Philippines Catastrophe Risk Assessment and Modeling: Component 3 – Country Catastrophe Risk Profiles

Technical Report Submitted to the World Bank

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1 Introduction

The Philippines is exposed to a multitude of natural hazards such as earthquakes, typhoons (tropical cyclones[1]), and flooding (see Figure 1.1) that result in significant property damage and socio-economic impacts. The Philippines is also widely acknowledged as one of the most disaster[2]-prone countries in the world (Delica, 1994).

According to Benson (1997), roughly 20 tropical disturbances enter the Philippines Area of Responsibility (PAR) on average per year, of which about 11 are classified as typhoons. According to Brown et al. (1991), it is highly likely that at least four typhoons will make landfall in any given year, while an average of eight to nine tropical cyclones would actually reach land and a further two offshore tropical cyclones would result in damage every year. While different studies may differ in their estimates of the frequency and severity of tropical cyclones, the general consensus is that the country is severely impacted by tropical cyclones. The eastern part of the country, particularly the north east, is considered most vulnerable to typhoons.

Severe flooding is normally associated with the heavy rains accompanying typhoons. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has estimated that some 47% of the average annual rainfall is due to typhoons, 14% to monsoons, and 39% to other weather systems. In December 2011, flash floods caused by typhoon Washi killed over 1,000 people and left hundreds of thousands homeless on the island of Mindanao. In September 2009, typhoon Ondoy impacted Metro Manila. Less than a week later typhoon Pepeng carved a trail of destruction in Northern Luzon for almost two weeks. Consequences of the two typhoons included casualties due to flooding and landslides brought about by continuous rain.

In addition, the Philippines is located between two major tectonic plates, the Pacific and Eurasian plates, and within the Philippine Sea plate (USGS, 2011). The Pacific plate is pushing the Philippine Sea plate beneath the eastern side of the country at a rate of about 7 cm per year (NDCC, 1990), generating regular seismic and volcanic activity. According to the Philippines Institute of Volcanology and Seismology (PHIVOLCS), the country experiences an average of five sizeable earthquakes per

[1] The term “tropical cyclone” is used as a generic version of the term “typhoon”. Both terms are used in the report.
[2] In this report, the term “disaster” is used interchangeably with the term “catastrophe.”

day, in turn resulting in ground shaking, and potentially ground rupture, liquefaction, lateral spreading, landslides, and tsunamis.

In terms of their broader economic impacts, natural hazards experienced in the Philippines can be divided into two distinct categories depending on their frequency of occurrence. Tropical cyclones and floods are the principal hazards falling into the category of more frequently occurring hazards. Both occur annually, although the rate of incidence and severity varies between years. Tropical cyclones alone have been estimated to cause damage equivalent to 0.6% of the gross national product (GNP) every year (ADB, 1994), which significantly impacts the Philippines' economic recovery. The second category comprises more severe disasters with considerably longer return periods, such as major earthquakes, volcanic eruptions, or droughts (Benson, 1997).

The Government of the Philippines (GoP) has begun taking a proactive approach to disaster risk management by approving the Disaster Risk Reduction and Management (DRRM) Act in May 2010 (Republic Act No. 10121). One of the priority areas identified by the DRRM Act is the establishment of appropriate risk finance policies and instruments that will help reduce the fiscal burden of the GoP to natural disaster impacts. Furthering the work on risk finance, the GoP is implementing a technical assistance program that would lead to the formulation of a risk finance strategy. Alongside, the GoP has requested a catastrophe risk assessment study that would provide the quantitative underpinnings for the design of an ensuing catastrophe liquidity facility, especially addressing the higher layers of risk.

The World Bank, which is assisting the GoP with its disaster risk management objectives, has retained AIR Worldwide Corporation (AIR) in partnership with the Asian Disaster Preparedness Center (ADPC) for conducting the catastrophe risk modeling and assessment study.

According to the project's Terms of Reference (ToR), the natural hazards to be considered in this study are earthquake ground shaking, typhoon wind and typhoon-induced precipitation, and flooding due to non-typhoon induced precipitation (i.e., monsoonal precipitation induced flooding). The study is built over five distinct but interconnected components, which are as follows:

- **Component 1:** Hazard Data and Loss Data Collection and Management
- **Component 2:** Exposure Data Collection and Vulnerability Function Development
- **Component 3:** Catastrophe Risk Assessment at the National and Local Levels
- **Component 4:** Design of Parametric Indices for Financial Transactions
- **Component 5:** Support for Placement of Parametric Risk Transfer Products (study can be extended to include this optional component depending on the GoP's decision regarding the use of the parametric risk transfer products towards the disaster risk financing strategy)

This report serves as a summary of Component 3, which focuses on using state-of-the art catastrophe risk modeling methods to develop risk profiles for earthquake ground shaking, tropical cyclone (wind and precipitation flooding) and non-tropical cyclone induced precipitation flooding in the Philippines. The impact of historical events on the people and assets of the Philippines has been investigated to understand the extent of adverse consequences that possible future events may bring. Ten thousand simulations of potential future annual earthquake, tropical cyclone and non-tropical cyclone precipitation activity have been carried out to estimate the risk in terms of monetary loss and casualties. While other hazards such as storm surge associated with typhoons, secondary hazards such as landslides and liquefaction, volcanoes, and a comprehensive treatment of riverine flooding is outside the scope of this study, the country risk profile derived from this study can be used to improve the resilience of the Philippines to the modeled natural hazards. Additionally, various components of the study can be utilized to extend the evaluation to include the other hazards, as and when considered appropriate.

This report provides details on AIR/ADPC's catastrophe risk methodology which consists of the following modules:

1. The Exposure Information Module
2. The Hazard Assessment Module, which is comprised of the Event Generation Module and the Intensity Calculation Module
3. The Damage Estimation Module
4. The Casualty and Loss Calculation Module

The details of these modules for each peril are overviewed in following sections of this report. While all modules will be summarized in this report, the report will primarily focus on the hazard and loss modules. The reader is directed to the Component 2 report, which has more detailed information on the exposure information and the damage estimation modules. The reader is also directed to documentation available on AIR's website for additional information pertaining to the catastrophe risk models that have been employed, in part, for the purposes of the study. For brevity and confidentiality reasons, the discussion on the existing models is not being included in this report; information on these models has been provided separately to the World Bank and Geoscience Australia (peer reviewer for this project); the detailed model document is subject to specific confidentiality provisions. Note that specific modules of these existing models have been modified or developed anew for the purposes of this study.

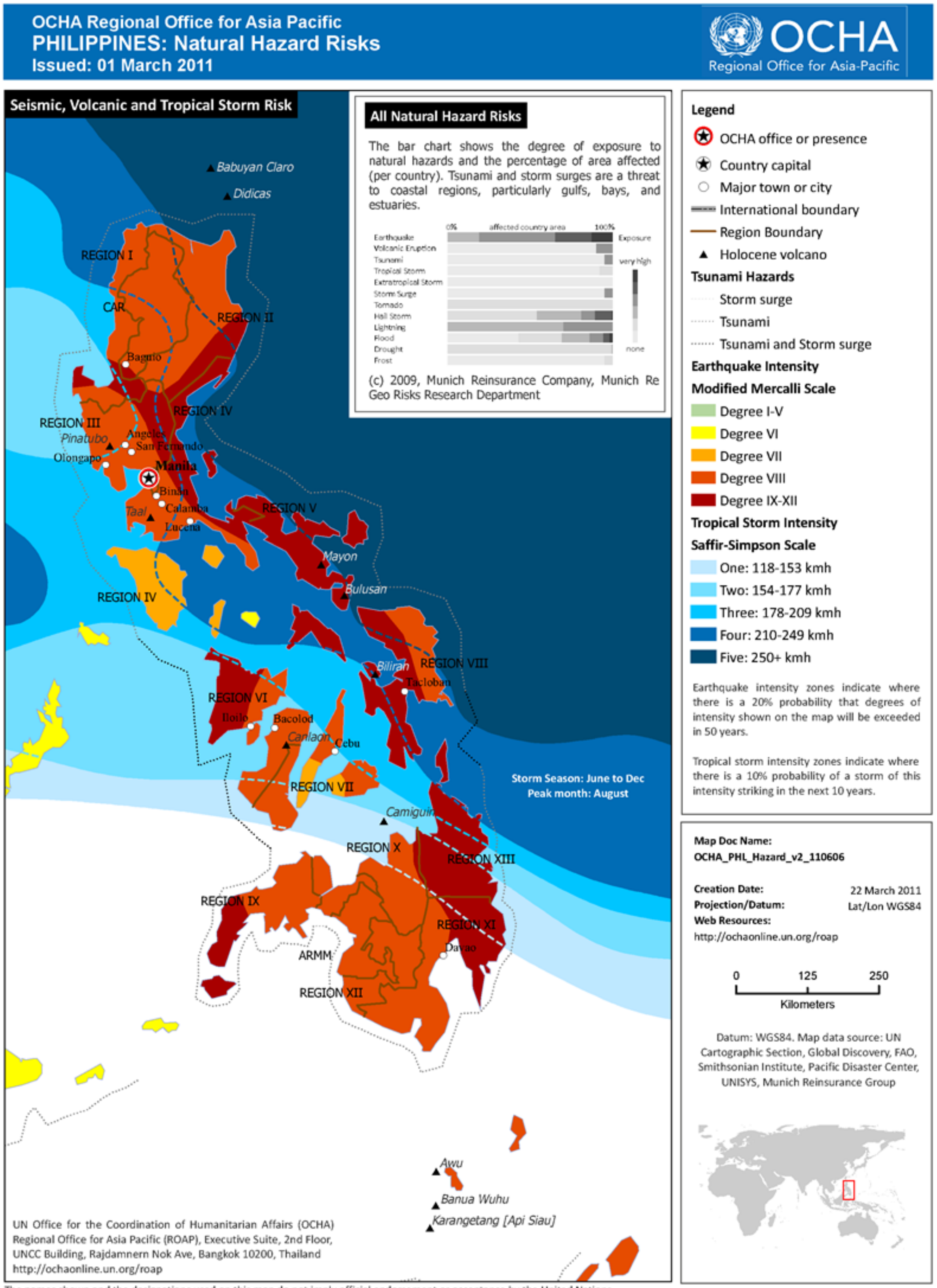

Figure 1.1. Hazards in the Philippines (Source: OCHA)

1.1 Limitations

The study summarized in this report is intended for use by the Government of the Philippines and the World Bank to assist them with quantifying the catastrophe risk associated with the population and built environment in the Philippines, and with the process of development and implementation of disaster risk finance strategies. Proper application of this study requires explicit recognition and understanding of the limitations of both the scope and methodology of the entire study.

The physical loss estimates that have been presented for the assets are neither facts nor confirmed predictions of loss that may occur either collectively or to any particular asset as a result of future events or any specific event; as such, the actual damage for a particular event may be materially different from that presented in this study. Furthermore, the assumptions adopted in determining the loss estimates do not constitute the exclusive set of reasonable assumptions, and the use of a different set of assumptions or methodology may produce materially different results. The results presented in this study simply represent our best assessment of the potential for physical losses, based on information and data available to us at the time of this study and that collected during the study.

The scope of services performed during this assessment may not adequately address the needs of other users, and any re-use of (or failure to use) this report or the findings, conclusions, or recommendations presented herein are at the sole risk of the user. Our conclusions with respect to the loss and hazard estimates are based on our professional opinion, engineering experience and judgment, analyses conducted in the course of the study, information and data available in the literature and that provided by the World Bank and various local agencies, and are derived in accordance with current standards of professional practice.

2 Objectives & Methodology

The main objective of Component 3 of this catastrophe risk assessment and modeling study for the Philippines is the development of risk profiles for earthquake ground shaking, tropical cyclone (wind and precipitation) and non-tropical cyclone induced precipitation. The general methodology adopted by AIR for its probabilistic catastrophe risk models and risk assessments is shown in Figure 2.1. Every step of the methodology relies, to some extent, on empirical data collected in the region, as will be described later in this report.

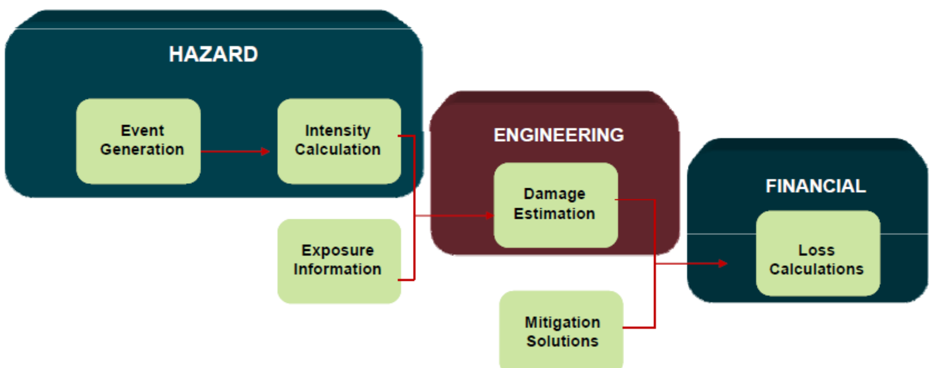

Figure 2.1. AIR Risk Modeling Methodology

The individual modules are as follows:

- **Hazard Module**: quantifies the natural catastrophe hazard across the Philippines in terms of intensity measures (e.g. peak ground acceleration, wind speed, etc.) using AIR's proprietary models for the Southeast Asia region. These models have the capability to generate probabilistic estimates of each peril at any location within the Philippines using regional information on historical events, earthquake faults and seismicity, land use, soil conditions, etc. The models utilize stochastic event catalogs of thousands of events and allow for the determination of the probability of exceedance of different levels of hazard intensity at any location within the Philippines. The resolution at which the hazard is quantified varies by peril. The existing AIR proprietary models were enhanced for the perils of earthquake ground shaking and non-tropical cyclone induced precipitation, for the purposes of this study.

- **Exposure Module**: assesses the distribution of the built environment that would be impacted by the natural catastrophe events. Exposure databases for private property and government assets have been developed. AIR's proprietary models for the Philippines include an Industry Exposure Database (IED), which estimates the location, characteristics and value of private property in the country. This database includes commercial, industrial and residential exposure and classifies assets by their construction type and occupancy. The Industry Exposure Database captures the physical value distribution across the entire country associated with private property assets. A similar database for government assets was compiled by contacting various government agencies and supplementing this data with information from publicly available sources and analysis.

- **Damage Estimation Module**: determines the potential physical and societal damage given the information generated in the preceding Hazard and Exposure modules. This module leverages vulnerability functions that have been previously developed and are applicable to the physical assets in the Philippines; these vulnerability functions were reviewed, updated, and expanded as necessary to ensure they appropriately represent the vulnerability of the assets contained in the private property and government asset databases.

- **Mitigation Module**: includes the ability to structure various financial (or if needed, physical) mitigation options. The module allows for incorporation of various financial structures (e.g., deductibles, limits) that can be leveraged to determine the loss potentials under various financial structures, which allows for determination of optimal financial structures in a convenient manner. Also, the module permits the modification of the vulnerability functions to reflect hypothetical physical mitigation measures and the quantification of the impact of the same thereby allowing for direct quantitative evaluation of the cost of the mitigation measures versus the projected benefit of the same. This approach allows for ranking of the risk mitigation measures and provides a powerful tool based on quantitative values to effect informed decision-making regarding mitigation. This module was not actively applied in Component 3, however, can be used in Component 4 and future risk assessment studies.

- **Loss Calculation Module**: combines the hazard, exposure, and engineering (damage estimation) modules to generate probabilistic estimates of the physical loss to the exposure considered in the private property and the government asset databases, and for estimation of the casualties based on the exposed population. Loss values associated with different probabilities of exceedance can be generated thereby providing different views of the risk (e.g., the risk ranking may be performed in terms of different metrics such as different levels of annual probabilities of exceedance or of mean return periods, or of average annual losses) to holistically capture the engineering and societal based risk.

Component 3 includes the following primary outputs:

- Tables and figures of probabilistic loss estimates (i.e., direct and emergency losses[3]) by province and by exposure category (i.e., private property, total government assets, individual government sectors and total country exposure)
- Assessment of provincial population impact by peril
- Maps visualizing the provincial loss distributions by peril
- A geo-referenced database of the hazard intensities and loss estimates for given mean return periods

The following sections provide details on the modules shown in Figure 2.1. Section 3 briefly describes the characteristics of the exposure assets in the Philippines (refer to the Component 2 report for additional details). Section 4 presents the salient features of the Hazard Assessment Module developed in Component 3. Section 5 discusses the Damage Estimation Module (refer to the Component 2 report for additional details). Finally, Sections 6 and 6 provide details on the methodology employed for loss calculation and population impact and summarize the country risk profiles.

[3] Emergency losses are expenditures the government may sustain as a result of providing necessary relief and undertaking recovery efforts. Such efforts include debris removal, setting up shelters for those made homeless, or supplying medicine and food.

3 Exposure Databases

The exposure module of AIR's risk modeling methodology (refer Figure 2.1) includes an assessment of the distribution of the built environment and population that could be impacted by natural catastrophe events. Three primary exposure databases were developed for this risk assessment: (1) a population database, (2) a private property database (also referred to as the Industry Exposure Database), and (3) a government asset database. A brief summary of these databases is included this section; interested readers are directed to the Component 2 report for more details on this part of the risk assessment.

3.1 Population Exposure

The population database identifies the population at risk in the Philippines and its spatial distribution across the country. This database was compiled from official government data, including the 2010 Philippine Census of Population and Housing and contains various statistical metrics. The population exposure data is provided at two levels of granularity – Province level (locally known as *Probinsya/Lalawigan*) and Municipality/City level (*Munisipalidad/Bayan* or *Siyudad/Lungsod*). The Province Level population database includes data for 82 Provinces in the Philippines. The Municipality Level population database includes data for 1,627 Municipalities and Cities in the Philippines. The vintage of the geographic extent of the political divisions in the administrative boundaries is between 2006 and 2008[4]. The population exposure across the Philippines, at the Municipality level, is as shown in Figure 3.1

[4] The administrative boundaries of the Philippines were acquired from the GADM database of Global Administrative Areas (Version 2.0, issued December 2011) obtained by ADPC from the Philippine Ministry of Agriculture.

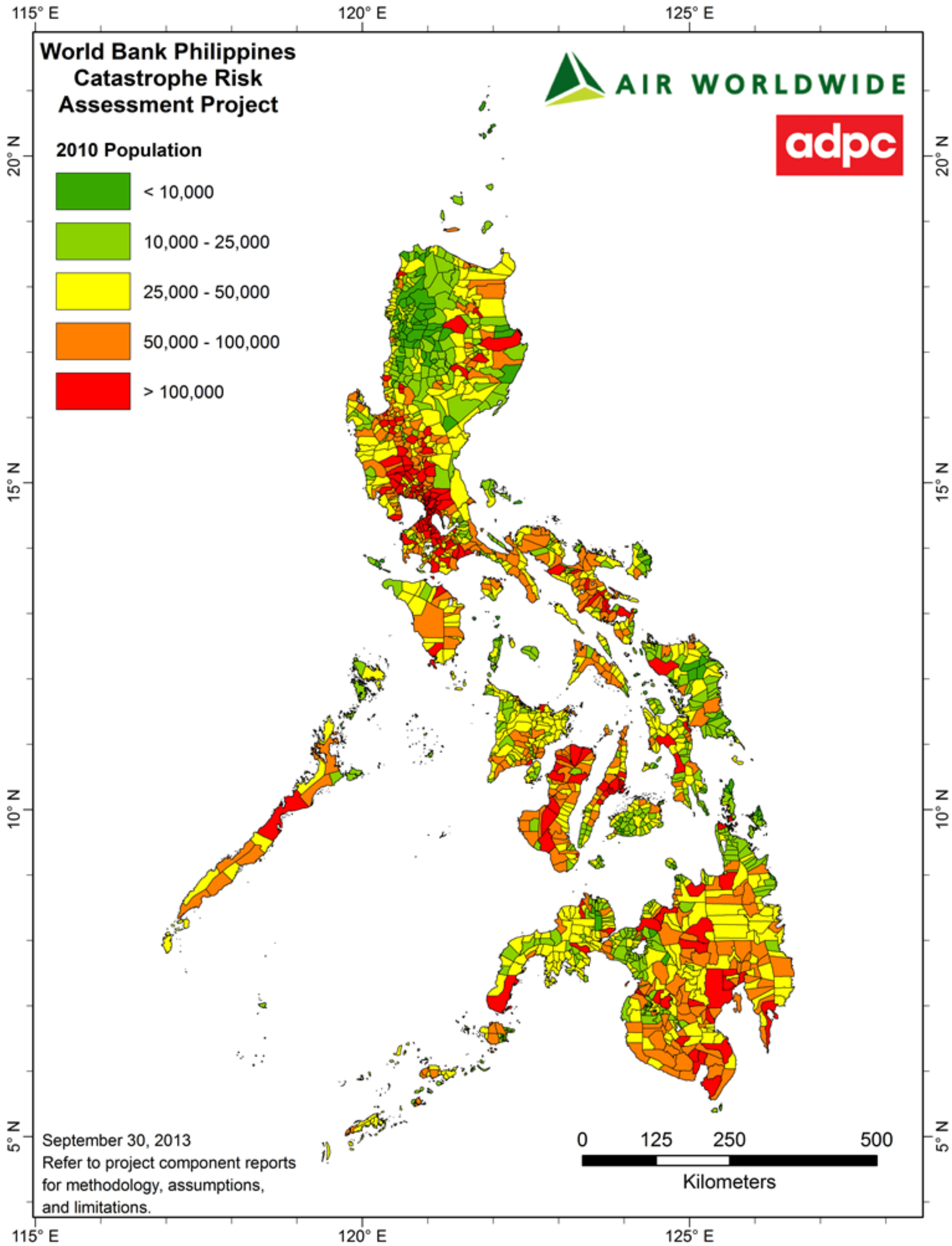

Figure 3.1. Municipality Level 2010 Population of the Philippines.

3.2 Private Property Assets (Industry Exposure Database)

The private property exposure database (otherwise known as the Industry Exposure Database) for the Philippines is a country specific database containing risk counts, locations and respective replacement values, along with information about the assets' occupancy (residential, commercial or industrial) and physical characteristics, such as construction type (e.g., non-engineered, wood, steel, etc.) and height classification (low-, mid- or high-rise).

A wide variety of data sources were used to develop the Philippines' private property exposure database. Detailed data on risk counts, building characteristics and construction costs were obtained from the most recent available census data, construction manuals and other reports. These sources were supplemented with other ancillary data from various regional and global data sets.

AIR has developed a comprehensive disaggregation method that combines high-resolution auxiliary datasets such as land-use, impervious surface areas, elevation, slope, and regional data. This method was used to distribute the available risk data from coarse to fine geographic resolutions and achieve a final spatial resolution of 1 km^2 for the Philippines' private property exposure database.

Risk replacement values were determined using AIR's rebuild cost approach where construction cost, which is usually expressed in terms of a unit cost per square foot (or square meter), is multiplied by floor area estimates. The private property exposure value across the Philippines is as shown in Figure 3.2.

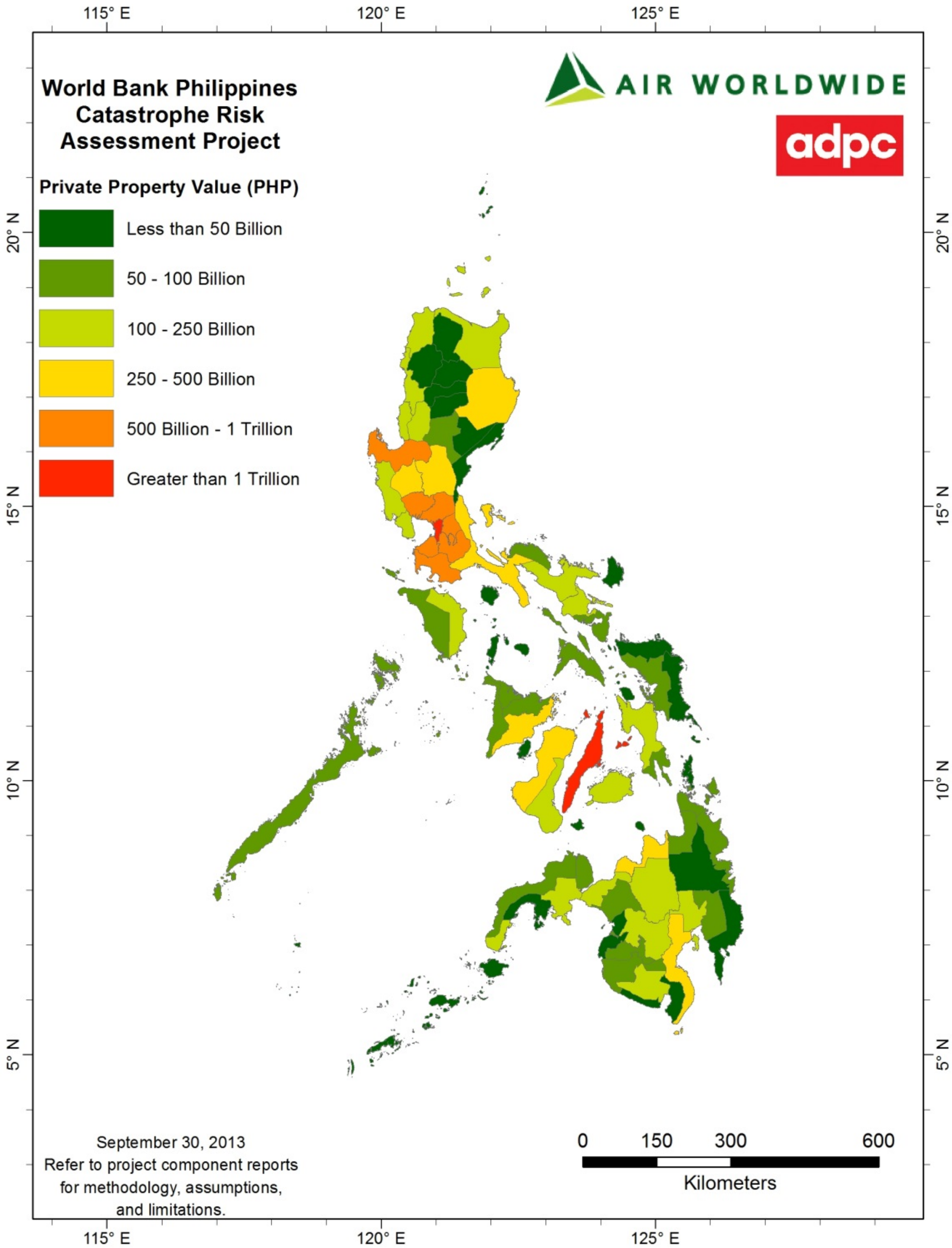

Figure 3.2. Private Property Asset Database – Estimated Replacement Value by Province.

The intermediate steps of the database development process, as well as the overall resulting private asset database, are validated and calibrated against alternative regional and global data sets containing reported building and economic attributes (e.g., satellite imagery, statistical reports, known risk locations and, where available, high-resolution risk data). In addition to checking the input data sets, AIR also benchmarks its total national private property exposure values against various independent sources, such as gross capital stock and client data aggregates.

3.3 Government Assets

A detailed inventory of national government assets including state-owned enterprises and specific infrastructure assets was assembled for the purposes of this study. Data necessary for the catastrophe risk modeling of the government assets such as location, structural and non-structural characteristics, and replacement value was collected directly from the local government agencies and/or was derived and supplemented with information available in the public domain and field surveys conducted during the study. When data was unavailable, incomplete or inaccurate, a variety of modeling techniques and/or expert judgment were used to simulate, estimate or improve the quality of the assets' characteristics. The government assets exposure value across the Philippines is as shown in Figure 3.3.

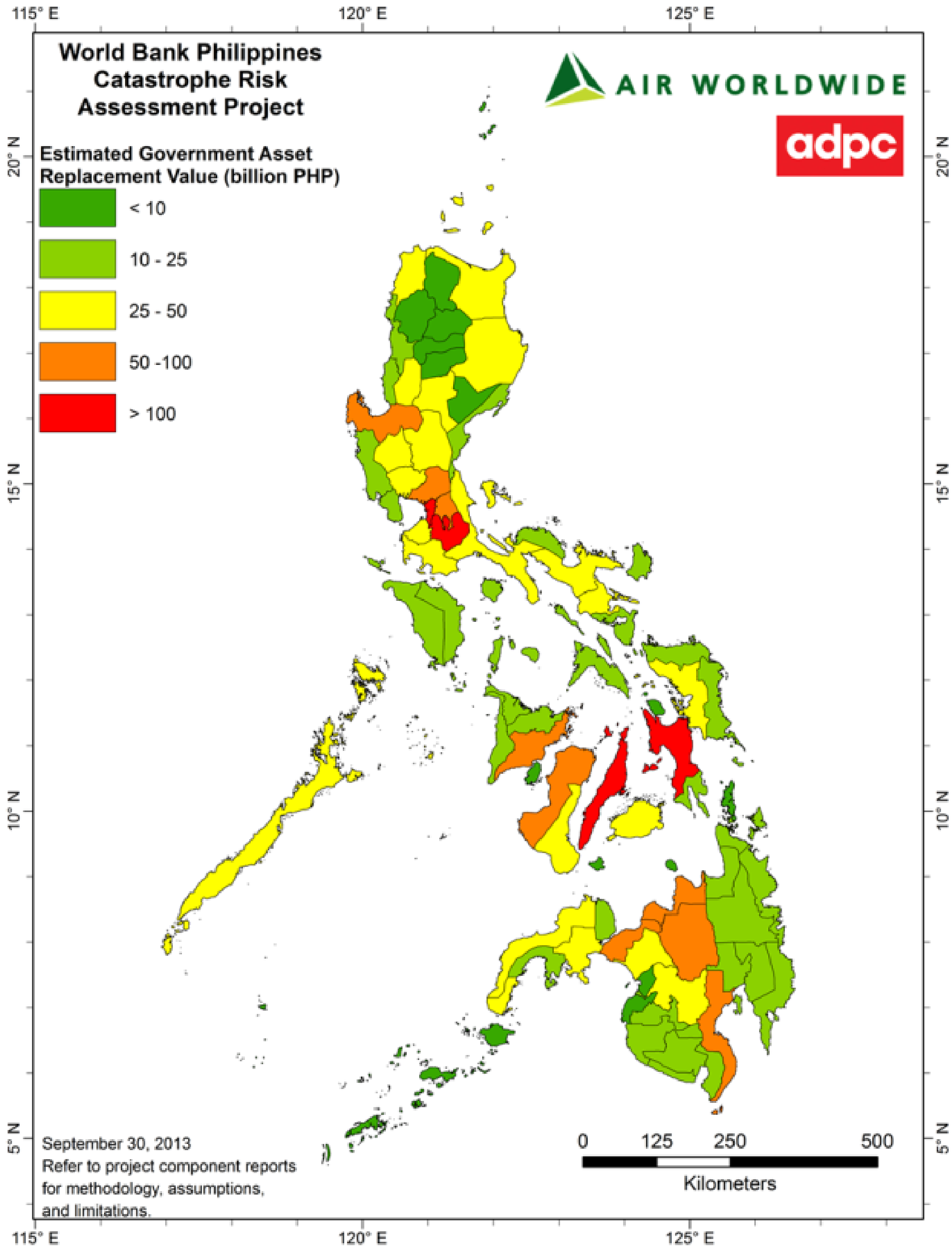

Figure 3.3. Government Asset Database – Estimated Replacement Value by Province

Table 3.1 provides a summary of the government asset exposure database by government sector. For ease of reference, Table 3.2 provides a summary of the private property and government assets exposure values; these values represent the building value only, i.e., contents values are not included in the data shown in this table.

Table 3.1. Summary of the Government Asset Exposure Database

Asset Type	Representative Unit Replacement Cost*	Number	Estimated Replacement Value (PHP)**
Road	25 to 36 million PHP per km	≈30,673 km of paved national primary and secondary roads	680,566,613,326
Residual Institutions	5,000 PHP per person	n/a	461,674,455,000
Bridge	0.5 to 1.0 million PHP per meter	7,860 bridges maintained by the national government under the Bridge Management System	326,790,678,987
Power Plant	40 to 90 million PHP per MW of installed capacity	24 large NPC and NPC/IPP power plant facilities	295,667,261,120
Public School	7,000 to 12,000 PHP per square meter	46,606 public elementary and secondary school facilities	294,944,436,274
Airport	Runway: 40,000 to 100,000 PHP per meter Buildings: 65,000 to 115,000 PHP per square meter	85 CAAP airports	232,017,926,000
Public University	12,000 PHP per square meter	113 state school, college and university institutions	123,874,249,854
Port	Data given in the raw datasets	190 government ports	111,280,700,659
Light Rail	Track: 650 million PHP per km Station: 730 million PHP per station	≈49 km of track & 45 stations	65,470,607,012
Government Hospital	17,500 PHP per square meter	774 government hospitals	49,986,422,951
Public Administration Building	Data given in the raw datasets	4,417 buildings	28,750,872,283
Government Medical Facility	Small Facility: 0.65 million PHP Medium Facility: 4.38 million PHP Large Facility: 12.13 million PHP	17,969 government medical facilities	25,867,915,868
Rail	Track: 6 million PHP per km Station: 370 million PHP per station	≈530 km of track & 32 stations	14,829,614,040
Prison	Data given in the raw datasets	122 buildings in 7 prisons	509,850,000
Total	-	-	**2,712,231,603,374**

* The representative unit cost is shown for informative purposes; the actual methodology to estimate the total replacement value involves several metrics not detailed in the table (refer to the Component 2 Report)
** All values listed are for Coverage A only (structure value)

Table 3.2. Summary of the private property and government assets exposure values (building value only)

Asset Category	Estimated Replacement Value (PHP)
Private Property Assets	22,085,381,106,929
Government Assets	2,712,231,603,374
Total Assets	24,797,612,710,302

4 Hazard Assessment

The hazard module of AIR's risk modeling methodology (refer Figure 2.1) considers the primary natural hazards affecting the Philippines. The scope of this study includes evaluation of the earthquake ground shaking, tropical cyclone (wind and precipitation), and non-tropical cyclone precipitation hazard across the Philippines. This section presents the details of the hazard models developed by AIR for the selected perils. The hazard models are based on regional information such as historical event records, earthquake faults and seismicity, local topography, regional meteorological conditions, land use, soil conditions, etc. Utilizing stochastic event catalogs containing thousands of simulated events, the hazard models have the capability to generate probabilistic hazard intensity estimates at any location within the Philippines, although the resolution at which the hazard is quantified varies by peril. The hazard assessment module comprises two main components: (1) generating possible future events that may affect the Philippines (i.e. event annual frequency, storm track, meteorological parameters, etc.) and (2) estimating the simulated events' local intensity.

AIR's previously developed Earthquake and Typhoon Models for Southeast Asia were used and updated as necessary for the purposes of this study[5]. The existing hazard module for earthquake ground shaking was reviewed to 1) verify the validity of the stochastic catalog and 2) improve the local intensity computation by updating the ground motion prediction equations (GMPEs). The existing tropical cyclone wind and precipitation hazard module was used as is because the stochastic catalog was recently updated and the time constraints of the study did not allow further enhancements. A recognized limitation of the existing Typhoon model is that it can only compute local intensities at a coarse resolution (postal code level) due to the lack of available physical property (e.g. land use, topography) data sets at the time of development. More extensive enhancements were made to the exposure and vulnerability modules, which are explained in Section 3 and Section 5 of this report, and in greater detail in the Component 2 report.

A simplistic, but entirely new model was also developed to capture the effects of non-tropical cyclone (NTC) precipitation in the Philippines. This model aims to quantify the hazard due to extreme

[5] More detailed background and information on the existing models that were leveraged in this study can be found in the model documentation of AIR's Earthquake and Typhoon Models for Southeast Asia (available upon request).

precipitation events (e.g. monsoonal rain) outside of tropical cyclones and use it as an index that can be related directly to economic loss and population impact. The model is simplistic in nature as it is not a comprehensive riverine flooding model, which can take several years to develop and is outside the scope and time constraints of this study. To accommodate software implementation of the new model within the timeline of the study, AIR expanded the existing tropical cyclone platform to include the non-tropical cyclone precipitation peril. Thus, the NTC hazard module also uses postal code resolution. Although it is recognized that this is an important limiting factor in quantifying this type of peril, the model provides a first-order estimate of the hazard and its consequences for severe precipitation in the Philippines, which can be further improved upon in subsequent studies.

4.1 Event Generation

The spatial and temporal occurrence and severity of past events, which are discussed in the Component 1 report, are used as background for simulating potential earthquake, tropical cyclone, and non-tropical cyclone precipitation events that may affect the Philippines in the future. The simulated events are not identical to those that have occurred in the past, but are statistically consistent with them. In general, this means that the location and severity of the simulated events may not have been observed in the relatively short historical record, but such events are possible and the likelihood of their occurrence has been derived based on the empirical data collected in the region.

The statistical consistency of the stochastic earthquake catalog with the historical record is illustrated in Figure 4.1, for example, which compares simulated and observed earthquake event frequencies. Figure 4.1 shows that earthquake events (both modeled and historical) of magnitude 7.1 or larger occur, on average, once every 2 years (i.e., annual rate of about 1/2) in the Philippines. The blue line, representing the simulated events in Figure 4.1, extends beyond the green line, representing the observed data, because earthquakes with a magnitude larger than 8.3 have not been observed in the historical record, but the subduction zones in the Pacific are capable of generating them, albeit very rarely. For example, until 2011, magnitude 9 or larger events such as the Tohoku earthquake in Japan had never previously been observed on the Japan Trench.

Figure 4.2 shows a similar comparison for tropical cyclones of different severities at landfall as measured by the Saffir-Simpson scale (refer Table 4.1). For example, tropical cyclones of category 4 that make landfall in the Philippines are expected to occur with an annual probability of 7% (i.e., approximately once every 14 years).

It is emphasized that generation of the events comprising the stochastic catalogs involves significant additional scientific information and analysis beyond the historical record. Any stochastic catalog that is developed has to be able to represent the historical record, which is being shown in Figure 4.1 and

Figure 4.2. AIR employs a comprehensive methodology for development of the stochastic catalogs, which is not discussed in the report for brevity, but is discussed in detail in the model documentation.

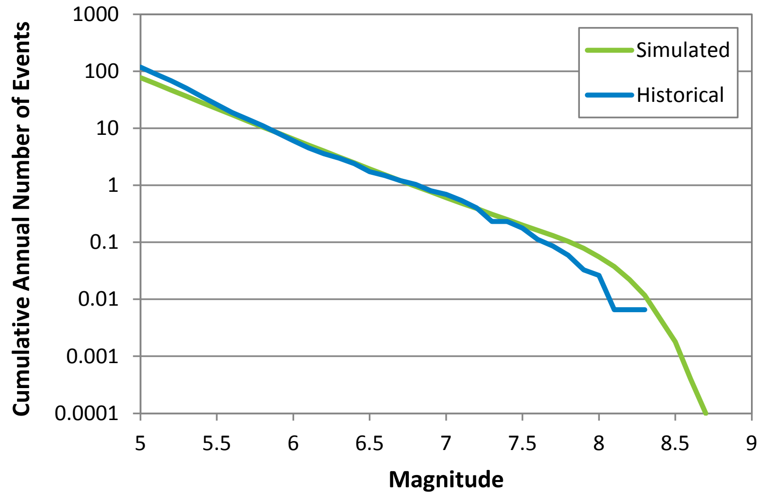

Figure 4.1. Annual Rates of Historical and Simulated Earthquake Events in the Philippines

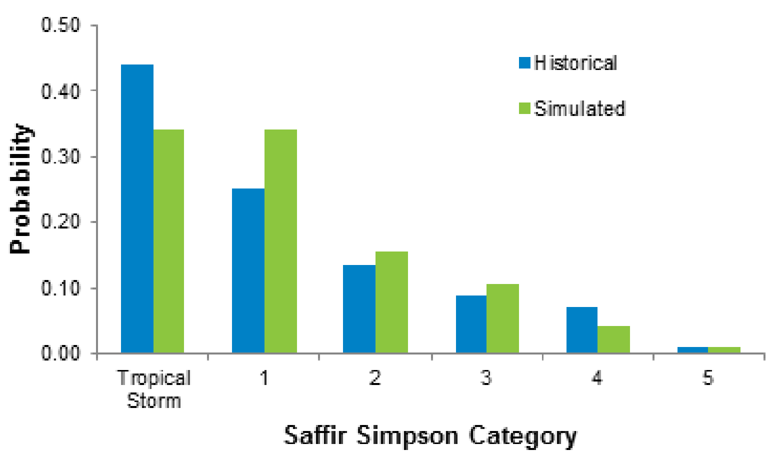

Figure 4.2. Comparison of Historical and Simulated Tropical Cyclone Intensity at Landfall for the Philippines

Table 4.1. Saffir-Simpson Scale

Storm Category	Wind Speed (mph)	Storm Surge (ft)	Central Pressure (mbar)
TS	< 74	< 4	> 980
1	74 - 95	4 - 5	965 - 979
2	96 - 110	6 - 8	945 - 964
3	111 - 130	9 - 12	920 - 944
4	131 - 155	13 - 18	945 - 964
5	> 155	> 18	< 920

Similar validation of the stochastic catalog of non-tropical cyclone induced precipitation events against the historical record is also conducted and is described in more detail later in this report.

4.1.1 Stochastic Catalog of Earthquakes

The catalog of simulated earthquakes in the Philippines region contains almost 775,000 events which represent 10,000 potential realizations of what may happen in the next year. The number of earthquake events and their respective magnitude bins are shown in Table 4.2. As would be expected, earthquakes of lower magnitude (5.0 - 6.0) exhibit a larger number of events, indicating a much higher frequency of occurrence as compared to, say, magnitude 7.0 or greater earthquake events, which occur much less frequently. Epicenters and magnitudes of the simulated earthquake events of magnitude 5.0 or greater in the catalog are presented in Figure 4.3.

Table 4.2. Number of Events in the Earthquake Stochastic Catalog

Magnitude Bin	Number of events
5.0 – 6.0	710,390
6.0 – 7.0	58,276
7.0 – 8.0	5,485
8.0 or greater	554

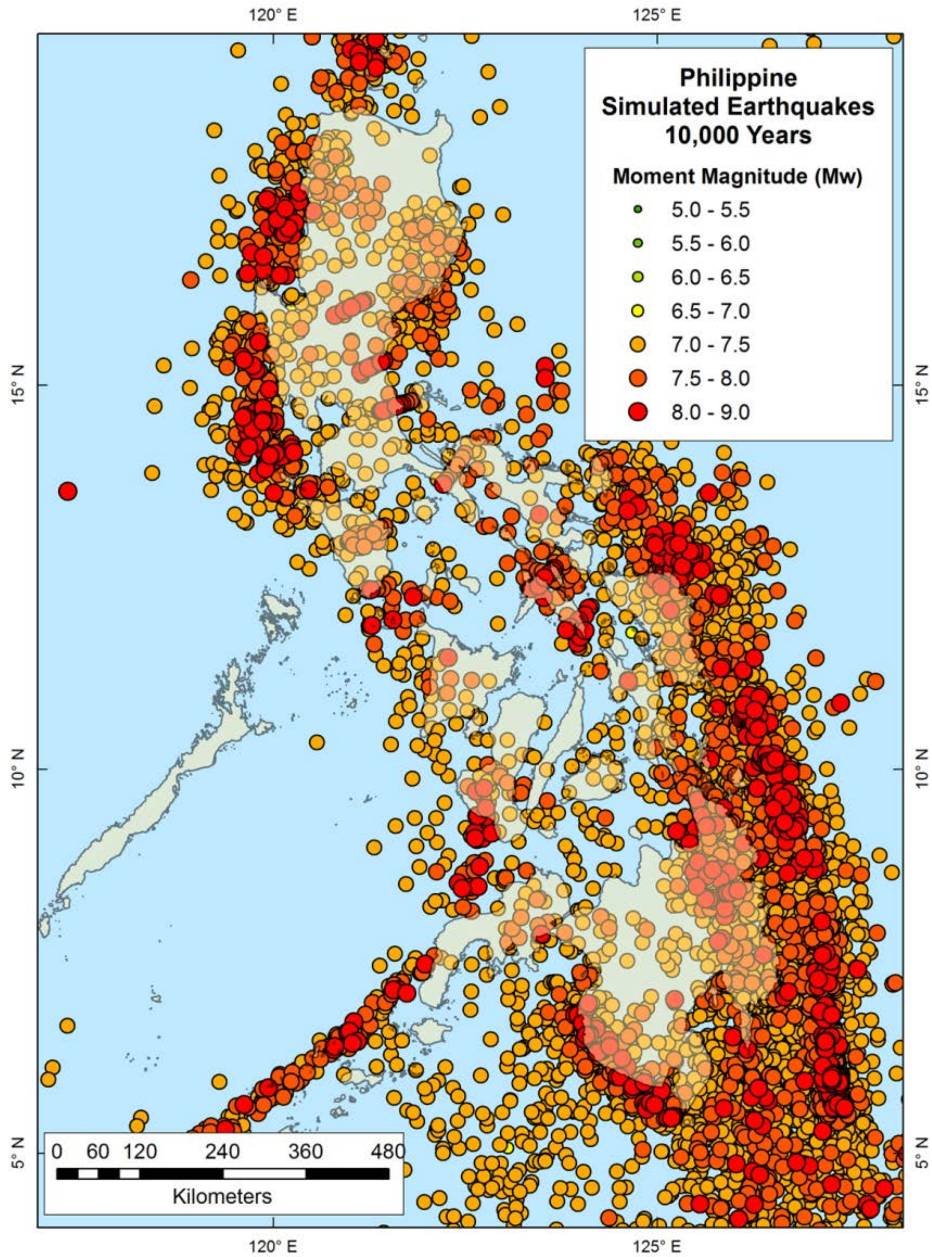

Figure 4.3. Epicenters of Simulated Earthquake Events (Mw ≥ 5.0) in the 10,000-year Catalog

4.1.2 Stochastic Catalog of Tropical Cyclones

The 10,000 year stochastic event catalog of the AIR Typhoon Model for Southeast Asia contains more than 293,000 storms in the model domain that represent 10,000 potential realizations of what may happen in the next year. Of these simulated events, more than 91,000 storms either make landfall or pass close enough to generate loss in the Philippines. The total number of simulated loss causing tropical cyclone events and their respective severities are presented in Table 4.3. As expected, tropical storms (TS), which are the weakest form of tropical cyclones, are demonstrated to occur much more frequently than category 5 storms, which are the strongest. The characteristics of the simulated events tend to approach the mean of historical observations, as demonstrated in the comparison of average tropical cyclone parameters presented in Table 4.4 for the stochastic and historical event catalogs.

Table 4.3. Number of Loss-Causing Simulated Events by Saffir-Simpson Category

Storm Category	Number of Storms
TS	31,340
1	31,308
2	14,340
3	9,667
4	3,952
5	863
Total	91,470

Table 4.4. Comparison of Historical and Simulated Values at First Landfall

Model Variable	Average of Historical TC Events (1951-2006)	Average of 10,000 Years of Model Simulations
Central Pressure	984 mb	986 mb
Radius Max Winds	26 km	26 km
Forward Speed	25 km/h	23 km/h

4.1.3 Stochastic Catalog of Non-Tropical Cyclone Induced Precipitation

4.1.3.1 Construction of Non-Tropical Cyclone Rainfall Climatology

Across the Philippines, non-tropical cyclone (NTC) rainfall, particularly that associated with the northeast and southwest monsoons, produces many significant rainfall events throughout the country. As a result, it is prudent to account for these types of events when modeling the precipitation hazard for the Philippines.

In order to generate a stochastic catalog of non-tropical cyclone rainfall, first a climatology of non-tropical cyclone rainfall must be constructed. Here, the Tropical Rainfall Measuring Mission (TRMM) multi satellite precipitation 3B42 product is used (Huffman et al 2007). This continuous, gridded dataset relies on both satellite-based precipitation radar as well as total microwave imagery to derive three hourly measurements of rainfall at 0.25 x 0.25 degree spatial resolution from 50N to 50S. Here TRMM measurements from the years of 2000 through 2007 are used for analysis. A more comprehensive treatment of the climatology can be implemented using general circulation models and regional climate models as carried out by AIR for various other regions of the world; however, the project scope of work and timeline necessitated a simpler approach using a stochastic weather generator with input from TRMM data. This aspect can be further improved in future studies.

Given that the geometric size of tropical cyclones ranges over an order of magnitude, yet their intensity measured by central pressure or wind speeds bears no perceptible relation to their size, it becomes problematic to use such atmospheric quantities to determine the spatial extent of a system's rain shield (Emanuel, 1991). Much work, like that of Merrill, 1984, has shown that the mean size of tropical cyclones in the Pacific is significantly larger than their counterparts over the Atlantic (mean radius of 4.4 degrees versus 3 degrees). To this point, research has shown that the 75th percentile of Northwest Pacific basin tropical storms have a radius of 5 degrees or approximately 550km.

As a result, to remove tropical cyclone induced rainfall, an approach that is common in the literature (e.g. Rodgers, et al 1999, Adler, 2000, Jiang and Zipser, 2010) is followed—a threshold distance based on best track data for tropical cyclones. That is, using the Japanese Meteorological Agency (JMA) best track data, all rainfall within 500km of a tropical system's center location is removed from the TRMM dataset. The JMA best track data is a collection of the location (central pressure's latitude and longitude) and other storm parameters for each tropical system in the Northwest Pacific basin at a 6 hourly time-scale from the 1950s to present. Given that the TRMM data is available at three hourly intervals, the JMA data was linearly interpolated to pinpoint the storm's location in the three hour intervals (i.e. 03Z, 09Z, 15Z, 21Z).

An example of the resulting non-tropical cyclone dataset is shown below in Figure 4.4. As can be seen, the methodology is able to successfully remove all rainfall caused by Typhoon Imbudo across the Philippines while leaving the NTC rainfall found near southern Vietnam untouched. Also shown are the satisfactory results of using a linear interpolation for the three hourly TRMM data at 03Z and 18Z.

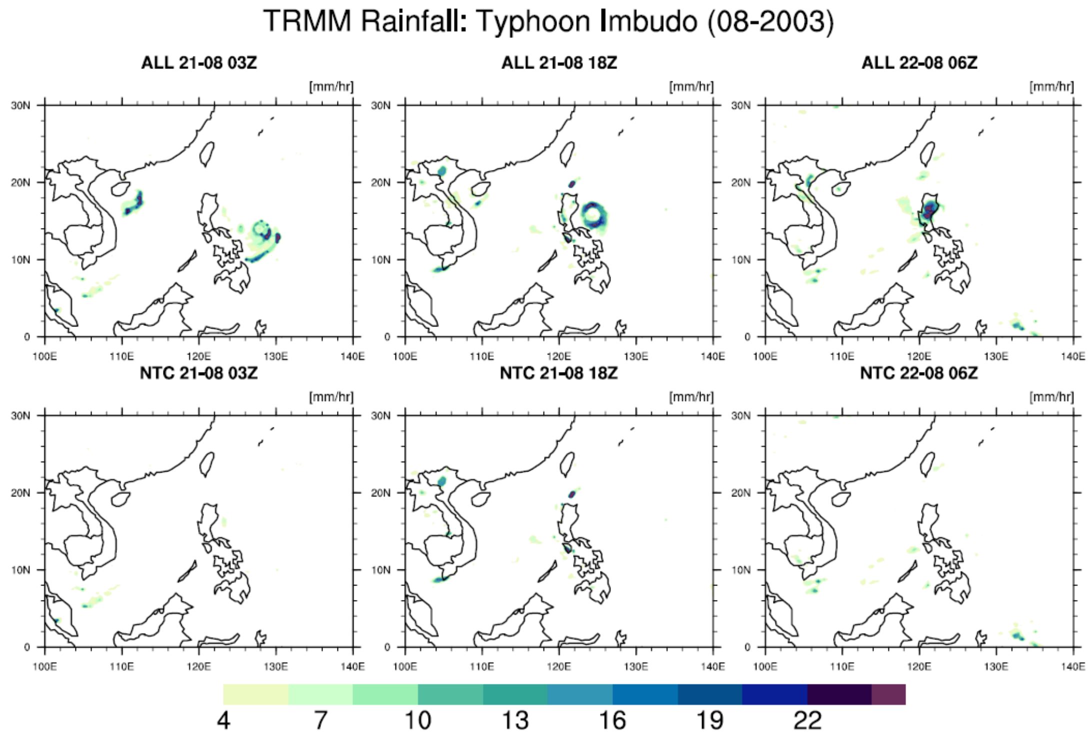

Figure 4.4. Example of Results from NTC Rainfall Climatology Construction: TRMM Rainfall Induced from Typhoon Imbudo (8-21-03Z to 8-22-06Z) Shown in the Top Row and the Corresponding NTC Related Rainfall in the Lower Row

The results of the NTC TRMM rainfall climatology for a sample year are shown in Figure 4.5. In 2003, an active tropical storm season set up just across the northern Philippines and Taiwan. As can be seen, the methodology is able to pick up this dominant active region where nearly 500-1500mm of rainfall during the year is caused by tropical activity. These results validate well with many studies that find nearly 35-50% of the annual rainfall across this region can be attributed to tropical cyclone rainfall (Jiang and Zipser, 2010). Given the large amount of rainfall in this region to begin with, this still leaves nearly 1000-2000mm of annual rainfall that is non-tropical cyclone induced—particularly across the southern region of the country which is outside the active tropical cyclone belt due to low Coriolis forces close to the equator. Therefore, accounting for NTC rainfall-induced precipitation becomes necessary across the entire region.

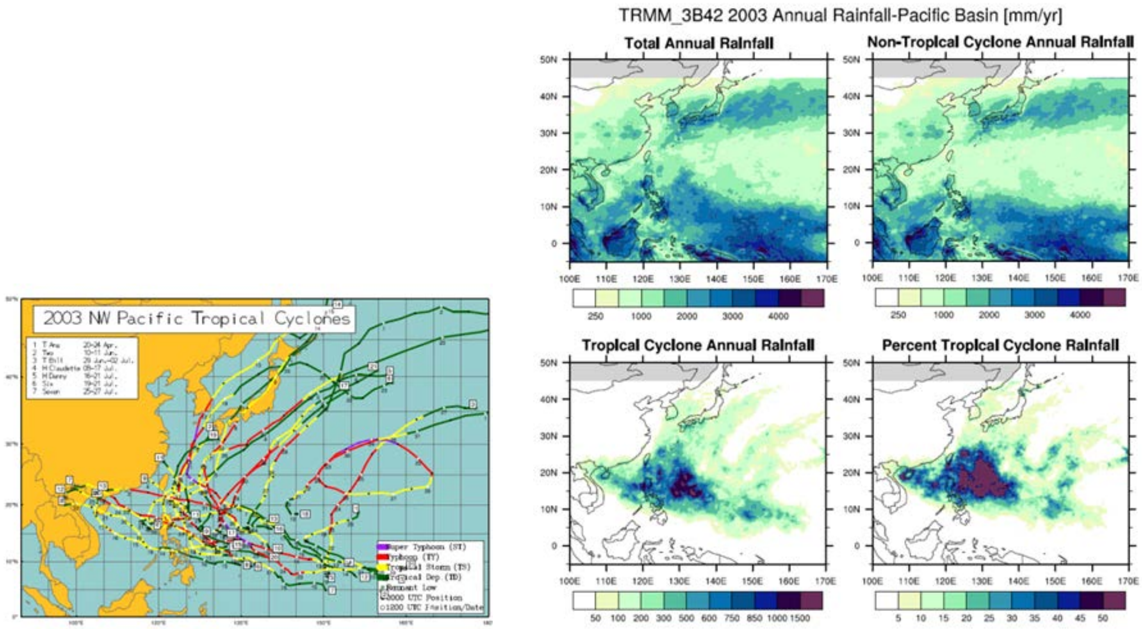

Figure 4.5. Tropical Cyclone Activity in the NW Pacific Basin for 2003 (Left) and (Moving Clockwise in the Right Figure) the Resulting Total TRMM Rainfall, NTC Rainfall, Tropical Cyclone Rainfall (mm/yr) and Percent Contribution of Tropical Cyclone Rainfall

4.1.3.2 Generation of Stochastic Catalog for Non-Tropical Cyclone Rainfall

A stochastic catalog of daily NTC rainfall for 10,000 years was developed based on the NTC rainfall climatology derived from the TRMM data discussed above. To do this, a stochastic weather generator is employed to construct synthetic precipitation data for the eighty three station sites corresponding to the centroid points of the Philippine postal code areas in the AIR Typhoon Model for Southeast Asia—the resolution at which all precipitation hazard, vulnerability, and losses are calculated within the model. Here, the grid-cell point value from TRMM is treated as the station site data for input into the stochastic weather generator. In general, stochastic weather generators use the statistics of weather station rainfall to construct synthetic, but physically real, time-series of rainfall at a site which preserve the basic statistics of the station. For this study, a more sophisticated stochastic weather generator, which also accounts for both temporal and spatial correlation across multiple stations, is used: Geospatial-temporal Weather Generator (GiST; Baigorria and Jones, 2010). GiST utilizes a two-step method that generates rainfall at multiple sites followed by rainfall amounts at sites where rainfall events occur. The first step, the generation of a rainfall event, is based on an orthogonal Markov chain for discrete distributions where the probability is based on whether rainfall is occurring at two stations close-by as well as if rainfall occurred in the preceding three days at the actual station. From here, a vector of random numbers (from a uniform distribution), of order equal to the number of locations with rainfall events for a given day, is matrix-multiplied by the corresponding factorized correlation matrix to create spatially correlated random numbers. These values are then transformed to a gamma distribution using cumulative probability functions for each site location and rescaled to rainfall amounts (see Baigorria and Jones, 2010). GiST was thoroughly tested over the southeast United States (another humid, tropical climate zone) and was found to have excellent success in replicating the climatic rainfall statistics while preserving spatial correlations between stations.

GiST was run for the Philippines to create 10,000 years of daily NTC rainfall. Figure 4.6 compares the GiST (stochastic) simulated annual rainfall to the TRMM (historical) record for NTC rainfall. In general, the stochastic catalog does well in representing the spatial distribution of rainfall with local peaks across the southeast (Mindanao) and northwest (Luzon) regions of the Philippines and local minima in the south central region of the Negros Islands (see Figure 4.6). Likewise, the model is able to capture the annual magnitudes of these regions as well, with most centroid points having an annual percent bias of less than 10%.

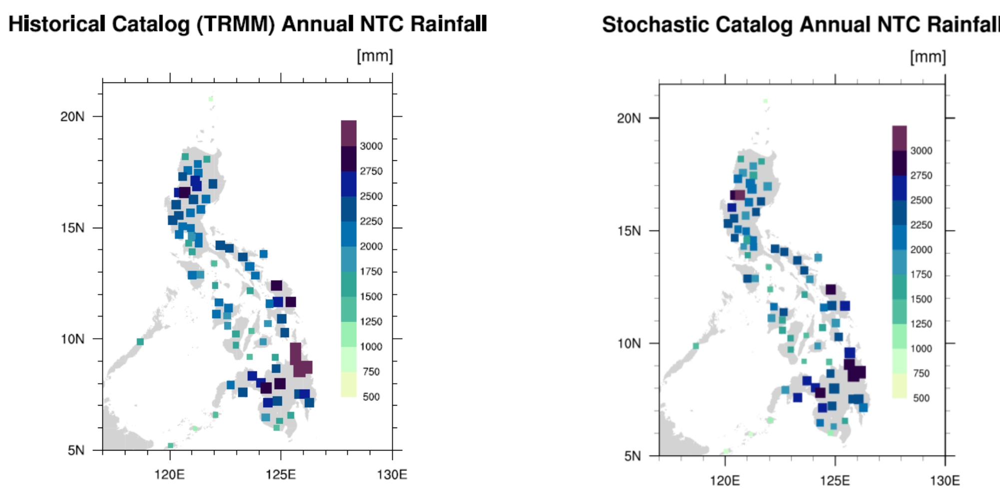

Figure 4.6. Comparison of Annual NTC Rainfall (mm) from TRMM Dataset (Left) to the Stochastically Generated Annual Rainfall for the 83 Postal Code Stations (Right)

Next, validation was performed on the daily timescale for each postal code in the model (Figure 4.7). Again, GiST is able to successfully capture the daily mean, standard deviation and coefficient of variation across stations and climate zones as the points are all clustered along the one-to-one line in the scatterplots. For example, rainfall in the south (warm colored stations) demonstrates less daily variability and lower total values than those stations in the north (cool colored stations) where rainfall is both highly variable and larger in magnitude (see Figure 4.7). For all three basic statistics, the correlation coefficient between the historical and stochastic catalog ranges from 0.87 to 0.94, suggesting a very strong linear relationship between the two datasets. Lastly, it is important to note that the GiST generated catalog is able to generate extreme rainfall events, that is, rainfall events that are within the top 10th percentile of the observed daily rainfall. To capture heavy precipitation events, it is imperative that a model is able to replicate these extreme values and the corresponding distribution; the stochastic catalog for NTC rainfall developed for this study is able to do both.

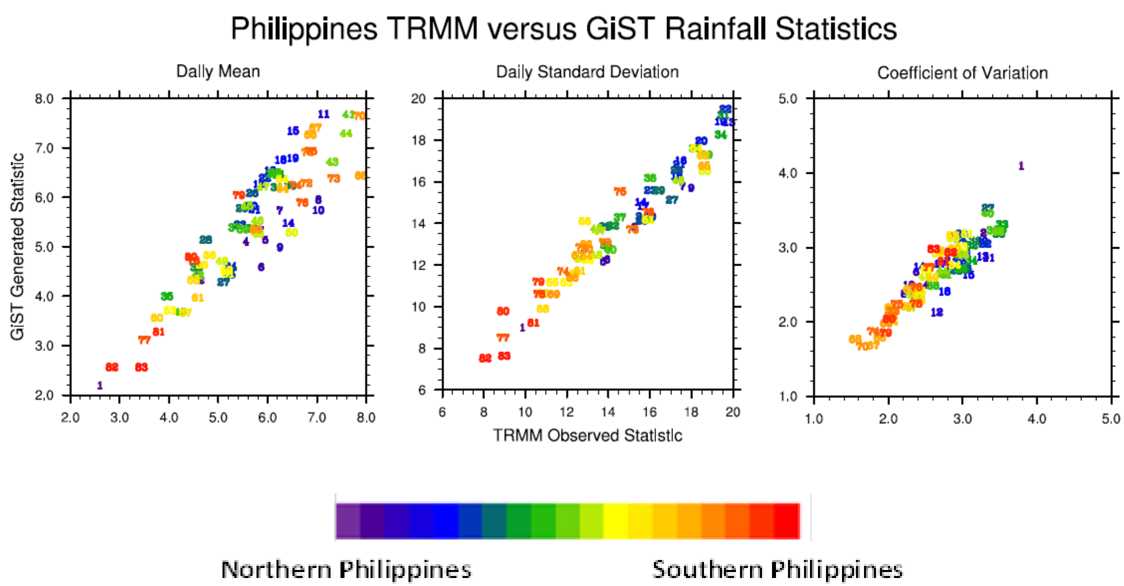

Figure 4.7. Scatterplot of Daily Mean, Standard Deviation, and Coefficient of Cariation for Rainfall in All Eighty-three Stations in Stochastic Event Generation versus Observed TRMM Data. Also Shown are Correlation Coefficients of the Best Fit Line

4.2 Intensity Calculation

After generating simulated events, mathematical models are used to estimate the intensity of these events in the affected region. Each peril produces an intensity measure that in turn can be associated with losses based on the estimated level of damage. The hazards considered in this analysis include earthquake ground shaking, tropical cyclone wind and precipitation, and non-tropical cyclone precipitation. The models that characterize these effects are developed using both empirical data and the underlying physics of each phenomenon.

4.2.1 Earthquake Ground Shaking

Empirical ground motion prediction equations, or GMPEs, are practical tools used to estimate ground-shaking intensity as a function of the magnitude, location, and rupture mechanism of an earthquake. These equations, which were more commonly called attenuation relationships in the past, describe the rate at which certain ground-motion parameters evolve as the seismic waves propagate outward from the rupture source. Typically, ground motion decreases due to geometric spreading and the absorption and scattering of energy as the waves travel through the earth. However, depending on the soil type present at a specific location, the ground motion may experience amplification as well.

The general form of the GMPEs used in the AIR Earthquake Model for Southeast Asia is as follows:

Sa = f (M, D, d, C, F, T)

where

Sa = spectral acceleration or peak ground acceleration (m/s2)

M = earthquake magnitude

D = distance from rupture plane (km)

d = focal depth (km)

C = site condition

F = faulting mechanism

T = period (inverse of frequency) (s)

The ground motion intensities which earthquakes generate in the region depend on the location of the rupture with respect to the site, the dynamic of the rupture, the traveling path of the waves from the source to the site, and the soil conditions at the site. Frequently for ground motion prediction equations, empirical data is extracted from recordings of past earthquakes of similar characteristics and supplemented by scientific and analytical simulations to provide insight into areas where data are scarce. Therefore, the ground motion prediction equations are developed under the generally tenable assumption that the attenuation of seismic waves in different regions of the world with the same tectonic setting is very similar. In the absence of regional data, it is customary to use ground motion prediction equations (GMPEs) based on data from other parts of the world as was done for this study. Two sets of GMPEs were used to predict shaking intensity to correctly represent the types of seismic activity present in the Philippines: one set for crustal earthquakes and another set for subduction type earthquakes.

As there currently are no published standard GMPEs for the Philippines, multiple GMPEs were reviewed as candidates for computing intensities generated by crustal earthquakes. Several Japanese GMPEs – specifically, equations developed by Fukushima and Tanaka (1990) and Torregosa et al. (2001) – have been proposed for use in the Philippines because they are based on regional ground motion recordings. Modern U.S. GMPEs (e.g. the Pacific Earthquake Engineering Research Center's Next Generation Attenuation - PEER NGA - equations) have also been used by previous researchers to assess local hazard within the Philippines due to certain tectonic similarities between the Philippines and the western US.

Ultimately, the PEER NGA GMPEs [Abrahamson & Silva (2008); Boore & Atkinson (2008); Campbell & Bozorgnia (2008); Chiou & Youngs (2008)] were selected to calculate earthquake intensity of ground shaking for crustal events. Although the Japanese GMPEs are considered regional, they are still not based on Philippine-specific recordings. The PEER NGA equations were developed more recently than the other candidate equations and are derived from a much larger global database of ground motion recordings. Further, the NGA GMPEs use the average shear wave velocity in the upper 30 meters of sediments, VS30, as a parameter for characterizing the effects of sediment stiffness on ground motions. Using VS30 in place of generic soil and rock categories differentiates shaking intensities between stiff and softer soils. Lastly, the PEER NGA equations can output spectral accelerations at different fundamental periods, whereas, the Japanese equations only compute peak ground acceleration (PGA). Converting PGA to spectral accelerations at different periods can introduce additional uncertainties in the process.

It can also be shown that the mean of the NGA equations does not differ significantly from the mean of the Japanese equations. A comparison between these two sets of GMPEs for earthquakes with M=7.0 is shown in Figure 4.8. The mean peak ground acceleration (PGA) is presented for the NGA GMPEs, as the AIR model uses the mean value of the four PEER NGA models. At short distances, the PGA for the mean NGA response is slightly less than the GMPEs by Fukushima and Tanaka (1990) and Torregosa et al. (2001). By approximately 10 km, the mean NGA response converges with the other two GMPE results, and by 100 km, it appears to represent an approximate average of the other two GMPE results.

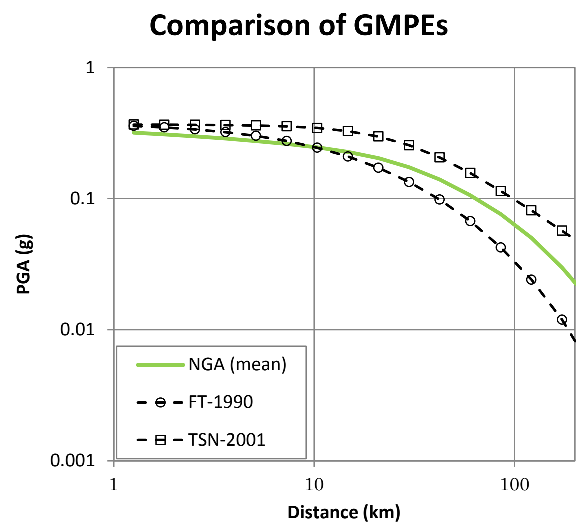

Figure 4.8. Comparison of GMPEs for Mw 7.0: Peak Ground Acceleration (PGA) versus Distance from the Source. [Fukushima and Tanaka (1990); Torregosa et al. (2001); (Mean) NGA is the Average PGA from Abrahamson & Silva (2008); Boore & Atkinson (2008); Campbell & Bozorgnia (2008); Chiou & Youngs (2008)

Several validation exercises were conducted to verify use of the NGA equations for the local ground shaking intensity computation. For example, Figure 4.9 presents a comparison of PGA generated with the AIR model and that from the USGS Shakemap Atlas for the Mw 7.7 July 16, 1990, Luzon earthquake. The colors on the maps represent PGA in units of %g; the highest PGA (greater than 40% g) is indicated by the red color centered about the epicenter of the earthquake event. The match between the colors on the USGS Shakemap Altas (Figure 4.9b) and the simulated mean PGA from the AIR model (Figure 4.9a) indicates that the value of the peak ground acceleration is close to the mean value predicted by the GMPEs. In general, the agreement is very good. However, note that, given the large uncertainty in the ground motions predicted by GMPEs for any given earthquake, some discrepancy between the predicted ground motion values is to be expected. Also, note that the USGS Shakemap is itself a modeled representation of the ground shaking footprint.

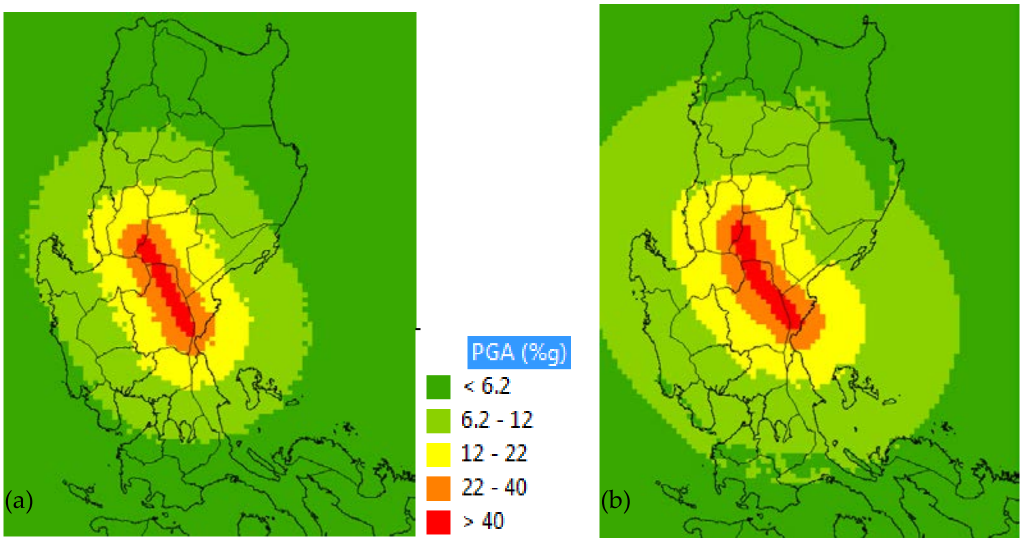

Figure 4.9. Comparison of simulated mean PGA (%g) for (a) Mean of PEER NGA GMPEs and (b) USGS Shakemap Atlas for the Mw 7.7 July 16, 1990, Luzon Earthquake

In addition to shallow crustal earthquakes, subduction zone earthquakes also occur in the Philippines and are included in the stochastic catalog. Attenuation relationships for interface and deep intra-slab subduction events differ from those used for shallow crustal events; however currently there are no published standard subduction GMPEs for the Philippines. As with the selection of shallow crustal GMPEs, attenuation equations derived for areas with similar faulting mechanisms are customarily used when regional data is unavailable. Therefore, the ground motion is calculated under the generally tenable assumption that the attenuation of seismic waves in different regions of the world with the same tectonic setting is similar. This means, for example, that large subduction zone earthquakes occurring in the regional Pacific trenches generate ground motion fields similar to those generated by events along the plate boundaries elsewhere in the world (e.g., Pacific Plate in Japan, Nazca Plate in South America, or the Cascadia region in North America). The following widely accepted GMPEs for subduction and deep earthquakes are applied herein:

- For large interface earthquakes on subduction zones
  - Youngs, R.R., et al., 1997
  - Atkinson, G.M. and Boore, D.M., 2003
  - Zhao, J.X., et al., 2006
- For deeper earthquakes on subduction zones:
  - Youngs, R.R., et al., 1997
  - Atkinson, G.M. and Boore, D.M., 2003

4.2.2 Tropical Cyclone-Induced Wind

The generation of the local wind field involves first computing the gradient wind at each model domain point as a function of central pressure, radius of maximum winds, latitude, distance from the storm center, and storm forward speed and direction—and then downscaling the gradient wind to the surface. In the current AIR tropical cyclone model for the Philippines, gradient wind speed as well as the gradient wind profile is calculated based on the formulation in the NOAA Technical Report NWS-23 (Schwerdt et al., 1979). Several phenomena are specifically considered in the Philippines tropical cyclone model, including asymmetry effects, topographical effects, surface friction effects, gust effects, and wind field directionality. A summary of these phenomena is provided herein.

Asymmetry Effects: In the Northern Hemisphere, tropical cyclone winds circulate in a counterclockwise direction around the storm center. The combined effects of tropical cyclone winds and forward motion (or translational speed) produce higher wind speeds on the right-hand side of the storm as viewed facing the forward direction

Topographical Effects: Wind speeds increase on the windward slopes of mountains, hills and escarpments because of amplification. Such features restrict the passage of wind causing a compression of the streamlines. Wind speed is inversely proportional to the spacing of the streamlines, or the area through which the wind must travel, so wind accelerates as it moves uphill.

The slope of the incline determines the degree of compression. Thus, the amplification effect is accentuated on steeper hills. In addition, if the angle of incline is sharp, wind flow separates because momentum near the ground is insufficient to overcome the pressure gradient at the top. A turbulent "separation bubble" sets up, which causes local vortices and high suction loads/stresses on buildings, increasing damageability.

The tropical cyclone model for the Philippines considers the high mountains that act to disrupt the primary surface circulation of tropical cyclones and decrease overall storm intensity. This modeled phenomenon is supported by research that suggests that the mountains in the Philippines can reduce average storm intensity by up to 33% (Brand and Blelloch, 1972 and 1974).

Surface Friction Effects on Wind Speeds: Smaller scale differences in surface terrain also affect wind speeds. Wind speeds are typically higher at higher elevations as illustrated in the velocity profile in Figure 4.10. Winds are slower at ground level because of the horizontal drag force of the earth's surface, or surface friction (Figure 4.10, left). The addition of obstacles, such as buildings, can reduce wind speed even further (Figure 4.10, right).

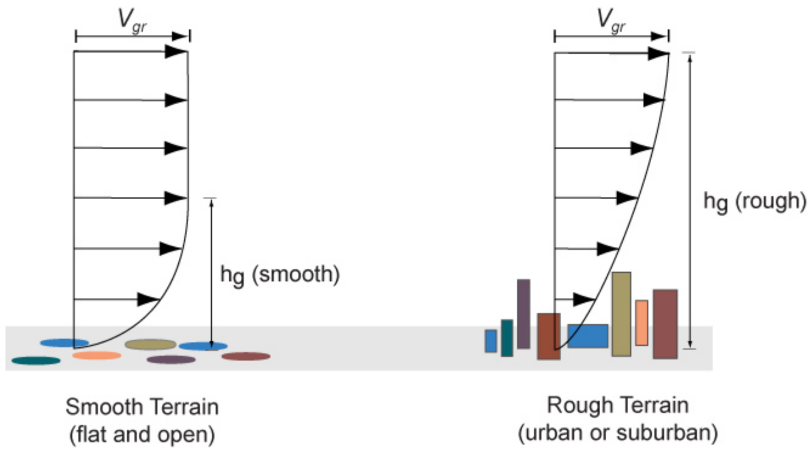

Figure 4.10. Terrain Effects on Wind Velocity Profiles where hg is the Height of the Wind Gradient and V_{gr} is the Gradient Wind Speed.

The model applies a friction coefficient at each location of interest to reflect estimates of surface roughness derived from digital land use/land cover data. The land use/land cover categories include built-up land (urban), agricultural land, forest, wetlands, and water. Each terrain type has a different "roughness value" that will lead to different frictional effects on wind speeds. In general, the rougher the terrain, the more quickly wind speeds dissipate.

Gust Effects on Surface Winds: Just as surface roughness exerts a frictional drag on the winds near the surface, so too can surface roughness enhance gust, which is a measure of how the wind speed near the surface varies as a function of time. These gusts range from very extreme ones that last only several seconds, to weaker ones that can last for several minutes. Typically, very rough surfaces increase gusts, while smooth surfaces are associated with lower gusts. The wind gust factor has a direct relationship with the level of gust - a higher gust factor indicates a higher ratio of gust to sustained speed, and vice versa.

Gusts are important to consider when modeling the destructive forces of tropical cyclone winds. For example, Figure 4.11 shows AIR's modeled accumulated wind field for Typhoon Joan (1970), one of the most destructive storms ever encountered in the Philippines. Sustained winds are estimated to have reached 280 km/h in the Lagonogy Gulf, where the storm made landfall. About 30 miles north, at the Loran U.S. Coast Guard station, sustained winds reached 170 km/h with gusts above 200 km/h. At the Ninoy Aquino International Airport, sustained winds reached 139 km/h with gusts as high as 155 km/h.

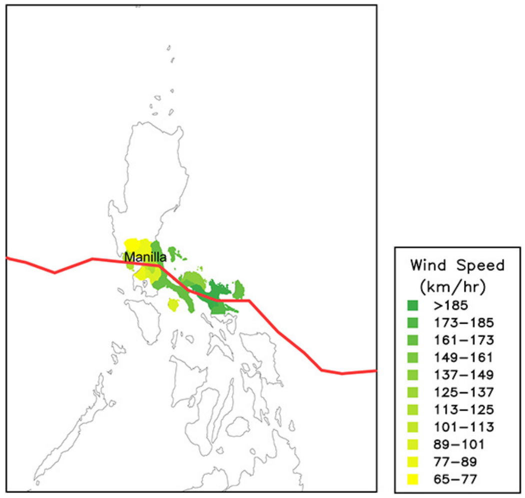

Figure 4.11. Storm Track (red line) and Modeled Wind Speeds for Typhoon Joan (1970)

Wind Field Directionality: The model explicitly includes directional effects of surface friction and gustiness on locally estimated wind speeds. The wind-field model employs land use/land cover data to estimate the roughness in eight wind directions: north, northeast, east, southeast, south, southwest, west, and northwest. The influence of the maritime environment on the wind is explicitly quantified, which yields a realistic wind field at the local level for the duration of the event.

Validation of the wind module for the Philippines is presented using four significant historical tropical cyclone events. A comparison of simulated and observed maximum ground wind speeds for each event is provided in Table 4.5, while the path and wind field for tropical cyclone Fengshen are provided in Figure 4.12. In general, the simulated wind speed intensities for the investigated events demonstrate good agreement with available observed data.

Table 4.5. Maximum Modeled and Observed Ground Wind Speeds (in km/h) for Four Historic Tropical Cyclone Events in the Philippines

TC Event Name (year)	Model	Observation
Joan (1970)	220	209
Angela (1995)	176	200
Durian (2006)	172	151
Fengshen (2008)	129	140

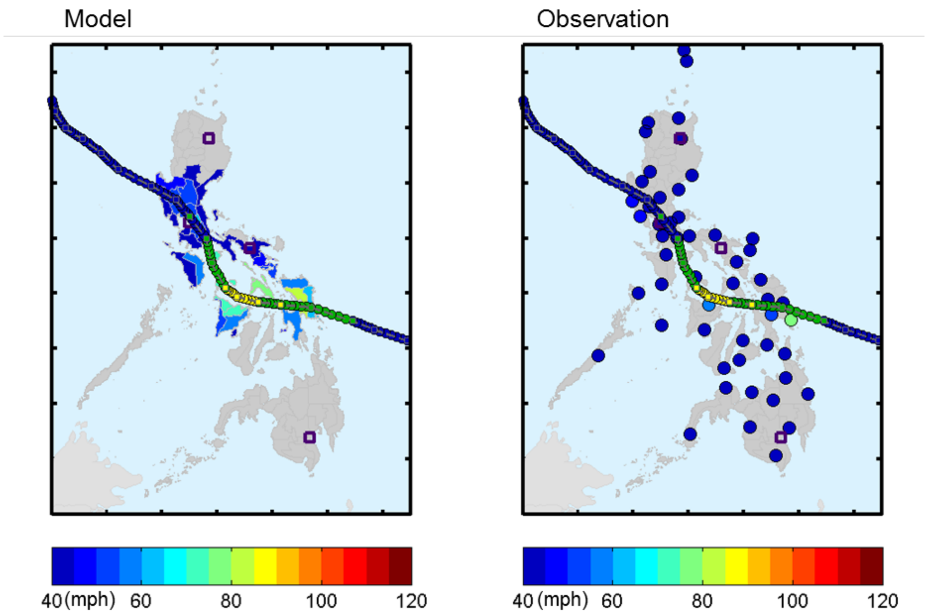

Figure 4.12. Comparison of Modeled and Observed Wind Speeds for Tropical Cyclone Fengshen (2008).

4.2.3 Tropical Cyclone-Induced Precipitation

Unlike tropical cyclone winds, which generally decrease as storms move inland, the intensity of storm-related precipitation can increase in inland regions. Consequently, significant economic losses from typhoons are not limited to the coastal regions.

As tropical cyclones approach the Philippines, the conceptual model of a circularly symmetric storm and its associated precipitation shield is typically valid. The precipitation intensity associated with the storm can change however. This evolution is spurred by several factors; particularly terrain, the storm's forward speed, South China Sea monsoon influences, and other approaching weather systems.

Coastal mountains enhance precipitation on the windward side, typically the east-facing parts of the Philippines. This enhancement occurs because air that is forced over the mountainous terrain cools in its ascent then forms clouds and precipitation (i.e., orographic effects). Northern Luzon is the most mountainous part of the Philippines and experiences, on average, the most tropical cyclones, making precipitation a serious concern in that region.

The annual South China Sea Monsoon can also enhance precipitation by driving tropical moisture north- and east-ward across the western Philippines in the summer. This moisture can feed and rejuvenate a tropical cyclone approaching the Philippines.

Figure 4.13 compares historical Tropical Rainfall Measuring Mission (TRMM) accumulated precipitation data with AIR's modeled accumulation from Typhoon Fengshen (2008). Both historic and modeled precipitation levels demonstrate heavy accumulation in the central Philippines, with over 400 mm observed across parts of Samar and Panay islands and with the Manila region experiencing over 225 mm.

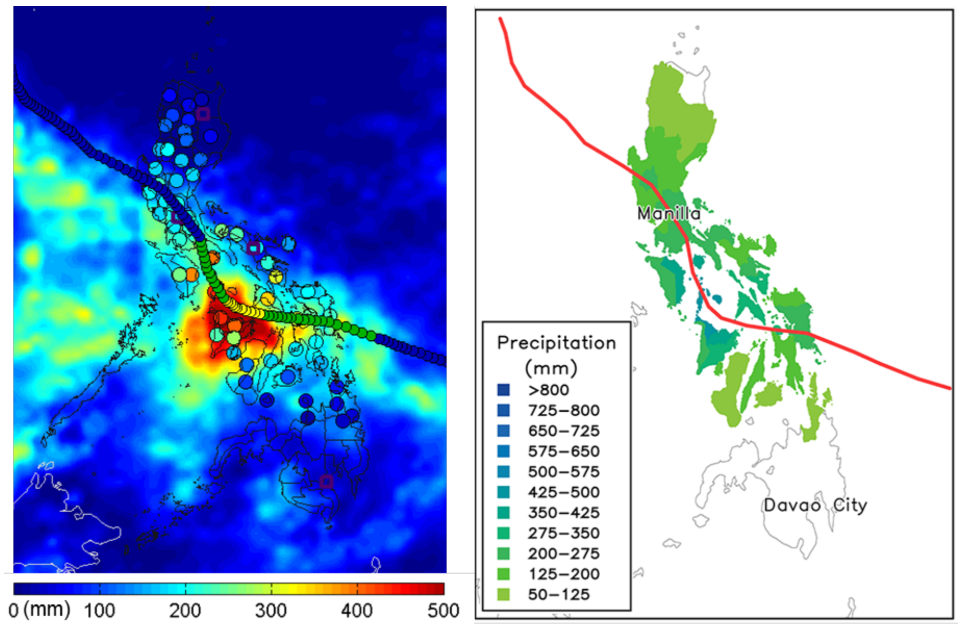

Figure 4.13. TRMM (left) and Modeled (right) Accumulated Precipitation from Typhoon Fengshen (2008).

4.2.4 Non-Tropical Cyclone Induced Precipitation

In this section, the process of determining which NTC storms trigger a damaging precipitation event is explained via the stochastically generated NTC rainfall of Section 4.1.3.

To accommodate the nontrivial nature of NTC rainfall, a "7-5-days clause" is used to determine the occurrence of an NTC precipitation event — a seven-day minimum total rainfall threshold (350 mm) and a five-day inter-storm period. The clause reflects the observed duration of extreme precipitation events associated with monsoon-like weather systems, and the 350 mm threshold value (which is close to the 7-day rainfall depth with return periods of 2–5 years across the Philippines according to a recent intergovernmental technical report, IHP-VII 2008) can represent the tipping point of a damaging event occurring.

In the AIR model, the rules for constituting storm and precipitation events are as follows:

- An event starts when a storm occurs anywhere within the country if at least 5 days have passed after the peak of the rainfall from the previous event;
- An event ends if the inter-storm period, the time period between the peak rainfall from the last storm (STi) and the beginning of the next storm (STj), is at least 5 days;
- If the inter-storm period is less than 5 days, but the time from the beginning of STi is more than 7 days, then the end of the event and the beginning of a new one is set up at the point of minimum precipitation between STi and STj;
- In contrast, if the inter-storm period is less than 5 days, and the time from the beginning of STi is also less than 7 days, then two (or more) events are considered to be a single event with multiple rainfall peaks. The end of such event is set up at the end of STj (or the very last event), implying that events can actually last longer than 7 days;
- The event is considered damaging if the cumulative rainfall during the storm period is at least 350 mm;
- If two events occur within different start dates but overlap in their 7-day (or actual duration) coverage, then they are considered one event, regardless of spatial location.

Figure 4.14 illustrates the event-composition process, using an example of three NTC precipitation events identified from precipitation series at three stations (Northern Samar, Masbate, and Western Samar) in the country. Black bars in the figure show the daily rainfall derived from the NTC TRMM data at the three stations. Pink columns indicate when the concatenation of two storms is triggered according to the clause rules; that is, the duration from the previous peak to the beginning of the next storm is less than 5 days. Cyan columns enclose events identified based on the 350 mm threshold value. If any of the events at different stations overlap in their temporal coverage, they belong to the same event, represented by dash boxes.

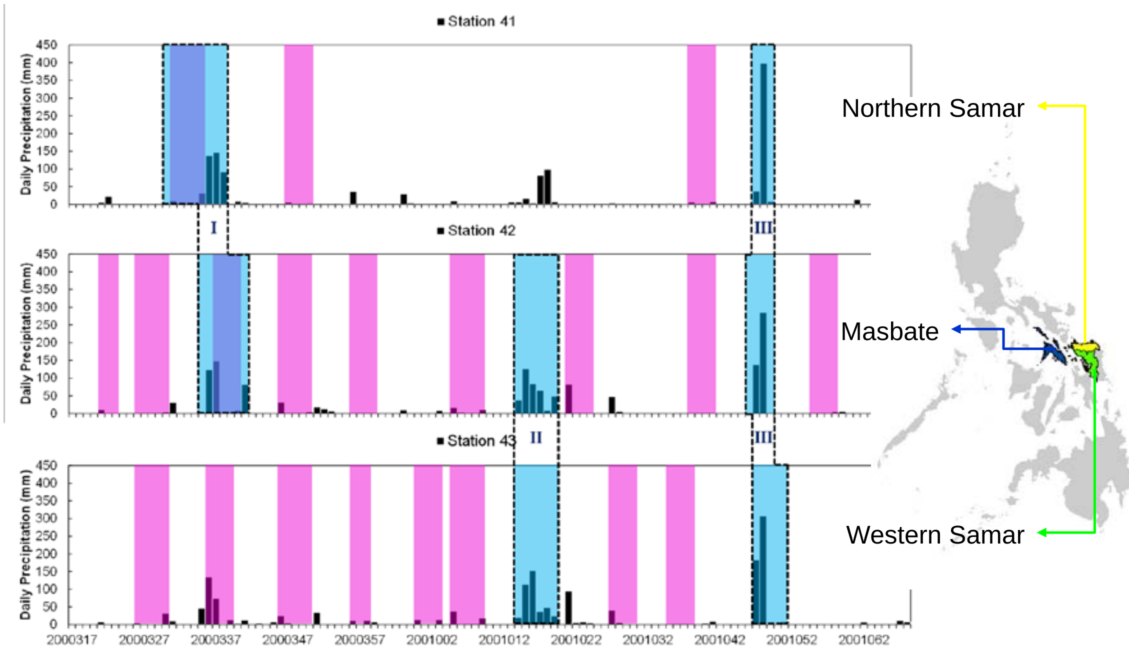

Figure 4.14. Composition of Precipitation Events for the 7-5-Days Clause. Black Bars are Daily NTC Rainfall, Pink Columns Represent the Concatenation of Two Storms, and Cyan Columns Indicate Events According to the Clause Rules

The 7-5-days clause is applied to both the NTC TRMM data and the stochastic catalog for the Philippines. To examine if the identified NTC flood events exhibit a realistic frequency of occurrence, the Consequence Database developed in Component 1, which consists of a list of significant loss-causing historical events, is compared to the event definition applied to the historical (TRMM) rainfall catalog. Multiple filters (e.g., no named storms and no tropical cyclone related annotations) are first used to identify the reported NTC precipitation events in the Consequence Database, and the total number of such events is derived for each year from 2000 to 2007. The annual frequency of NTC precipitation events based on the Consequence Database is plotted against that derived from the NTC TRMM data in Figure 4.15, which shows that the inter-annual variation of both data bears high resemblance.

The frequency of NTC precipitation event occurrences can also be examined at different stations over the Philippines. The total number of NTC event occurrences at each station is classified into three occurrence rates (high, middle, and low) based on the quartile information of the whole country, and the occurrence rates at all 83 stations for both the NTC TRMM data and the stochastic catalog can be plotted as shown in Figure 4.16). The results from this comparison indicate similar areas prone to NTC precipitation events in the historical and stochastic catalog — along a spine transecting from the northwest to the southeast portion of the country.

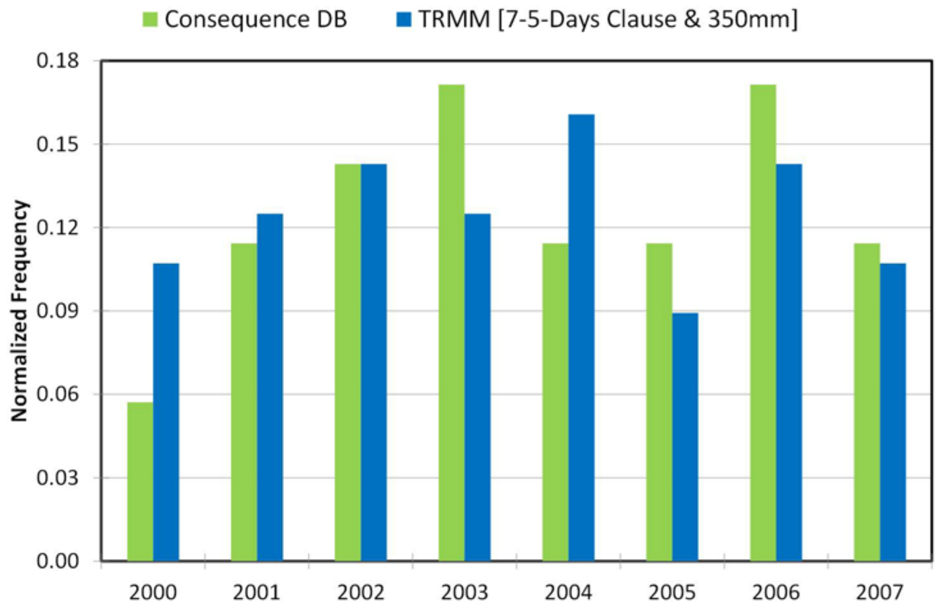

Figure 4.15. Comparison between Consequence Database and TRMM-based NTC Precipitation Event Occurrence by Year

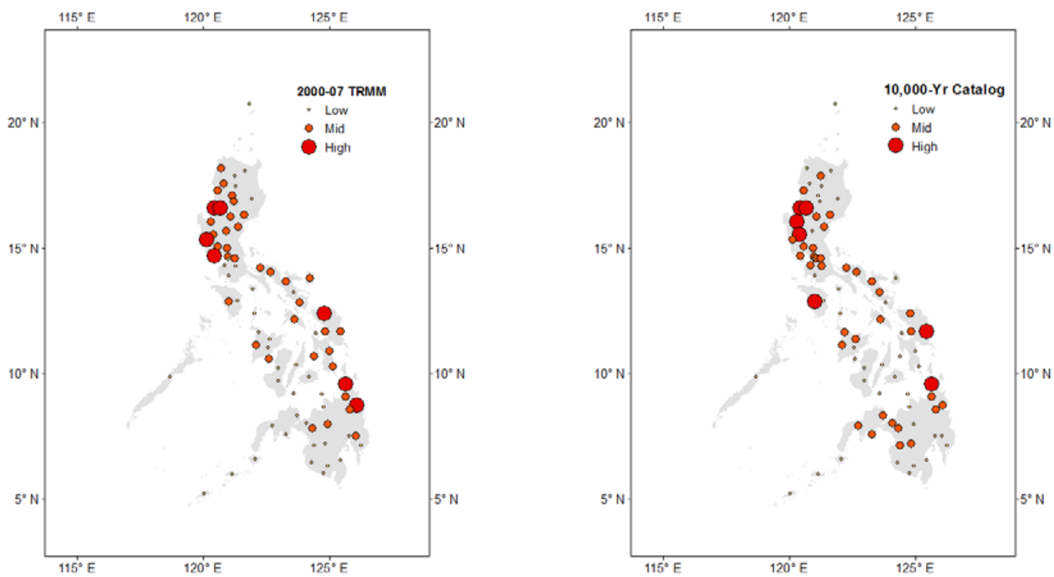

Figure 4.16. Comparison between the NTC Precipitation Event Occurrence Frequency of the NTC TRMM Data and that of the Stochastic Catalog

4.3 Probabilistic Hazard Maps

The stochastic event catalogs and local intensity computation methods described in the preceding sections can be used to develop probabilistic seismic, tropical cyclone wind and non-tropical cyclone precipitation hazard maps. A hazard map provides the estimated value of an intensity measure that is expected to be observed or exceeded at least once in a time period of interest for a given location. Here, intensity is measured in terms of horizontal peak ground acceleration (PGA) for earthquake ground shaking, and maximum 1-minute sustained wind speed for tropical cyclones.

Figure 4.17 to Figure 4.20 show examples of probabilistic hazard maps for the Philippines. For earthquakes, hazard maps that consider soil conditions are plotted for the 72- and 475 mean return period (MRP)[6]. Figure 4.18, for example, shows that peak ground accelerations of 0.5g or greater are expected to be exceeded at least once in the next 475 years in the southeastern portions of the Philippines.

The tropical cyclone wind hazard maps are presented for the 100- and 500-year MRPs. For instance, Figure 4.20 shows that 1-minute sustained wind speeds greater than 190 km/h are expected to be exceeded at least once in the next 500 years in the central eastern provinces of the Philippines.

Maps are not generated for non-tropical precipitation because the model is intended to work as a single module and calibrated on the overall loss results. That is, since accumulated precipitation is used as an index that is directly related to loss and population impact, there is not much insight to be gleaned from intermediate results produced by the hazard computation.

[6] The mean return period (MRP) is defined as the time period over which, on average, a particular hazard intensity or loss value can be expected to occur or be exceeded. The inverse of the mean return period is the annual probability of exceedance, i.e., the probability that the particular hazard intensity or loss value will be exceeded in the next year.

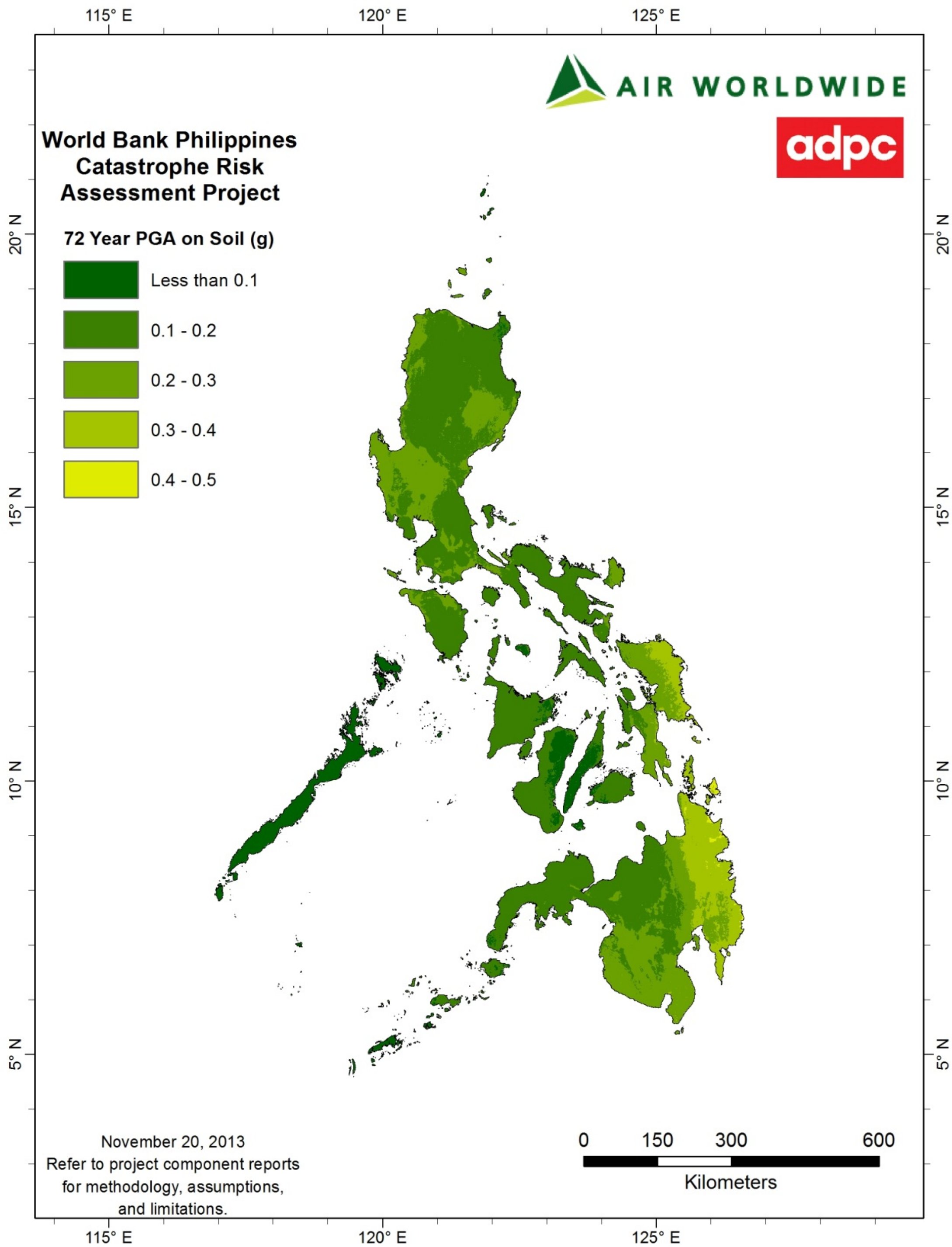

Figure 4.17. Seismic Hazard Map: 72-year MRP PGA on Soil

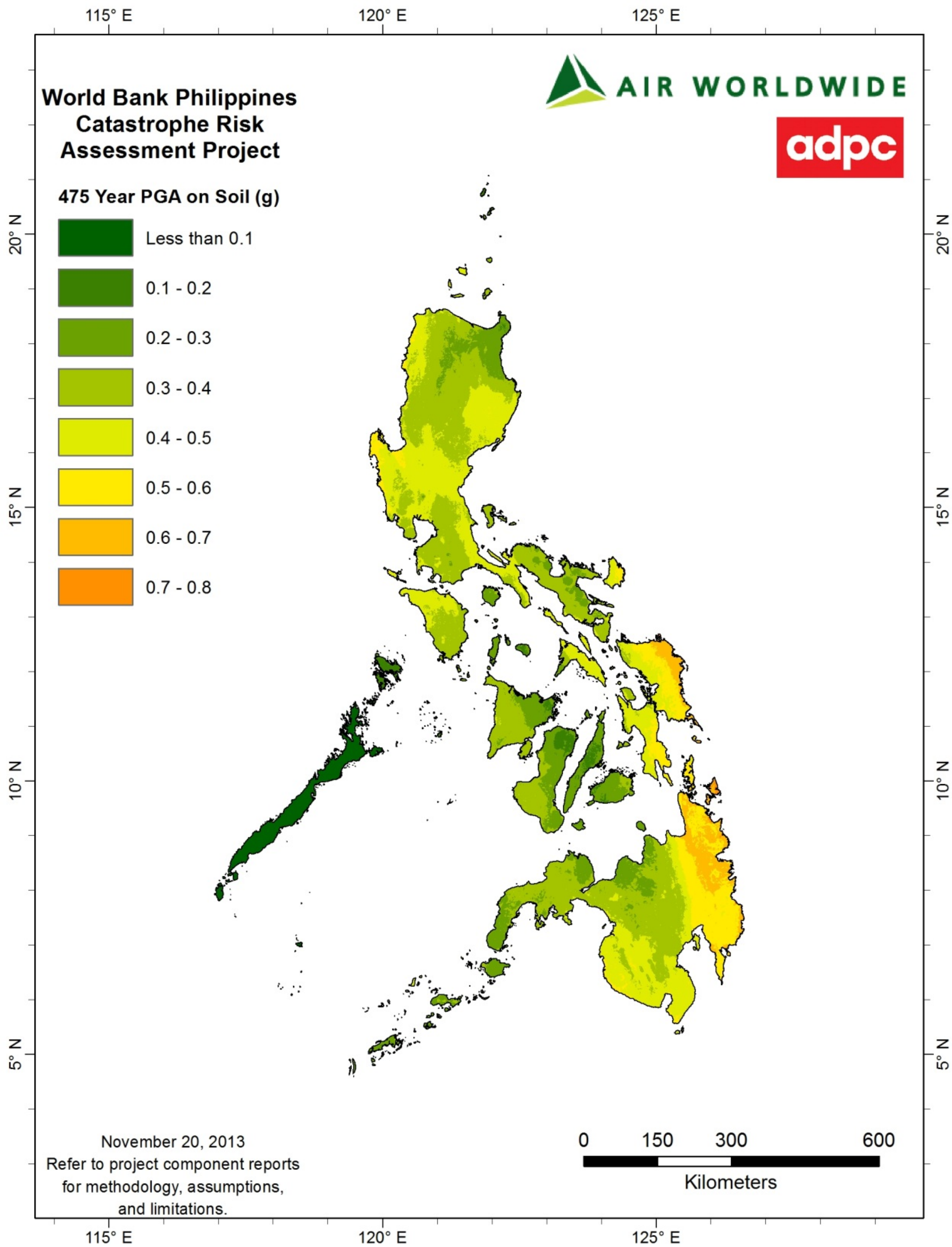

Figure 4.18. Seismic Hazard Map: 475-year MRP PGA on Soil

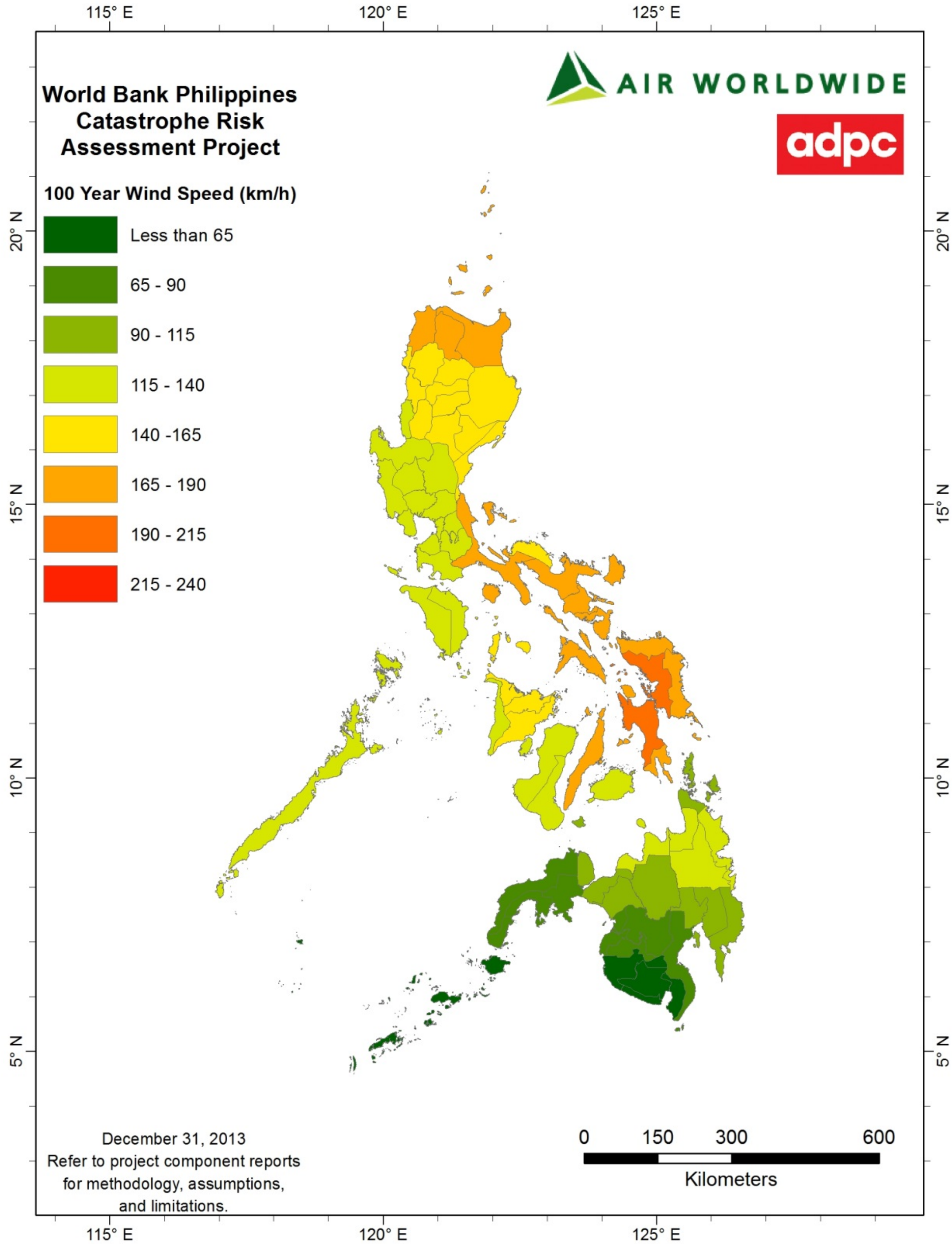

Figure 4.19. Tropical Cyclone Hazard Map: 100-year MRP Maximum 1-Minute Sustained Wind Speed

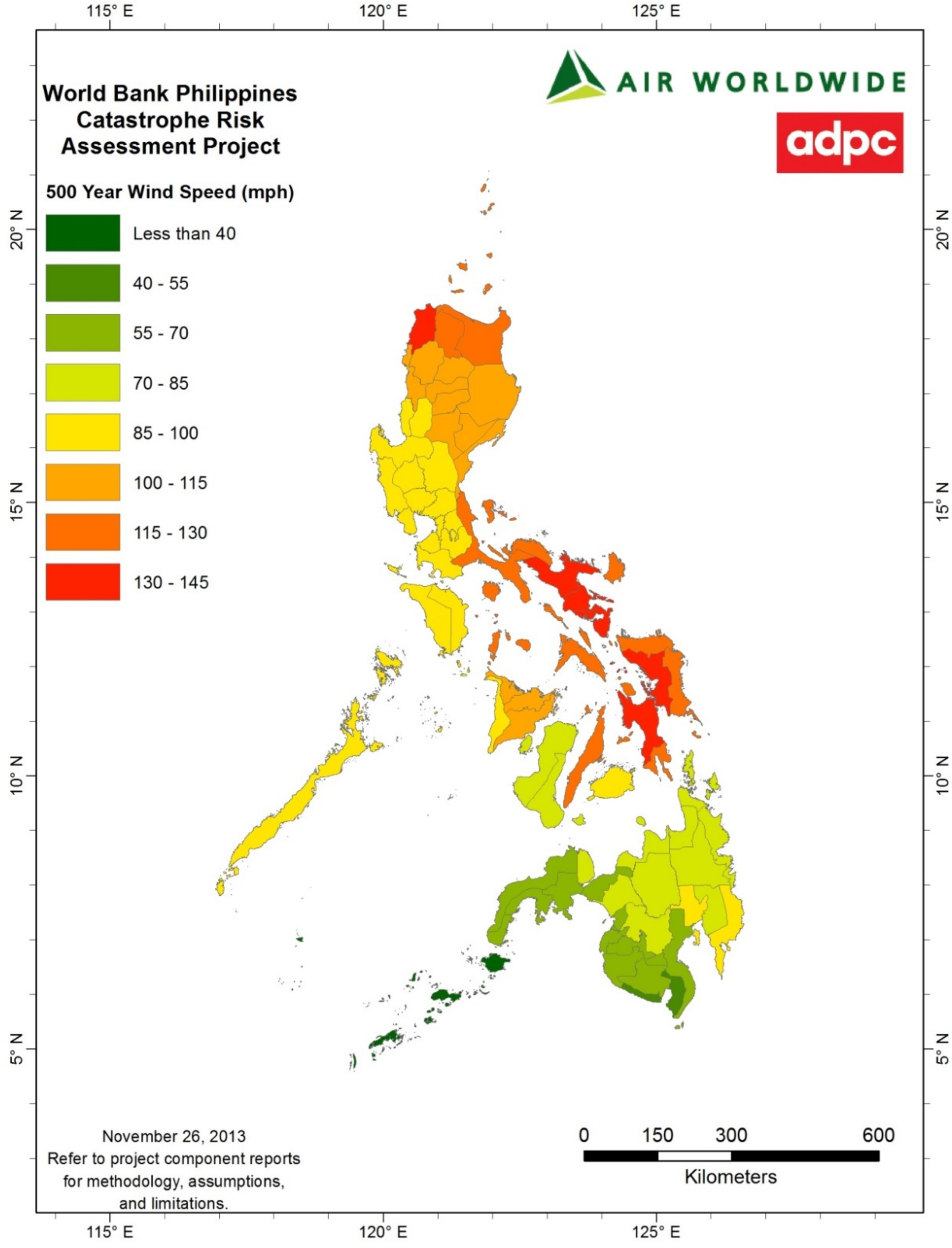

Figure 4.20. Tropical Cyclone Hazard Map: 500-year MRP Maximum 1-Minute Sustained Wind Speed

5 Damage and Loss Estimation

The damage estimation module determines the potential physical and societal damage given the information generated in the Hazard and Exposure modules discussed in the previous sections. This task requires knowledge of the vulnerability of occupied structures to wind, flood or ground shaking hazards.

For this purpose, all of the assets in the exposure database have been categorized into various *vulnerability classes*. Vulnerability classes are defined based on physical characteristics governing the assets' vulnerability with respect to natural catastrophe events. The main characteristics that influence vulnerability, and hence used for defining vulnerability classes, are type of construction (based on construction material and structural system), type of occupancy or functionality of the structure, height of the structure, and year of construction (for the peril of earthquake ground shaking only).

The vulnerability of an asset to a natural hazard is represented using a *damage function* which is a relationship between the expected damage and the severity of the natural catastrophe event. The damage is usually calculated as the ratio between the monetary loss and the total replacement cost of the asset. The severity of an event is represented by intensity measures such as ground acceleration for earthquakes, accumulated precipitation for flooding, or 1-min sustained wind speed for tropical cyclones. For example, in the damage function shown in Figure 5.1, a 100 mph wind is expected to cause a mean loss of 20% of the total replacement cost of the asset. The damage functions for different vulnerability classes are derived from engineering analyses, current literature research, and available damage data; they are validated using damage and loss data from past events in the region. A detailed discussion of the damage functions developed for the different vulnerability classes of exposure assets is provided in the Component 2 report.

In addition to deriving vulnerability relationships that link the intensity of an event to the damage sustained by an asset, models are also developed to estimate the number of casualties (i.e., fatalities and injuries) caused by each type of event. The earthquake ground-shaking casualty model estimates casualties as a function of the shaking intensity and the number of people exposed to such intensities. The tropical cyclone and non-tropical cyclone precipitation casualty model predicts the number of casualties as a function of the total event economic losses, which are used as a proxy for the number of damaged buildings.

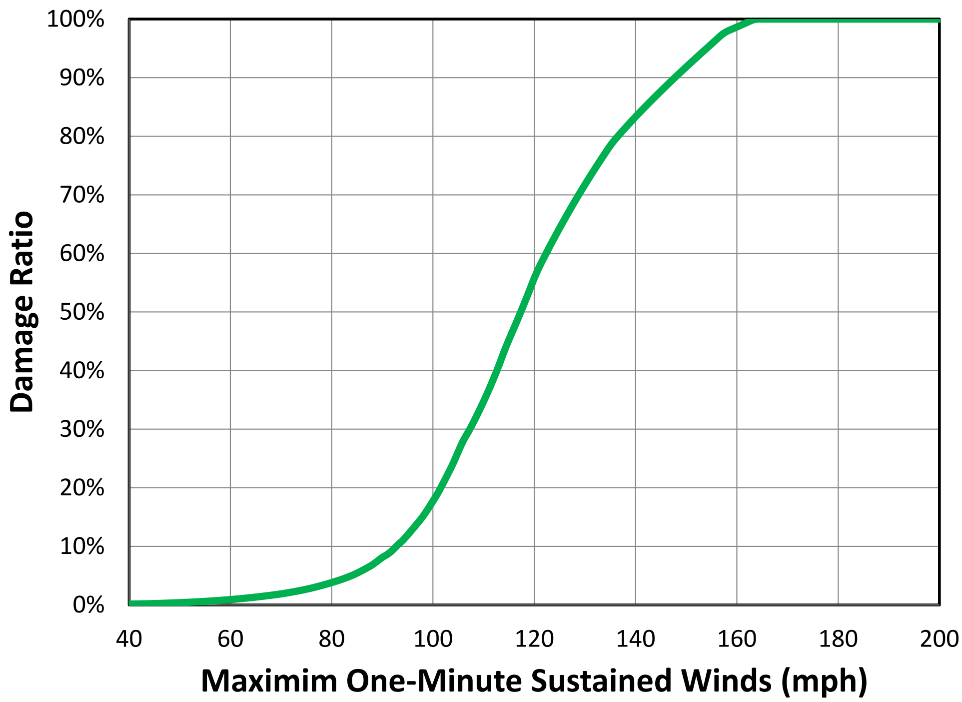

Figure 5.1. Relationship between Wind Speed and Expected Level of Loss in a Building

6 Casualty Estimation

In addition to developing damage functions that relate the intensity of an event to economic losses, relationships were developed to estimate the number of fatalities and injuries (casualties) for each simulated event. In general, estimating the number of human casualties from disasters with reasonable accuracy is considerably more difficult than estimating economic losses. In addition to the severity of the event and its proximity to population, the number of casualties is often dependent on several aspects, such as human behavior, time of the event, efficiency of communication to the affected population (e.g., early warning of tropical cyclone or flood), the occurrence of non-modeled effects (e.g., landslides, fire following earthquakes, etc.), and/or the destruction of critical assets (e.g., hospitals, dams, lifelines). These aspects are often unrelated to the severity of the event and are generally episodic, making them difficult to predict. For example, an earthquake that occurs at night time may cause more casualties since more people are in buildings and are not as alert as in the day time. Likewise, the total number of casualties for a typhoon could be much less if the storm is well forecasted and the affected area is evacuated.

Nevertheless, two casualty models have been developed – one for earthquake ground shaking and one for tropical cyclone and non-tropical cyclone induced precipitation. These models are primarily empirical and rely mostly on historical data in the region (such as data compiled in the consequence database developed specifically for this project). For simplicity, the earthquake casualty model assumes that all of the population resides in residential dwellings at the time of the event. Furthermore, the tropical cyclone and non-tropical cyclone induced precipitation casualty model is not explicitly dependent on human decisions.

The earthquake fatality model is based primarily on USGS's PAGER system (Wald et. al., 2010), which uses empirical methods to estimate fatalities as a function of the shaking intensity and the number of people exposed to such intensities. The PAGER system prescribes empirical parameters that are specific to the Philippines; these parameters are also adopted for this project. At the location of each residential dwelling simulated in the industry exposure database (IED), the fatality rate is estimated as a function of the ground shaking intensity at that location (measured in terms of PGA from the earthquake model). An average of 4.25 people per residential dwelling is assumed. Figure 6.1 shows the simulated number of fatalities compared to reported numbers for some recent significant historical earthquake events, if they were to occur in 2013. The reported numbers reflect the estimated range of fatalities as reported by the various agencies, and are trended to the year 2013 using the methodology outlined in the Component 1 report. Events older than 20 years, such as the 1990 Luzon Earthquake, are not presented herein since there is very high uncertainly in trending the exposed assets and population at risk for older events.

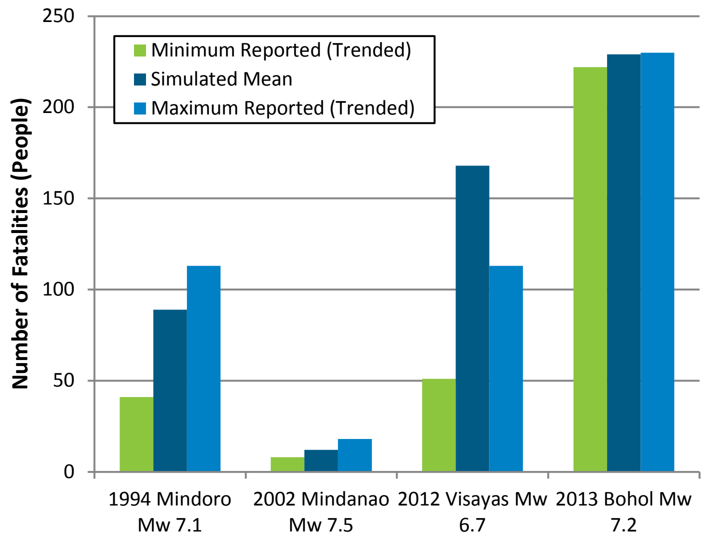

Figure 6.1. Comparison of Simulated and Reported Fatalities for Recent Significant Historical Earthquakes

A casualty model for the tropical cyclone and non-tropical cyclone induced precipitation perils was also developed specifically for this project. Estimating casualties from tropical cyclones and floods is extremely complex and very limited information on such models is available in the literature. As such, the casualty model developed for this study is strictly empirical and is based on reported data of historical events in the Philippines. The model estimates the number of fatalities as a function of the total economic losses, which is used as a proxy of the damage to the built environment. The model assumes an average fatality rate, which is derived primarily from fitting a linear regression trend-line through the estimates of trended economic losses versus lives lost for historical tropical cyclone and flood events from 1993 to 2013 (see Figure 6.2). Mainly due to the similarity of the hazards (both perils include precipitation effects, which is typically the major contributor to fatalities for weather-related hazards in the region) and limitations in the historical data, a single casualty model was developed for both perils. Upon review, the available data did not indicate a significant peril-specific bias for the casualty model selected for both tropical cyclone and NTC induced precipitation. Figure 6.3 shows the simulated number of fatalities compared to reported numbers for recent significant tropical cyclones events, if they were to occur in 2013. Similarly, Figure 6.4 shows the simulated number of fatalities compared to reported numbers for recent significant flood events, if they were to occur in 2013. Note that the figures indicate that the model underestimates fatalities for some events, notably 2011 TC Washi, 2012 TC Bopha, and the December 2003 floods. However, a closer inspection of these events reveals a significant amount of fatalities were reported due to non-modeled secondary hazards, such as landslides and riverine flash-flooding.

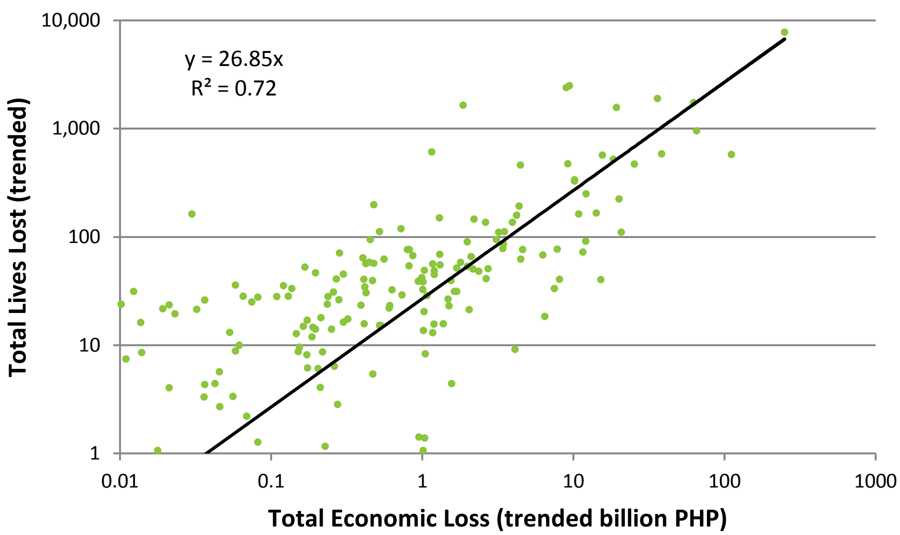

Figure 6.2. Reported Economic Losses versus Lives Lost for Historical Tropical Cyclones and Floods in the Philippines from 1993 to 2013

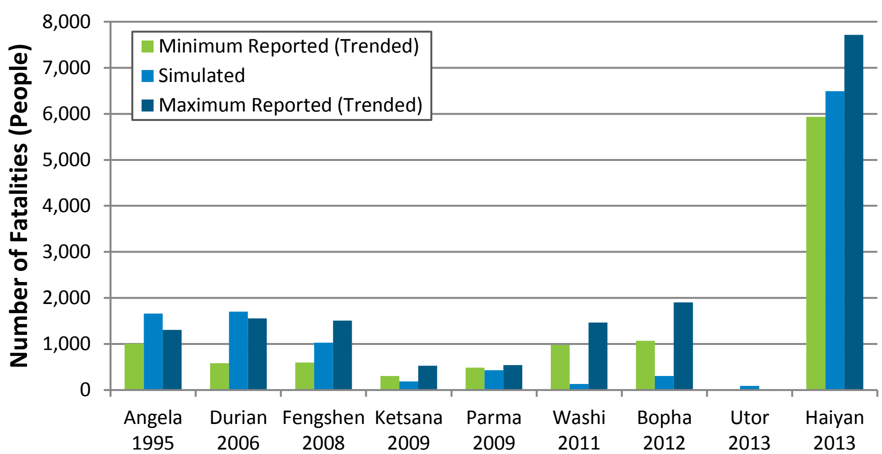

Figure 6.3. Comparison of Simulated and Reported Fatalities for Recent Significant Historical Tropical Cyclones

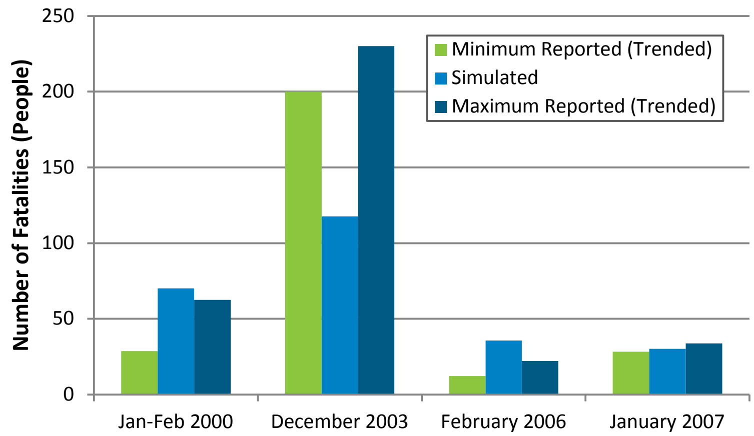

Figure 6.4. Comparison of Simulated and Reported Fatalities for Recent Significant Historical Flood Events

Estimating injuries is even more of a challenging exercise than estimating fatalities, mainly due to lack of data. Most casualty models available in the literature do not provide methods to estimate the number of injuries. Injuries caused by historic events are not as well reported as fatalities, and therefore provide a less robust empirical basis to support a model. Nevertheless, empirical injury models were developed specifically for this project. These models assume that the number of injuries per event is proportional to the number of fatalities. These relationships are derived from historical data in the region, and are peril-specific. For earthquake, a tri-linear relationship is used, and assumes that roughly eight people are injured for every one fatality for large events. For tropical cyclone and NTC induced precipitation, it is assumed that, on average, four people are injured for every one fatality.

7 Casualty and Loss Results

The modules of the AIR catastrophe risk modeling methodology described in the preceding sections are combined to compute the likelihood of various levels of casualties and losses due to earthquake ground shaking, tropical cyclones (wind and precipitation) and non-tropical cyclone (NTC) precipitation. For each of the events in the stochastic catalogs, the hazard module computes the intensities of ground motion due to earthquakes, wind speed and precipitation due to tropical cyclones, and precipitation due to non-tropical cyclone weather systems. The model also accounts for the uncertainty in the intensity computation for each event of a given magnitude. The hazard intensity values are computed for all assets in the exposure database. Then for every event, the vulnerability module calculates the mean damage ratio and loss for every asset. Further, population impact is calculated by the casualty models based on the methodology summarized in Section 6.

The results from this extensive simulation are then used to develop the probabilistic catastrophe risk profile for the Philippines. The risk profile expresses the likelihood that adverse consequences due to natural hazard events of different severities will occur within a certain time frame (for example, in the next year or in the next 50 years). The adverse consequences are measured in terms of economic losses to buildings and by the number of casualties in the affected area.

This section presents a summary of the loss results for the earthquake, tropical cyclone (wind and precipitation) and non-tropical cyclone precipitation perils separately, as well as for the combination of these perils. The results are presented in a variety of formats to facilitate their understanding. Specifically:

- The loss values are presented by peril and for all perils combined.
- Loss estimates are reported for the total country exposure, as well as a disaggregation of the same by private property only and government only assets.
- Results for emergency loss estimates for the Philippines by peril and for all perils combined are also included.

- Average annual loss estimates (AAL)[7] are reported for the total country exposure and are also shown disaggregated by province. These results are useful in identifying the primary risk driving provinces in the Philippines. AAL values are listed by peril and also by exposure type.
- Government asset AAL distribution by government sector is provided.
- All results are reported in terms of absolute loss values.

The results are presented in the following formats:

- Loss exceedance probability (EP) curves (bar charts) showing mean loss estimates at particular mean return periods (MRP). The data is also tabulated to facilitate its use.
- Average annual loss pie charts.
- Maps of the geographic distribution of the AAL estimates.

Other characteristics of the results presented in this section are as follows:

- "Ground-up" loss estimates are provided, i.e., insurance policy conditions, deductibles, etc. are not included in the analysis.
- The loss results are based on building damage only; contents and business interruption loss potentials are not included.
- Damage from earthquake ground shaking, wind and precipitation due to tropical cyclones, and non-tropical cyclone precipitation is considered. Other effects, such as liquefaction, landslides, sprinkler leakage and fire-following earthquake, and storm surge are not explicitly modeled.
- The results do not include Demand Surge, i.e. an increase in demand for construction materials and labor following a sufficiently large catastrophic event, which can temporarily inflate repair prices and thus increase potential losses.
- All results are annual aggregates, i.e., if multiple events occur in any particular year the aggregate loss from the multiple events is considered as the loss for the particular year. To avoid confusion, occurrence losses (as opposed to aggregate losses), i.e., the maximum value of the loss for all given events in any particular year, are included in Appendix A of this report.
- Loss estimates are provided in 2012 PHP (Philippine pesos).

[7] Average Annual Loss (AAL) is a long-term measure of loss that, on average, can be expected to be experienced annually. For instance, if the loss profile for a portfolio over five years is $10M, $0M, $0M, $0M, and $20M, then the average annual loss is the average of the five annual loss values or $6M. The average annual loss is computed by summing all the aggregate loss estimates for each year from the events in the stochastic catalog and dividing the total by the number of years in the catalog. The AAL is a commonly used metric for purposes of insurance premium computations. When normalized to the exposure value it returns a normalized loss-cost that can be used for relative risk evaluation between provinces, regions, and also between different hazards.

These various views of the risk can be useful in identifying and developing the optimal disaster risk mitigation strategies, whether in the form of physical mitigation of the risk or financial mitigation of the risk.

The results included in this section reflect both the cost to repair or replace the damaged assets, and the emergency losses that the government may sustain as a result of providing necessary relief and undertaking recovery efforts. Such efforts include debris removal, setting up shelters for those made homeless, or supplying medicine and food. In this study, emergency losses have been estimated as a fraction of the direct losses. Research on historical tropical cyclones and earthquakes (Bitran, 2003a and b) has revealed that an "average" estimate of the emergency losses, as a percentage of the direct losses suffered by residential dwellings, commercial establishments, public buildings, schools, and hospitals, is about 16% for earthquake ground shaking and 23% for tropical cyclones and flood. This approach has been applied for the computation of emergency losses in this study.

7.1 Loss Results for Earthquakes

Figure 7.1 presents the mean aggregate earthquake loss exceedance probability (EP) curve for the total building exposure in the Philippines (24,800 B PHP) at selected mean return periods. The figure also shows the loss EP curve disaggregated by exposure type (i.e., private property only and government assets only). The results presented in Figure 7.1 are also reported in Table 7.1. For example, at a mean return period of 100 years, the total country-level earthquake mean loss is estimated to be 1,047 billion PHP. This means that there is a 1.0% chance that a loss of 1,047 billion PHP or greater will be sustained in the next year. Losses at other mean return periods can similarly be read and interpreted from Figure 7.1and Table 7.1. The country-level earthquake losses are driven by losses to private property. This is primarily due to the private property assets' high proportion of the total country exposure replacement value. Additionally, the government assets are typically less vulnerable than private property. For instance, government buildings are usually expected to be better constructed and contain a large proportion of assets with low seismic vulnerability such as roads. On the other hand, a higher percentage of the private property assets exhibit relatively higher vulnerability (e.g., residential buildings are not subject to stringent design standards and quality control).

Figure 7.2 shows the mean aggregate earthquake EP curves for government asset only losses, emergency losses (computed as a percentage of the direct country-level earthquake losses), as well as the combination of the two. These results are also included in Table 7.1. For example, at a mean return period of 100 years, the government asset only mean loss is estimated to be 76 billion PHP, while the estimated values of the emergency losses and the combination of government asset losses and emergency losses are 168 and 228 billion PHP, respectively (note, that due to the methodology for computation of mean losses associated with various return periods, the sum of the government asset only losses and emergency losses does not necessarily need to equal the independently calculated combination loss).

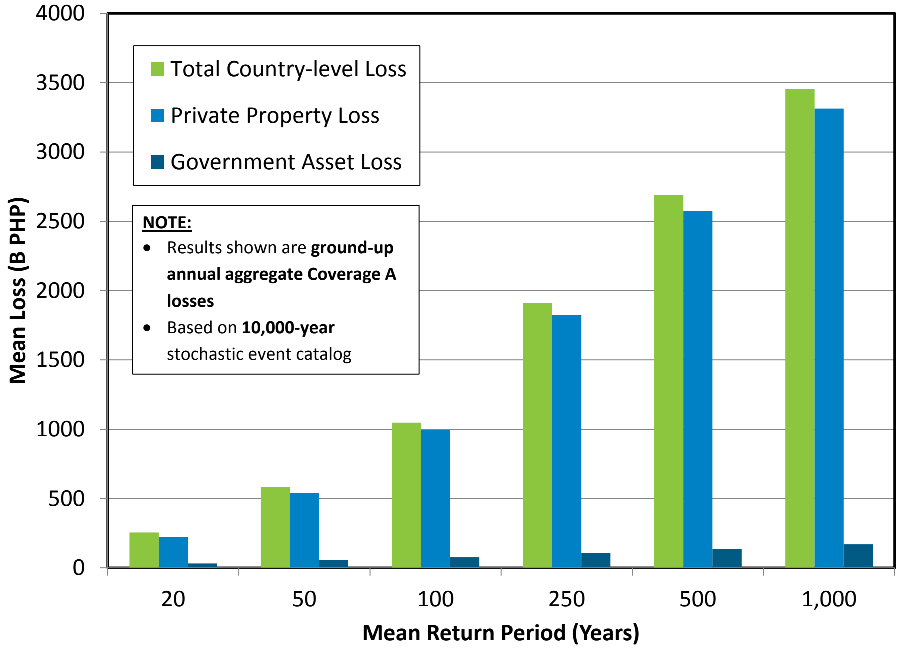

Figure 7.1. Philippines Mean Aggregate Earthquake Loss EP Curves by Asset Type

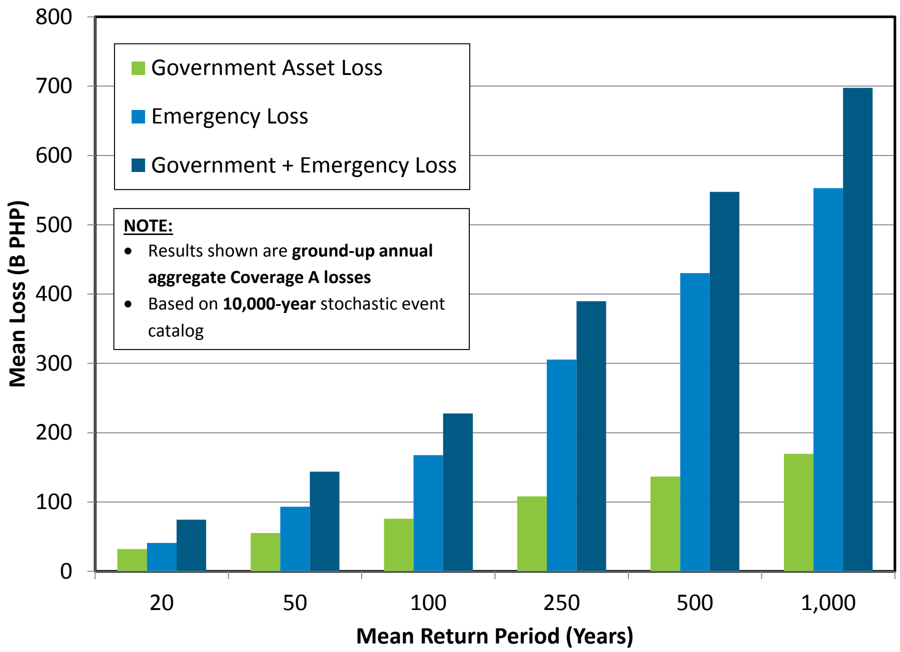

Figure 7.2. Philippines Mean Aggregate Earthquake Loss EP Curves for Government and Emergency Losses

Table 7.1. Philippines Mean Aggregate Earthquake Loss EP Curves

MRP (Years)	Aggregate Loss (Billion PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government + Emergency Loss
AAL	8.3	64.4	72.7	11.6	19.9
20	32	223	256	41	74
50	55	539	582	93	144
100	76	993	1047	168	228
250	108	1826	1908	305	390
500	137	2575	2689	430	547
1,000	169	3313	3456	553	698

Philippines GDP = ~10,200 B PHP (Source: World Bank, 2012)
Total building replacement values
Government Assets = 2,700 B PHP, Private Property = 22,100 B PHP, Total Value = 24,800 B PHP

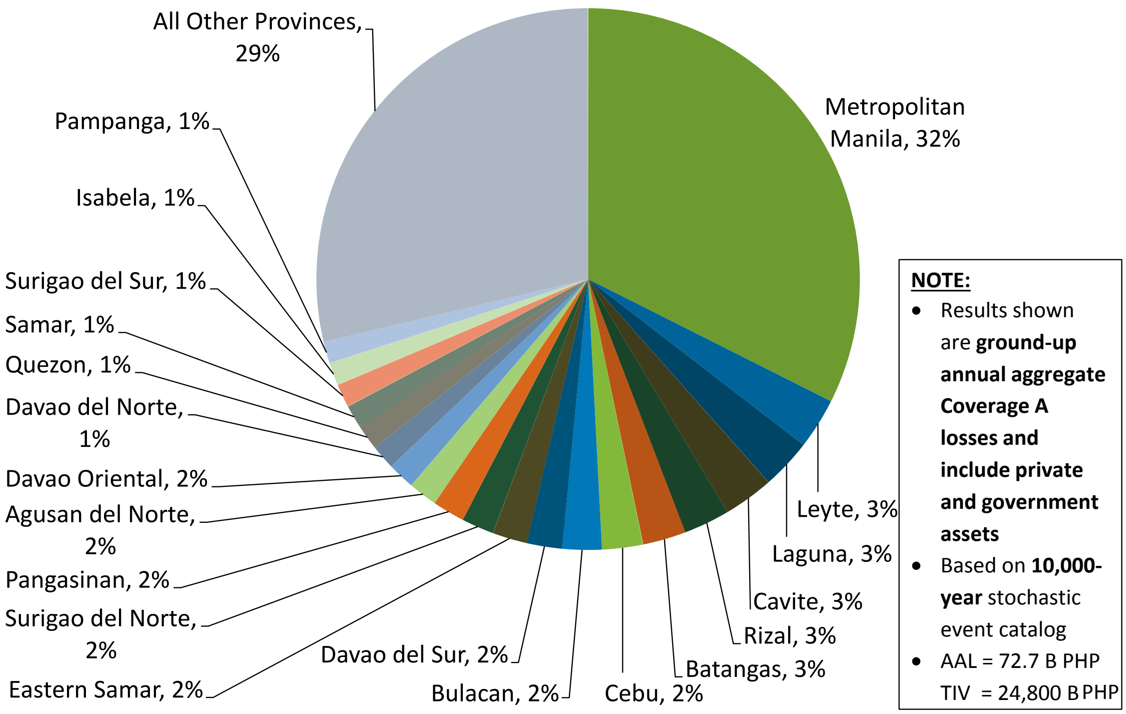

Figure 7.3. Total AAL Disaggregation by Province for Earthquake

The disaggregation by province of the country-level AAL due to the earthquake peril is presented in shown in Figure 7.3 above. As shown, a substantial portion of the AAL, about 32%, is attributable to Metropolitan Manila, which is due to the high private property and government asset replacement value concentrations, as well as the relatively high seismicity in the capital region. Figure 7.4 shows the geographic distribution of the total earthquake AAL estimate. The provinces with high exposure replacement value and significant seismicity are the primary risk drivers in terms of AAL.

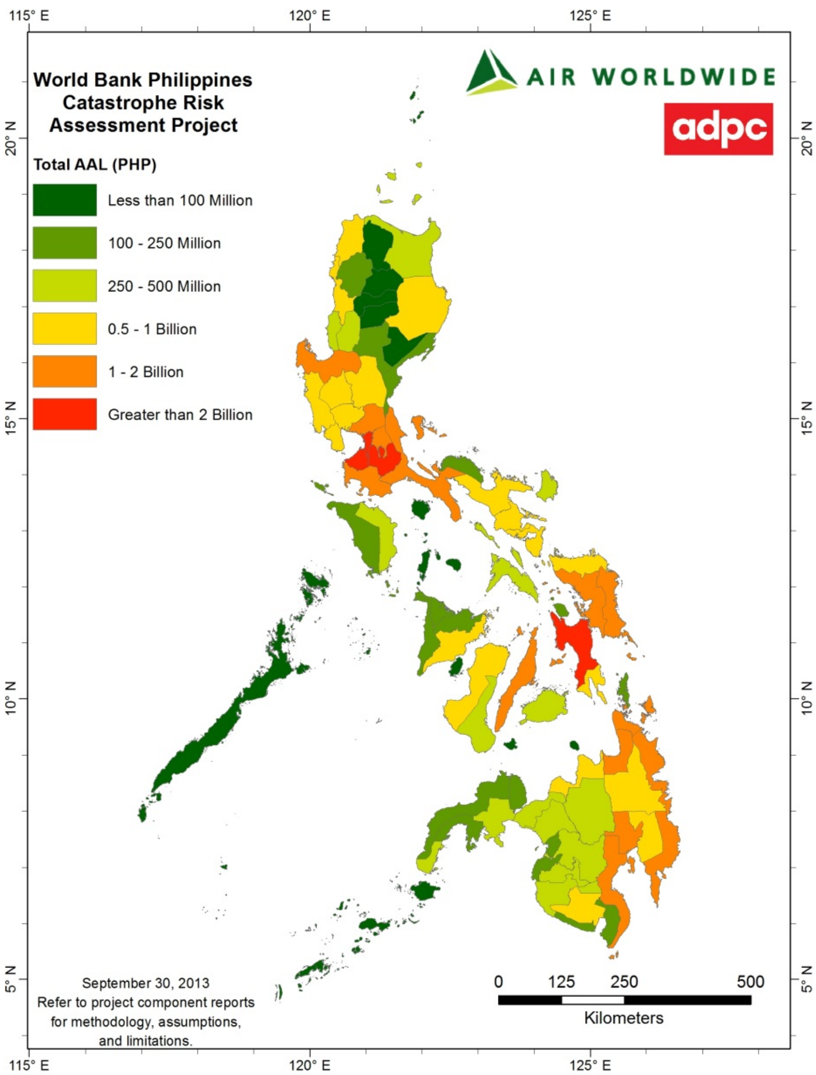

Figure 7.4. Geographic Distribution of the Total AAL for Earthquake

Figure 7.5 shows the disaggregation of the estimated government asset earthquake AAL by government sector. The figure shows that on average nearly 60% of the government asset AAL for the earthquake peril would be sustained by three government sectors, namely Residual Institutions, Public Schools and Bridges, or about 24%, 19% and 16% of the AAL, respectively. Note that Residual Institutions is a catch-all category for all assets left over after ascribing particular asset values to well defined sectors such as Schools, Hospitals, Roads, etc.

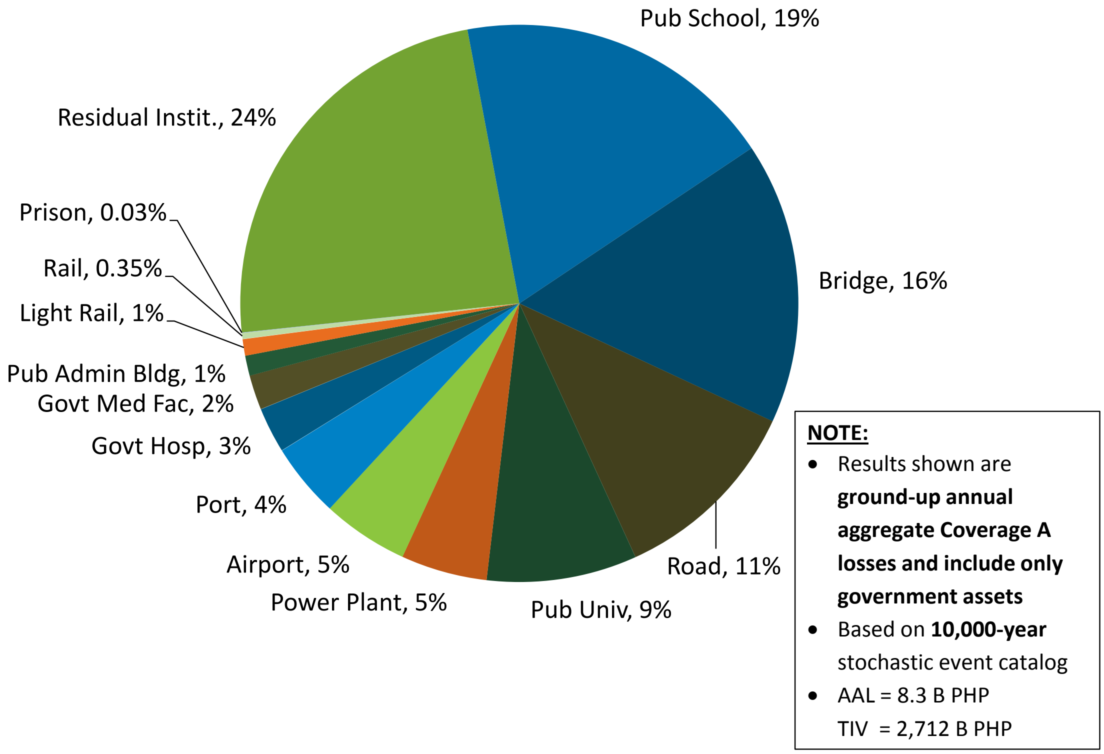

Figure 7.5. Government Asset Earthquake AAL Disaggregation by Government Sector

7.2 Loss Results for Tropical Cyclones

Figure 7.6 presents the mean aggregate tropical cyclone loss EP curve for the total building exposure in the Philippines (24,800 B PHP) at selected mean return periods. The figure also shows the loss EP curve disaggregated by exposure type (i.e., private property only and government assets only). The results presented in Figure 7.6 are also reported in Table 7.2. For example, at a mean return period of 100 years, the total country-level tropical cyclone mean loss is estimated to be 598 billion PHP. This means that there is a 1.0% chance that a loss of 598 billion PHP or greater will be sustained in the next year. Losses at other mean return periods can similarly be read and interpreted from Figure 7.6 and Table 7.2. As in the case of the earthquake peril, the country-level tropical cyclone losses are driven by losses to private property.

Figure 7.7 shows a comparison of the mean aggregate tropical cyclone EP curves for government asset only losses, emergency losses (computed as a percentage of the direct country-level tropical cyclone losses), as well as the combination of the two. These results are also included in Table 7.2. For example, at a mean return period of 100 years, the government asset only mean loss is estimated to be

29 billion PHP, while the estimated values of the emergency losses and the combination of government asset losses and emergency losses are 138 and 164 billion PHP, respectively.

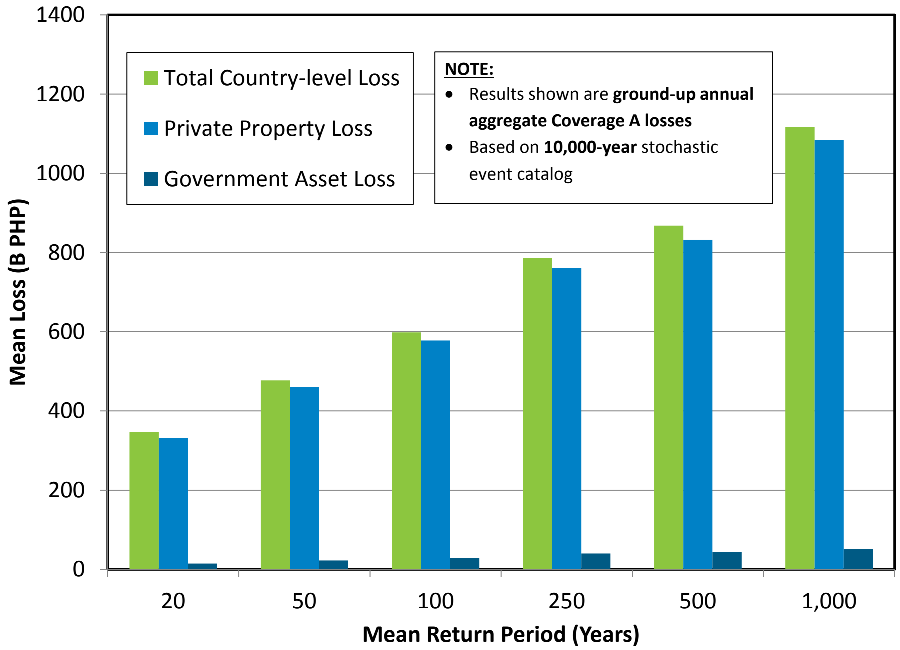

Figure 7.6. Philippines Mean Aggregate Tropical Cyclone Loss EP Curves by Asset Type

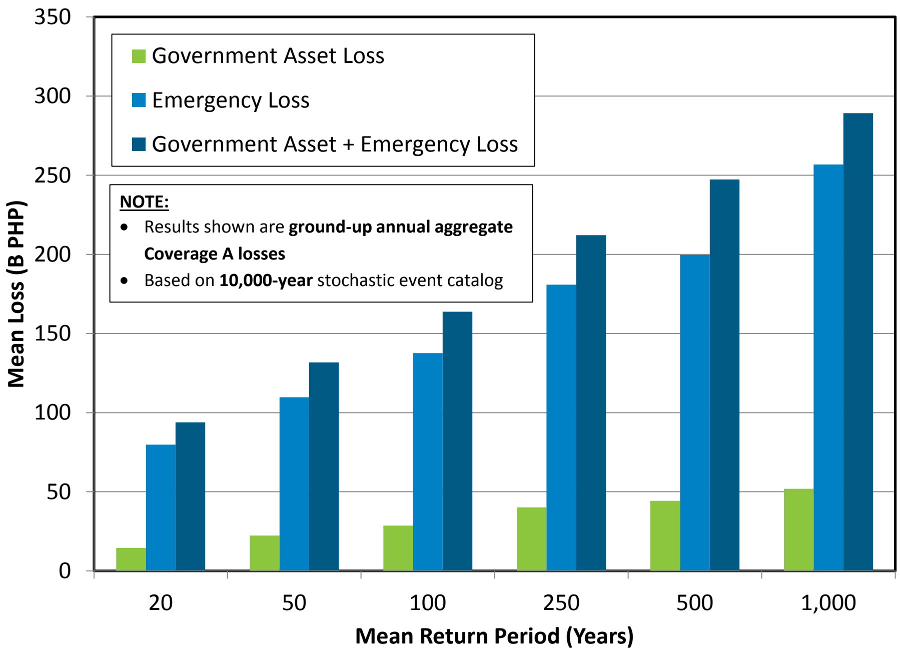

Figure 7.7. Philippines Mean Aggregate Tropical Cyclone Loss EP Curves for Government and Emergency Losses

Table 7.2 Philippines Mean Aggregate Tropical Cyclone Loss EP Curves

MRP (Years)	Aggregate Loss (Billion PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government Asset + Emergency Loss
AAL	4.6	112.1	116.7	26.8	31.4
20	15	332	347	80	94
50	22	461	477	110	132
100	29	578	598	138	164
250	40	761	786	181	212
500	44	832	868	200	247
1,000	52	1084	1117	257	289

Philippines GDP = ~10,200 B PHP (Source: World Bank, 2012)
Total building replacement values
Government Assets = 2,700 B PHP, Private Property = 22,100 B PHP, Total Value = 24,800 B PHP

The disaggregation by province of the country-level AAL due to the tropical cyclone peril is presented in Figure 7.8. The provinces with the relatively highest contributions to the total tropical cyclone AAL are Metropolitan Manila, Leyte and Camarines Sur with about 9%, 8% and 6% of the AAL, respectively. Figure 7.9 shows the geographic distribution of the total tropical cyclone AAL estimate. The provinces with high exposure replacement value and significant tropical cyclone hazard (eastern part of the country) are the primary risk drivers in terms of AAL.

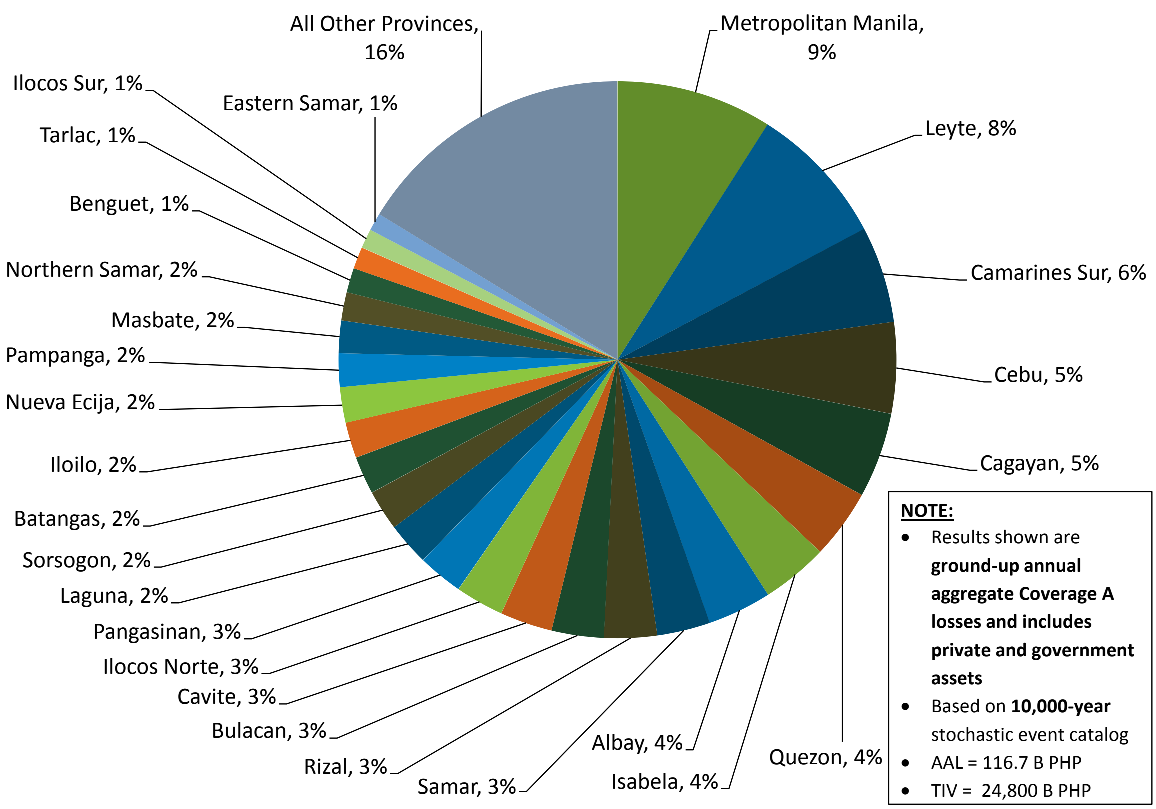

Figure 7.8. Total AAL Disaggregation by Province for Tropical Cyclone

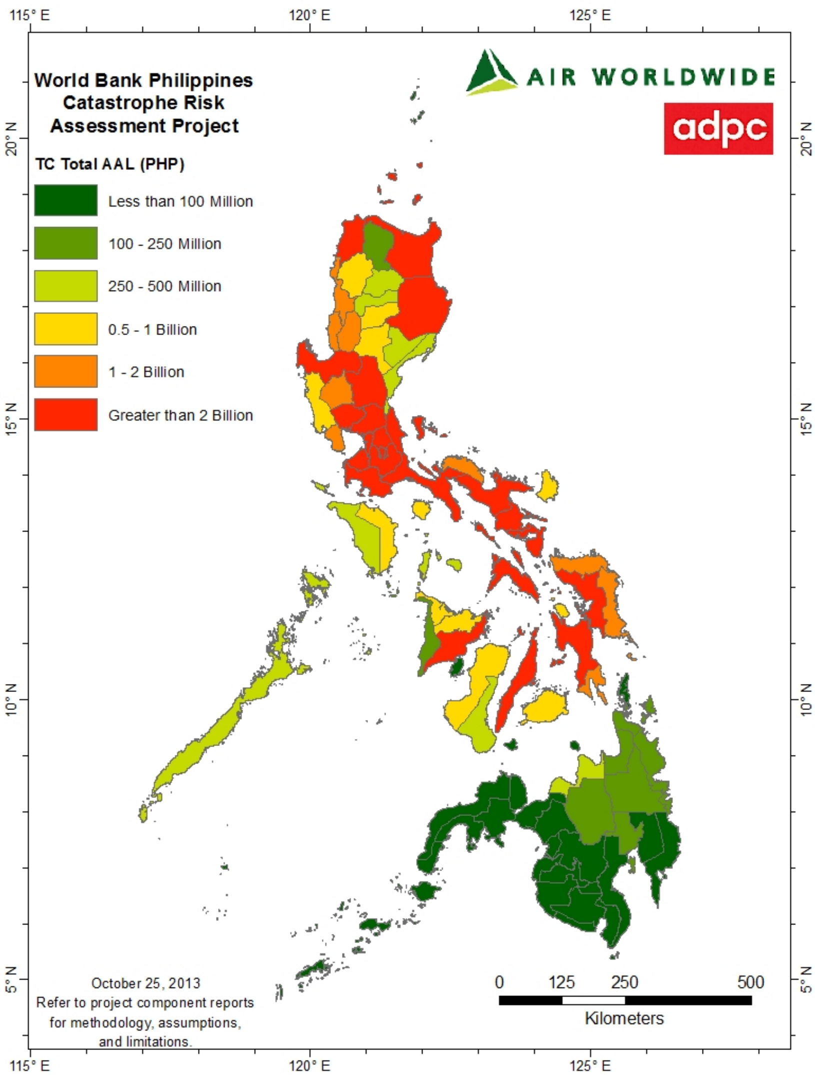

Figure 7.9. Geographic Distribution of the Total AAL for Tropical Cyclone

Figure 7.10 shows the disaggregation of the estimated government asset tropical cyclone AAL by government sector. The figure shows that on average about 70% of the government asset AAL for the tropical cyclone peril would be sustained by four government sectors, namely Residual Institutions, Public Schools, Roads and Power Plants, or about 22%, 19%, 15% and 14% of the AAL, respectively.

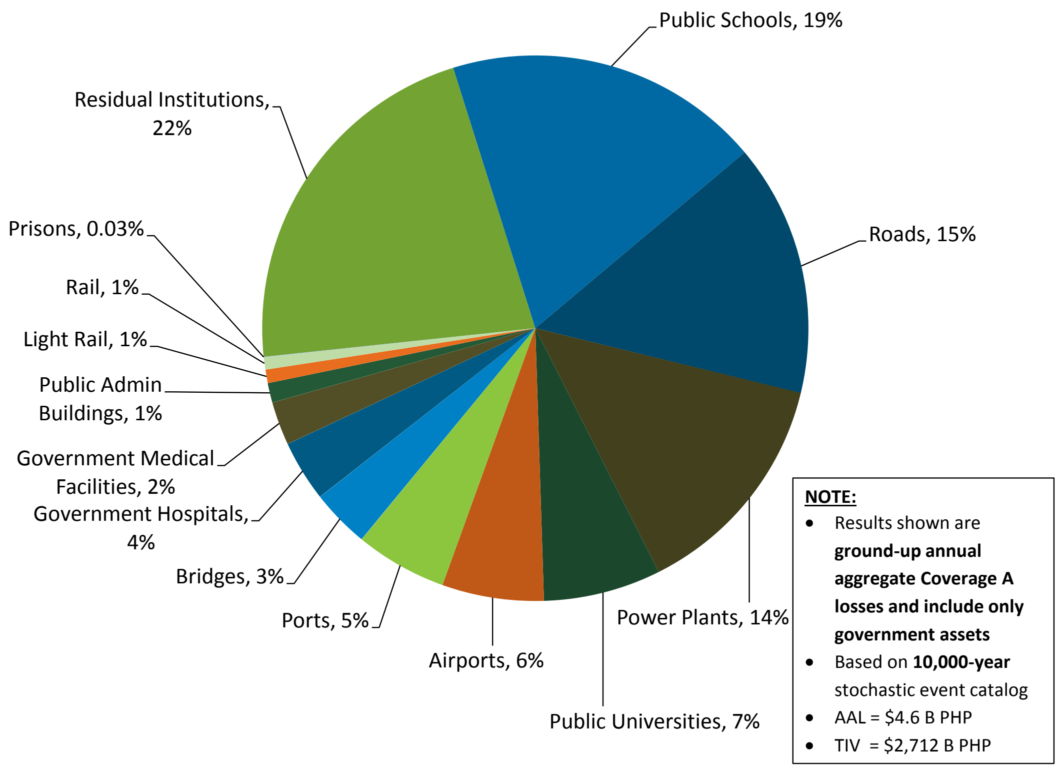

Figure 7.10. Government Asset Tropical Cyclone AAL Disaggregation by Government Sector

7.3 Loss Results for Non-Tropical Cyclone Precipitation

Figure 7.11 presents the mean aggregate non-tropical cyclone (NTC) precipitation loss EP curve for the total building exposure in the Philippines (24,800 B PHP) at selected mean return periods. The figure also shows the loss EP curve disaggregated by exposure type (i.e., private property only and government assets only). The results presented in Figure 7.11 are also reported in Table 7.3. For example, at a mean return period of 100 years, the total country-level NTC precipitation mean loss is estimated to be 38 billion PHP. This means that there is a 1.0% chance that a loss of 38 billion PHP or greater will be sustained in the next year. Losses at other mean return periods can similarly be read and interpreted from Figure 7.11 and Table 7.3. As with the other two perils, the country-level NTC precipitation losses are driven by losses to private property. Note that due to limitations in scope and timeline for the project, the NTC precipitation losses should not be confused with results that may be obtained from a comprehensive riverine flood model, which will have much higher resolution in terms of hazard and exposure. The NTC precipitation losses should at best be only seen as a poor surrogate for losses that would be generated using a comprehensive flood model.

Figure 7.12 shows a comparison of the mean aggregate NTC precipitation EP curves for government asset only losses, emergency losses (computed as a percentage of the direct country-level NTC precipitation losses), as well as the combination of the two. These results are also included in Table 7.3. For example, at a mean return period of 100 years, the government asset only mean loss is estimated to be 1.7 billion PHP, while the estimated values of the emergency losses and the combination of government asset losses and emergency losses are 9 and 10 billion PHP, respectively.

Figure 7.11. Philippines Mean Aggregate NTC Precipitation Loss EP Curves by Asset Type

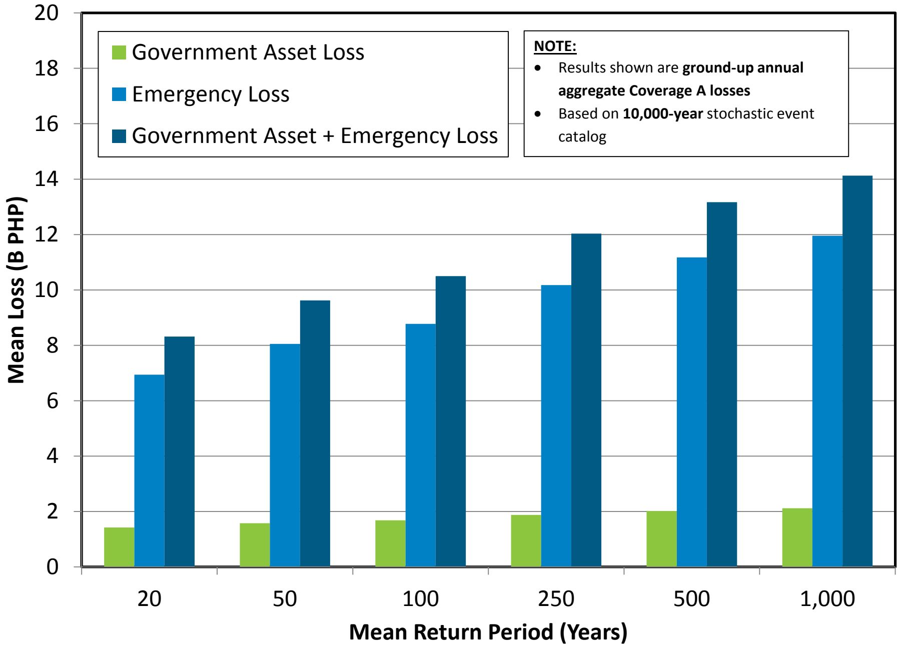

Figure 7.12. Philippines Mean Aggregate NTC Precipitation Loss EP Curves for Government and Emergency Losses

Table 7.3. Philippines Mean Aggregate NTC Precipitation Loss EP Curves

MRP (Years)	Aggregate Loss (Billion PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government Asset + Emergency Loss
AAL	0.9	16.1	17.0	3.9	4.9
20	1.4	29	30	7	8
50	1.6	33	35	8	10
100	1.7	37	38	9	10
250	1.9	42	44	10	12
500	2.0	47	49	11	13
1,000	2.1	50	52	12	14

Philippines GDP = ~10,200 B PHP (Source: World Bank, 2012)
Total building replacement values
Government Assets = 2,700 B PHP, Private Property = 22,100 B PHP, Total Value = 24,800 B PHP

The disaggregation by province of the country-level AAL due to the NTC precipitation peril is presented in Figure 7.13. The provinces with the relatively highest contributions to the total tropical cyclone AAL are Metropolitan Manila, Benguet and Pangasinan with about 26%, 12% and 9% of the AAL, respectively. Figure 7.14 shows the geographic distribution of the total NTC precipitation AAL estimate. Relatively higher NTC precipitation AAL estimates are observed in the northern part of the country, where NTC rainfall is typically highly variable and of larger magnitude than that in the southern parts of the Philippines.

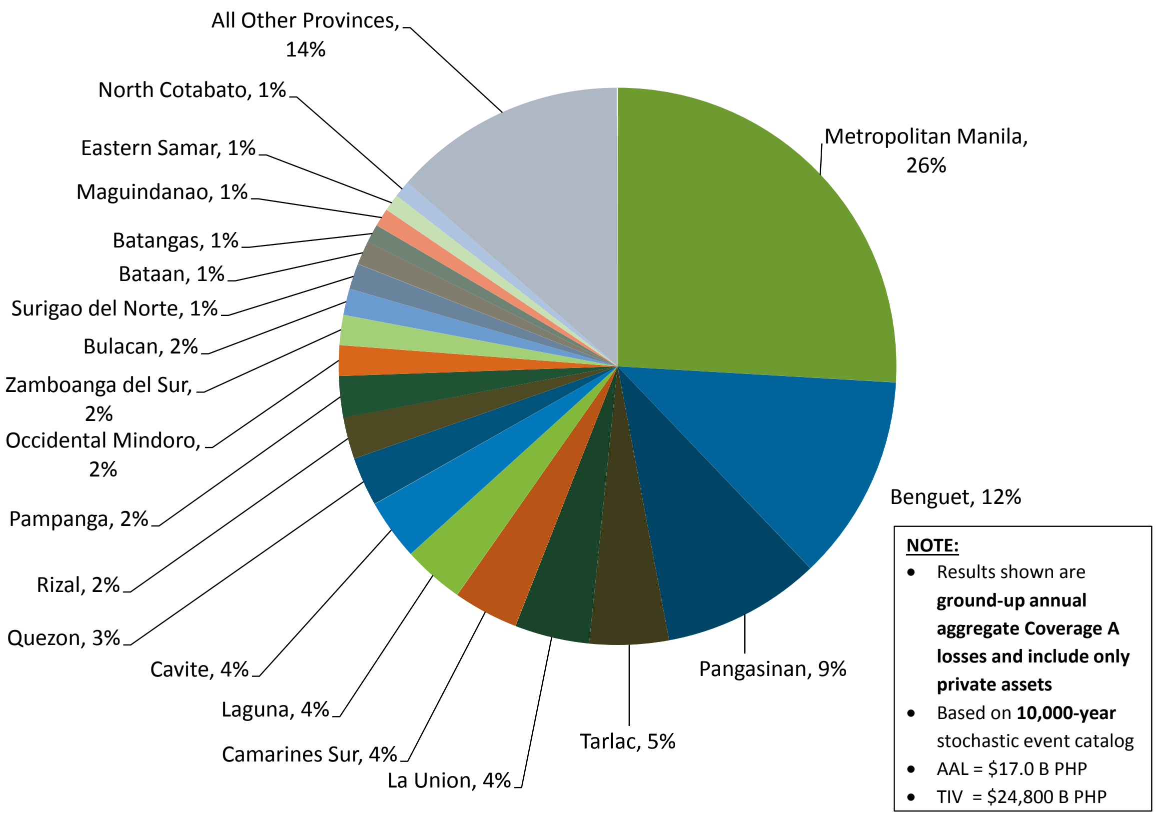

Figure 7.13. Total AAL Disaggregation by Province for NTC Precipitation

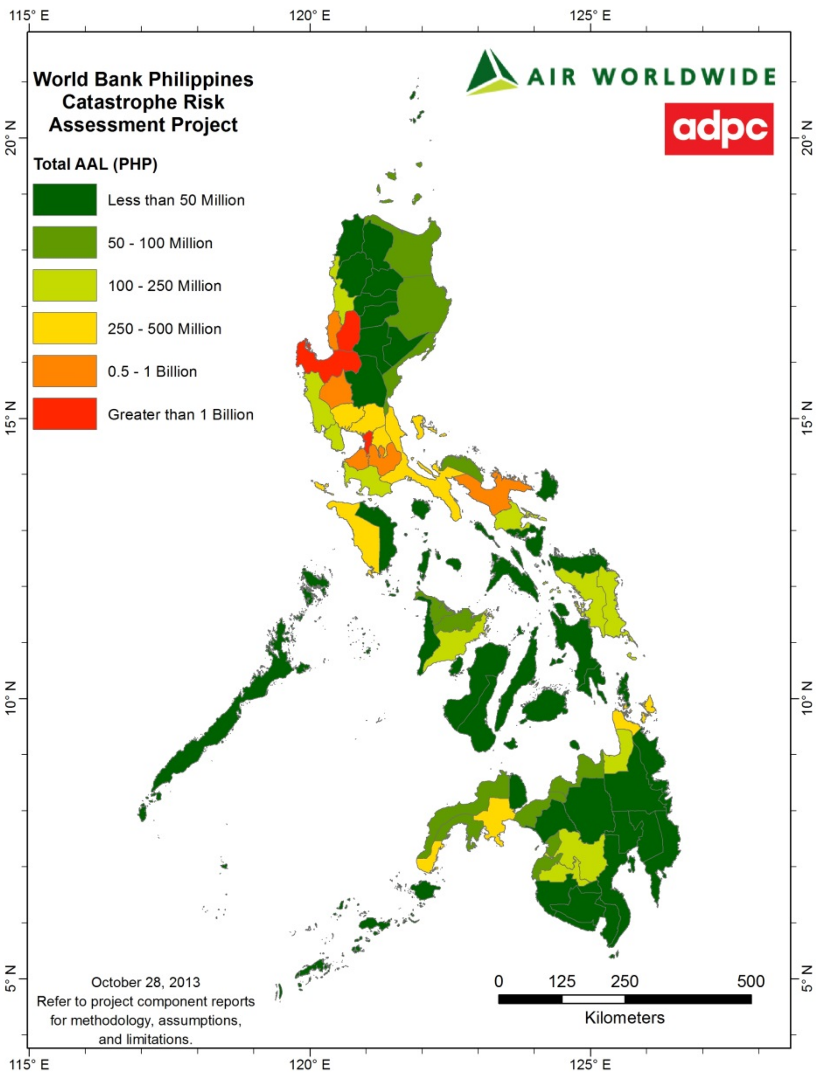

Figure 7.14. Geographic Distribution of the Total AAL for NTC Precipitation

Figure 7.15 shows the disaggregation of the estimated government asset NTC precipitation AAL by government sector. The figure shows that on average nearly 60% of the government asset AAL for the NTC precipitation peril would be sustained by four government sectors, namely Roads, Residual Institutions and Public Schools, or about 22%, 22% and 14% of the AAL, respectively.

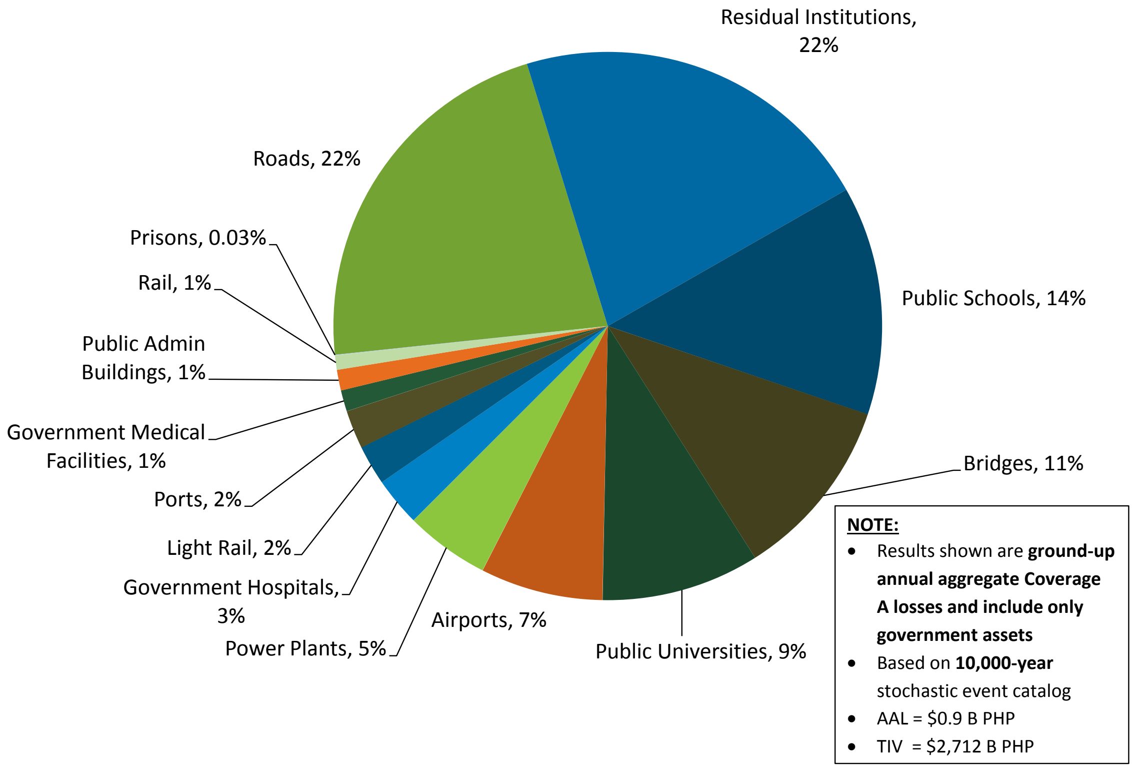

Figure 7.15. Government Asset NTC Precipitation AAL Disaggregation by Government Sector

7.4 Combined Loss Results for all Perils

Figure 7.16 presents the mean aggregate loss EP curves by peril and for all perils combined for the total building exposure (24,800 B PHP) in the Philippines at selected mean return periods. The results in Figure 7.16 are also reported in Table 7.4. The NTC precipitation losses are significantly smaller when compared to losses due to earthquakes and tropical cyclones. This is because a significant amount of the precipitation loss in the Philippines is typically associated with tropical cyclones and is reflected in the tropical cyclone losses. NTC precipitation events also tend to cover smaller areas causing more localized damage, whereas earthquakes and tropical cyclones tend to be widespread and affect larger regions. Figure 7.16 also shows that earthquake losses are higher compared to those from tropical cyclones for larger mean return periods (greater than 25-30 years). Conversely, tropical cyclone losses govern at smaller mean return periods. This is primarily because tropical cyclones occur more frequently than earthquakes in the Philippines but strong earthquakes typically cause greater losses compared to large tropical cyclones. For example, Figure 7.16 shows that at a mean return period of 100 years, the earthquake, tropical cyclone, NTC precipitation and all peril combined mean losses are estimated to be 1047, 598, 38 and 1250 billion PHP, respectively. This means that there is a 1.0% chance that these or greater losses will be sustained in the next year. Losses at other mean return periods can similarly be read and interpreted from Figure 7.16 and Table 7.4. The estimated AAL values for the individual perils and the all peril combined case are also listed in Table 7.4.

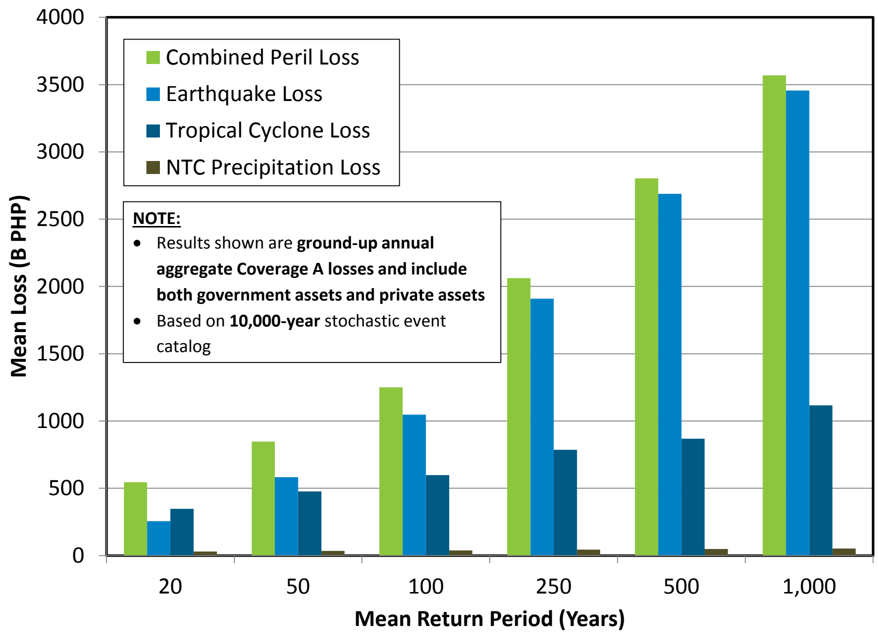

Figure 7.16. Philippines Mean Aggregate Total Loss EP Curves by Peril

Table 7.4. Philippines Mean Aggregate Total Loss EP Curves by Peril

MRP (Years)	Aggregate Loss (Billion PHP)			
	Earthquake Loss	Tropical Cyclone Loss	NTC Precipitation Loss	Combined Peril Loss
AAL	72.7	116.7	17.0	206.4
20	256	347	30	545
50	582	477	35	847
100	1,047	598	38	1,250
250	1,908	786	44	2,062
500	2,689	868	49	2,804
1,000	3,456	1,117	52	3,568

Philippines GDP = ~10,200 B PHP (Source: World Bank, 2012)
Total building replacement values
Government Assets = 2,700 B PHP, Private Property = 22,100 B PHP, Total Value = 24,800 B PHP

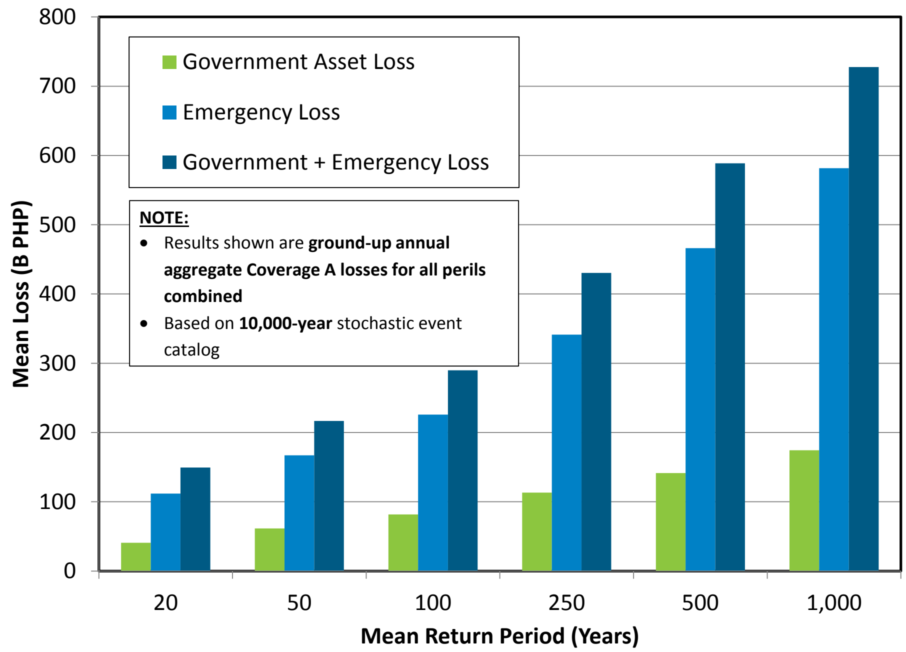

Figure 7.17. Philippines Mean Aggregate Loss EP Curves for Government and Emergency Losses for All Perils Combined

Table 7.5. Philippines Mean Aggregate Loss EP Curves for Government and Emergency Losses for All Perils Combined

MRP (Years)	Aggregate Loss (Billion PHP)		
	Government Asset Loss	Emergency Loss	Government + Emergency Loss
AAL	13.8	42.4	56.2
20	41	112	149
50	62	167	217
100	82	226	290
250	113	341	430
500	141	466	589
1,000	174	582	728

Philippines GDP = ~10,200 B PHP (Source: World Bank, 2012)
Total building replacement values
Government Assets = 2,700 B PHP, Private Property = 22,100 B PHP, Total Value = 24,800 B PHP

Figure 7.17 shows a comparison of the mean aggregate EP curves for government asset only losses, emergency losses (computed as a percentage of the direct country-level losses for all perils combined), as well as the combination of the two. These results are tabulated in Table 7.5. For example, at a mean return period of 100 years, the government asset only mean loss is estimated to be 82 billion PHP, while the estimated values of the emergency losses and the combination of government asset losses and emergency losses are 226 and 290 billion PHP, respectively.

The contribution of each peril to the total combined peril AAL estimate is shown in Figure 7.20. The figure shows that tropical cyclones have the highest contribution to the AAL (about 57% of the AAL), followed by earthquakes (about 35% of the AAL) and NTC precipitation (about 8% of the AAL). The geographic distribution of the total combined peril AAL is shown in Figure 7.19. The provinces with high exposure replacement value and significant earthquake, tropical cyclone or NTC precipitation hazard are the primary risk drivers in terms of AAL.

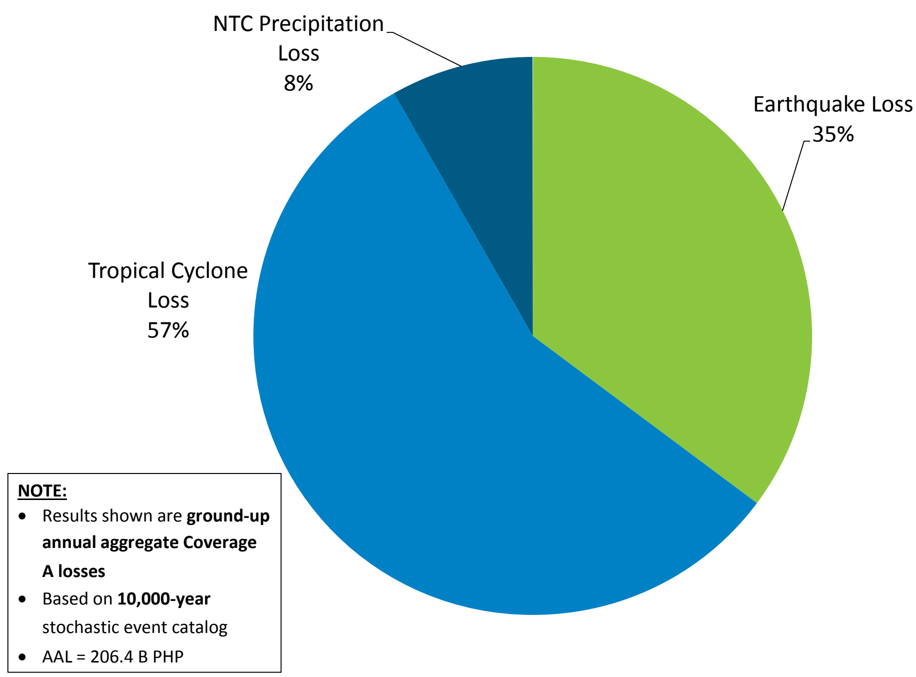

Figure 7.18. Total AAL Disaggregation by Peril

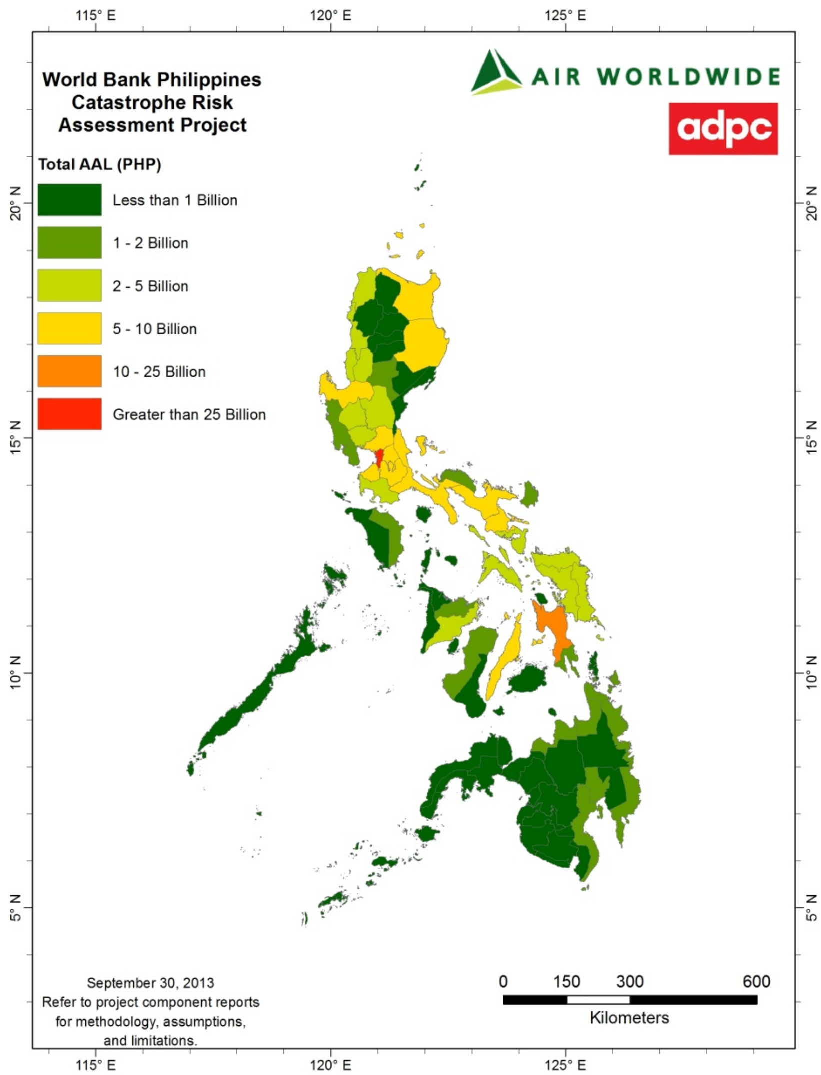

Figure 7.19. Geographic Distribution of the Total AAL for All Perils Combined

7.5 Combined Casualty Loss Results for all Perils

Figure 7.20 presents mean aggregate EP curves for casualties (including fatalities and injuries) by peril and for all perils combined at selected mean return periods. As shown, across all mean return periods, casualties due to the NTC precipitation peril are lower than these for the other two perils. Also, tropical cyclones cause the greatest number of casualties for small mean return periods. This reverses for large mean return periods where earthquake casualties are the greatest. For example, Figure 7.20 shows that at a mean return period of 100 years, the earthquake, tropical cyclone, NTC precipitation and all peril combined mean number of casualties are estimated to be about 14800, 68,800, 4,400 and 74,100, respectively. This means that there is a 1.0% chance that these or greater number of casualties will be sustained in the next year. Losses at other mean return periods can similarly be read and interpreted from Figure 7.20.

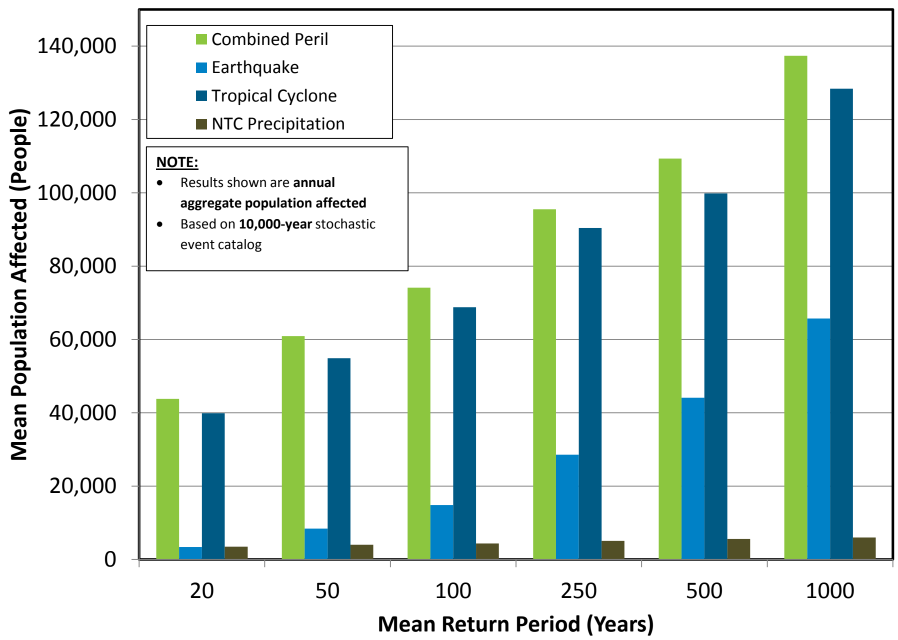

Figure 7.20. Philippines Mean Aggregate EP Curves for Casualties by Peril

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Note: Other references for development of the Typhoon hazard can be found in the model documentation for the Typhoon Model for the Southeast Asia Region.

About AIR Worldwide Corporation

AIR Worldwide Corporation (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 50 countries. More than 400 insurance, reinsurance, financial, corporate and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, agricultural risk management, and property replacement cost valuation. AIR is a member of the ISO family of companies and is headquartered in Boston with additional offices in North America, Europe and Asia. For more information, please visit www.air-worldwide.com.

About Asian Disaster Preparedness Center (ADPC)

As a leading regional resource center, Asian Disaster Preparedness Center (ADPC) works towards the realization of disaster reduction for safer communities and sustainable development in Asia and the Pacific. Since its inception in 1986, ADPC has been recognized as the major independent center in the region for promoting disaster awareness and the development of local capabilities to foster institutionalized disaster management and mitigation policies. ADPC was originally established as an outreach center of the Asian Institute of Technology after a feasibility study conducted jointly by two agencies of the United Nations, the Office of the United Nations Disaster Relief Coordinator (current the UN Office for the Coordination of Humanitarian Affairs) and the World Meteorological Organization in January 1986. Funding for the study was provided by the United Nations Development Program in response to requests from countries in the region for international assistance to strengthen their national disaster management systems. Thus, the initial role conceived for the center was mandated by an expressed need to assist countries of the Asia and the Pacific region in formulating their policies and developing their capabilities in all aspects of disaster management.

Appendix A: Occurrence Loss Results

A.1 Earthquake Occurrence Loss Results

MRP (Years)	Occurrence Loss ($B PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government + Emergency Loss
AAL	5.8	52.5	58.0	9.3	15.0
20	25	188	213	34	60
50	46	495	530	85	127
100	66	941	985	158	208
250	98	1752	1826	292	371
500	125	2500	2608	417	525
1,000	158	3226	3376	540	686

A.2 Typhoon Occurrence Loss Results

MRP (Years)	Occurrence Loss (B PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government + Emergency Loss
AAL	2.94	68.0	70.8	16.3	19.1
20	10	224	234	54	64
50	17	332	349	80	98
100	24	418	433	100	120
250	34	596	621	143	167
500	38	687	714	164	200
1,000	46	920	973	224	259

A.3 Non-tropical Cyclone Precipitation Occurrence Loss Results

MRP (Years)	Occurrence Loss (B PHP)				
	Government Asset Loss	Private Property Loss	Total Country-level Loss	Emergency Loss	Government Asset + Emergency Loss
AAL	0.31	6.90	7.21	1.66	1.96
20	0.60	16.86	17.45	4.01	4.61
50	0.74	21.32	22.09	5.08	5.81
100	0.84	24.81	25.62	5.89	6.71
250	1.00	29.79	30.81	7.09	8.11
500	1.11	32.86	33.94	7.81	8.88
1,000	1.22	36.52	37.74	8.68	9.90