2) Results

The results are summarized in Figure 12.7.4 to Figure 12.7.6.
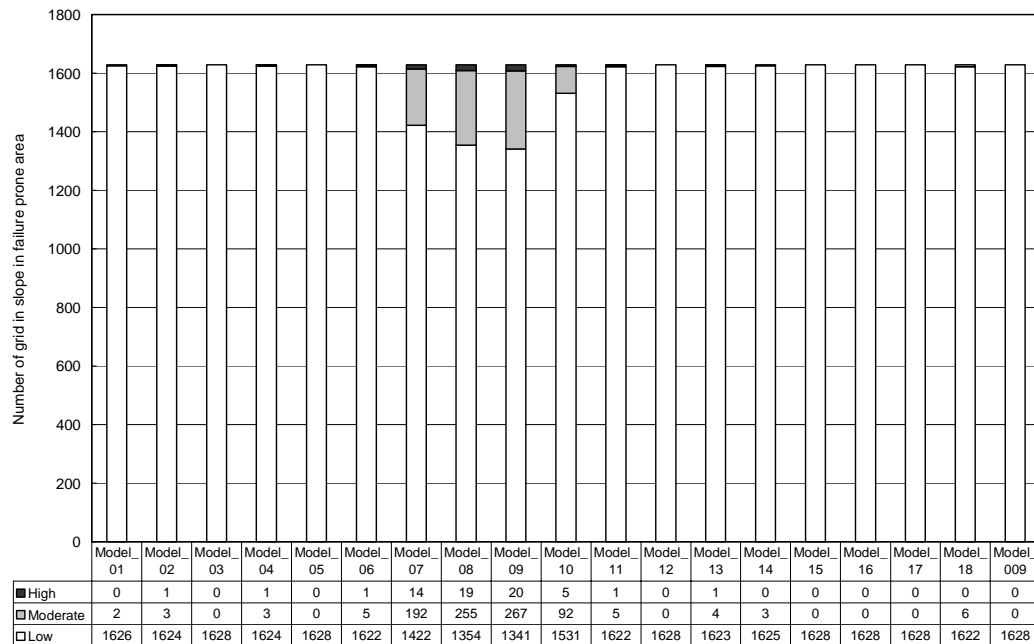

	Model_01	Model_02	Model_03	Model_04	Model_05	Model_06	Model_07	Model_08	Model_09	Model_10	Model_11	Model_12	Model_13	Model_14	Model_15	Model_16	Model_17	Model_18	Model_009
■High	0	1	0	1	0	1	14	19	20	5	1	0	1	0	0	0	0	0	0
▨Moderate	2	3	0	3	0	5	192	255	267	92	5	0	4	3	0	0	0	6	0
□Low	1626	1624	1628	1624	1628	1622	1422	1354	1341	1531	1622	1628	1623	1625	1628	1628	1628	1622	1628

Figure 12.7.4   Results of Slope Stability Analysis for Each Scenario Earthquake

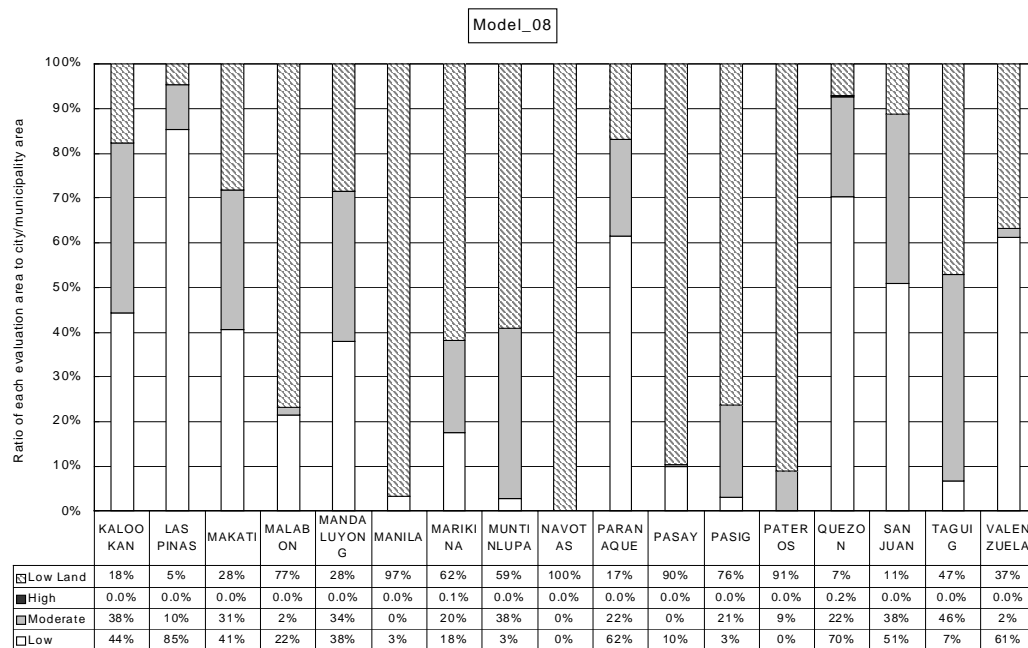|	KALOOKAN	LAS PINAS	MAKATI	MALABON	MANDALUYONG	MANILA	MARIKINA	MUNTINLUPA	NAVOTAS	PARANAQUE	PASAY	PASIG	PATEROS	QUEZON	SAN JUAN	TAGUIG	VALENZUELA
▨Low Land	18%	5%	28%	77%	28%	97%	62%	59%	100%	17%	90%	76%	91%	7%	11%	47%	37%
■High	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
▨Moderate	38%	10%	31%	2%	34%	0%	20%	38%	0%	22%	0%	21%	9%	22%	38%	46%	2%
□Low	44%	85%	41%	22%	38%	3%	18%	3%	0%	62%	10%	3%	0%	70%	51%	7%	61%

Figure 12.7.5   Variation of Slope in Failure Potential in Each City/Municipality Area, Case of Scenario Earthquake Model 08
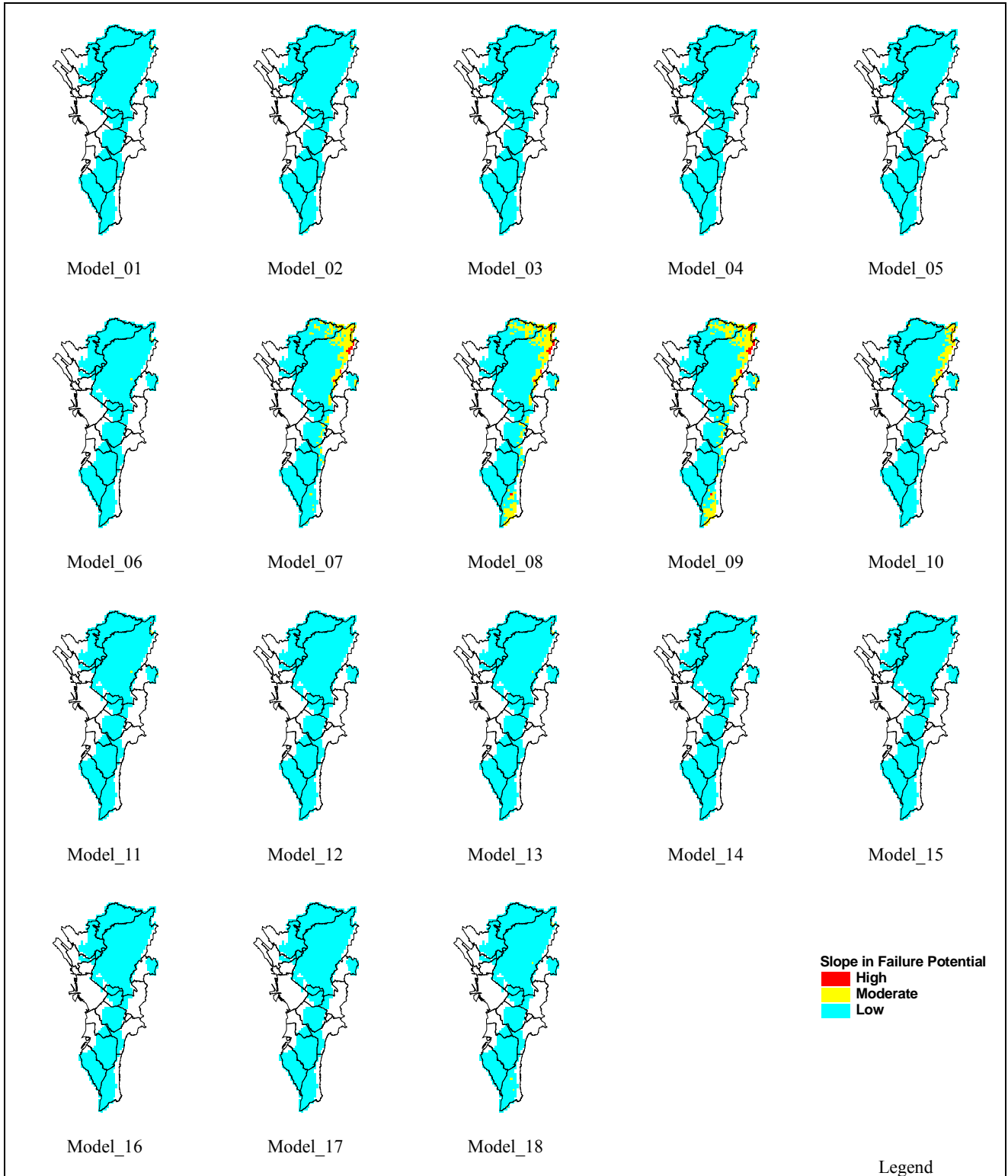
Figure 12.7.6   Slope in Failure Potential Map

3) Description

The results of slope stability analysis are described as follows,

- Slope in failure potential is low for all the Study area. (Figure 12.7.4)
- High potential area is quite limited.
- In Model07, 08 and 09, which will cause huge earthquakes, high potential area (shown in red color in Figure 12.7.6) appears northeast part of Quezon City.

4) Discussion

Followings are necessary works in the future.

- It is necessary to investigate individual slope condition in detail, where area is evaluated as high potential.
- Relatively small size failures, such as surface failure or rock fall are considered in this evaluation. Possibility of large size failure as landslide is individually investigated in detail.
- Introduction of slope inspection chart is recommended for management and maintenance of individual slopes or landslides. This chart is effective for slope stability evaluation during earthquake and also for ordinary management or maintenance of slope.

Reference to section 12.7

ISSMFE, 1993, Manual for Zonation on Seismic Geotechnical Hazards, Technical Committee for Earthquake Geotechnical Engineering, TC4, International Society of Soil Mechanics and Foundation Engineering.

Matsuoka, Masashi, Saburoh Midorikawa, 1995, Earthquake Induced Slope Failure potential Mapping Using the Digital National Land Information, J.Struct. Constr. Eng., AIJ, No474, pp.59-66

Siyahi, Bilge G., 1998, Deprem Etkısindeki Normal Konsolide Zemin Şevlerinde Yari-Statik Stabilite Analizi, İMO Teknik Dergi, Yazı 112, 1525-1552.

Siyahi, Bilge G., 2003, Privarte Interview.

Abramson, Lee, Tom Lee, Suil Sharma, Glenn Boyce, 1996, Slope Stability and Stabilization Methods, John Willy & Sons, pp94.

Chapter 13.   Earthquake Damage Estimation

CHAPTER 13. EARTHQUAKE DAMAGE ESTIMATION

This chapter describes earthquake damage estimation. Earthquake scenario and earthquake hazards are briefly described as background of the damage estimation. Details of these are written in "Interim Report" of the Study, which was issued in March 2003.

13.1   Earthquake Scenario

Out of the 18 scenario earthquakes for hazard analysis, three earthquakes are selected as the scenario earthquakes for damage analysis.

a. Model 08

This model supposes a break of West Valley Fault. The central 67 km segment was modeled considering the low continuity in the north and south. The serious threat of the earthquake occurrence along the WVF is pointed out based on the trenching survey.

b. Model 13

This is the model of huge subduction type earthquake along Manila Trench. This model may generate Tsunami.

c. Model 18

This model is the re-occurrence of 1863 event that occurred in Manila Bay.

The fault model parameters of scenario earthquakes for damage estimation are shown in Table 13.1.1. The source faults of scenario earthquakes are shown in Figure 13.1.1.

Table 13.1.1   Fault Model Parameters of Scenario Earthquakes for Damage Estimation

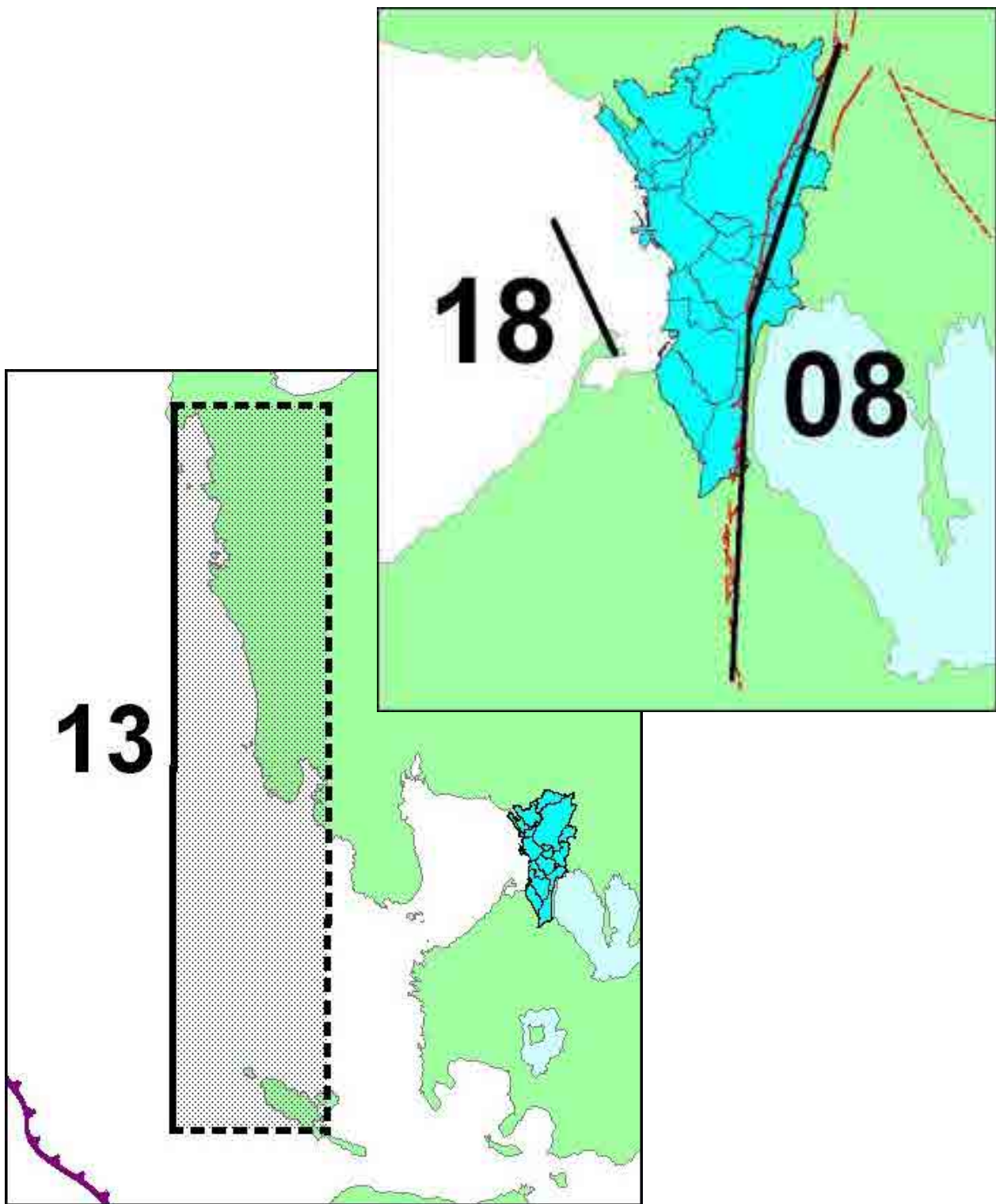| Model	Magnitude	Fault Length (km)
08	7.2	67
13	7.9	255
18	6.5	15

Figure 13.1.1   Scenario Earthquake Fault Model for Damage Estimation

13.2 Hazards

13.2.1 Earthquake Ground Motion

Distributions of the peak ground acceleration for three models are shown in Figure 13.2.1 to Figure 13.2.3. Distribution of the seismic intensity in MMI scale for three models are shown in Figure 13.2.4 to Figure 13.2.6. Table 13.2.1 shows definition of the seismic intensity in MMI Scale.

Table 13.2.1   Modified Mercalli Intensity Scale(1956 Version)

Intensity Scale	Description
I	**Not felt.** Marginal an d long period effects of large earthquakes.
II	**Felt by persons at rest**, on upper floors, or favourably placed.
III	**Felt indoors.** Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	**Hanging objects swing.** Vibration like a passing heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Window, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.
V	**Felt outdoors**; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	**Felt by all.** Many frightened and run outdoors.. persons walk unsteadily. Windows, dishes, glassware broken. Knick-knacks, books, etc. fall off shelves. Pictures fall off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church and school). Trees, bushes shaken visibly, or heard to rustle.
VII	**Difficult to stand.** Noticed by drivers. Hanging object quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets and architectural ornaments. Some cracks in masonry C. waves on ponds, water turbid with mud. Small slides and caving-in along sand or gravel banks. Large bell ring. Concrete irrigation ditches damaged.
VIII	**Steering of cars affected.** Damage to masonry C; partial collapse. Some damage to masonry B.; none to masonry A. fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken off trees. Changes inflow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	**General panic.** Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Conspicuous cracks in ground. In alluvial areas, sand and mud ejected, earthquake fountains, sand craters.
X	**Most masonry and frame structures destroyed with their foundations.** Some well-built wooden structures and bridges destroyed. Serious damage to dams, dykes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	**Rails bent greatly.** Underground pipelines completely out of service.
XII	**Damage nearly total.** Large masses displaced. Lines of sight and level distorted. Objects thrown into the air.

To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following letters:

Masonry A	Good workmanship, mortar and design; reinforced, specially laterally, and bound together by using steel, concrete etc.; designed to resist lateral forces.
Masonry B	Good workmanship and mortar; reinforced but not designed in detail to resist lateral forces.
Masonry C	Ordinary workmanship and mortar; no extreme weaknesses like failing to tie-in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D	Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

13.2.2 Liquefaction Potential

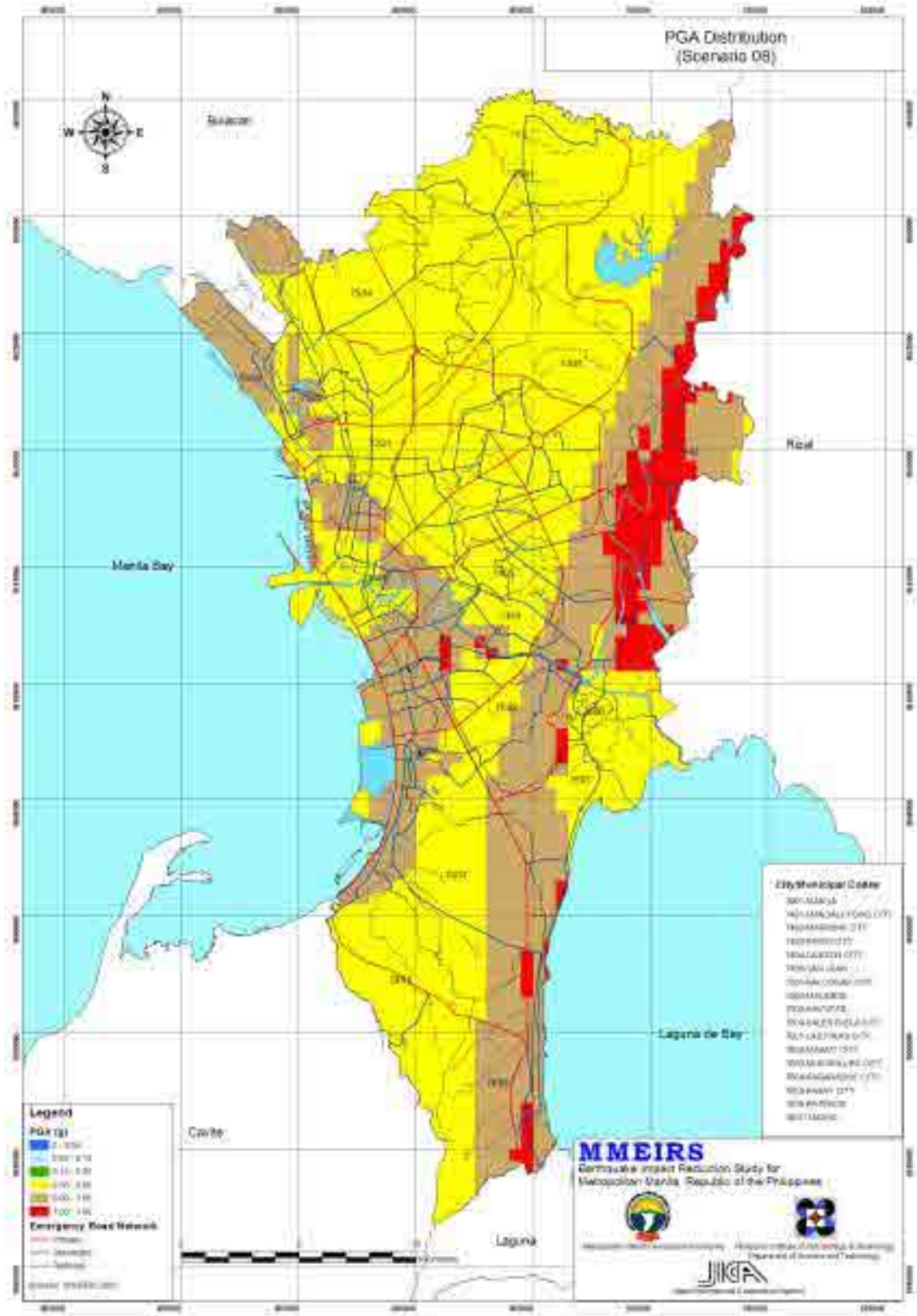The liquefaction potential are shown in Figure 13.2.7 to Figure 13.2.9.

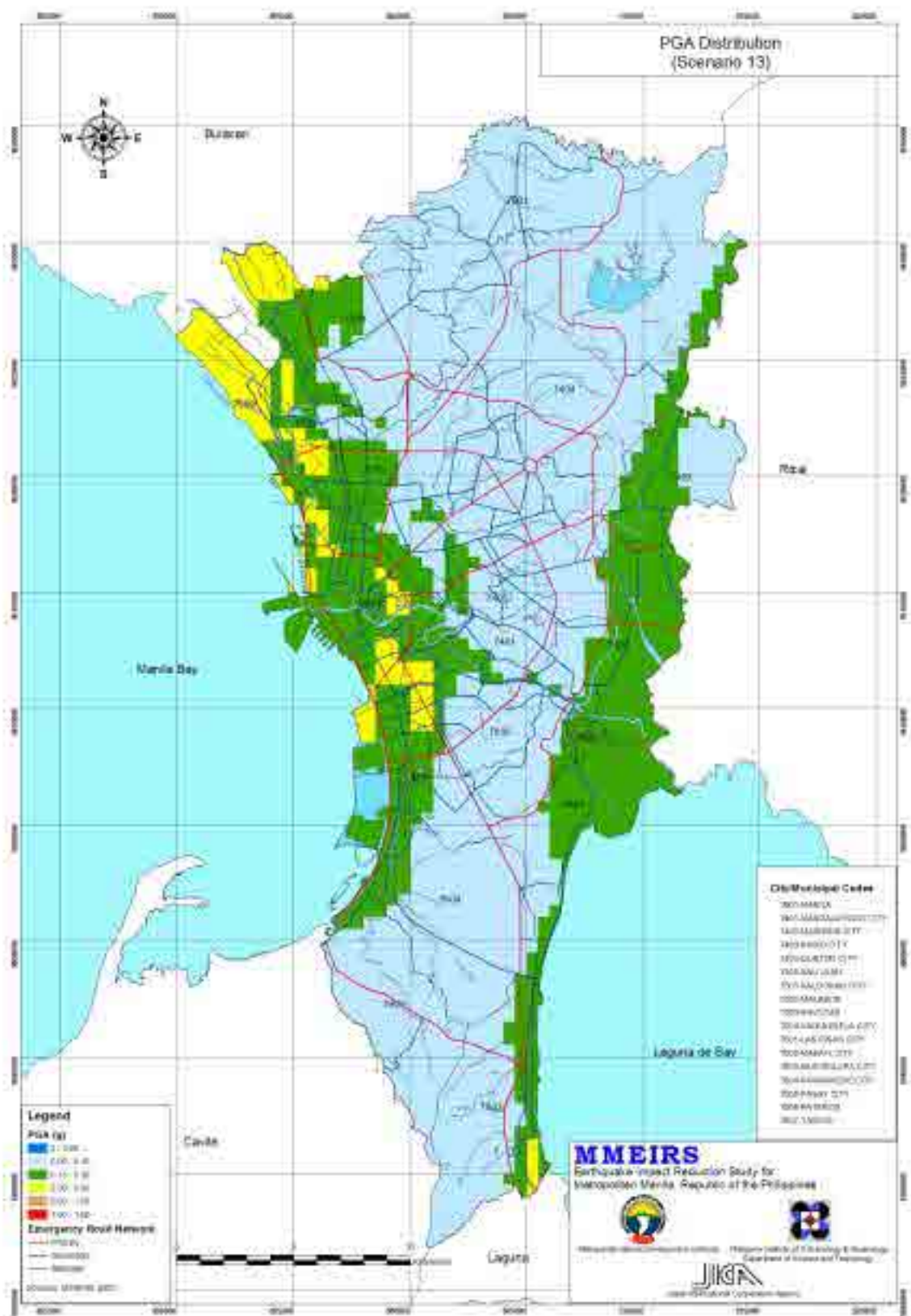**Figure 13.2.1   Distribution of Peak Ground Acceleration: Model 08**

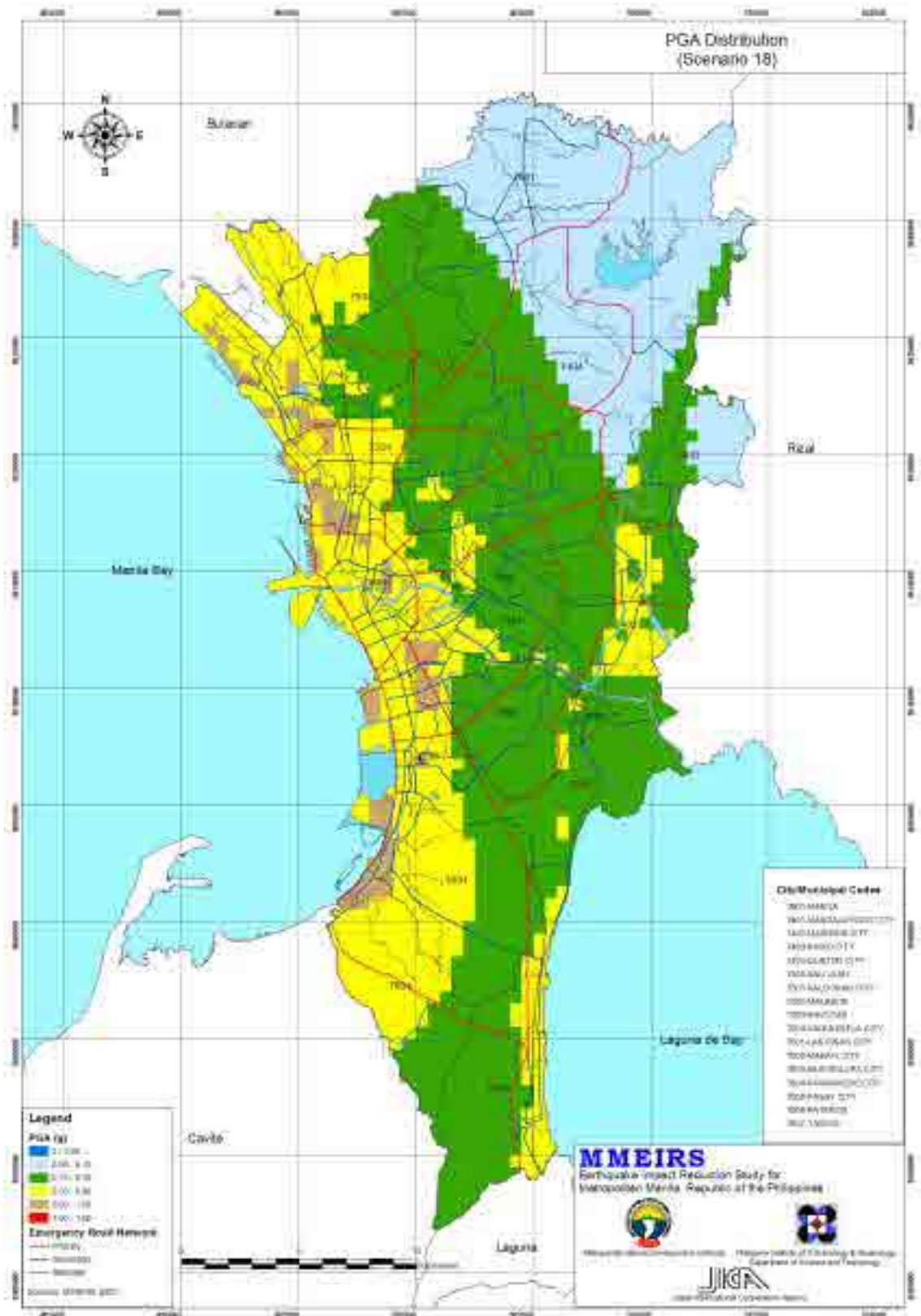**Figure 13.2.2   Distribution of Peak Ground Acceleration: Model 13**

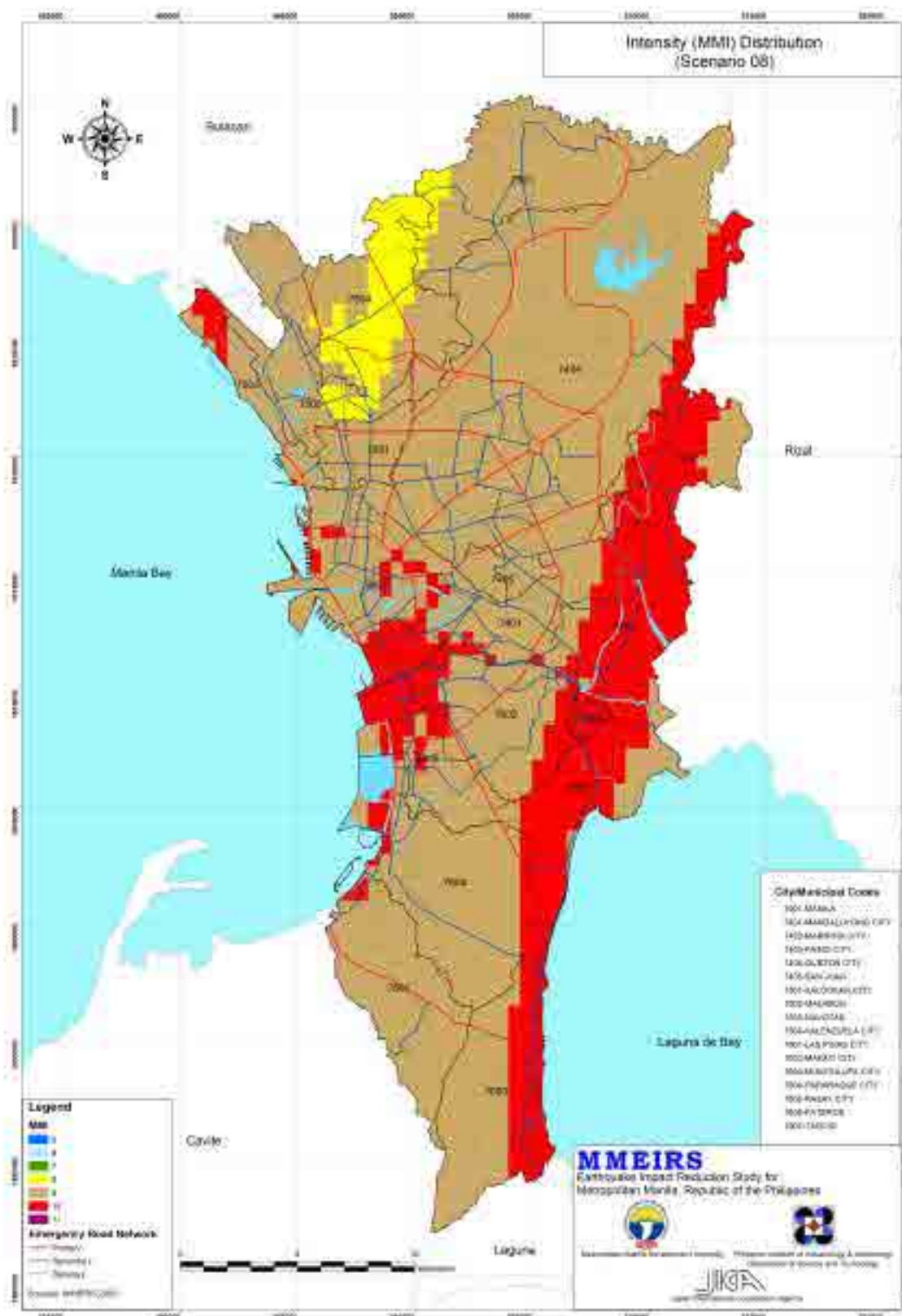**Figure 13.2.3   Distribution of Peak Ground Acceleration: Model 18**

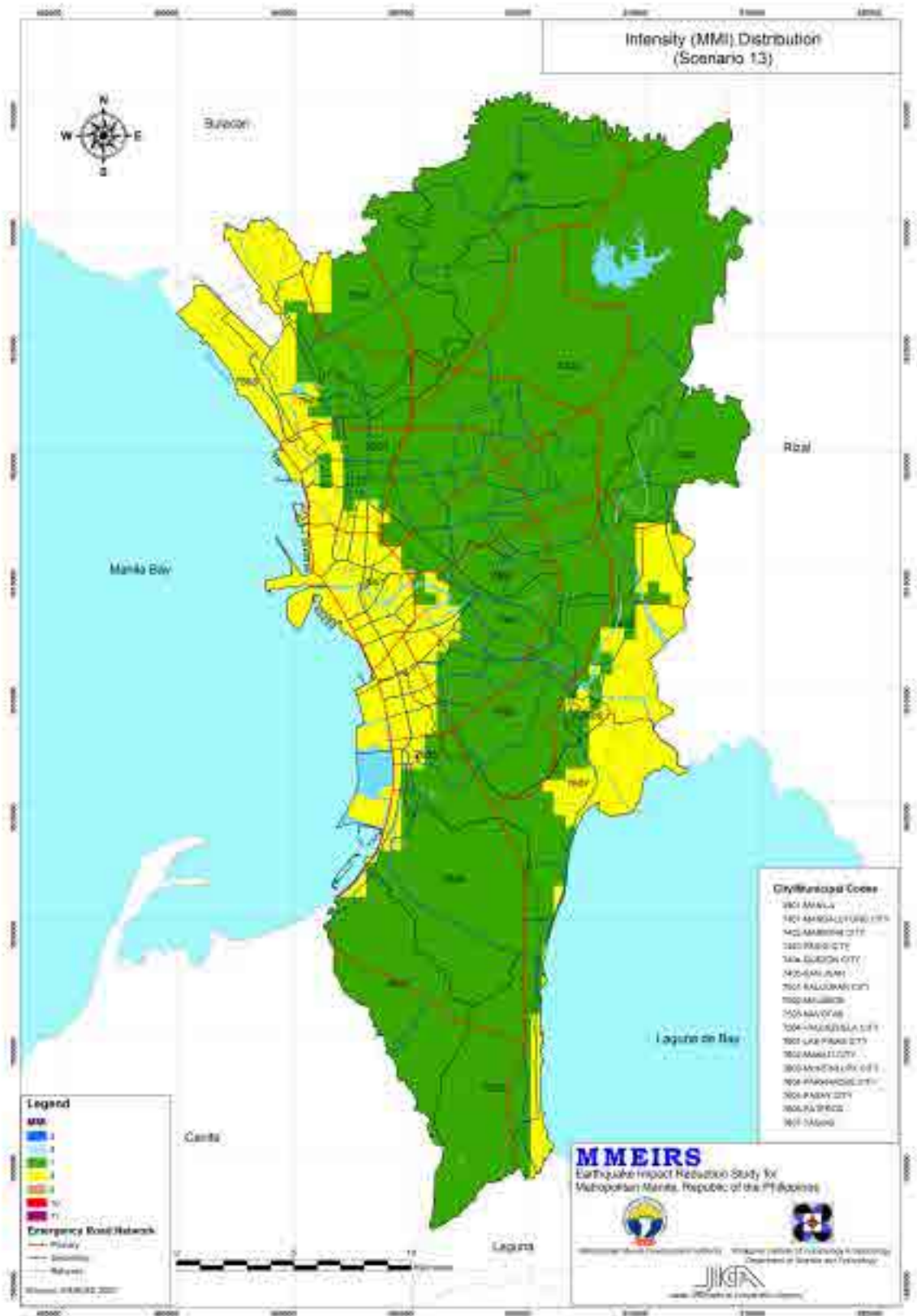**Figure 13.2.4   Distribution of Seismic Intensity in MMI Scale: Model 08**

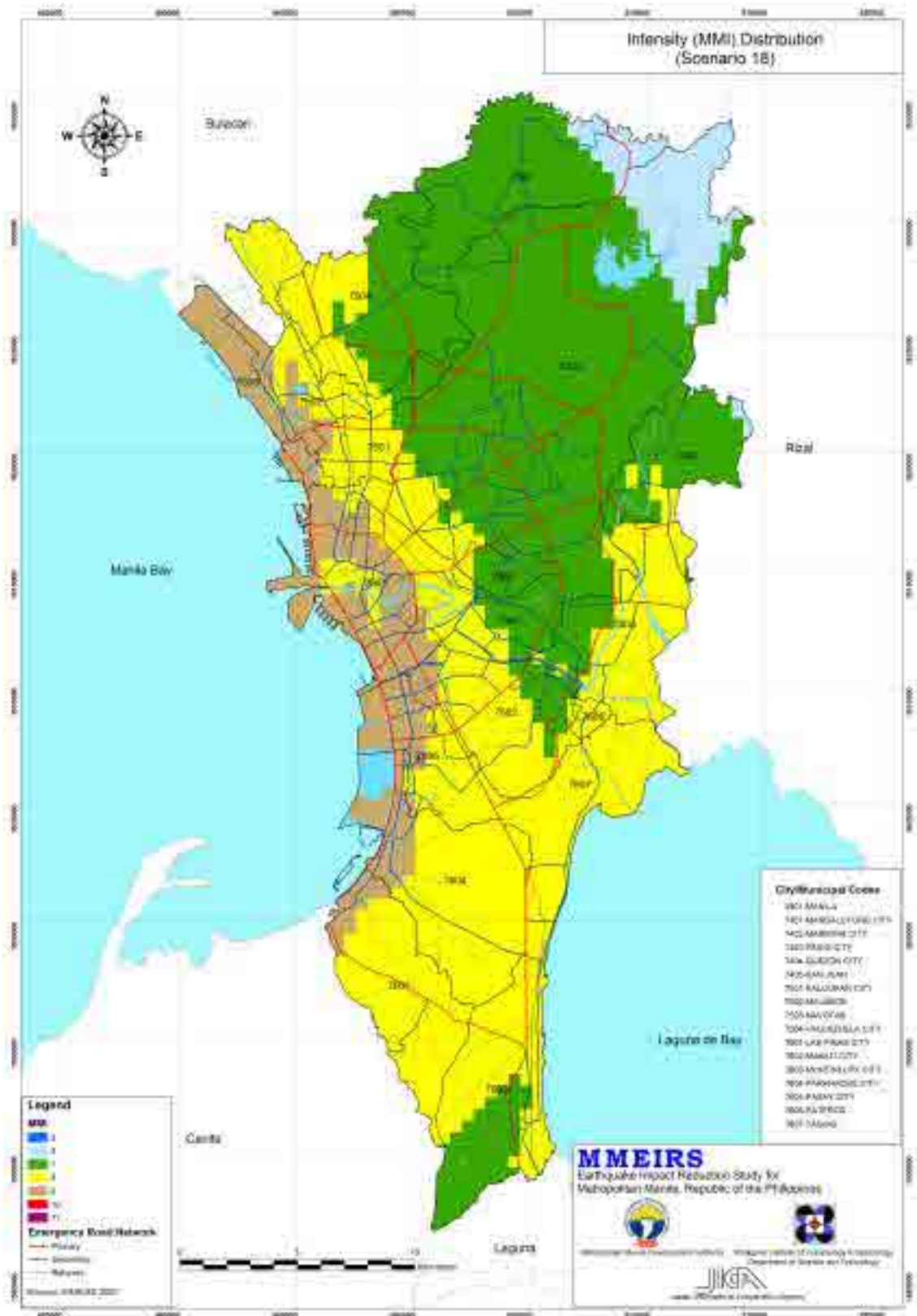**Figure 13.2.5   Distribution of Seismic Intensity in MMI Scale: Model 13**

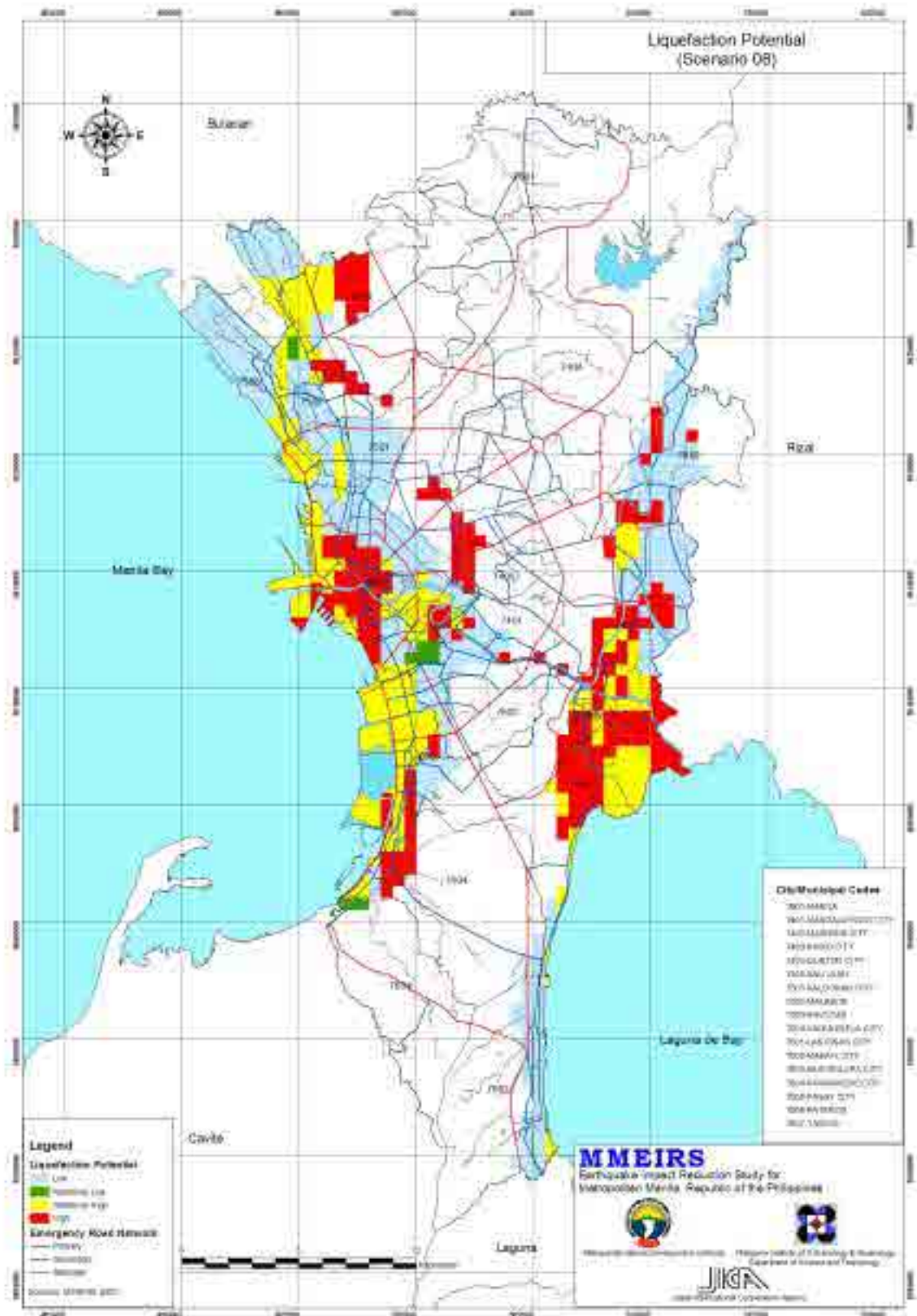**Figure 13.2.6   Distribution of Seismic Intensity in MMI Scale: Model 18**
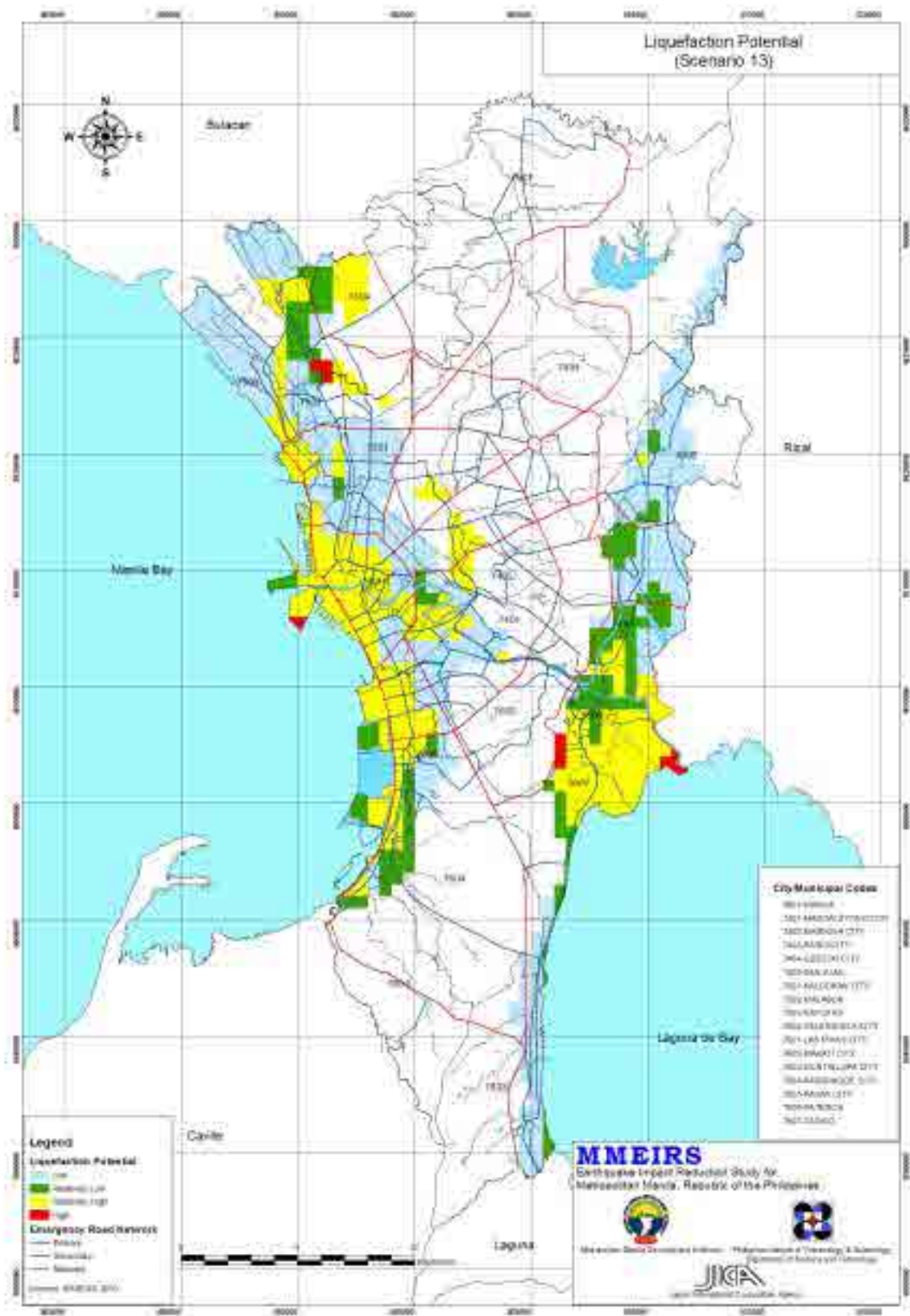
Figure 13.2.7   Liquefaction Potential Map: Model 08

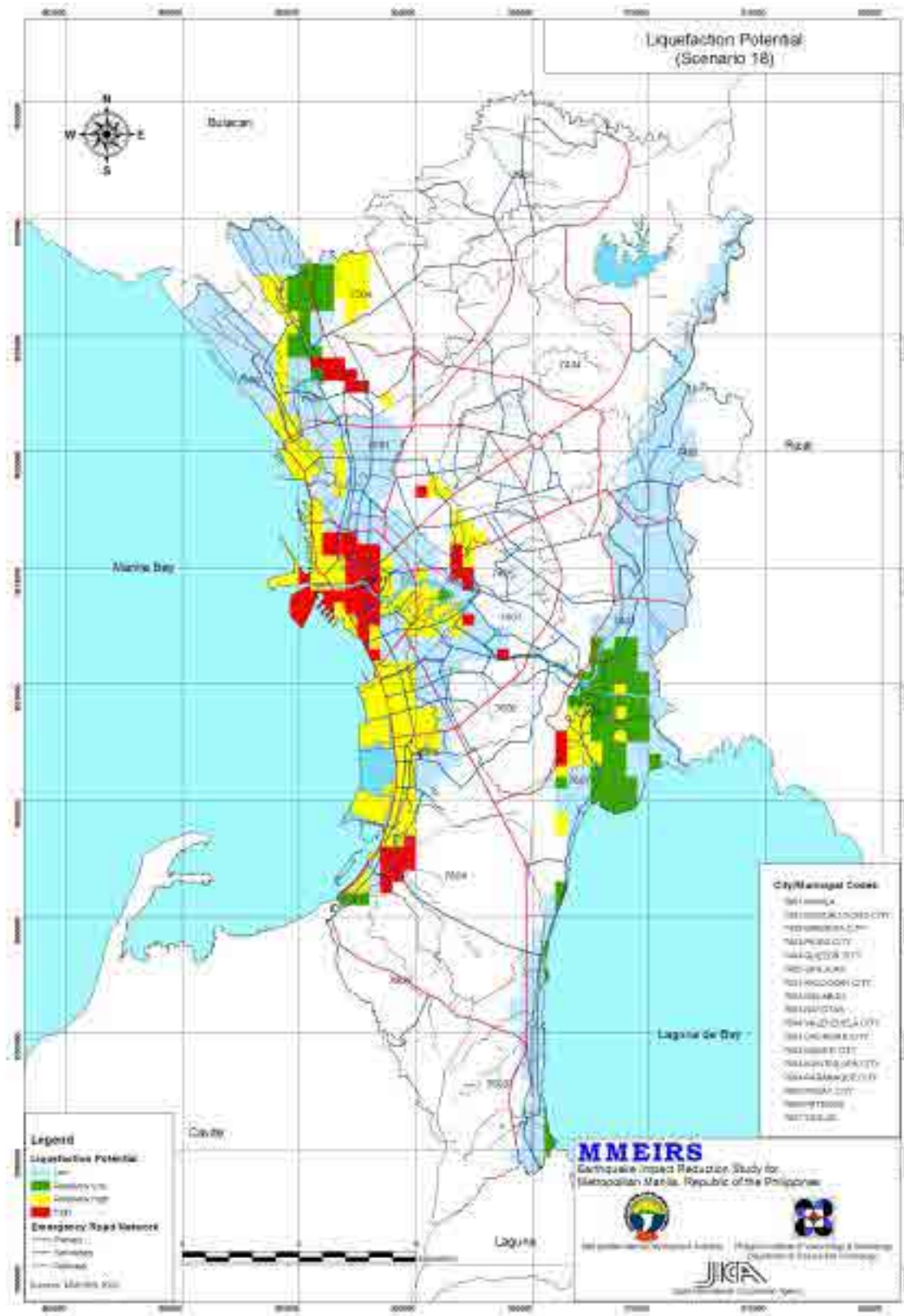**Figure 13.2.8   Liquefaction Potential Map: Model 13**

Figure 13.2.9   Liquefaction Potential Map: Model 18

13.3   Building Damages

It is necessary to classify the existing buildings in Metropolitan Manila, to know the distribution of them quantitatively and to establish the damage function of each building classifications for the estimation of the building damage by the earthquake. Figure 13.3.1 shows the schematic flow of the building damage estimation. For the present condition of the buildings in Metropolitan Manila, the building inventory of each 500m grids are estimated base on the "2000 Census of Population and Housing" by NSO and newly constructed Land Use Map in this study. The damage function was established in this study through the analysis of the 1990 Luzon Earthquake damage.

The seismic vibration and liquefaction are picked up as the direct cause of building damage. Damage due to the other causes, such as fault dislocation and landslide are not included. These phenomena will not be main cause of earthquake disasters in Metropolitan Manila because the affected area will be limited.
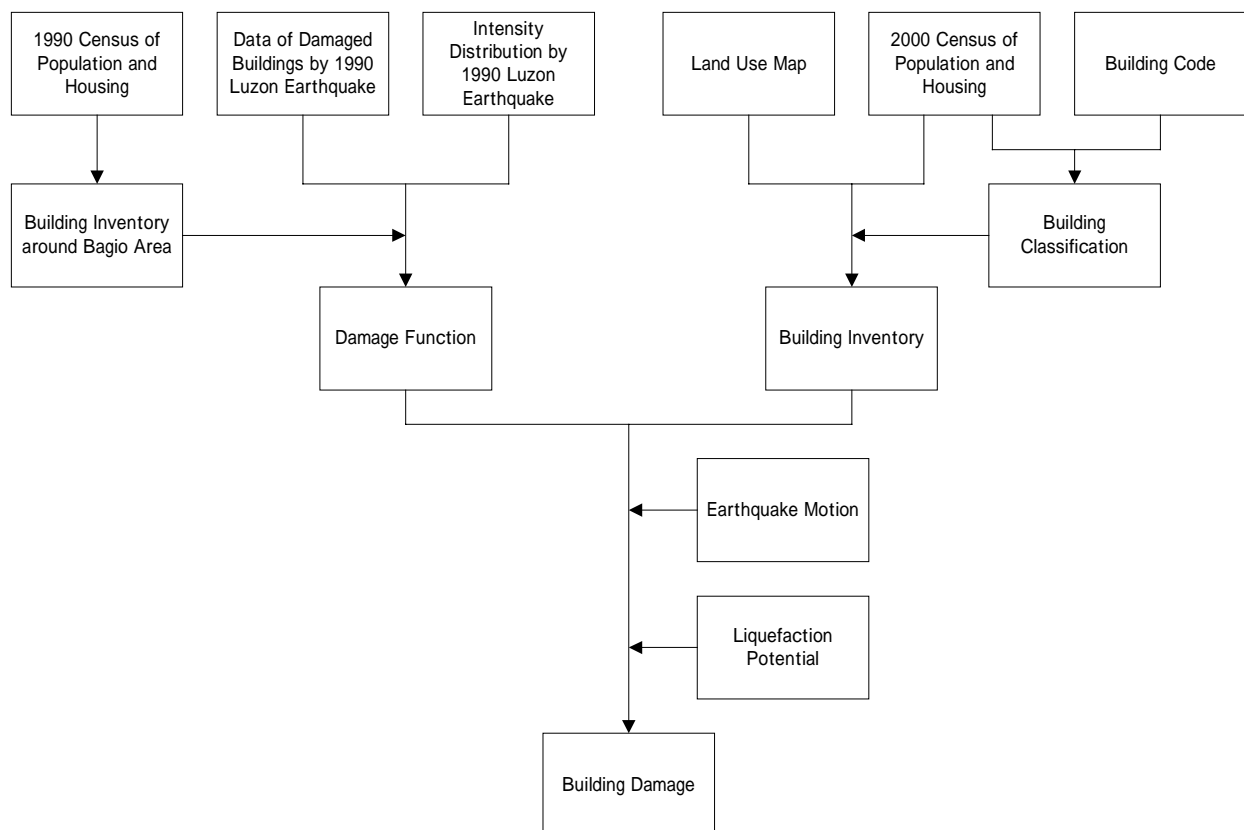
Figure 13.3.1   Flowchart of Building Damage Estimation

13.3.1 Building Inventory

1)   Census and Building Classification

The "Census for Population and Housing" includes many information and the items that is useful for damage estimation are summarized in Table 13.3.1. The building damage by past earthquake hazards show that the building structure, constructed year and floor number have strongly affected to the damage situation, but, unfortunately the information of floor number is not included in Census. The buildings with over 13 meters height, almost over 4 stories, count about 13,000 in Metropolitan Manila with the aerial photograph, which was taken in this study. This number is the 1% of the 1,300,000 buildings of Metropolitan Manila in total. This means that the 99% of the buildings in Metropolitan Manila are less than 4 stories. Therefore, the damage estimation without the information of building floor will not affect the result so much. The building was classified with Census information that is shown in Table 13.3.1.

Table 13.3.1   Important Information Items in Census for Building Damage Estimation

Item	Value
B3 Construction Materials of the Outer Walls	01 Concrete/brick/stone 02 Wood 03 Half concrete/brick/Stone/and half Wood 04 Galvanized iron/Aluminum 05 Bamboo/sawali/Cogon/Nipa 06 Asbestos 07 Glass 08 Makeshift/Salvaged/Improvised Materials 09 Others 10 No walls
B5 Year Building/House was Built	01 2000 02 1999 03 1998 04 1997 05 1996 06 1991-1995 07 1981-1990 08 1971-1980 09 1961-1970 10 1960 or earlier
D1 Floor Area of the Housing Unit	01 Less than 10 sq. m. 02 10 - 19 sq. m. 03 20 - 29 sq. m. 04 30 - 49 sq. m. 05 50 - 69 sq. m. 06 70 - 89 sq. m. 07 90 - 119 sq. m. 08 120 - 149 sq. m. 09 150 - 199 sq. m. 10 200 sq. m. and over

Before the building classification execution, basic information about buildings and building constructions in Philippines was collected by the research of building codes and interviews to the well-informed persons. The results are summarized as follows.

(1)   Building Code and Regulation

- Building code (NBCP: National Building Code of Philippines, Presidential Decree 1096) and earthquake resistant regulation (related chapter of NSCP: National Structural Code of Philippines) were first established in 1972. The earthquake resistant regulations were revised in 1981, 1986 and 1992. The newest revision of earthquake resistant regulations was decided in 2001 and soon will be promulgated.
- These code and regulation are based on the American Code (Uniform Building Code). The design seismic coefficient used in these code and regulation, the base shear coefficient is 0.1, is about half of Japanese standard.
- Before 1972, buildings were designed based on the American Code.
- The revision of seismic regulation in 1981 introduced the concept of ground condition consideration and the design seismic coefficient was increased.
- The design seismic coefficient of seismic regulation was modified in 2001 to be calculated using the distance from the fault.

(2)   Practice of Building Construction

- Every construction acts are requested to get a permit of building supervisor in LGU and display the permission number at the building site. The rule provides penalty to the offender but there are many unauthorized constructions.
- The examination of building supervisor is necessary to get a building permission, but in many cases, the investigation is limited only on drawings.
- Most of the high-rise buildings, which increased in these 20 years, seem to have been designed and constructed by systematized engineers. The seismic safety of these buildings may be secured.

(3)   Others

- - The building code regulates that all dwelling buildings should have over 10m2 floor area but there exists many smaller houses in squatter area. These illegal small houses were also treated as detached houses in census.
- - Wood was cheaper than concrete till 1970's and used as construction materials commonly. Wood is expensive in recent years and concrete is the main material for buildings.
- - Steel is very rare for building materials because of its high costs.

The census includes only the information about outer wall materials instead of column and beam materials and structures, which may have large effect to the building strength. It is known from site investigation that the outer wall materials and the column and beam materials have high

correlation. For example, most of the buildings with concrete outer wall have concrete column and beam and also most wood wall buildings have wooden column and beam. Therefore, the building classification based on the outer wall materials highly reflects the building strength.

Based on these information, site investigation and consideration, buildings in Metropolitan Manila were classified to seven categories as shown in Table 13.3.2 from census data. The census was conducted basically for the household unit and the several households in one building were treated separately in published database. To convert the household based database to building based database, the optional code to distinguish the households in one building was collected and used in the analysis.

Table 13.3.2   Classification of Buildings in Metropolitan Manila

Code	Outer Walls	Year Built	Floor Area	Number of Buildings		Number of Habitants
CBB	Concrete/brick/stone	-1980		162,988	(12%)	1,298,954
CBA		1981-		422,963	(32%)	3,015,957
CWB	Half concrete/brick/Stone/and half Wood	-1980		156,143	(12%)	1,435,172
CWA		1981-	> 10m^2	224,609	(17%)	1,670,382
WB	Wood	-1980		65,781	(5%)	623,557
WA		1981-		141,124	(11%)	1,016,235
S	Galvanized iron, Makeshift/Salvaged	All		152,292	(11%)	819,744
	All		≤ 10m^2			
Total				1,325,896		9,880,004

2)   Land Use Map and Building Density

The name of Barangay is written in census as the location of each building/household but the precise location in Barangay cannot be known from census data. The assumption of uniform distribution of the buildings in each Barangay is unrealistic because several Barangay are very wide and the difference of building type and density distribution cannot be neglected. The Land Use Map, which was made from aerial photo of this year in this study, has much precise resolution. To make the precise building distribution database, the Land Use Map was used and the building distribution in Barangay was estimated. Please refer to Chapter 7 for precise of Land Use Map.

The Land Use Map has the information not only the usage of the land but the building density for the residential area. Following five ranks was used for classification.

    a. Very Low Density (1 – 5 dwelling units/hectare)
    b. Low Density (6 – 20 dwelling units/hectare)
    c. Middle Density (21 – 65 dwelling units/hectare)
    d. High Density (66 – 90 dwelling units/hectare)
    e. Very High Density (91 & above dwelling units/hectare)

So, these building density ranks are used as the weight to estimate the precise building distribution within Barangay.

3)   Building Distribution

The precise building distribution was estimated and re-compiled to each 500m grids. The distributions of buildings by each classification are shown in Figure 13.3.2 to Figure 13.3.5. These figures show that the buildings of class "CBB + CBA" and "CWB + CWA" distribute in all area in Metropolitan Manila. The buildings of class "WB + WA" mainly exists from Manila to South Kalookan and the buildings of class "S" concentrates to north part of Manila to Navotas.
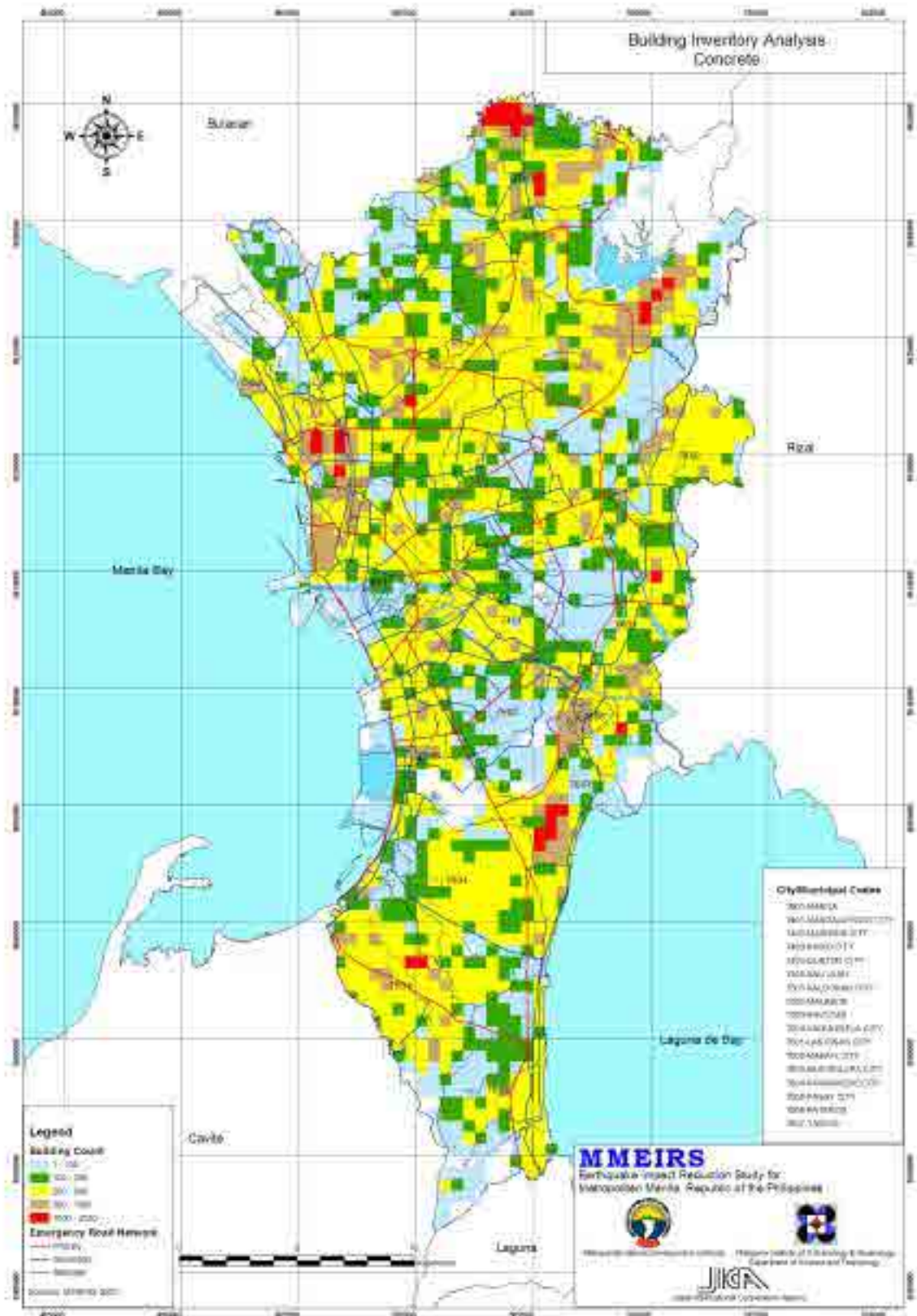
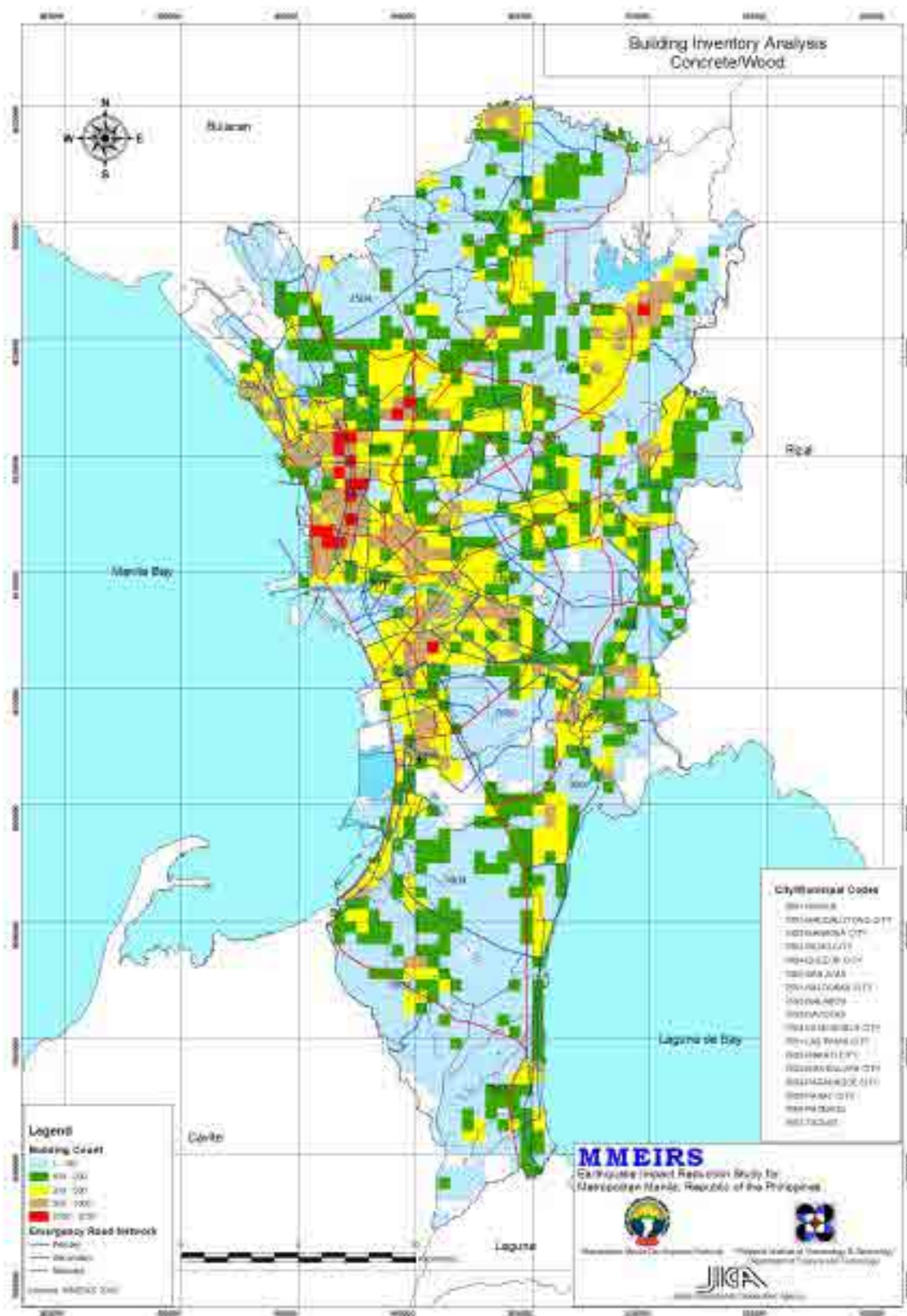**Figure 13.3.2   Classified Building Distribution - CBB + CBA -**

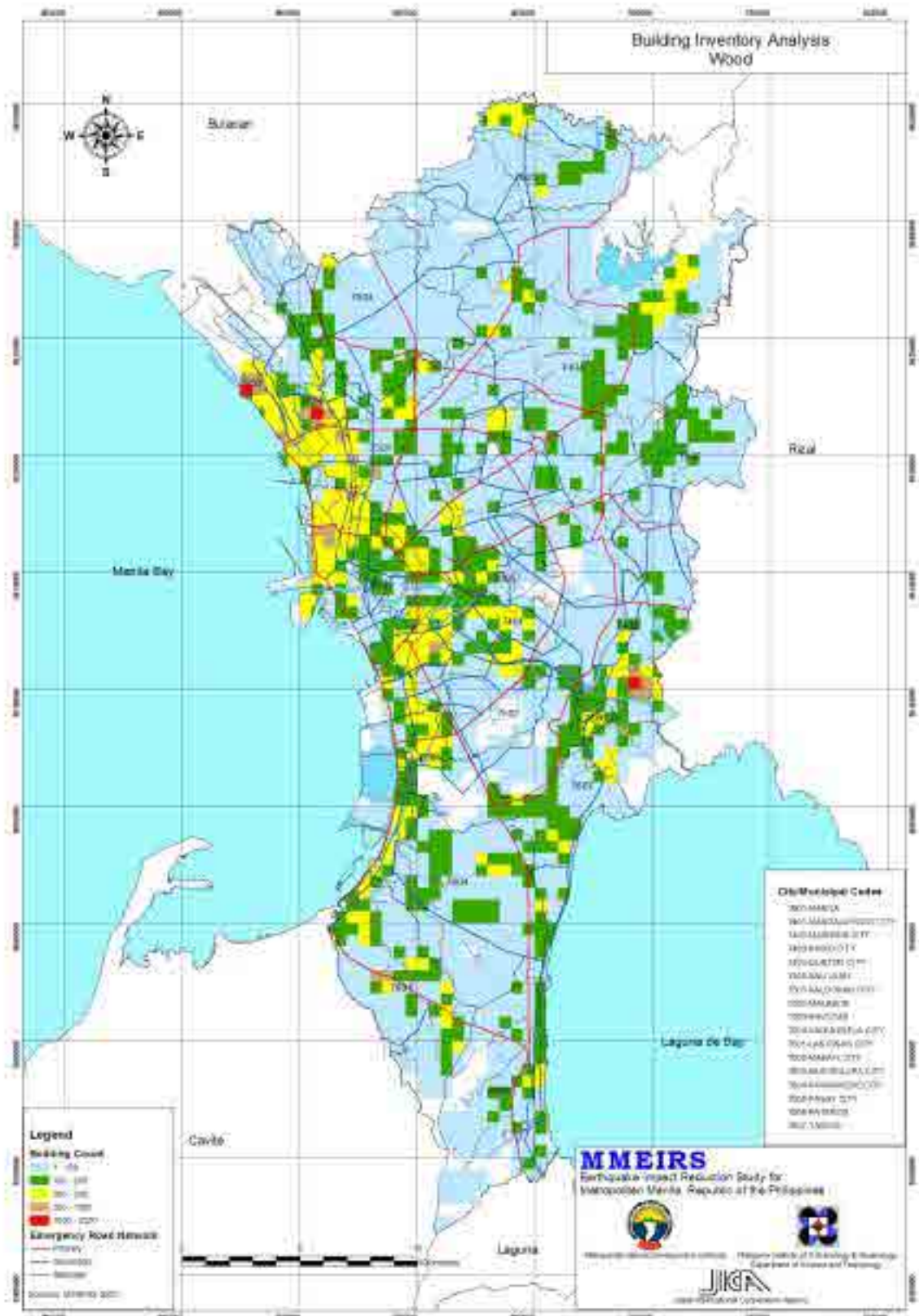**Figure 13.3.3   Classified Building Distribution - CWB + CWA -**

Figure 13.3.4   Classified Building Distribution - WB + WA
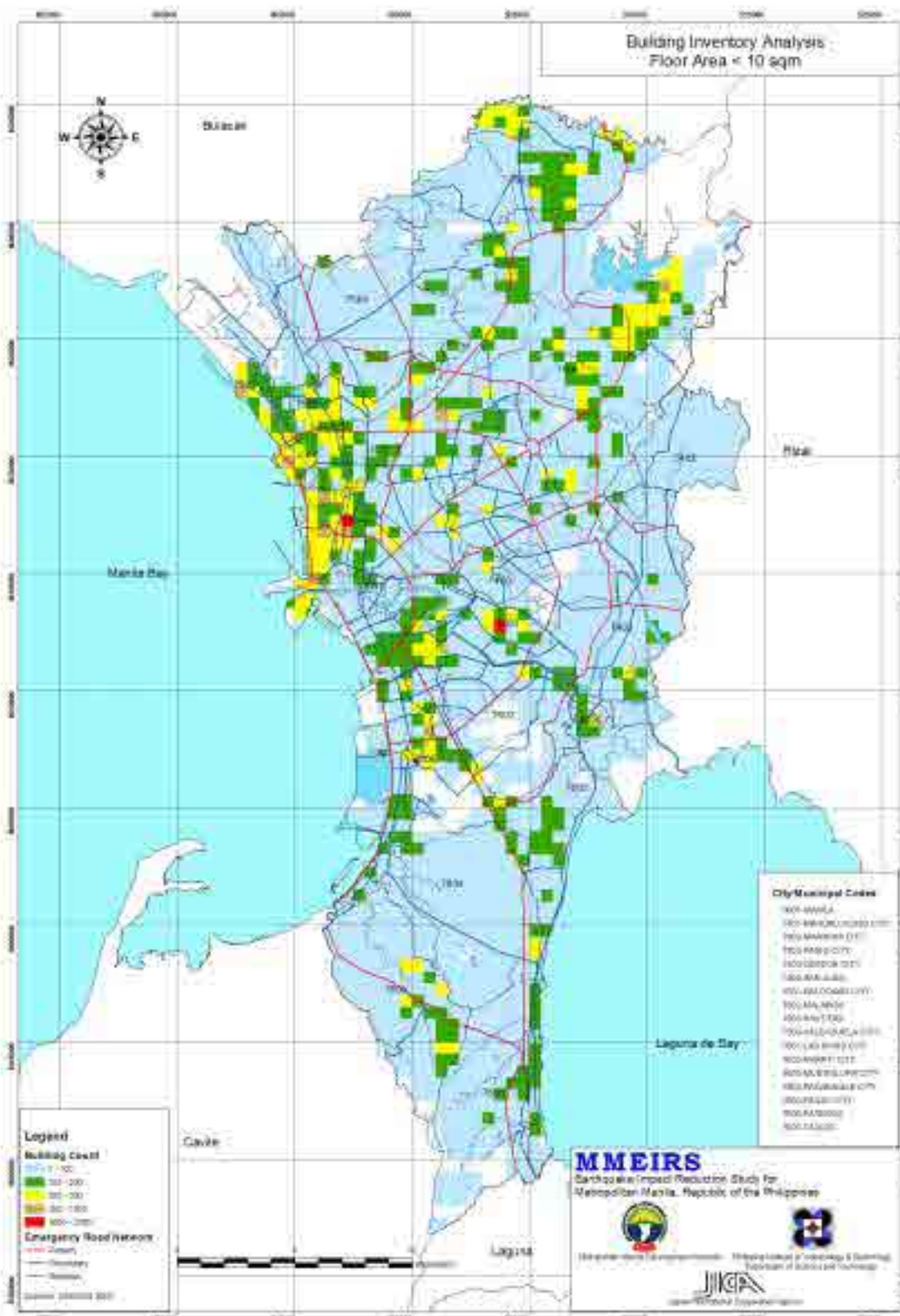
Figure 13.3.5   Classified Building Distribution - S -

13.3.2 Methodology

The building damage by the seismic vibration can be calculated comparing the seismic resistance of the buildings and the input motion to the buildings. The seismic intensity, acceleration, velocity, response spectrum, etc. are used as the earthquake motion. To express the seismic resistance of the buildings, the damage ratio to the earthquake motion and capacity spectrum are used. The relation with the seismic resistance and the input motion is usually called as damage function or fragility function/curve. This relation is strongly affected by not only the building structure but also the construction work. Therefore, the damage function is greatly different by country or region even if the structure is classified into same category, for example reinforced masonry shear-wall, because of the difference of building code or construction condition.

In this study, the damage function was made from the recent seismic damage experience in Philippines. The building damage by 1990 Luzon Earthquake was studied and the damage function, which is applicable to Metropolitan Manila, was derived.

1) The Damage by 1990 Luzon Earthquake

The damage by 1990 Luzon Earthquake is compiled and published by several organizations but there are significant differences in each other. AIJ(1992) compared several damage statistics and conducted site investigation of damaged area. They concluded that "Terminal Report on 16 July Earthquake Disaster Relief Operation as of October 9, 1990" by DSWD is the most reliable. The casualty, injured number and totally/partly damaged building number by each city/municipality are included in the report. The building damage by 1990 Luzon Earthquake was studied based on this damage statistics.

The census has been conducted every 10 years in Philippines. The building number and population of each city/municipality at the time of earthquake are known from the 1990 census. The ratio of totally and partly damaged buildings by city/municipality are calculated form these data and shown in Figure 13.3.6.

As for the earthquake motion of 1990 Luzon earthquake, no strong motion was recorded in damaged area. AIJ(1992) conducted questionnaire survey after the earthquake and studied the seismic intensity distribution in damaged area. The seismic intensity distribution in MMI scale is shown in Figure 13.3.7. The damage function was derived from the building damage ratio and the seismic intensity by questionnaire survey. The relation of heavily damaged ratio and partly damaged ratio to the seismic intensity in MMI scale was made.
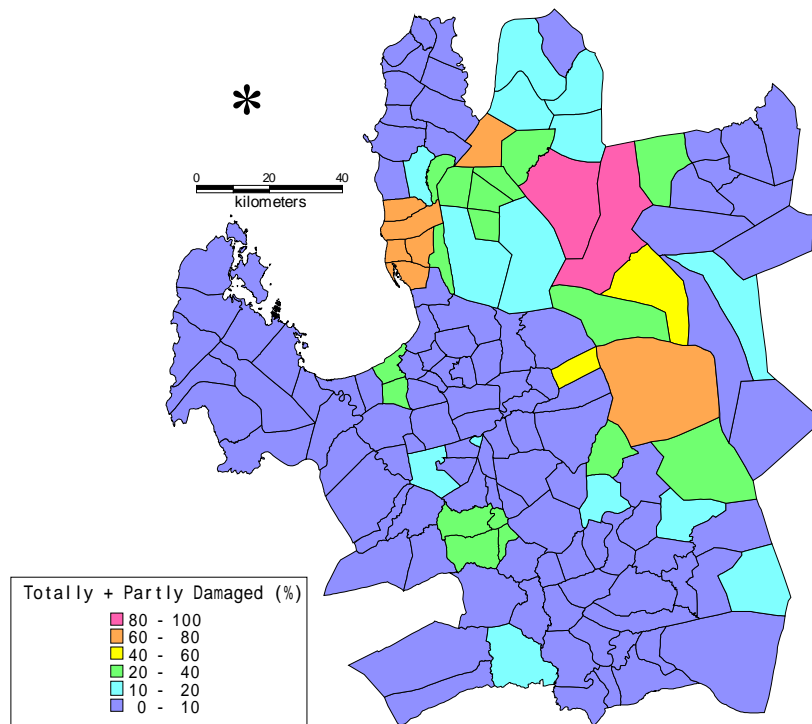
Figure 13.3.6   Distribution of Totally + Partly Damaged Buildings by 1990 Luzon Earthquake
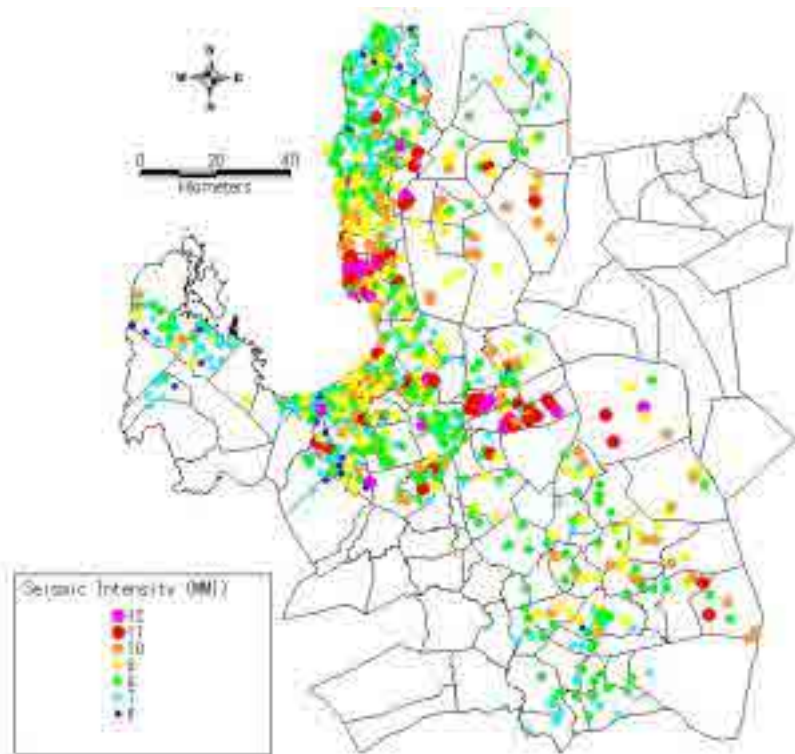

Figure 13.3.7   Seismic Intensity in by 1990 Luzon Earthquake

2) Damage Function

It is necessary to know the building structures in damaged area to make the building damage function. The same building classification to Metropolitan Manila, which is shown in Table 2.3.2, was applied to the damaged area by 1990 Luzon earthquake. The 1990 census data was used in the analysis and it is found that the bamboo is the main wall material in this area, which is not popular in Metropolitan Manila. Therefore the simple comparison of damage ratio and seismic intensity is not effective to make the damage function for Metropolitan Manila. The following assumptions and considerations are used to make the damage function.

a. The buildings in the damaged area by 1990 Luzon Earthquake were classified to following five classes based on the outer wall material.
- Concrete/brick/stone
- Half concrete/brick/Stone/and half Wood
- Wood
- Bamboo
- Galvanized iron

b. It is known that several areas are affected by liquefaction but the damage by the liquefaction cannot be distinguished in the damage statistics. The liquefied areas, such as Dagupan Agoo, etc., don't show different characteristics in the relation of damage ratio and seismic intensity, so these city/municipality were not excluded in the analysis.

c. The damage function was made after repeated trial and error based on the damage functions defined by ATC-13 considering that the building code in Philippines is based on UBC. The damage function for "concrete/brick/stone" and "half concrete/brick/stone and half wood" was made from "Reinforced Masonry Shear-Wall (with Moment-Resisting Frame) (Low Rise)" of ATC-13. The damage function for "wood", "bamboo" and "galvanized iron" was made from "Wood Frame (Low Rise)" of ATC-13.

d. The composition of classified buildings in each city/municipality was estimated and the damage function corresponding to the composition was made as initial model. Comparing the initial model to real damage, the damage functions for each building classification were shifted by trial and error to fit the damage situation in every city/municipality in total.

e. The effect of the difference of built year was estimated from the building code modification.

f. The damage function for buildings classified to "S (floor area is less than 10m^2)" was estimated from other damage functions because "S" class building was very little in damaged area by 1990 Luzon Earthquake.

The damage function for the city/municipality, where most outer wall is made by bamboo or half concrete/brick/stone and half wood, is shown for example in Figure 13.3.8. Heavily or partly damaged ratio of each city/municipality is also plotted in this figure. Every damage function was

made to explain the real damage situation in total but it should be kept in mind that the damage function corresponds to general damage situation and larger or smaller damage may occur.

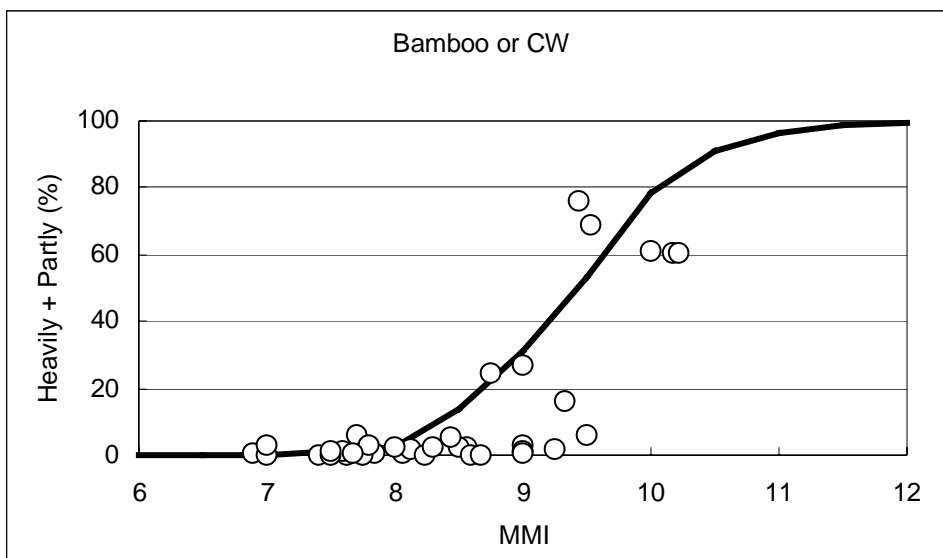The building damage functions for Metropolitan Manila are shown in Figure 13.3.9 to Figure 13.3.10.

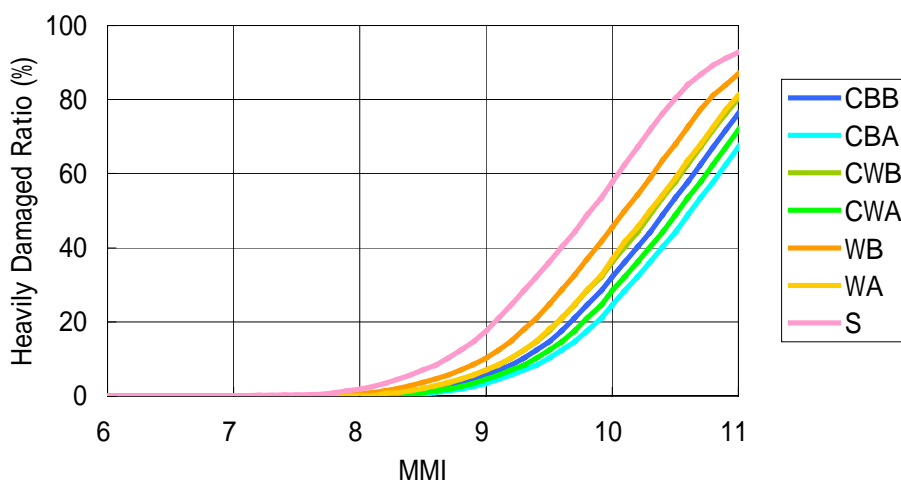**Figure 13.3.8   Example of Estimated Damage Function for 1990 Luzon Earthquake**

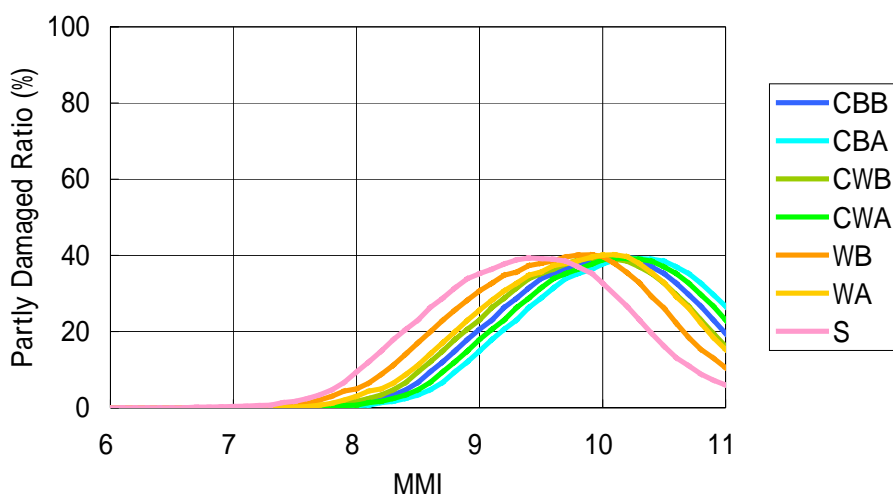**Figure 13.3.9   Heavily Damage Function for Metropolitan Manila**

Figure 13.3.10   Partly Damage Function for Metropolitan Manila

3)   Liquefaction Damage

The liquefaction never occurs in all of the expected liquefaction potential area. The experience of past earthquake hazard show that liquefaction occurs in part of the high liquefaction potential area. Based on the experience in Japan, Tokyo(1997) made the liquefaction area ratio in liquefaction potential area, which is shown in Table 13.3.3. Tokyo(1997) also estimated that 10% or 20% of wooden buildings in liquefied area will be heavily or partly damaged. Considering the difference of fragility of the buildings in Philippines and in Japan, the liquefaction area ratio and damage ratio by Tokyo(1997) were adopted to all the buildings in Metropolitan Manila. To avoid the overlap of liquefaction damage and vibration damage, the damage by seismic vibration was counted only in non-liquefied area.

Table 13.3.3   Liquefaction Area Ratio in Liquefaction Potential Area

Liquefaction Potential	Liquefaction Area Ratio
High ($15 < P_L$)	18%
Relatively High ($5 < P_L \leq 15$)	5%
Relatively Low ($0 < P_L \leq 5$)	2%
Low ($P_L = 0$)	0%

13.3.3 Damage Estimation

The definition of building damage estimation is shown in Table 13.3.4. Building damage was calculated based on scenario earthquakes Model 08, Model 13 and Model 18.   In these estimations, residential building included in the census for the year 2000 is included. Important

public facilities such as schools, hospitals, and fire stations will be studied separately in next section.

Buildings were calculated as "heavily" or "partly" damaged. "Heavily" damaged buildings are buildings that are severely damaged or have collapsed, and these buildings are unfit to occupy until they are repaired or rebuilt. "Partly" damaged buildings are buildings that are able to used for evacuation purposes just after the hazard, but they need to be repaired before occupied permanently. The cause of damage is limited to the seismic vibration and liquefaction. Damage due to fire will be calculated in next chapter.

Damage was calculated for each 500m grids and total damage number for each LGU was counted. A summary of results is shown in Table 13.3.5 and the damage for each LGU is shown in Table 13.3.6. The distribution of damage number is shown in Figure 13.3.11 to Figure 13.3.13 and damage ratio is shown in Figure 13.3.14 to Figure 13.3.16.

Characteristics of damage for three scenario earthquakes are as follows:

1) **Model 08**

The total number of heavily or partly damaged buildings is estimated as 170,000 or 340,000. This is 13% or 26% of total buildings in Metropolitan Manila, namely the buildings that need repair for occupy, is about 40%. The damage by liquefaction counts 9,300. Marikina and Pasig show most high heavily damage ratio of more than 30%. The lakeshore in Muntinlupa shows over 30% heavily damage ratio. More than 20% buildings from Manila to Pasig will be heavily damaged.

The area with high damage ratio corresponds to high seismic intensity zone along WVF, but the distribution of the area with large number of damaged buildings has different aspect. The damage number in one grid along WVF is almost same to Manila Bay area. The damage in central plateau is small in number and also in ratio because the earthquake motion is small and building density is low.

2) **Model 13**

This is the model of huge subduction type earthquake with magnitude 7.9 along Manila Trench. The earthquake motion in Metropolitan Manila is not large because the source region is far from Metropolitan Manila. Therefore, the building damage is much smaller than Model 08. The heavily Damage ratio is less than 5% in all of the Metropolitan Manila. About 1,900 buildings will be heavily damaged and 6,600 will be partly damaged. From North Port to Navotas along Manila Bay shows relatively heavy damage.

In addition, the damage by flooding is expected along Manila Bay if tsunami occurs. Low-rise wooden or half wooden buildings may be swept off by tsunami.

3)   Model 18

This is the earthquake that may occur in Manila Bay. The damage along Manila Bay is large in number and ratio. About 14,000 buildings will be heavily damaged and 53,000 will be partly damaged. From North Port to Navotas along Manila Bay shows especially heavy damage. The damage in Marikina Valley and the area along Lagna de Bay is small.

Table 13.3.4   Definition of Building Damage

Object	Residential Buildings (included in Census 2000)		
Cause of damage	Seismic vibration and Liquefaction		
Definition of damage grade	Heavily	Collapse or heavy structure damage	
		For evacuation: Unusable, Danger	
		For living: Unusable without repair or rebuild	
	Partly	Moderate structure damage	
		For evacuation: Usable	
		For living: Necessary for repair	

Table 13.3.5   Summary of Building Damage

Model	Heavily		Partly	
08	165,200	(12.7%)	333,600	(25.6%)
	3,100		6,200	
13	700	(0.1%)	4,100	(0.5%)
	1,300		2,600	
18	12,500	(1.1%)	49,300	(4.0%)
	1,700		3,400	

by Vibration
by Liquefaction

Table 13.3.6 Building Damage by LGU

| LGU Code	Name	Building Number	Damage by Model 08				Damage by Model 13				Damage by Model 18			
			Number (x 1,000)		Ratio		Number (x 1,000)		Ratio		Number (x 1,000)		Ratio	
			Heavily	Partly	Heavily	Partly	Heavily	Partly	Heavily	Partly	Heavily	Partly	Heavily	Partly
390	Manila	168,528	24.6	50.1	14.6%	29.8%	0.6	2.1	0.3%	1.2%	5.7	20.1	3.4%	11.9%
741	Mandaluyong	32,942	4.3	9.6	12.9%	29.2%	0.0	0.0	0.0%	0.1%	0.1	0.3	0.2%	0.9%
742	Marikina	53,422	15.0	18.8	28.1%	35.1%	0.0	0.1	0.0%	0.1%	0.0	0.1	0.0%	0.1%
743	Pasig	72,143	22.8	25.6	31.5%	35.5%	0.2	0.6	0.3%	0.8%	0.2	1.0	0.3%	1.4%
744	Quezon	302,818	25.8	69.6	8.5%	23.0%	0.1	0.2	0.0%	0.1%	0.1	0.5	0.0%	0.2%
745	San Juan	11,793	1.2	3.1	9.8%	26.4%	0.0	0.0	0.1%	0.2%	0.0	0.1	0.2%	0.8%
751	Valenzuela	62,778	2.1	7.3	3.3%	11.6%	0.1	0.2	0.1%	0.4%	0.2	0.9	0.3%	1.4%
752	Kalookan	168,480	6.5	23.4	3.9%	13.9%	0.1	0.2	0.0%	0.1%	0.4	1.9	0.2%	1.1%
753	Malabon	51,694	4.3	11.7	8.2%	22.7%	0.1	0.5	0.2%	1.0%	1.2	4.8	2.3%	9.3%
754	Navotas	35,124	5.1	10.9	14.6%	31.0%	0.2	1.0	0.6%	2.9%	2.4	7.5	6.8%	21.3%
761	Las Pinas	73,919	5.9	16.7	8.0%	22.6%	0.0	0.1	0.0%	0.1%	1.0	3.9	1.3%	5.3%
762	Makati	50,381	8.9	16.4	17.7%	32.5%	0.1	0.2	0.2%	0.4%	0.4	1.5	0.7%	3.1%
763	Muntinlupa	55,522	13.3	19.0	24.0%	34.1%	0.0	0.1	0.0%	0.2%	0.2	1.1	0.4%	2.0%
764	Paranaque	72,230	9.0	20.9	12.4%	28.9%	0.1	0.2	0.1%	0.3%	1.0	3.9	1.4%	5.4%
765	Pasay	39,968	6.8	12.8	17.0%	32.1%	0.1	0.4	0.4%	1.1%	1.0	4.0	2.6%	10.1%
766	Pateros	8,726	1.6	2.9	18.8%	33.0%	0.0	0.1	0.4%	1.1%	0.1	0.2	0.6%	2.6%
767	Taguig	65,428	11.2	21.0	17.1%	32.2%	0.1	0.4	0.2%	0.6%	0.2	0.8	0.3%	1.2%
	Total	1,325,896	168.3	339.8	12.7%	25.6%	1.9	6.6	0.1%	0.5%	14.2	52.7	1.1%	4.0%
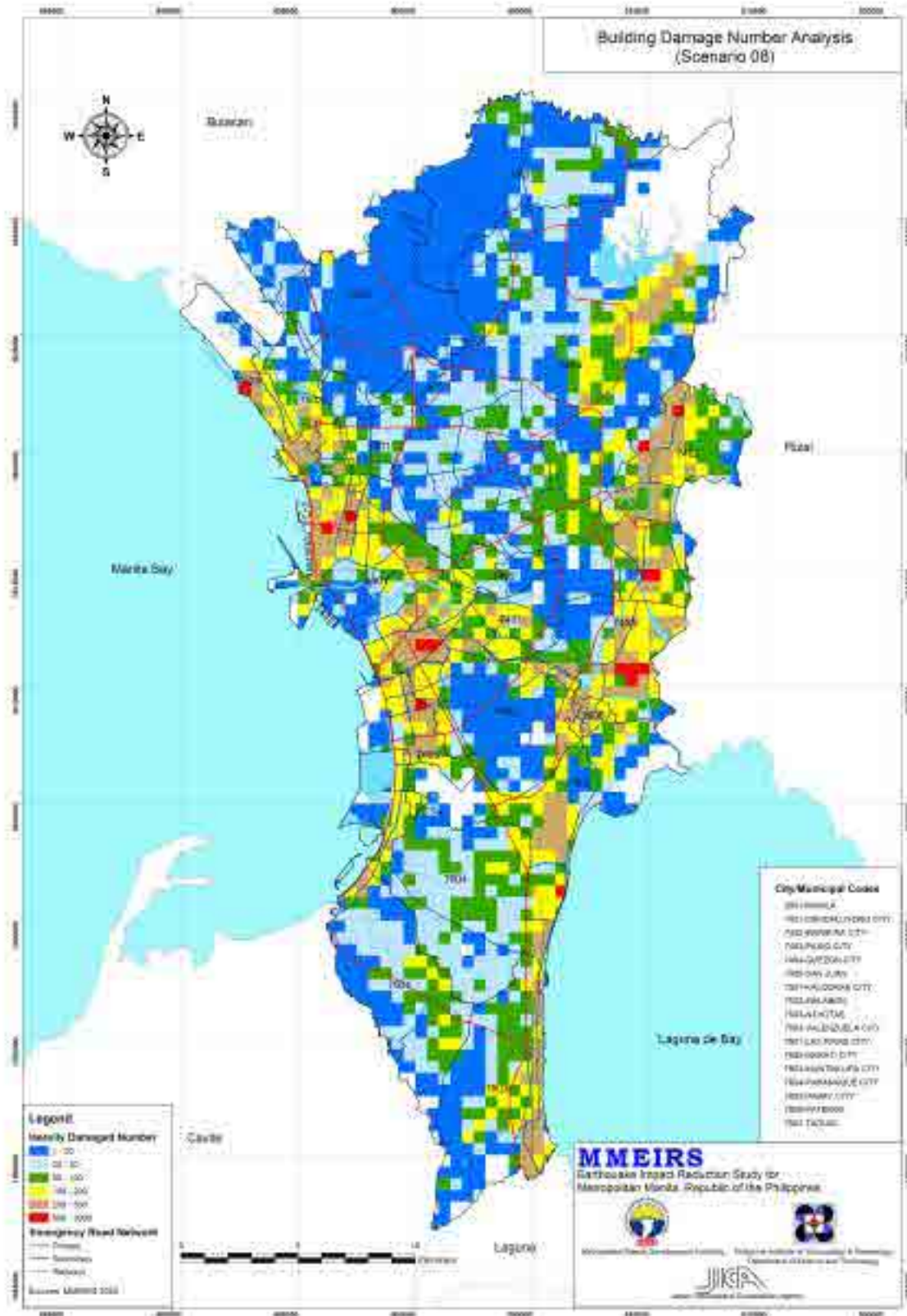
Figure 13.3.11   Number of Heavily Damaged Buildings : Model 08
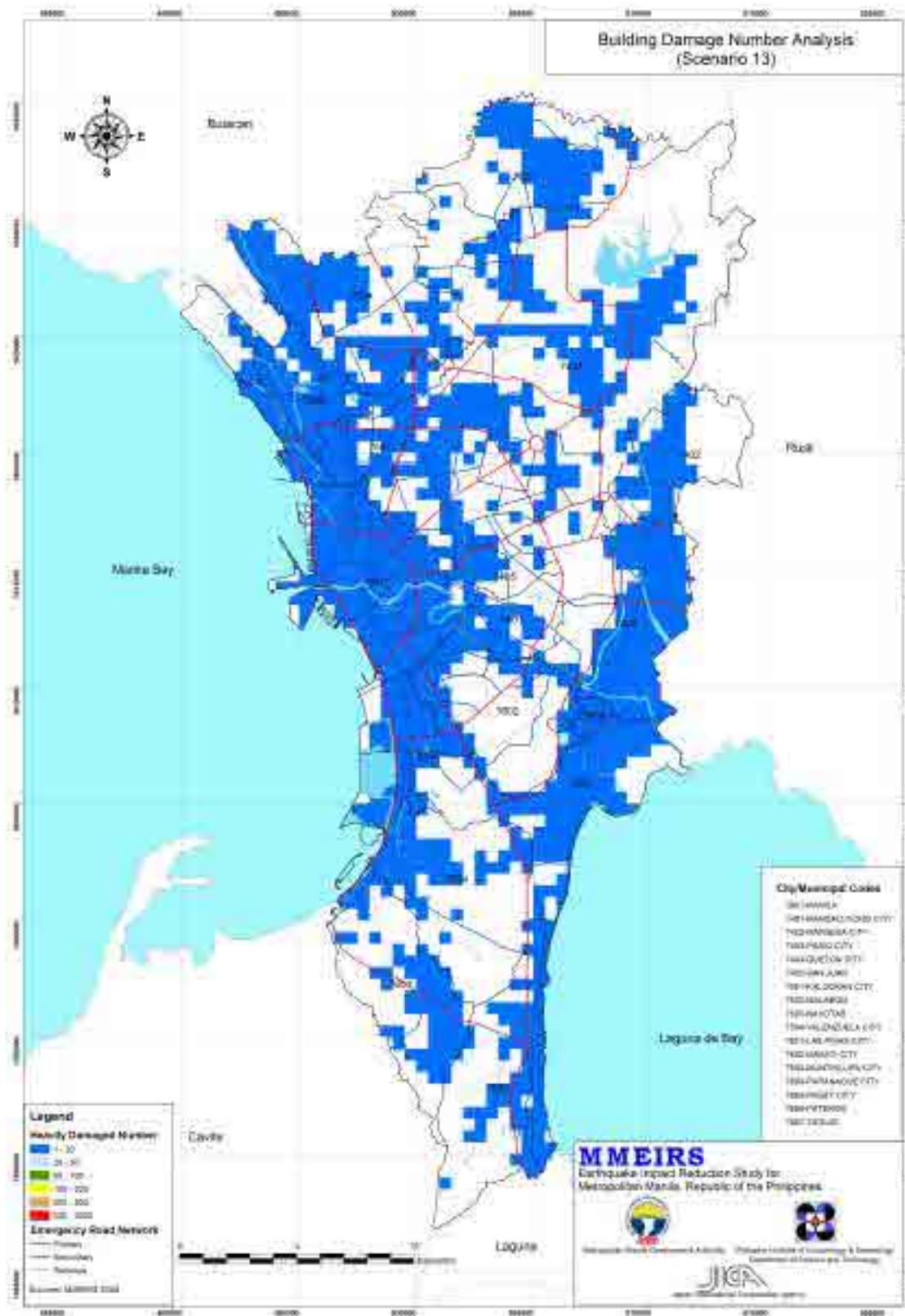
Figure 13.3.12   Number of Heavily Damaged Buildings : Model 13
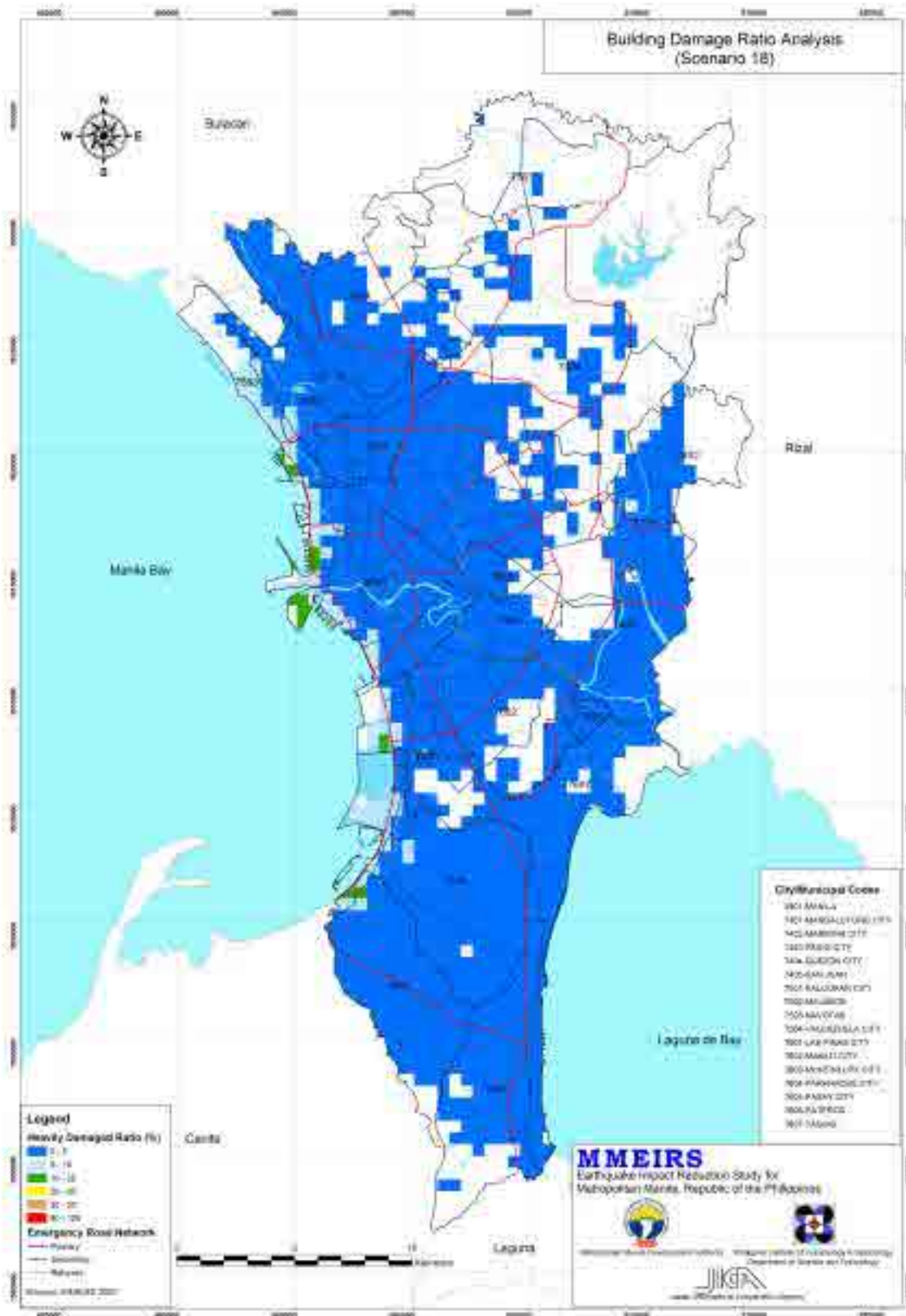
Figure 13.3.13   Number of Heavily Damaged Buildings : Model 18
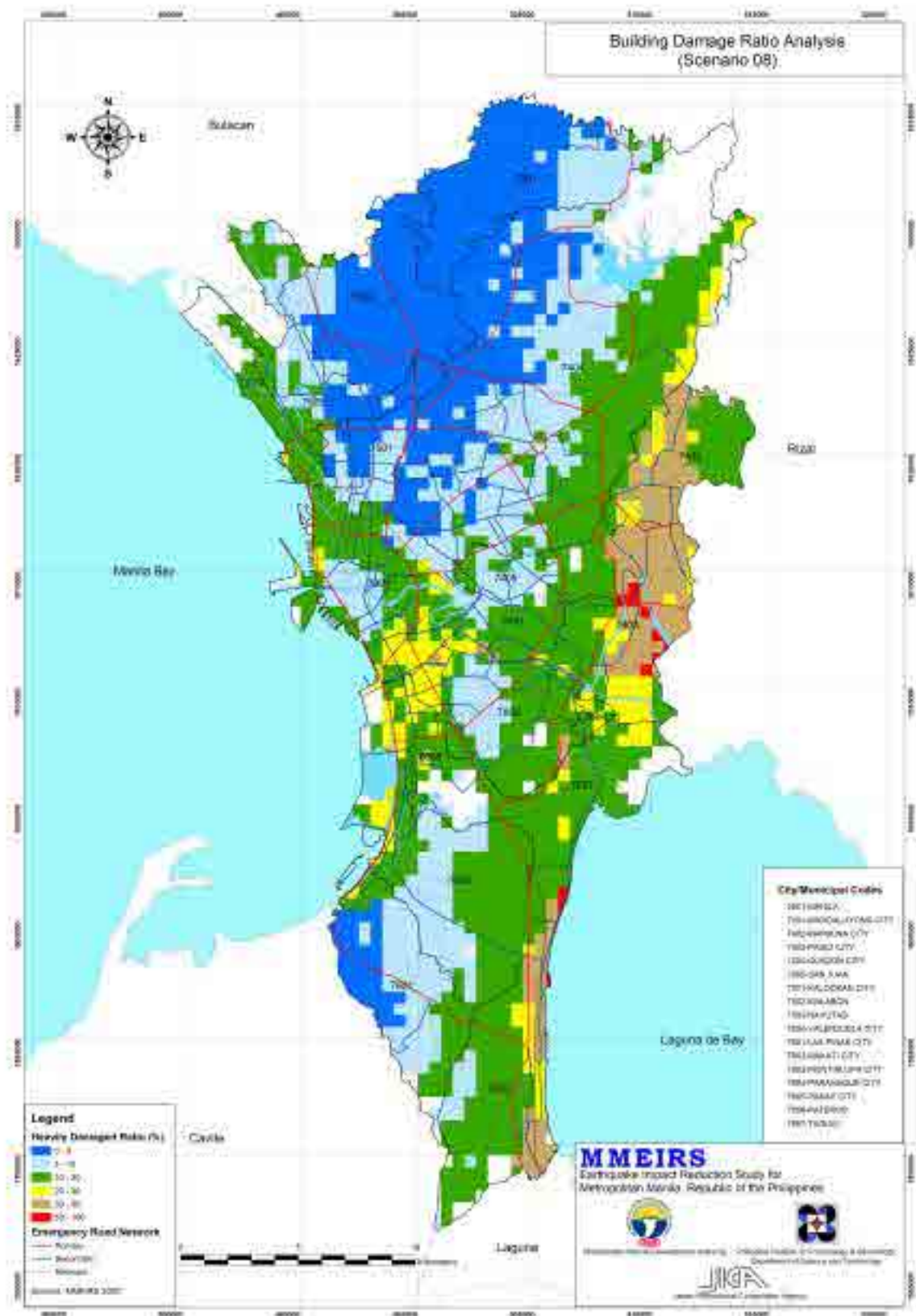
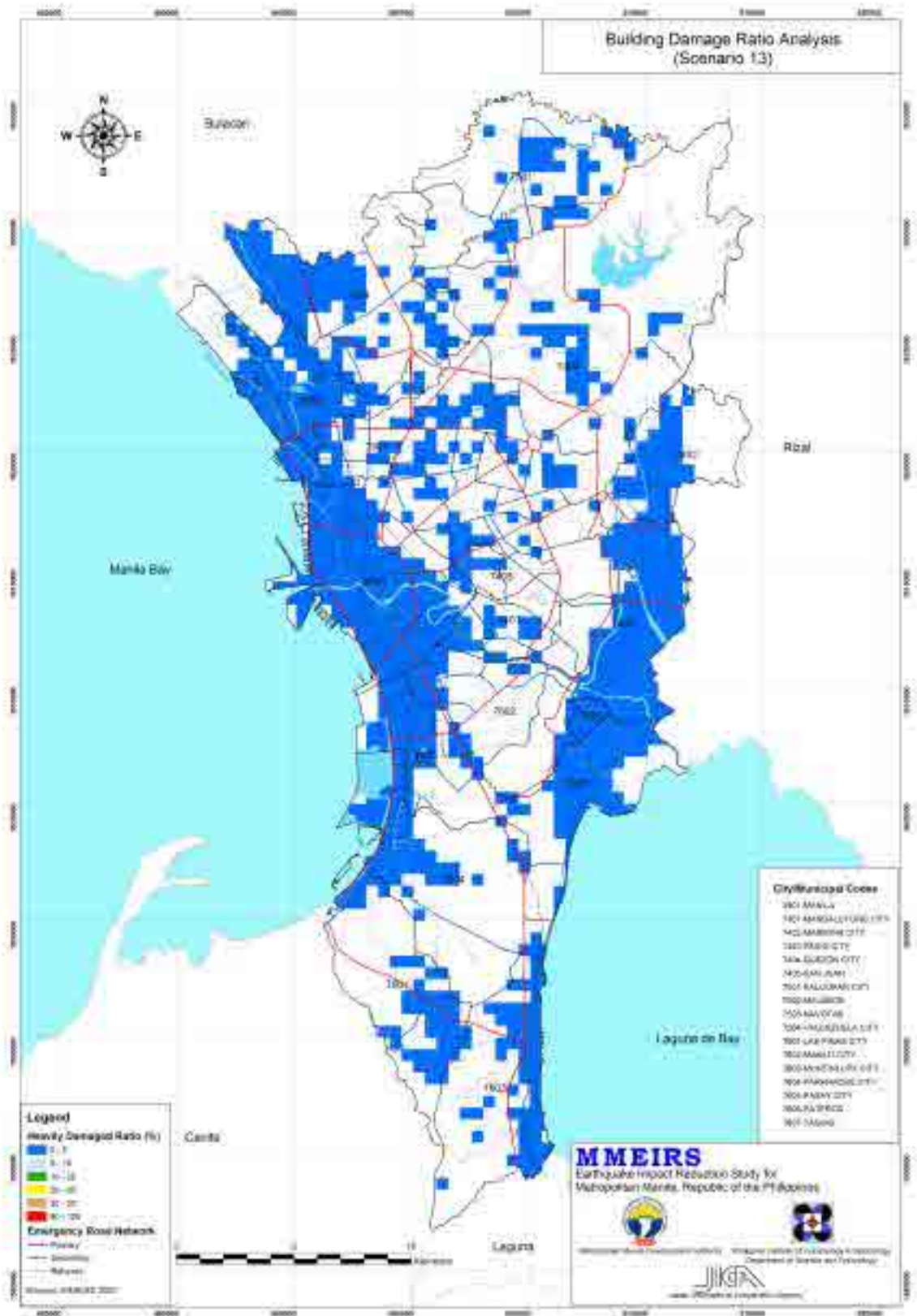**Figure 13.3.14   Ratio of Heavily Damaged Buildings : Model 08**

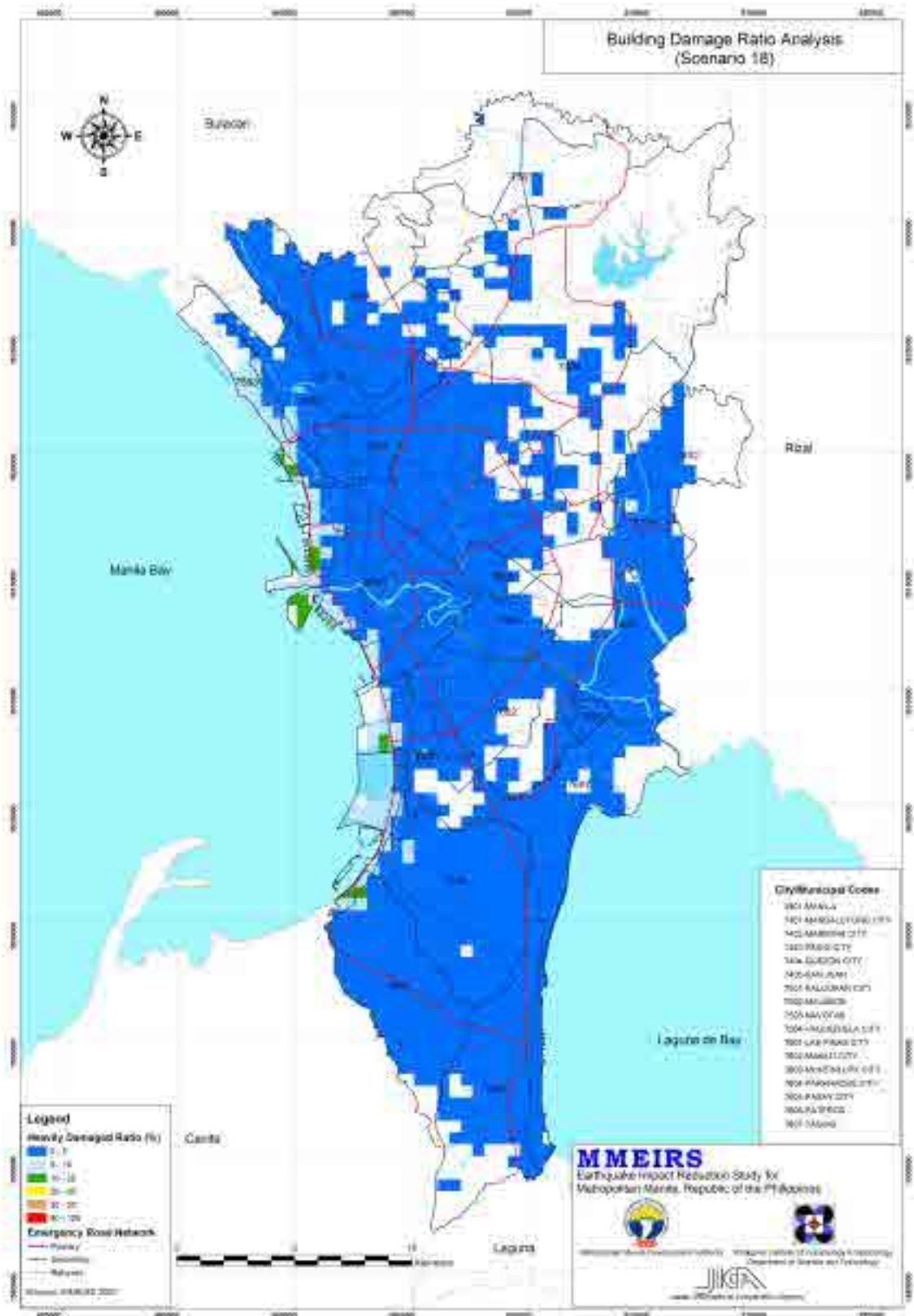**Figure 13.3.15   Ratio of Heavily Damaged Buildings : Model 13**

Figure 13.3.16   Ratio of Heavily Damaged Buildings : Model 18

13.3.4 Damage to Public Facilities

The damage of the following major public facilities was estimated. These public facilities should play critical roles as disaster management base or evacuation shelter on earthquake disaster.

a. School :

b. Hospital :

c. Police Station :

d. Fire Station :

e. MMDCC :

In general, the structure and layout of these public facilities is different in each other reflecting their different purposes. Therefore, the individual earthquake resistant diagnosis is recommended for damage estimation. Within the scope of this study, damage estimation on the public facilities was conducted using following simple assumption.

- Based on the site investigation of public facility buildings, most buildings have reinforced concrete column and beam and CHB outer wall. This structure is classified to "CB" of residential buildings.
- It is provided in building code that the importance factor of the buildings should be considered for design. Therefore the public facilities are expected to have higher earthquake resisting capacity than residential buildings in planning.
- Most public facility buildings are taller than residential buildings. If the structure is same, the earthquake resisting capacity becomes lower in proportion to the height of the buildings.
- Public facilities have both items of higher and lower earthquake resisting capacity than residential buildings as above mentioned. It is difficult to study the difference quantitatively based on the available data, however the difference of the earthquake resisting capacity may not be large from class "CBA" of residential buildings. The damage of public facility buildings was estimated using the damage function of "CBA" in this study.

A summary of results is shown in Table 13.3.7. Almost 8 to 10% of the public facility buildings will be heavily damaged in Model 08. More than 100 school building will be heavily damaged. If the earthquake of Model 08 may occur in daytime of weekdays, the casualty damage of students will become serious.

Table 13.3.7   Summary of Public Facilities Damage

Facility	Number of Facilities	Model 08		Model 13		Model 18	
		Heavily	Partly	Heavily	Partly	Heavily	Partly
School	1,412	115	300	2	4	8	30
Hospital	177	14	36	0	0	1	4
Police Station	43	4	9	0	0	0	1
Fire Station	124	12	28	0	0	1	3
MMDCC	53	4	12	0	0	0	1

13.3.5 Damage to High-rise Buildings

The commercial buildings or hotels are not included in census data because census was conducted for residential buildings. Therefore the estimated damage in section 13.3.3 doesn't include the damage of commercial buildings or hotels. The high-rise condominium is included in census data but it is impossible to distinguish them from the other low-rise buildings because the floor number of the buildings was not surveyed in census. It is desirable to estimate the damage of high-rise buildings separately because they have different characteristics from low-rise buildings. The 1/5,000 topographical maps, which were made in this study, have the information of building height. The building location and height more than 13 meters was digitized. The damage of high-rise buildings was conducted using this database. About 1,100 buildings in Metropolitan Manila are taller than 30 meters. Out of these, 120 buildings are taller than 100 meters.

There is no experience of earthquake damage of high-rise buildings in Philippines. The same procedure to make damage function for residential buildings cannot be used for high-rise buildings. So the high-rise building damage was estimated based on the capacity spectrum method, which is used in HAZUS99. The simplified bi-linear model was used as capacity spectrum of high-rise buildings. In case of Model 08, about 10% of building of 30m over and 2% of buildings of 100m over were estimate to be heavily damaged. However, the capacity spectrum that was used in the analysis was estimated from building code of Philippines and the standard value in Japan, it is not verified by individual structure calculation or damage experiences. Therefore, it should be noted that the estimation in this section is preliminary.

13.4   Human Casualties

Direct causes of earthquake casualty include collapse of buildings, fires, tsunamis, landslides, falling objects, die of shock, etc. Among them, human casualty due to building collapse is a general phenomena observed in all areas subject to earthquake disasters. The main cause of casualty may differ site-by-site depending on the ground, building and social environment. The fire sometimes killed many people after earthquake in Japan because most of residential houses in

Japan are made by wood. The crash of weak buildings is the main cause of casualties in Turkey and India, where the brick or stone masonry without reinforcement is the main structure of residential houses. The effect of Tsunami is sometimes very large in Indonesia.

In Metropolitan Manila, the effect of building collapse, fire after earthquake and tsunami are pointed out for the cause of human casualty. The casualty by building damage is studied in this section. The effect of fire will be studied in the next section. The effect of tsunami for human casualty is not estimated in this study.

13.4.1 Methodology

The relation between building collapse and human casualties differ depending on the country, region and period. The differences of building structure and residential condition may affect. Therefore, it is desirable to make the damage function based on the recent earthquake hazard in neighboring region. In this study, the relation of building damage to death toll was studied based on the damage by 1990 Luzon Earthquake. The flowchart of human casualty damage estimation is shown in Figure 13.4.1. The population distribution in Metropolitan Manila was estimated from "2000 Census of Population and Housing" by NSO.
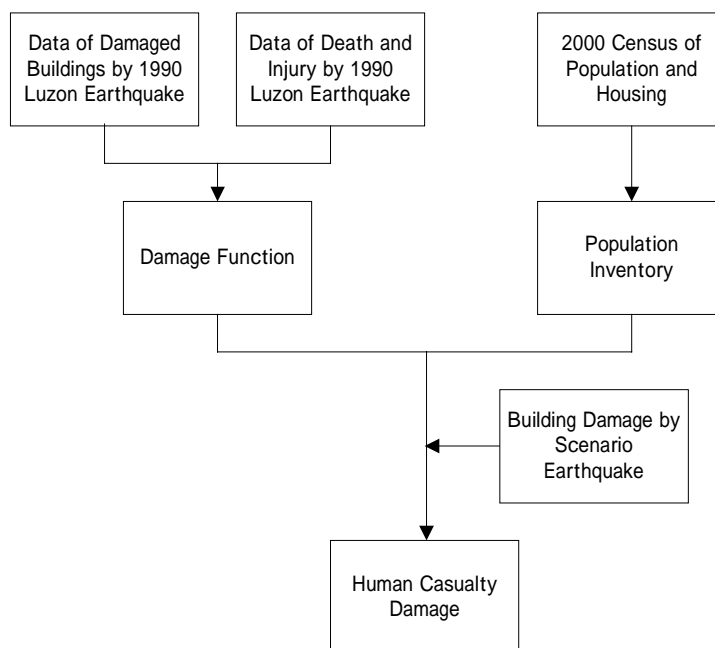

Figure 13.4.1   Flowchart of Human Casualty Damage Estimation

The damage statistics by DSWD, which was used in the analysis of building damage function, was also used in the analysis of human casualties of 1990 Luzon Earthquake. The relation between "totally + partly" damaged building ratio and death ratio is shown in Figure 13.4.2. It is

known that several areas are affected by liquefaction in this earthquake. Figure 13.4.2 shows that the death ratio in liquefied area is lower than non-liquefied area. The reason of this difference can be explained as follows. Most of the building damage by liquefaction is tilting. Liquefaction seldom leads building to collapse. Liquefaction occurs several minutes after the earthquake, so the residents can escape from the buildings. For non-liquefied area, Figure 13.4.2 also shows that the damage ratio in urban area is higher than rural area. In rural area, the lightweight materials such as bamboo are used for outer wall and this may have affected to the difference of death ratio. The damage by 1995 Kobe Earthquake is also shown in Figure 13.4.2. The death ratio by 1995 Kobe Earthquake is almost same to the death ration in urban area by 1990 Luzon Earthquake. The relation between death ratio and building damage in urban area was adopted for damage function to estimate the casualties in Metropolitan Manila.

Figure 13.4.3 shows the relation of death ratio and injured ratio. The data of liquefied area, urban area and rural area are plotted with different symbols but there aren't significant differences. The line in Figure 13.4.3 is the damage function for the estimation of injured person in Metropolitan Manila.

Following conditions are used in the estimation of human casualties based on the 1990 Luzon Earthquake damage and the building situation in Metropolitan Manila.

- No one, who is living in the damaged building by liquefaction, will be killed or injured. The building damage by vibration was used in estimating casualties.
- No one, who is living in "S" class building, will be killed by the collapse of building. The "S" class building uses lightweight material for building materials. Therefore, even if the building has totally collapsed, the people in the building may be injured but never die under the rubble. The calculated death amount by the damage function was treated as injured number.
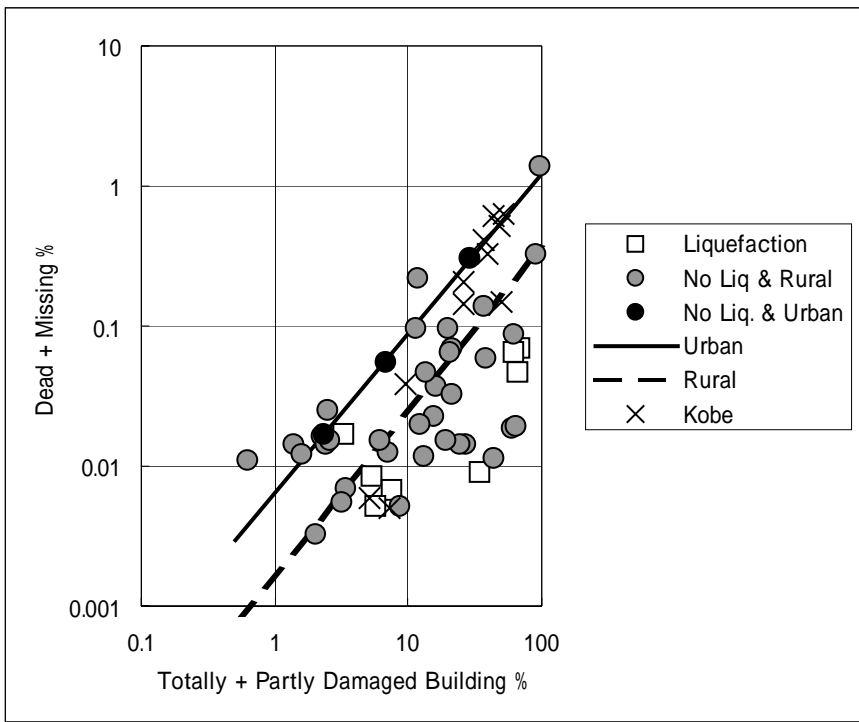
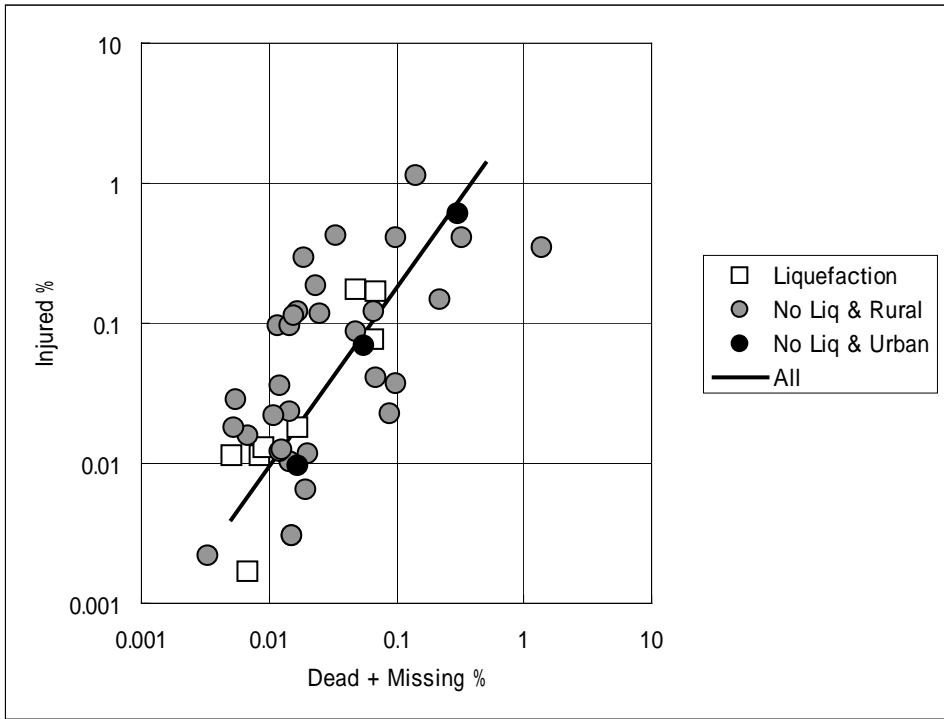**Figure 13.4.2   Damage Function for Death Estimation**

Figure 13.4.3   Damage Function for Injured Estimation