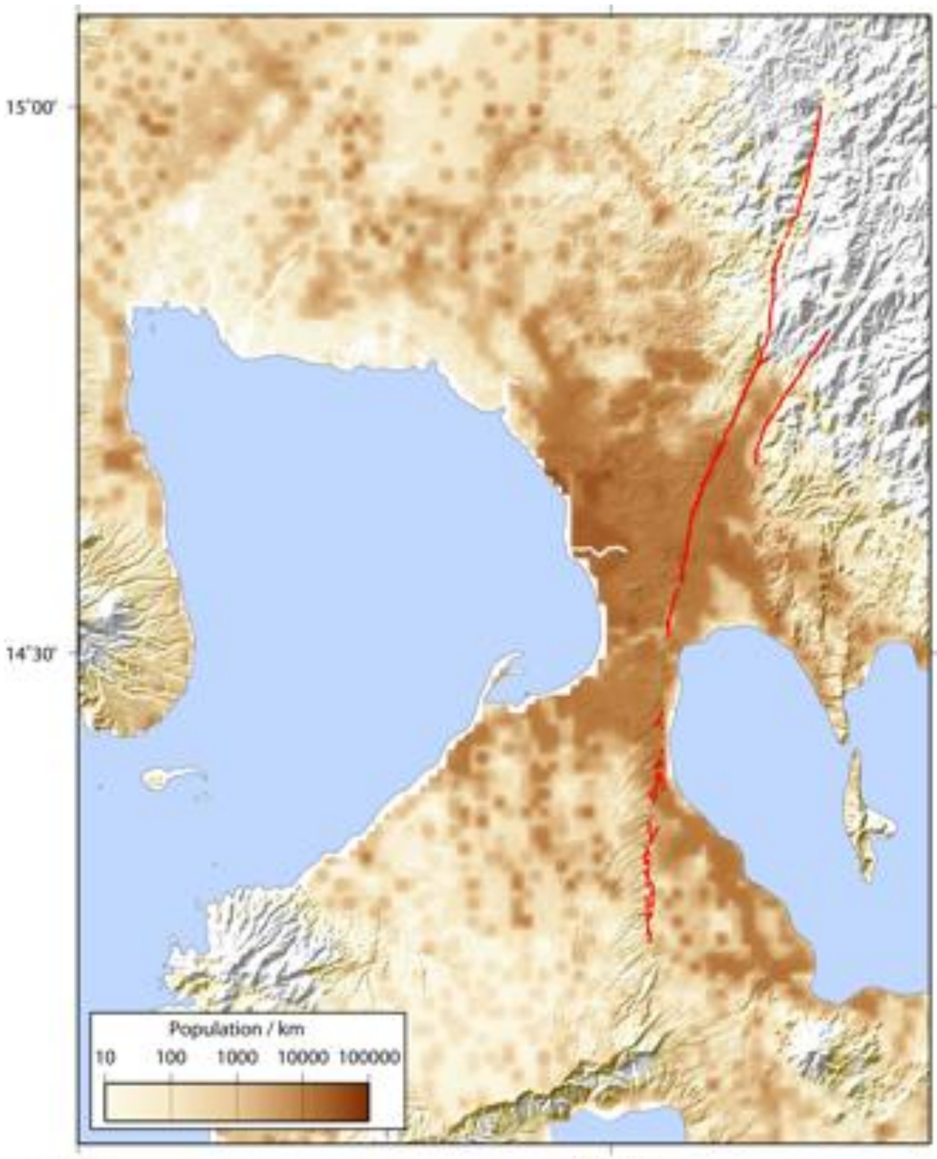

Figure 6.1. The MVFS (heavy red lines) relative to the 2008 Landscan global population dataset[22].

To generate the ground shaking intensity for GMMA, the West Valley Fault was used as the causative fault for the ground shaking simulations. The MMEIRS report[23] suggests that this fault will cause the greatest damage in Metro Manila should it generate an earthquake of M7.2, the estimated maximum size. The most probable earthquake, based on the disaggregation study by PHIVOLCS to identify

[22] Bhaduri, B., E. Bright, P. Coleman, and J. Dobson, 2002. LandScan – locating people is what matters. Geoinformatics 5, 34-37.

[23] MMEIRS, 2004. Earthquake impact reduction study for Metropolitan Manila, Republic of the Philippines. Tech. rep., Philippine Institute of Volcanology and Seismology.

events that impact GMMA significantly, is a M6.5. The relative impacts to GMMA from these two scenario events were evaluated, thereby providing critical guides for emergency response and mitigation planning. REDAS was used to model the ground shaking intensity. A key input to the modeling processes included VS30 values derived from a combination of measured borehole data and modeled SRTM-LiDAR data.

Figure 6.2 shows the ground shaking intensities in PEIS for both scenario earthquakes. Both simulation results show maximum intensity of high VIII, specifically in the Marikina plain regions adjacent to the West Valley Fault and on the coastal plain in the west underlying Pasig. The intensity distribution clearly reflects the effect of the underlying geology on the amplification of seismic motion.

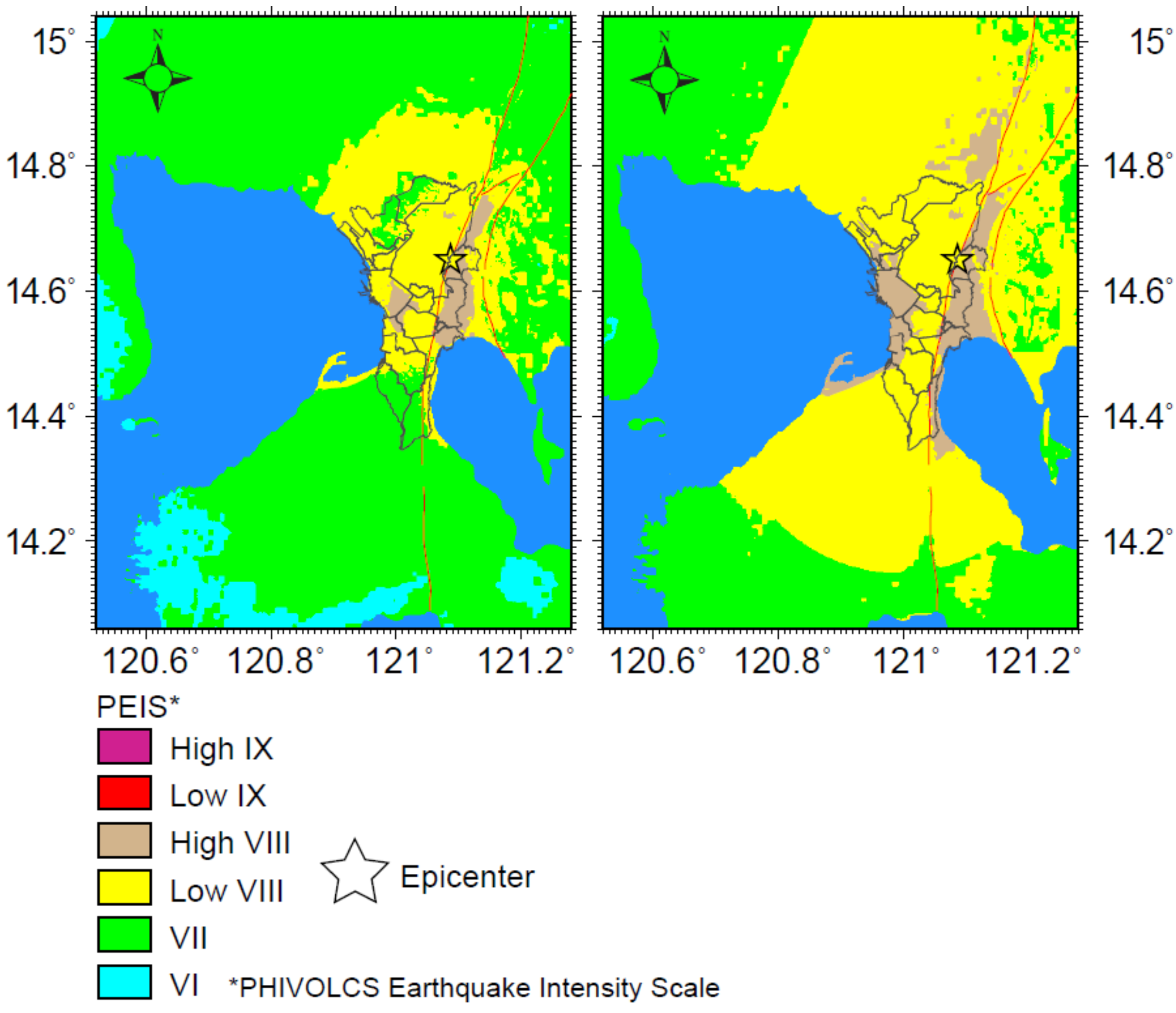

Figure 6.2. Ground shaking model for a M6.5 (left) and M7.2 (right) West Valley Fault Scenario earthquakes. Intensities are expressed in PEIS.

The five damage states (slight, moderate, extensive, complete with no collapse of collapse as well as economic loss) were derived from the fragility curves and these were computed for a Magnitude 7.2 and for a Magnitude 6.5 earthquake scenario along the West Valley Fault. Discussions are only presented for Magnitude 7.2 scenario as the values in both scenarios generally show the same peaks (although the values are lower for the Magnitude 6.5 scenario).

For a Magnitude 7.2 event scenario, high levels of floor area collapse are modeled for Barangay Mayamot in Antipolo City, Barangay Rosario in Pasig City and Barangay BF Homes in Paranaque (Figure 6.3). These high values may be due to their large barangay land area. Other high values are also found for Barangay Cupang also in Antipolo City, Barangays San Andres and San Isidro in Cainta, Barangay San Jose in Rodriguez, and Barangay Manggahan in Pasig City. Models indicate these barangays will experience “complete damage with no collapse”. The predominant Era of Construction classifications are Pre-1972 for the Makati barangays and Barangay Cupang in Muntinlupa City. Meanwhile the rest of the barangays have 1972-1992 Era of Construction except for the Taguig City barangay of Fort Bonifacio which has a predominant Post-1992 Era of Construction category.

The modelled total number of casualties within GMMA from the Magnitude 7.2 scenario is over 37,000 fatalities, and 605,000 injuries (from slight to life-threatening). The highest numbers of fatalities are found from among the same barangays where the “collapse” and “complete damage with no collapse” categories are found. These are Barangays Cupang and Mayamot in Antipolo City, Barangays San Andres and San Isidro in Cainta and Barangay Rosario in Pasig City (Figure 6.4). Models indicated that Batasan Hills Barangay in Quezon City will experience fatalities and injuries categories despite it not featuring prominently in terms of physical damage. A possible explanation for this could be the high population in the barangay. Similarly, what appear to be casualty ‘peaks’ for small-sized barangays are notably pronounced in the high-density ‘old’ areas like in the City of Manila.

The modelled total economic losses for GMMA from the Magnitude 7.2 scenario is almost 2.5 trillion pesos. The barangays which registered the highest economic losses were Barangays San Lorenzo and Bel-Air both in Makati City, Barangay San Antonio in Pasig City, Barangay Bagumbayan in Quezon City and Barangay Fort Bonifacio in Taguig City (Figure 6.5). The abovementioned two Makati barangays, and the barangays in Quezon and Taguig cities modelled high levels of “complete damage with no collapse”, possibly because both had predominant pre-1972 era of construction. The Pasig City barangay of San Antonio was among the top five barangays in terms of economic loss, despite only modelling slightly physical damage. The abovementioned barangays which sustained the highest economic losses were not from the barangays which registered the highest number of collapsed category. A major factor might be high replacement costs for these highly urbanized barangays rather than the amount of total floor area damaged.

The interpretation of these earthquake risk results should be done with caution, especially when presenting to local government units and other stakeholders. It should be emphasized that the results are indicative only and came from: a) an exposure database derived from a statistical approach and b) vulnerability curves derived from a population of buildings types. Results can be improved if the exposure database can be further enhanced with the help of LGUs through more field validation or through provision of actual local data. For example, if LGUs can provide data on building types per barangay and population per building modelled results of physical damage and casualties will be improved. Economic loss can also be improved if LGUs can provide local replacement costs.

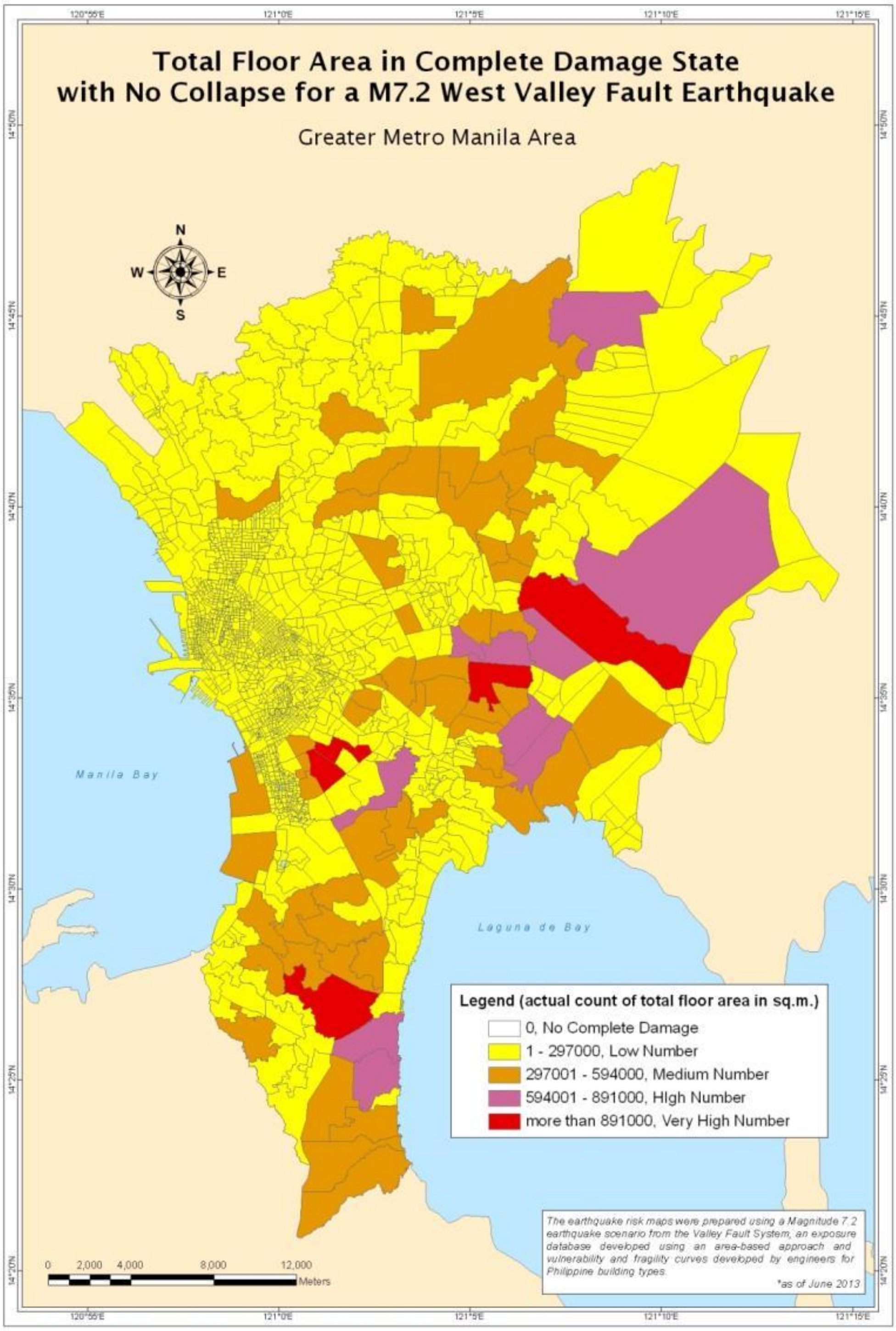

Figure 6.3. Total Floor Area in Complete Damage State with No Collapse for a M7.2 earthquake.

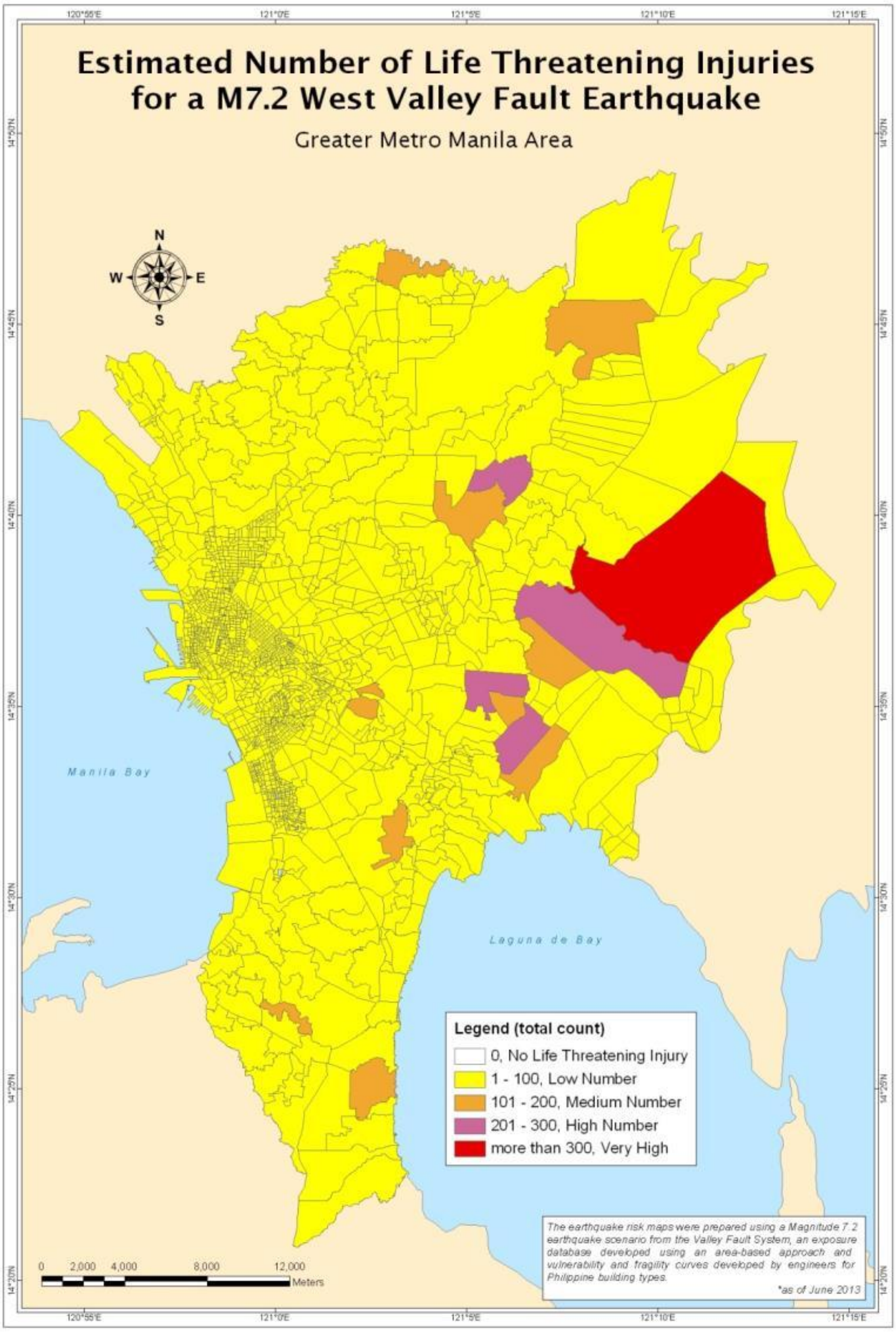

Figure 6.4. Estimated Number of Life Threatening Injuries for a M7.2 earthquake.

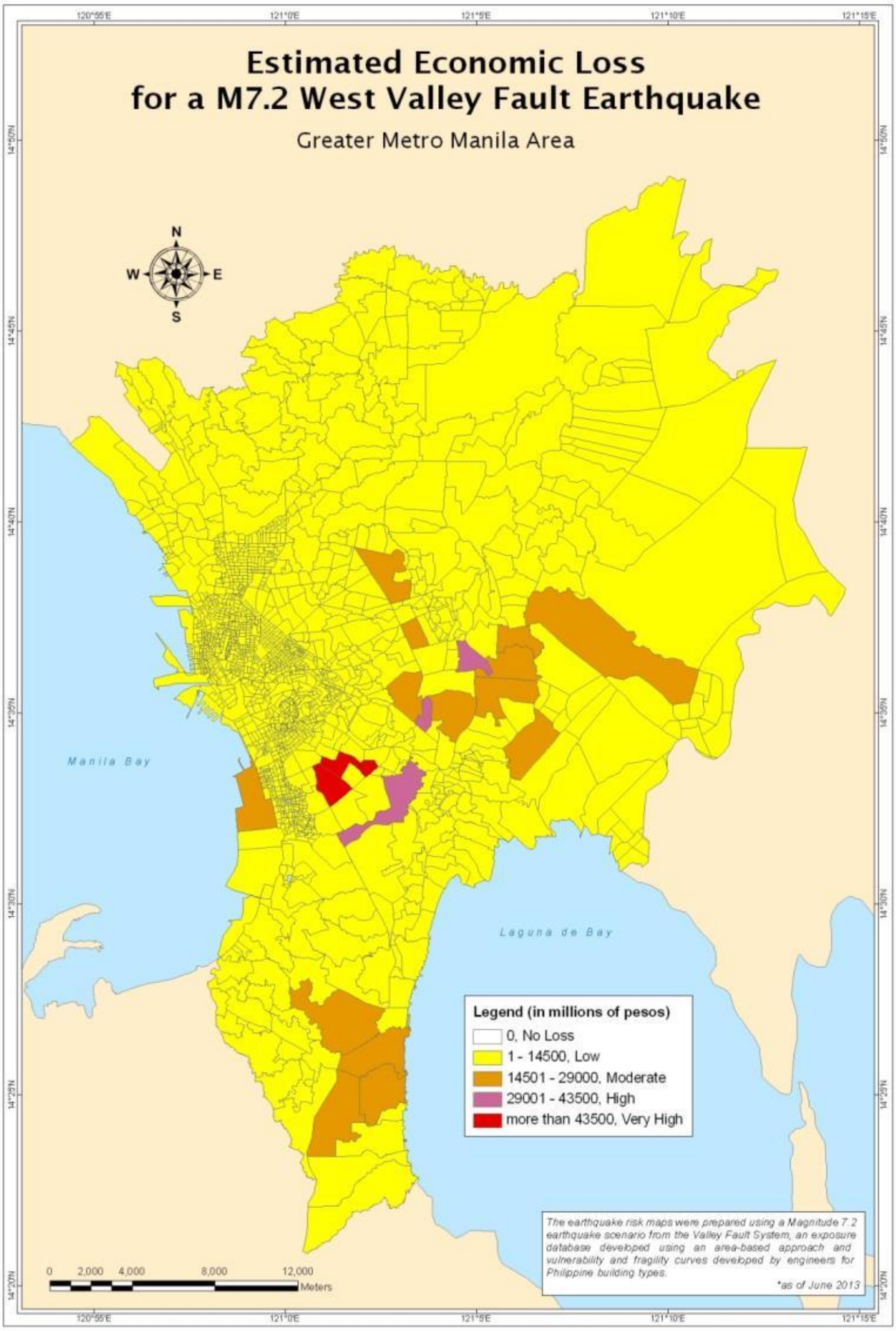

Figure 6.5. Estimated Economic Loss for a M7.2 earthquake.

7 Conclusions

Through the GMMA RAP collaboration, CSCAND and GA successfully acquired and developed base datasets fundamental to natural hazard risk analysis in The Philippines. The first of these is high resolution digital elevation data acquired with LiDAR in early 2011. 1,311 km^2 of data were captured covering GMMA, including the Pasig-Marikina river basin and the shoreline of Manila Bay extending from Bulacan to Cavite. These data formed the basis for the production of a DEM that was a key input to hazard and risk modelling for the project.

The second fundamental dataset that was developed through the GMMA RAP was the exposure database, which describes the ‘elements at risk’ from natural hazards, including buildings, structures and people. Spatial datasets were acquired from numerous agencies and analysed through a statistical Area-Based Approach. The exposure of buildings and population recorded key attributes needed to undertake natural hazard risk analysis for flood, tropical cyclone severe wind and earthquake across Metro Manila and western parts of Rizal Province adjacent to Metro Manila.

The other major outcome of the GMMA RAP was that CSCAND scientists were able to better assess the risk and impacts from flood, severe wind and earthquake in the Greater Metro Manila Area. This was achieved through undertaking the first multi-hazard risk assessment for megacity.

Flood modelling scenarios in the Pasig-Marikina River Basin highlighted that flooding can have very serious impacts on GMMA, beyond what has been experienced in recent disasters such as Tropical Storm Ondoy (Ketsana). In a hypothetical 1/200 AEP scenario, the deepest inundation (3+m) occurs along the Upper Marikina and San Juan Rivers, with almost 60 billion pesos in physical damage and over 2 million people with inundated homes.

Tropical cyclone severe wind modelling indicates that GMMA may suffer costly wind damages due to damaged structures (residential, commercial, industrial and critical facilities and other structures), with total costs in Greater Metro Manila of approximately PHP 77.61 Million/km^2 for the 0.2% AEP. The City of Mandaluyong has the highest expected economic loss amounting to PHP 163.87 Million/km^2, as it is densely built-up and has high proportions of vulnerable building types (makeshift (N), wood one-storey (W1), and concrete (C1) and pre-1972 building stocks).

Earthquake modelling in GMMA highlights the risk to the region from the Marikina Valley Fault System, and the West Valley Fault in particular, which runs directly beneath Manila. Two scenario earthquake were modelled on the WVF, a M7.2 event (the estimated maximum size to could occur on this fault) and a M6.5 event (the most probable earthquake size). The modelled total number of casualties within GMMA from the Magnitude 7.2 scenario is over 37,000 fatalities, and 605,000 injuries and the modelled total economic losses for GMMA from the Magnitude 7.2 scenario is almost 2.5 trillion pesos.

These outcomes together represent a significant leap forward in our understanding of natural disaster hazard and risk in GMMA, and will form a scientific basis that will influence policies and disaster mitigation measures in the region such as planning guidelines, land use planning, and risk insurance.

8 Acknowledgements

The authors gratefully acknowledge the support of our DFAT colleagues, particularly Mavic De Guzman and Anne Orquiza.