Evaluación de Riesgos Naturales
- América Latina -
Consultores en Riesgos y Desastres

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CAPRA

CENTRAL AMERICA PROBABILISTIC RISK ASSESSMENT

EVALUACIÓN PROBABILISTA DE RIESGOS EN CENTRO AMÉRICA

BELIZE

TASK III
RISK EVALUATION

TECHNICAL REPORT ERN-CAPRA-T3.3

COUNTRY RISK PROFILE, CONCENTRATION OF RISK AND RISK MAPS

CEPREDENAC

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Evaluación de Riesgos Naturales
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Consultores en Riesgos y Desastres

Consorcio de consultores:

Colombia
Carrera 19A # 84-14 Of 504
Edificio Torrenova
Tel. 57-1-691-6113
Fax 57-1-691-6102
Bogotá, D.C.

INGENIAR

iTEC
INGENIERIA TECNICA Y CIENTIFICA LTDA

España
Centro Internacional de Métodos Numéricos
en Ingeniería - CIMNE
Campus Nord UPC
Tel. 34-93-401-64-96
Fax 34-93-401-10-48
Barcelona

C I M N E

México
Vito Alessio Robles No. 179
Col. Hacienda de Guadalupe Chimalistac
C.P.01050 Delegación Álvaro Obregón
Tel. 55-5-616-8161
Fax 55-5-616-8162
México, D.F.

ERN
ERN Ingenieros Consultores, S. C.

ERN Evaluación de Riesgos Naturales – América Latina
www.ern-la.com

Direction and Coordination of Technical Working Groups – Consortium ERN America Latina

Omar Darío Cardona A.
Project General Direction

Luis Eduardo Yamín L.
Technical Direction ERN (COL)

Mario Gustavo Ordaz S.
Technical Direction ERN (MEX)

Alex Horia Barbat B.
Technical Direction CIMNE (ESP)

Gabriel Andrés Bernal G.
General Coordination ERN (COL)

Eduardo Reinoso A.
General Coordination ERN (MEX)

Martha Liliana Carreño T.
General Coordination I CIMNE (ESP)

Specialists and Advisors – Working Groups

Julián Tristancho
Specialist ERN (COL)

Carlos Eduardo Avelar F.
Specialist ERN (MEX)

Mabel Cristina Marulanda F.
Specialist CIMNE(SPN)

Miguel Genaro Mora C.
Specialist ERN (COL)

Benjamín Huerta G.
Specialist ERN (MEX)

Jairo Andrés Valcárcel T.
Specialist CIMNE(SPN)

César Augusto Velásquez V.
Specialist ERN (COL)

Mauro Pompeyo Niño L.
Specialist ERN (MEX)

Juan Pablo Londoño L.
Specialist CIMNE(SPN)

Karina Santamaría D.
Specialist ERN (COL)

Isaías Martínez A.
Technical Assistant ERN (MEX)

René Salgueiro
Specialist CIMNE(SPN)

Mauricio Cardona O.
Specialist ERN (COL)

Edgar Osuna H.
Technical Assistant ERN (MEX)

Nieves Lantada
Specialist CIMNE(SPN)

Sergio Enrique Forero A.
Specialist ERN (COL)

José Juan Hernández G.
Technical Assistant ERN (MEX)

Álvaro Martín Moreno R.
Associated Advisor (COL)

Mario Andrés Salgado G.
Technical Assistant ERN (COL)

Marco Torres
Associated Advisor (MEX)

Mario Díaz-Granados O.
Associated Advisor (COL)

Juan Pablo Forero A.
Technical Assistant ERN (COL)

Johoner Venicio Correa C.
Technical Assistant ERN (COL)

Liliana Narvaez M.
Associated Advisor (COL)

Andrés Mauricio Torres C.
Technical Assistant ERN (COL)

Juan Miguel Galindo P.
Technical Assistant ERN (COL)

Juan Camilo Olaya
Technical Assistant ERN (COL)

Diana Marcela González C.
Technical Assistant ERN (COL)

Yinsury Sodel Peña V.
Technical Assistant ERN (COL)

Steven White
Technical Assistant ERN (COL)

Local Advisors

SNET **Francisco Ernesto Durán & Giovanni Molina El** Salvador

Osmar E. Velasco
Guatemala

Oscar Elvir Honduras
Romaldo Isaac Lewis Belize

Interamerican Development Bank

Flavio Bazán
Sectorial Specialist

Cassandra T. Rogers
Sectorial Specialist

Sergio Lacambra
Sectorial Specialist

Tsuneki Hori
Internal Consultant

Oscar Anil Ishizawa
Internal Consultant

World Bank

Francis Ghesquiere
Regional Coordinator

Joaquín Toro
Specialist

Fernando Ramírez C.
Specialist

Edward C. Anderson
Specialist

Stuart Gill
Specialist

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1 Introduction

One of the key strategic activities of disaster risk management at country level is the assessment of the risk of disaster or of extreme events, which requires the use of reliable methodologies that allow an adequate estimation and quantification of potential losses in a given exposure time. However, although there have been developed, internationally diverse methodologies for detailed risk assessment for different types of natural hazards, few methods allow analysis at country level for two main reasons: first, the lack of detailed information that prevents the formation of a robust database to describe the exposure and, secondly, the lack of methodologies for an integrated modeling of the hazards, the vulnerability of the exposed elements and the risk from their convolution.

To achieve the overall goal of identifying and quantifying the catastrophe risk, it is necessary to use and even develop a method that takes into account the natural hazards in an integrated way that includes the total and detailed exposure of infrastructure assets with their main features. This in order to take into account the specific vulnerability of each component of the infrastructure and to assess the risk using an appropriate probabilistic methodology that takes into account the uncertainty of the process, the unavoidable limitations on information and the current computing capacity available.

In most cases it is necessary to use certain approaches and criteria for simplification and for aggregation of information due to the lack of data or the inherent low resolution of the available information. This fact sometimes means sacrificing some scientific or technical and econometric characteristics, accuracy and completeness that are desirable features when the risk evaluation is the goal of the process.

This report presents the catastrophe risk assessment for Belize taking into account that hurricanes and earthquakes are the natural events that represent the main natural hazards for the country. The probabilistic methodology used is considered the most robust for this type of modeling and identifies the most important aspects of catastrophe risk from financial protection perspective in according to the fiscal responsibility of the State. In addition, the results of the analysis may be particularly useful in guiding the priorities of the country's disaster risk management in general. The methodological and technical foundations of this risk assessment are the models made by this consultant group for the development of ERN-CAPRA-T3.2 (Probabilistic Risk Models, ERN 2010), and in the web site Wiki of CAPRA www.ecapra.org.

2 Methodology and scope

The frequency of catastrophic events is mainly low by definition, which is the reason why the historical information is generally very limited. Considering the probabilities of high destructive capacity events occurring, the risk estimate must focus on probabilistic models which use the limited historic information available to forecast, in the best possible way, the consequences of futures events considering at the same time unavoidable high uncertainties involved in the analyses.

A country may suffer the consequences of different types of natural events; however, for the present evaluation only earthquake hazards are considered and the hazard of hurricane when it is relevant. Without discarding the possibility that other types of hazards may also generate devastating events, the present analysis is concentrated on hazards that have demonstrated in the past that can generate critical events and that in most cases their losses contain or would be bigger than other small event or punctual events.

The risk assessment must be prospective, scientifically anticipating possible events that may occur in the future. For the case of seismic events, seismological and engineering bases are used to develop earthquake forecasting models that allow estimating damages, losses and effects as a result of catastrophic events. For the case of hurricanes, the hydro-meteorological information available of the historical hurricanes that have affected the area of study is used together with engineering methodologies; the effects of these phenomena upon the exposed assets are estimated. Due to the high uncertainties inherent to the models of analysis regarding the severity and frequency of occurrence of the events, the risk model is based on probabilistic formulations incorporating those uncertainties in the risk assessment. The probabilistic risk model (PRM) constructed as a sequence of modules quantifies the potential losses that arise from a given event, is illustrated in Figure 2-1.

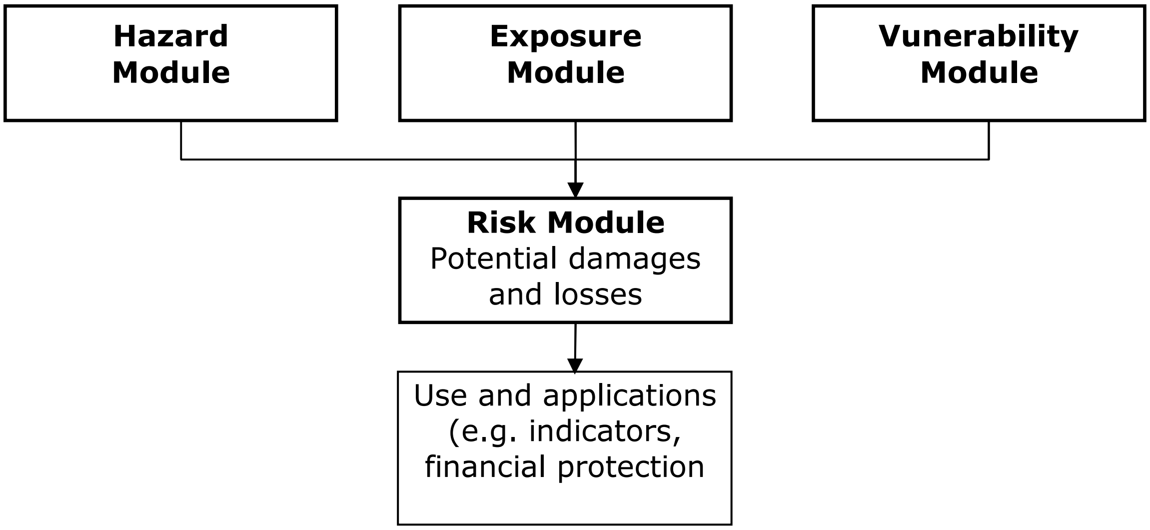

Figure 2-1
General scheme of the probabilistic risk analysis

The suggested analysis modules have the following specific functions:

- Hazard module: This module allows calculating the hazard associated to all possible events that could occur, a group of selected events, or even to a single relevant event. For each type of natural phenomena, using the module, it is possible to calculate the probable maximum value of the intensity that is characterized for different exceedance rates or return periods. An AME file type (.ame from *amenaza* in Spanish) is produced in this module for each type of hazard, which includes multiple grids, on the area of study, of the different parameters of intensity of the considered phenomena. Each grid is a scenario of the intensity level obtained from historical or stochastic generated events, with their frequency of occurrence. For this case the parameter of seismic intensity selected is the spectral acceleration. In the case of hurricanes, the maximum wind speed is used.

- Exposure Module: This module deals with the description of the exposed elements or assets that may be affected. It is based on files in "shape" format corresponding to the exposed infrastructure that will be included in the risk analysis. The information required for these files is the following:

    - Identification
    - Location
    - Exposure value
    - Vulnerability function associated to each type of hazard

  In this case the exposure module was developed based on a proxy model or simplified and aggregated description of the exposed assets.

- Vulnerability Module: This module allows the generation of vulnerability functions based on the direct use or modification of existing functions chosen from a library of functions, or by generating new functions from specific information of construction class of the exposed asset or element that has to resist or cope with the phenomena. The assignment of the vulnerability function to each element is carried out on the shape format file processed in the exposure module.

- Risk Module: This module performs the convolution of the hazard with the vulnerability of the exposed elements in order to assess the risk or the potential effects or consequences. Risk can be expressed in terms of damage or physical effects, absolute or relative economic loss and/or effects on the population.

Once the expected physical damage has been estimated (average potential value and its dispersion) as a percentage for each of the assets or infrastructure components included in the analysis, one can make estimates of various parameters useful for the proposed analysis as the result of obtaining the Loss Exceedance Curve (LEC). This study focuses, then, in the risk assessment of the country (overall, by sector and by geographic units) due to the hurricanes and earthquake hazards, using as measurement the Probable Maximum Loss (PML) for different return periods and the Average Annual Loss (AAL) or technical risk premium. Based on these results, it is estimated the specific risk at the country level and the concentration of risk and can be calculated the indicators of contingent liabilities (as are the figures currently used by the Disaster Deficit Index, DDI and DDI'). The values of PML and AAL are the main results of this report. These measures are of particular importance for the future design of risk retention (financing) or risk transfer instruments, and therefore they will be a particularly valuable contribution to further studies to define a strategy for financial protection to cover the fiscal liability of the State.

3 Earthquake catastrophic risk profile

3.1 Seismic hazard

The seismic hazard for Belize is calculated for all the seismic sources capable of generating earthquakes with possible adverse effects on the inhabitants and infrastructure. The seismic hazard assessment can be found on the report ERN-CAPRA-T1.3 (Probabilistic modeling of natural hazards, ERN 2010) and in the website www.ecapra.org.

3.2 Inventory of assets in the country

The inventory of exposed elements corresponds to the presented on the report ERN-CAPRA-T2.1 (Inventory of elements exposed, ERN 2010) which is also available at the website www.ecapra.org.

3.3 Seismic vulnerability of assets

3.3.1 *Generals aspects*

Seismic vulnerability is the ratio between any measure of intensity of the phenomenon (acceleration, velocity, displacement or any other, whichever shows the best correlation) and the level of damage of the physical exposed element to such seismic intensity. For example, for the case of several floor building constructions, the seismic intensity that best correlates to the expected damages is the drift or angular distortion between floors (related to the structural deformation due to earthquake forces). For other types of constructions, such as smaller buildings made of masonry or adobe, the maximum ground acceleration is used as correlation parameter regarding damage. In other cases, such as buried piping systems, it is more convenient to use the maximum ground velocity as an intensity parameter.

The procedure for classifying seismic vulnerability of the different exposed elements is the following:

(a) Typification of the more representing and predominant constructions classes of the portfolio of exposed elements, based on existing information and the opinions and criteria obtained in the local level.
(b) Calculation of the vulnerability functions of characteristic construction classes. For this purpose, several analytical models have been developed and some previously published applicable functions have been used, according to preceding national or international experiences.
(c) Conformation of the database of constructions and main elements representing the national inventory of assets.
(d) Assignment of a characteristic construction class and an associated vulnerability function to each element of the exposed inventory of assets.

Once the vulnerability function of each element is assigned, a seismic risk analysis is conducted.

A summary of the vulnerability functions used for the different exposed elements is presented. These curves are based either on the behavior of equivalent typical components obtained from previous studies or from specific analysis on design and construction conditions of the modeled elements.

3.3.2 *Seismic vulnerability functions*

Typical constructions of several stories include constructions of several structural systems such as momentum resistant frames, combined or dual systems, building systems with structural walls, prefabricated systems and others and, in general, constructions that share the characteristic of the major damage being mainly dependant on the relative story displacement. The vulnerability functions for these construction or building classes are graphically represented as the *damage percentage vs. the maximum story-drift of the building*.

On the other hand, for construction systems such as masonry structural walls, minor constructions built in adobe, tapia and local materials, and isolated structures such as retaining walls, tanks and the like, the vulnerability functions are best correlated to parameters such as maximum ground acceleration. In this case, the vulnerability functions are best represented as the *percentage of damage vs. the maximum spectral acceleration of the construction*.

The functions of vulnerability are generated with the system ERN-Vulnerabilidad (ERN 2010), based on information available http://www.ecapra.org/es/ (wiki - vulnerabilidad).

3.3.3 *Vulnerability functions for exposed elements*

The analysis demands vulnerability functions for each element comprised within the national asset inventory. These include:

<u>*Typical urban and rural constructions*</u>

(a) Residential LP: low income
(b) Residential MP: medium income
(c) Residential HP: high income
(d) Commercial
(e) Industrial (structures with a big built area)
(f) Health - Private
(g) Education - Private

(h) Health - Public
(i) Education - Public
(j) Governmental

<u>*Urban infrastructure*</u>

(a) Power substations and annex networks
(b) Communication substations and antennas
(c) Dams/reservoirs, tanks and water and sewage plants
(d) Water supply and sewage networks
(e) Gas supply network
(f) Airports
(g) Ports
(h) Urban bridges

<u>*National infrastructure*</u>

(a) Primary road network (roads and bridges)
(b) Secondary road network (roads and bridges)
(c) Hydroelectric power stations (dams and machinery sites)
(d) Thermal and geothermal power stations
(e) Power substations and annex networks
(f) Communication substations and antennas
(g) Fuel and gas substations and annex networks.

The vulnerability functions for each of these components are calculated using the system ERN-Vulnerabilidad (ERN 2009). The functions are generated in terms of spectral acceleration or in terms of structural drift and are then unified in terms of spectral acceleration, as previously explained. The curves are modified with factors that take into account particular aspects of local construction classes, such as material quality, general condition of constructions, typical design and construction practices and, in general, specific characteristics of predominant structural types.

At the link http://www.ecapra.org/es/ (wiki – vulnerabilidad) are shown the vulnerability functions used for the analysis.

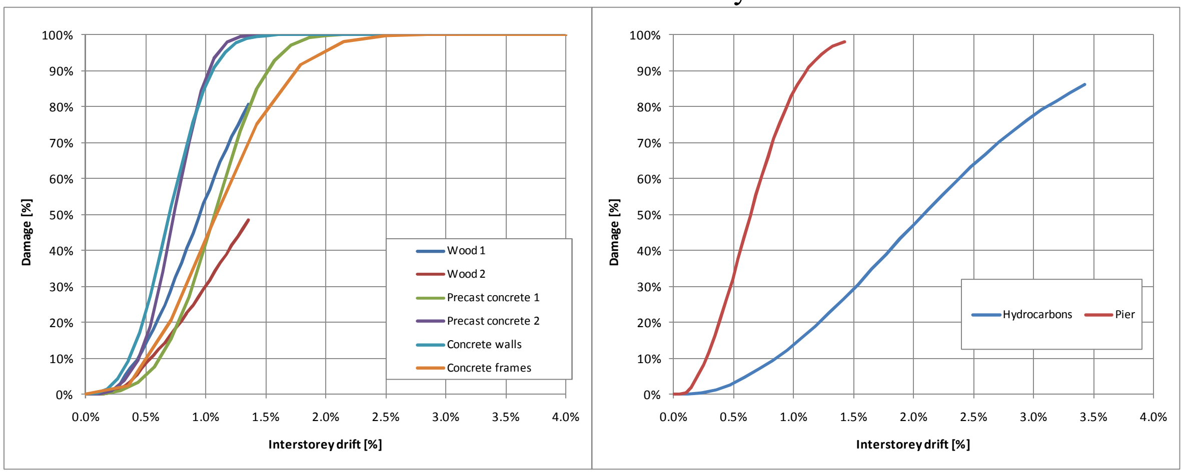

Figure 3-1 shows the vulnerability functions in terms of structural drift, while Figure 3-2 shows the vulnerability functions in terms of spectral acceleration for each case.

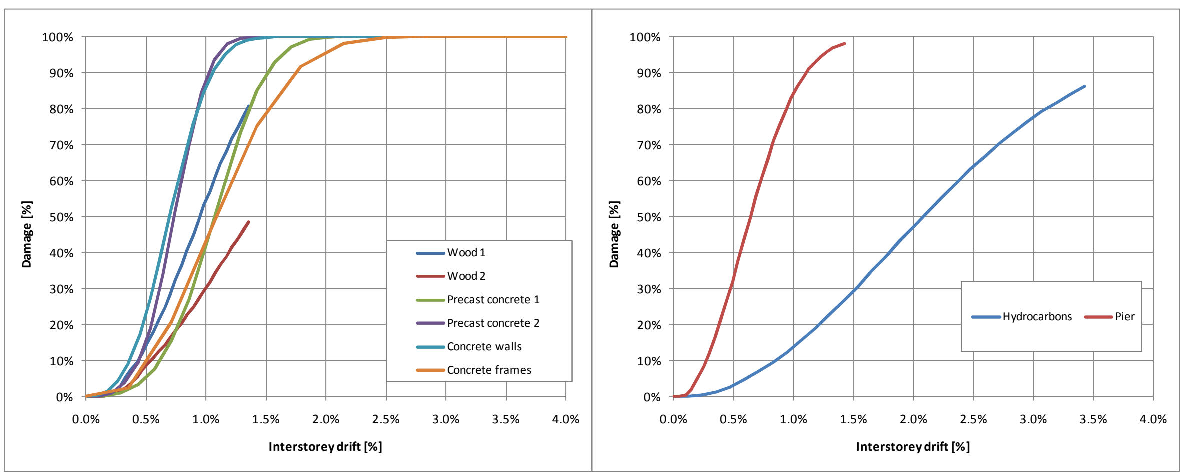

Figure 3-1
Vulnerability functions (base on interstory drift) for earthquake

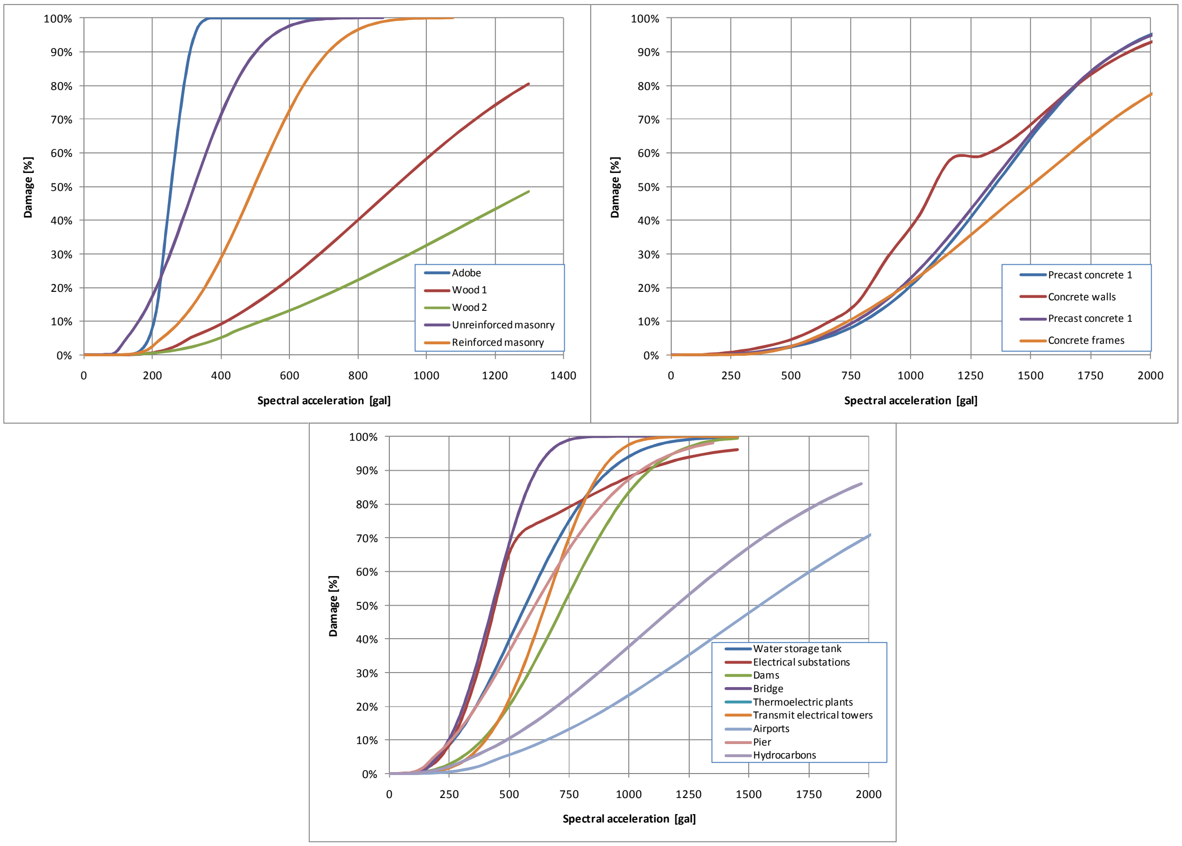

Figure 3-2
Vulnerability functions (based on spectral acceleration) for earthquake

Given that each of these functions is associated to a specific characteristic structural class, Table 3-1 summarizes the representative structural periods of each structural class, on which the corresponding seismic intensity assignment to be used on the analysis is done.

Table 3-1
Types of vulnerability functions, structural type and period of vibrations

Vulnerability function	Representative period
AD – Adobe	PGA
MD1 – Wood frame	0.50 seg
MD2 – Wood frame	0.50 seg
MS1 – Unreinforced Masonry	PGA
MS2 – Unreinforced Masonry	PGA
MR1 –Reinforced Masonry	PGA
MR2 – Reinforced Masonry	PGA
PCR – Reinforced concrete frame	0.75 seg

Vulnerability function	Representative period
Electrical Substation	PGA
Communications Substation	0.75 seg
Dams	PGA
Plants and Tanks	PGA
Water Supply Network	PGA
Sewage Network	PGA
Gas Network	PGA
Airports (Terminal)	0.75 seg
Ports (Warehouses)	0.75 seg
Ports (Pier)	0.50 seg
Urban Bridges	0.20 seg

Vulnerability function	Representative period
Primary road network (Bridges)	PGA
Secondary road network (Bridges)	PGA
Hydroelectric power stations (dams)	0.30 seg
Hydroelectric power stations (machinery sites)	0.75 seg
Thermal power stations	0.86 seg
Geothermal power stations	0.86 seg
Power distribution (Substations)	0.10 seg
Power distribution (Networks)	0.30 seg
Communications (Fixed lines/phones/numbers)	0.75 seg
Communications (Mobile lines)	0.75 seg
Hydrocarbon Derivates	0.86 seg
Hydrocarbons (Gas)	0.86 seg

At the link http://www.ecapra.org/es/ (wiki – vulnerabilidad) are shown the vulnerability functions used in the analysis and the explanation of the different damage levels expected for each specific structural type.

3.4 Seismic risk assessment

3.4.1 *General Aspects*

Based on the proposed probabilistic hazard models and on the exposed assets inventory and appraisal of exposed assets with respective vulnerability functions, a probabilistic risk analysis model is developed for the country.

As previously explained, the probabilistic risk analysis is done based on a series of hazard scenarios that adequately represent the effects of any event of feasible magnitude that can occur on the area of influence. Each of these scenarios has an associated specific frequency or probability of occurrence. The probabilistic calculation procedure comprises the assessment using appropriate metrics, in this case the economic loss, for each exposed asset considering each of the hazard scenarios with their frequency of occurrence, and the probabilistic integration of the obtained results.

Seismic risk was calculated using the platform CAPRA-GIS (ERN 2009). The methodology of evaluation is described in the link http://www.ecapra.org/es/ (wiki – riesgo).

3.4.2 *Total losses at national level*

Table 3-2 presents the consolidated information for the all country in terms of total exposed value, the expected annual loss in value and in thousands (also known as technical risk premium) and indicative values of probable maximum loss for different return periods.

Table 3-2
Generals Results of PML for earthquake

Results		
Exposure Value	US$ x10^6	$4,829
Average Annual Loss	US$ x10^6	$0.50
	‰	0.10
PML		
Return Period	**Loss**	
Years	**US$ x10^6**	**%**
50	$5	0.1%
100	$9	0.2%
250	$19	0.4%
500	$31	0.6%
1000	$46	0.9%

Figure 3-3 shows the loss exceedance curves for the country.

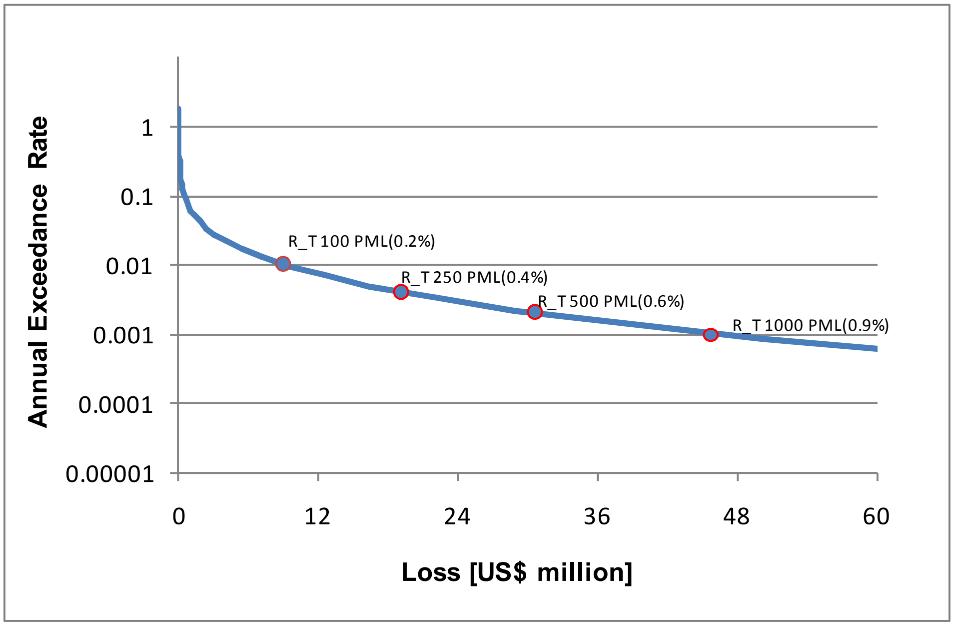

Figure 3-3
Loss exceedance for earthquake

Figure 3-4 presents the probable maximum loss curve, as exposed value and percentage of exposed value for different return periods. Also, the exceedance probability curves for different PML percentage values for different exposure periods, specifically 20, 50, 100 and 200 years, are presented in Figure 3-5.

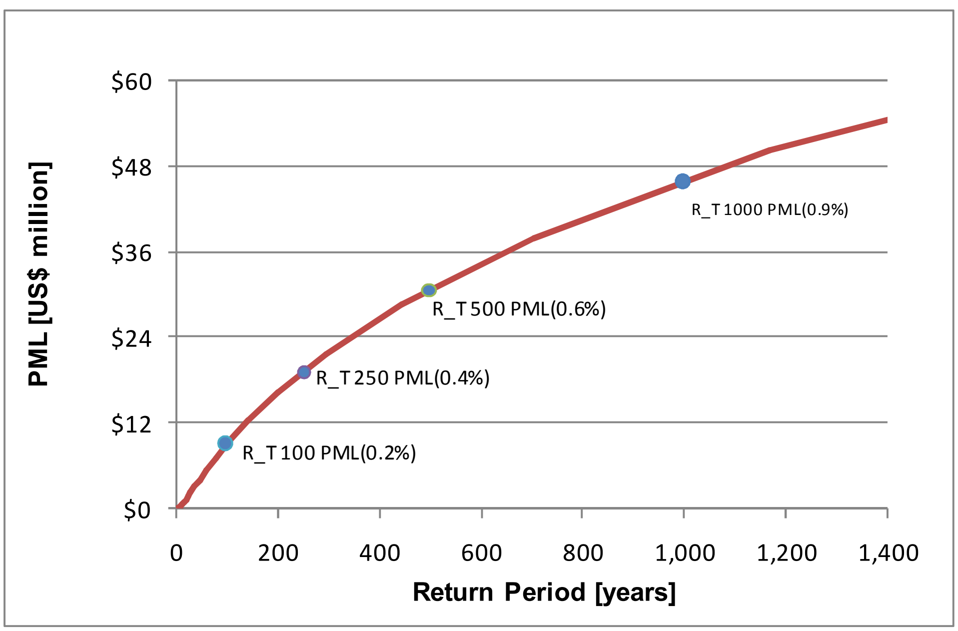

Figure 3-4
PML curve for earthquake

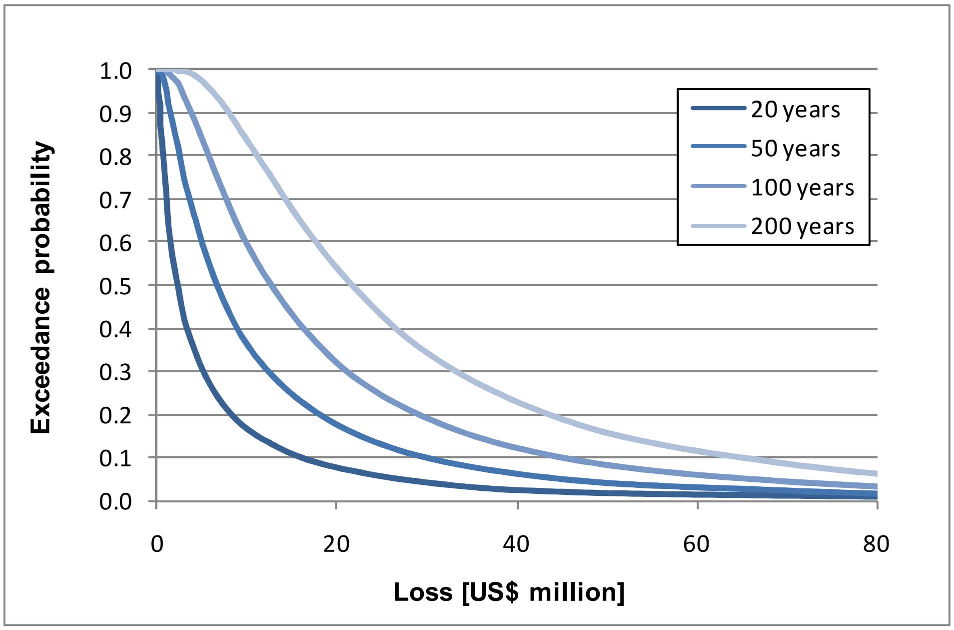

Figure 3-5
Earthquake exceedance probability curves for different PML values for different exposure

Table 3-3 summarizes the critical scenarios resulting from the analysis, that is, the scenarios resulting with the highest expected economic losses.

Table 3-3
Critical scenarios from earthquake analysis

N°	scenario	Loss		Frequency	Ret. Period
	Source	[US$ x 10^6]	%		scenario
224	CAc1_SF56_M=6.75	50.47	2.88%	9.06E-05	11042
208	CAc1_SF52_M=6.75	35.30	2.02%	9.06E-05	11042
216	CAc1_SF54_M=6.75	31.73	1.81%	9.06E-05	11042
284	CAc1_SF71_M=6.75	27.70	1.58%	9.46E-05	10575
223	CAc1_SF56_M=6.25	27.50	1.57%	2.40E-04	4169
1236	CAc2_SF165_M=7.45	24.33	1.39%	3.50E-05	28605
304	CAc1_SF76_M=6.75	23.47	1.34%	9.46E-05	10575
1164	CAc2_SF147_M=7.45	22.58	1.29%	3.82E-05	26190
1156	CAc2_SF145_M=7.45	22.02	1.26%	3.82E-05	26190
256	CAc1_SF64_M=6.75	21.92	1.25%	9.06E-05	11042

3.5 Concentration of seismic risk

The risk concentration analysis is carried out for districts and by sectors for public and private sectors of use, as well for main components of the national infrastructure.

3.5.1 *Comparison of losses per district*

Losses are assessed by district as a geographical unit. Figure 3-6 shows a comparison between the different districts.

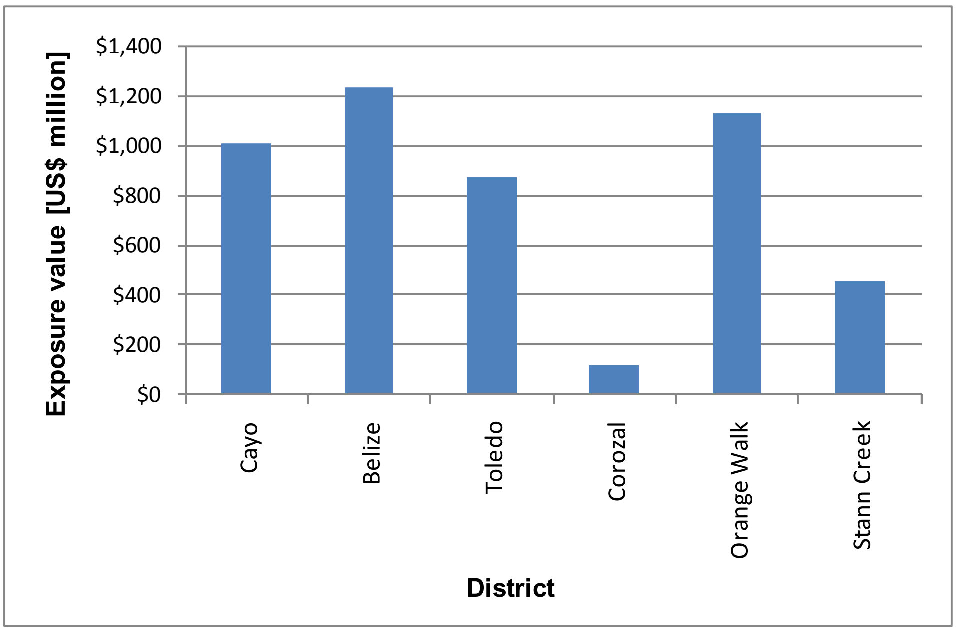

Figure 3-6
Exposure value per district

For each district, a complementary individual analysis is carried out. This allows estimating the probable maximum loss level and the individual premium level by district. In each case, results are presented as follows:

- A table summarizing the average annual loss (AAL) and the probable maximum loss (PML)
- Loss exceedance rate curves and PML with the corresponding return periods
- Bar diagram with AAL figures in exposed value and thousand of exposed value, for each sector of use.

Figure 3-7 shows an example of the format used for individual district results. In Annex ERN-CAPRA-T3.3-2 presented individual results for the other districts.

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	26/07/2010		
Results			Probable Maximum Loss			Exceedance probability of PML values			
District	Belize		Return Period	US$ $x10^6$	%	20 years	50 years	100 years	500 years
			100 years	$1.64	0.13%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ $x10^6$	$1,239	250 years	$10.89	0.88%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ $x10^6$	$0.22	500 years	$26.61	2.15%	3.92%	9.52%	18.13%	63.21%
	‰	0.18	1000 years	$48.77	3.94%	1.98%	4.88%	9.52%	39.35%

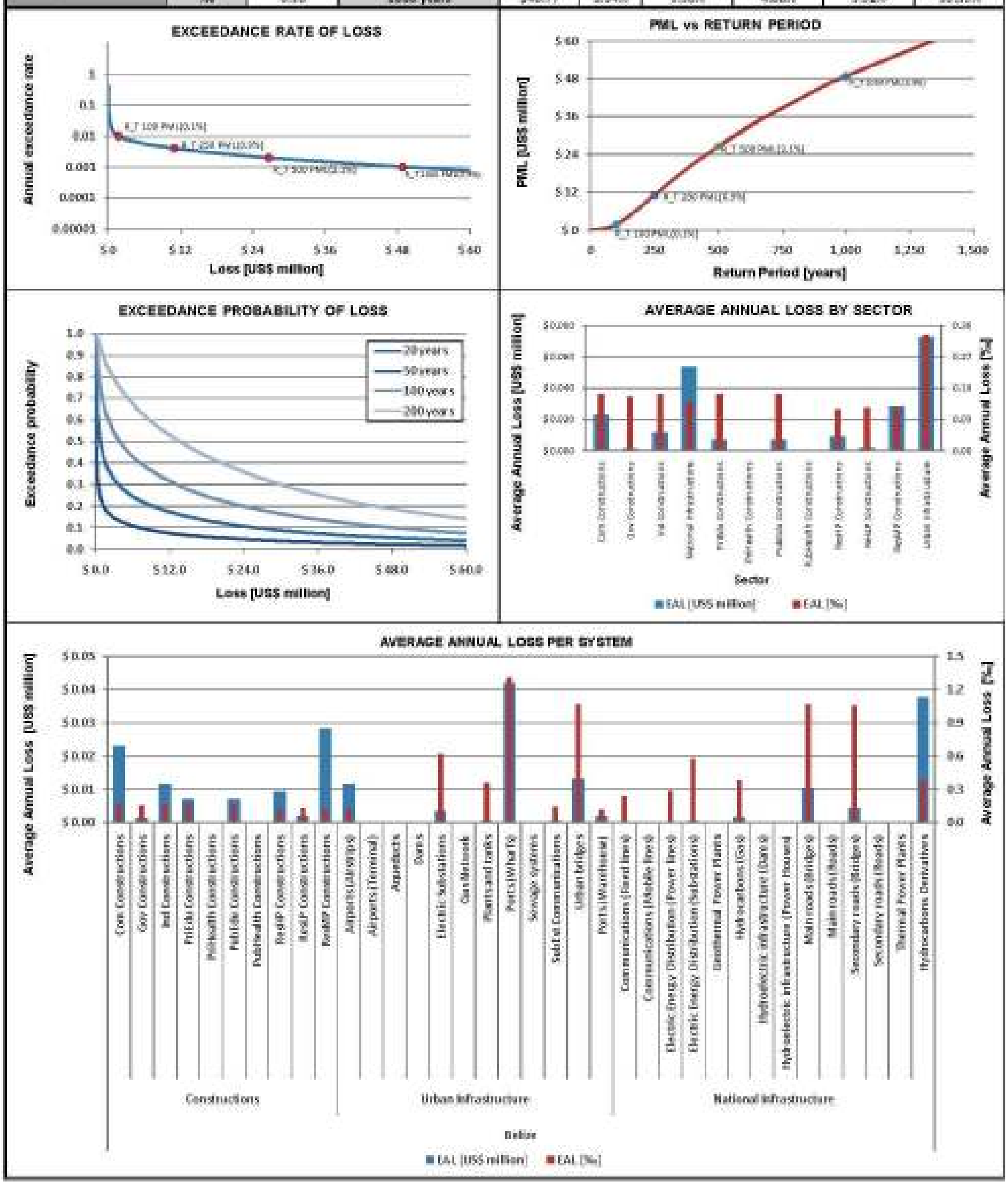

Figure 3-7
Example of results due to earthquake for Belize

Figure 3-8 summarizes PML values for return periods of 250, 500 and 1000 years for each district in values as well as in percentages.

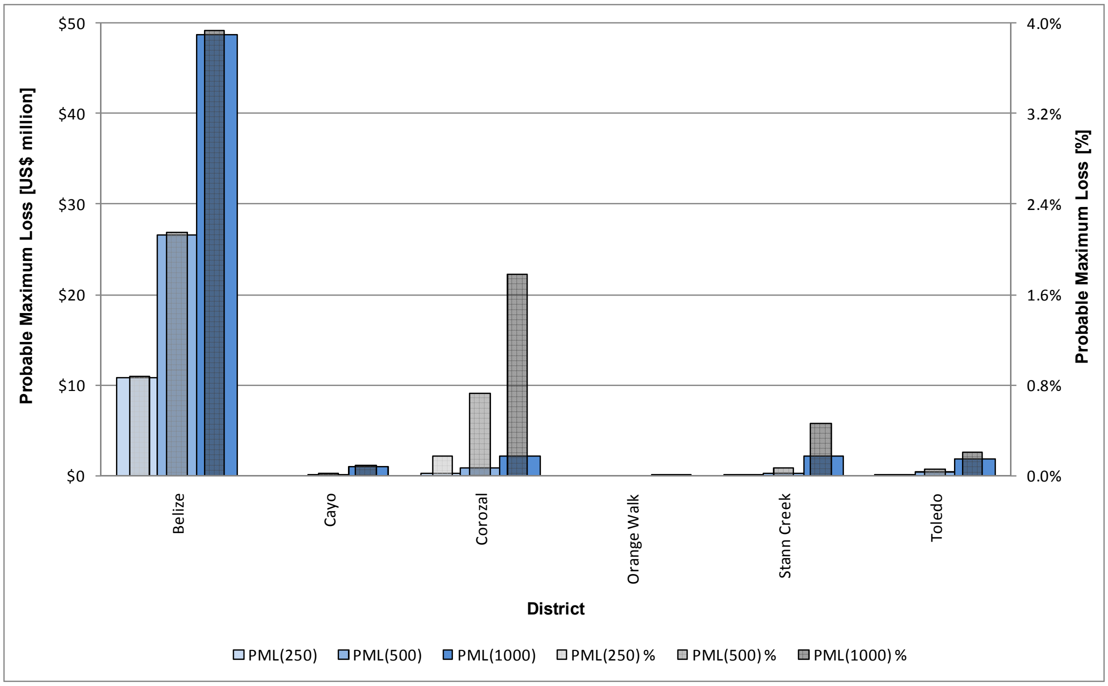

Figure 3-8
PML values for earthquake and for different return periods by district

On the other hand, Figure 3-9 displays values corresponding to average annual loss in value and thousands.

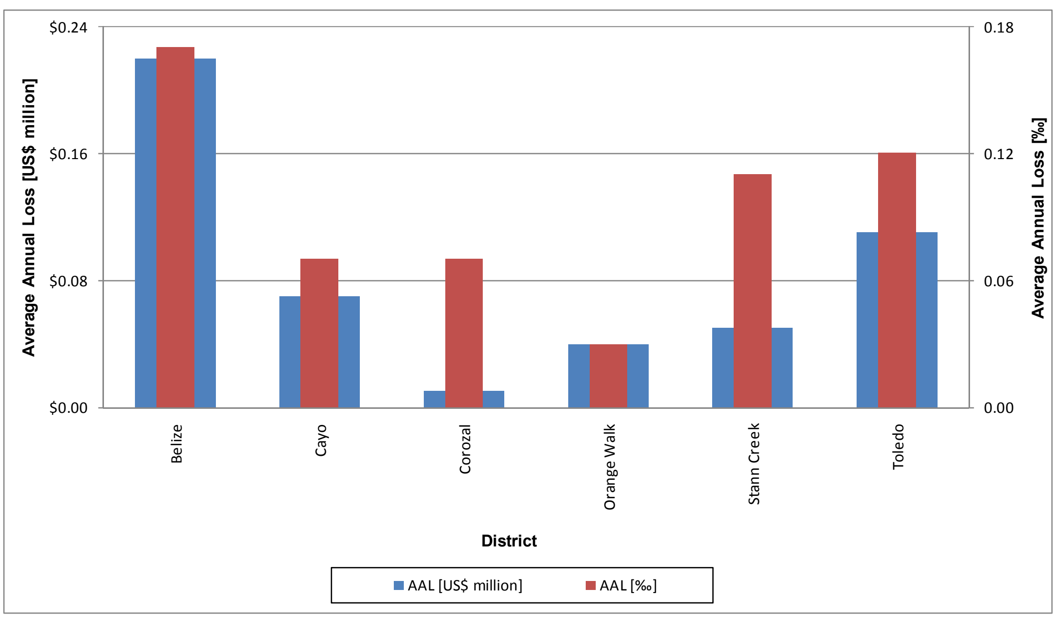

Figure 3-9
Values of AAL for earthquake per district

Figure 3-10 shows the average annual loss by sectors for each district. Urban constructions, urban infrastructure and national infrastructure associated with each district are considered.

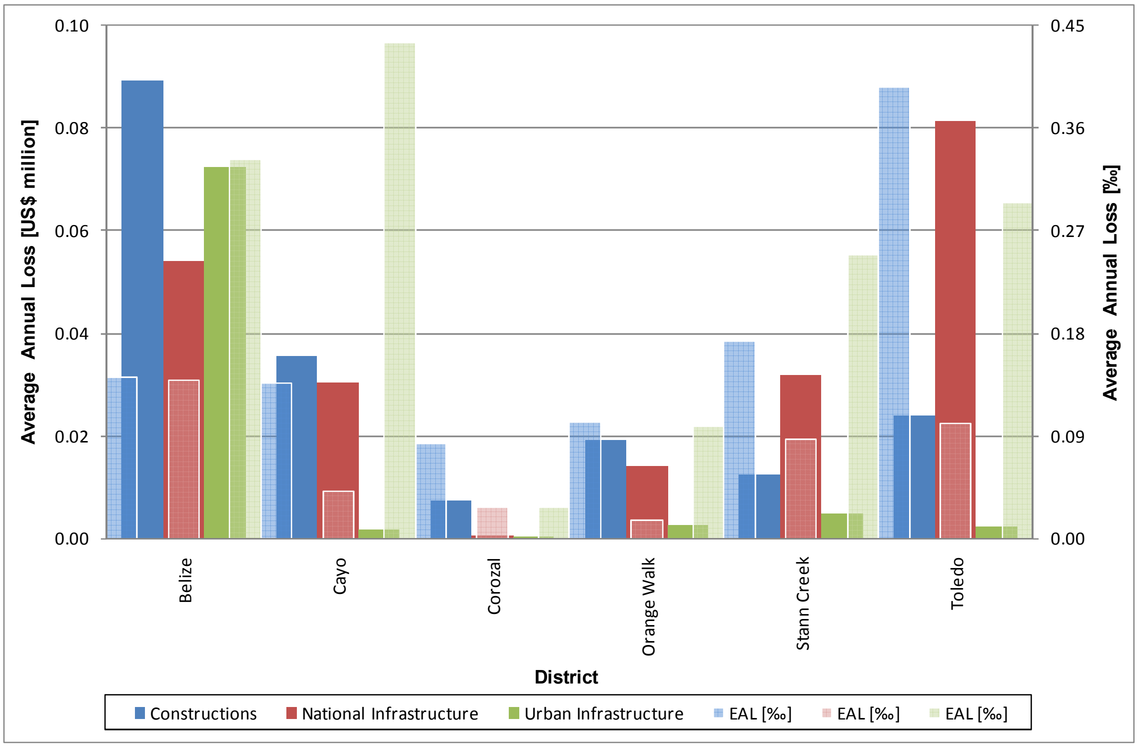

Figure 3-10
Values of AAL for earthquake, per district and for each use sector

Finally Figure 3-11 and Figure 3-12 present the geographic distribution of the average annual losses for each district. Figure 3-13 and Figure 3-14 show the values of the probable maximum loss for each district.

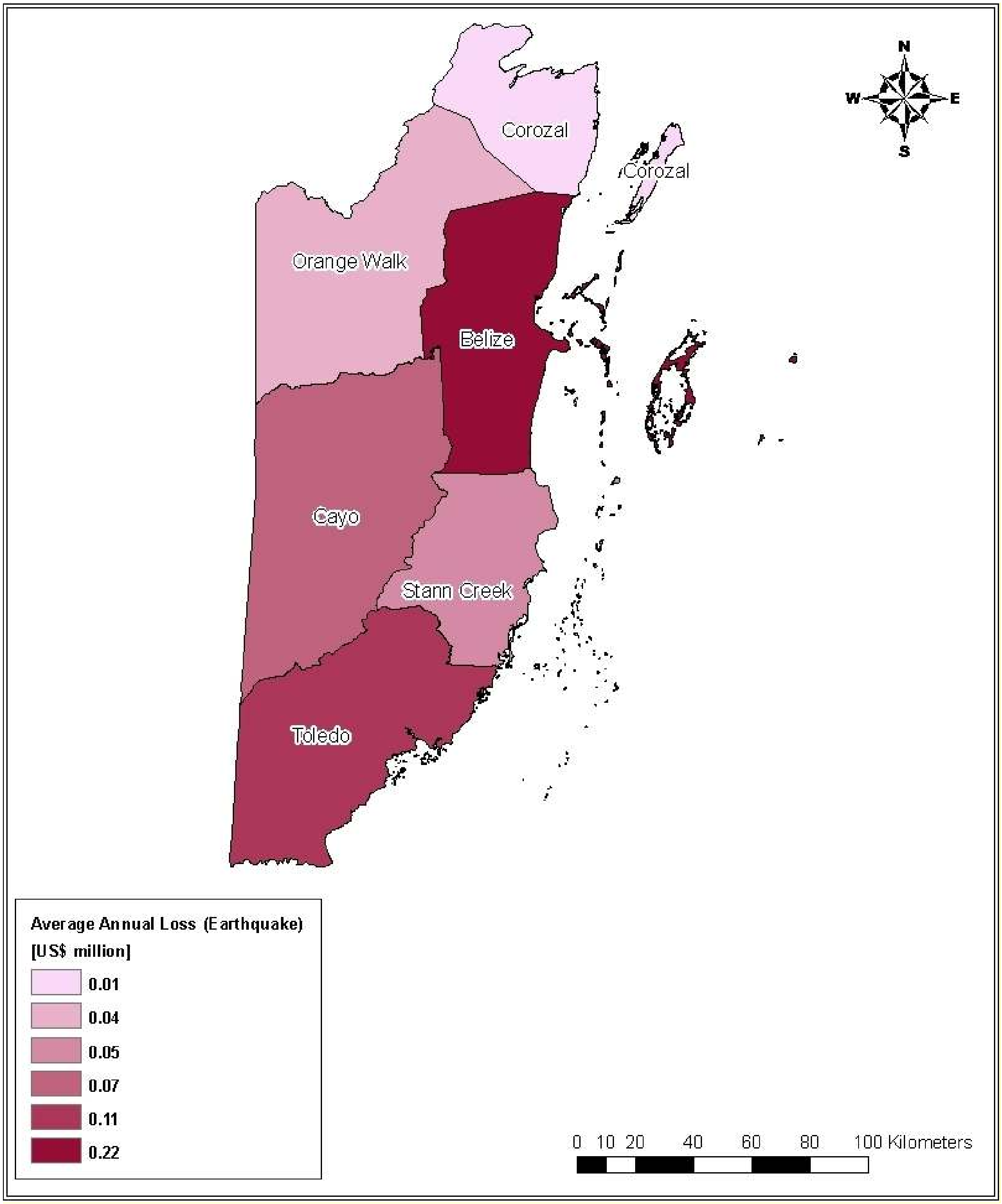

Figure 3-11
Geographic distribution of AAL (value) for earthquake per district

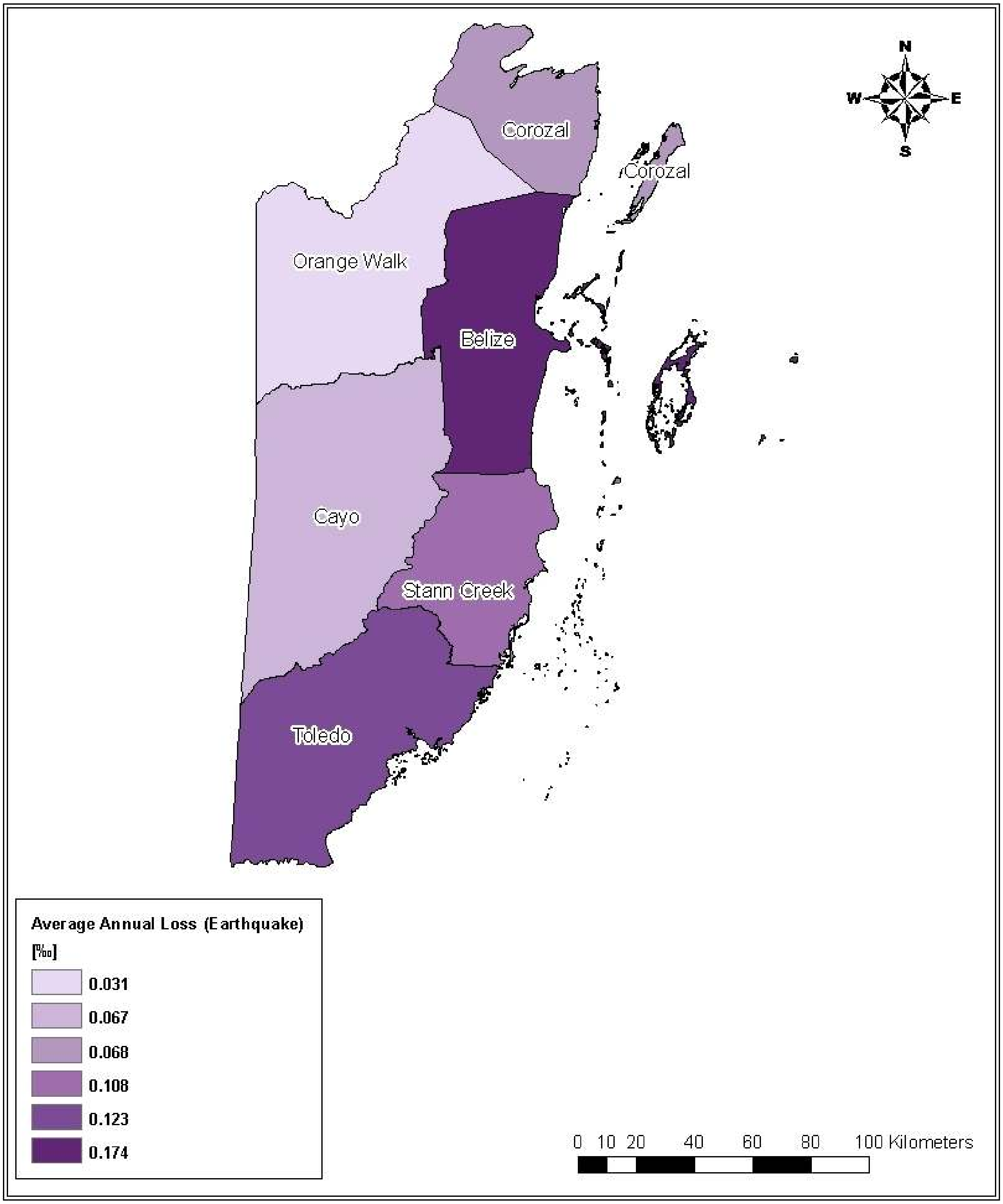

Figure 3-12
Geographic distribution of AAL (‰) for earthquake per district

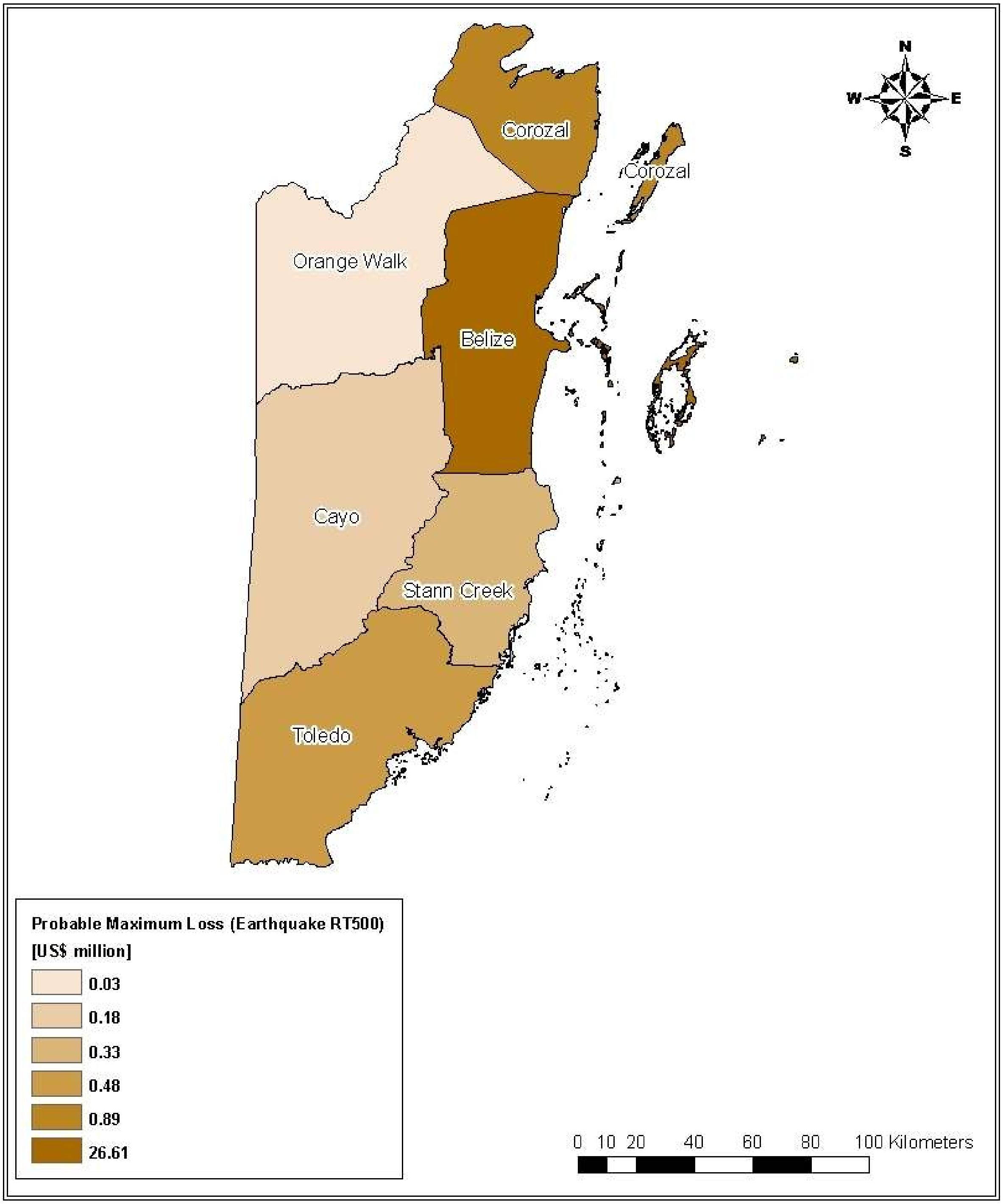

Figure 3-13
Geographic distribution of PML (value) for earthquake per district

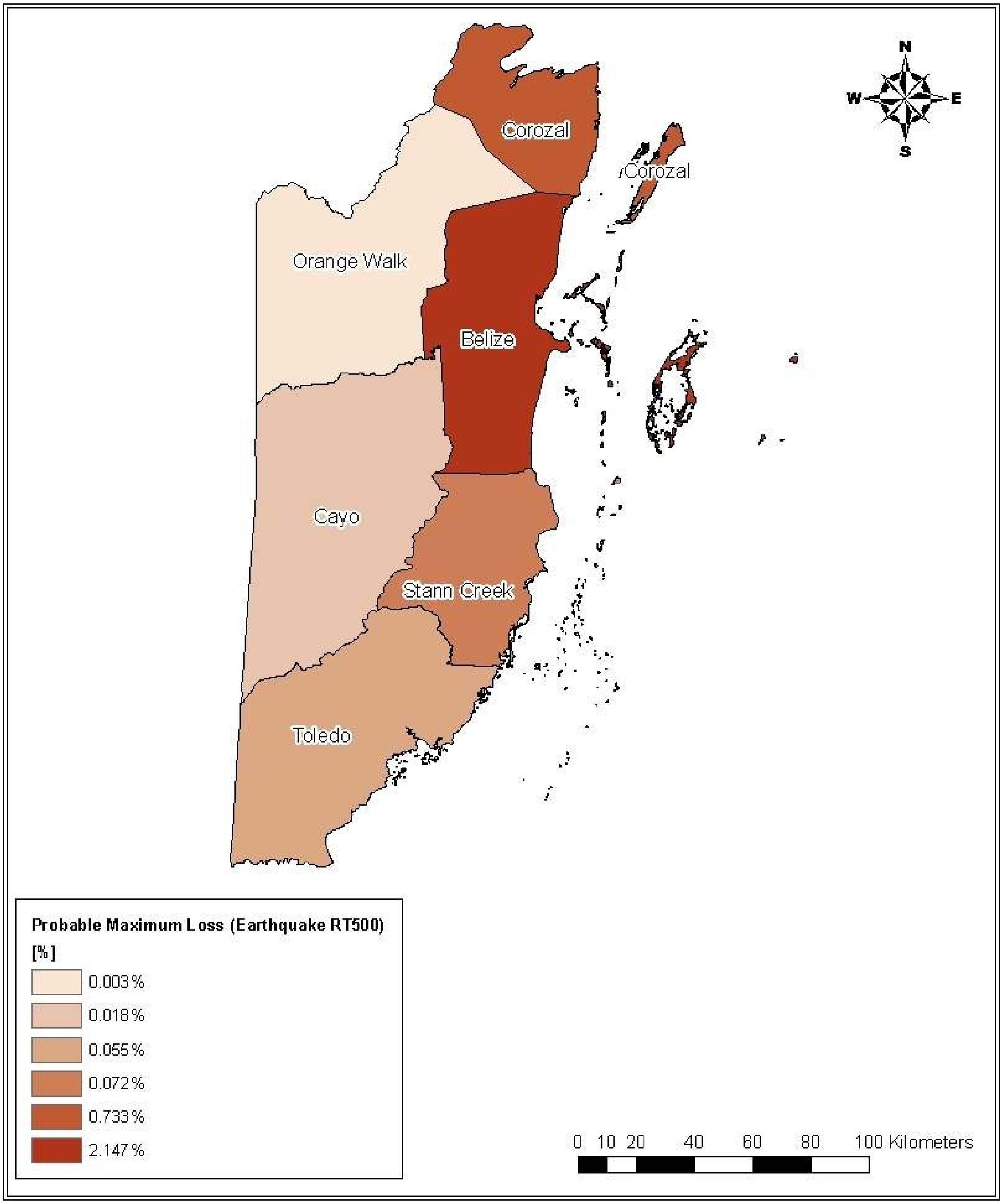

Figure 3-14
Geographic distribution of PML (%) for earthquake per district

3.5.2 *Comparison of losses by sector*

Figure 3-15 presents a comparison of the relative exposure values by sector at national level.

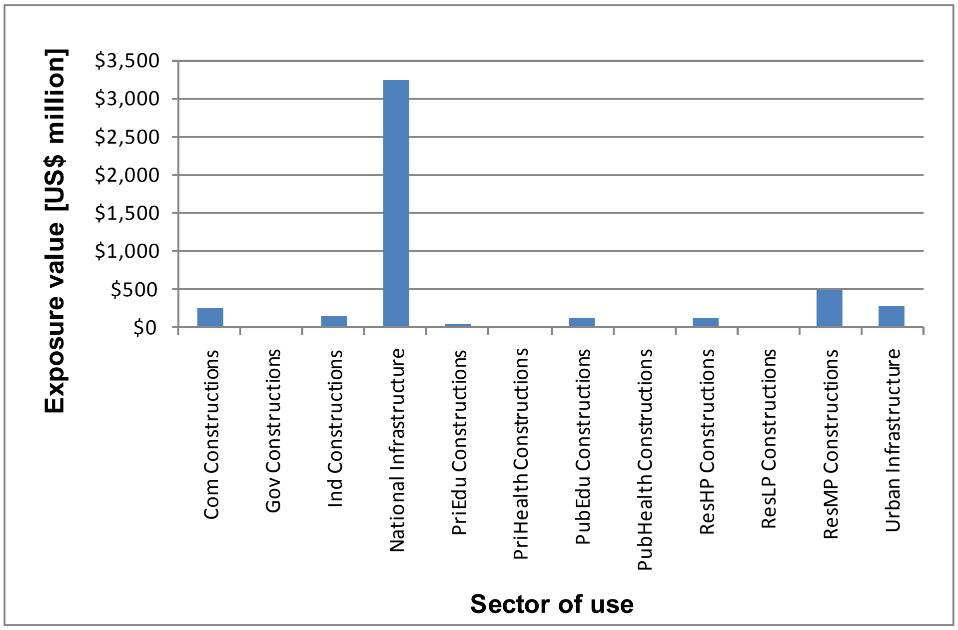

Figure 3-15
Exposure values per sector

Figure 3-16 includes the total average annual loss in exposed value and thousands of exposed value for each sector of use and for the country as a whole.

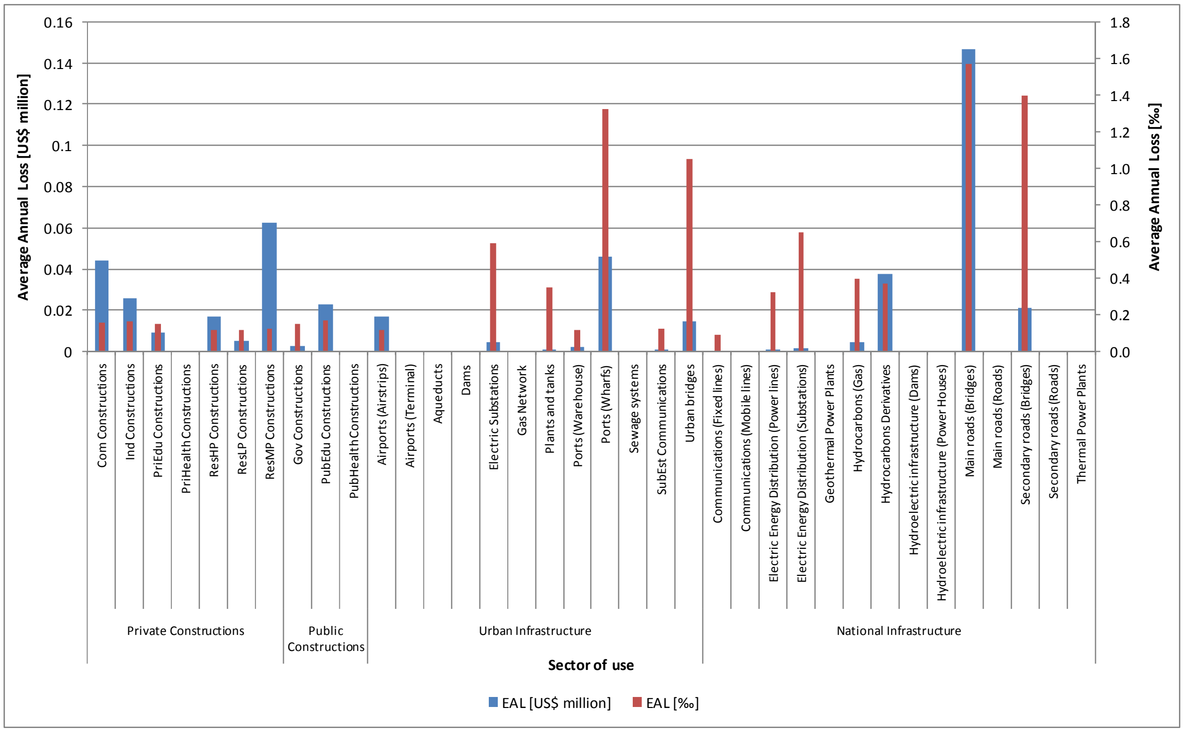

Figure 3-16
Values of AAL for earthquake and per sector

On the other hand and more specifically, Figure 3-17 presents the AAL results including the total results for the three main sectors of use: urban constructions, urban infrastructure and national infrastructure.

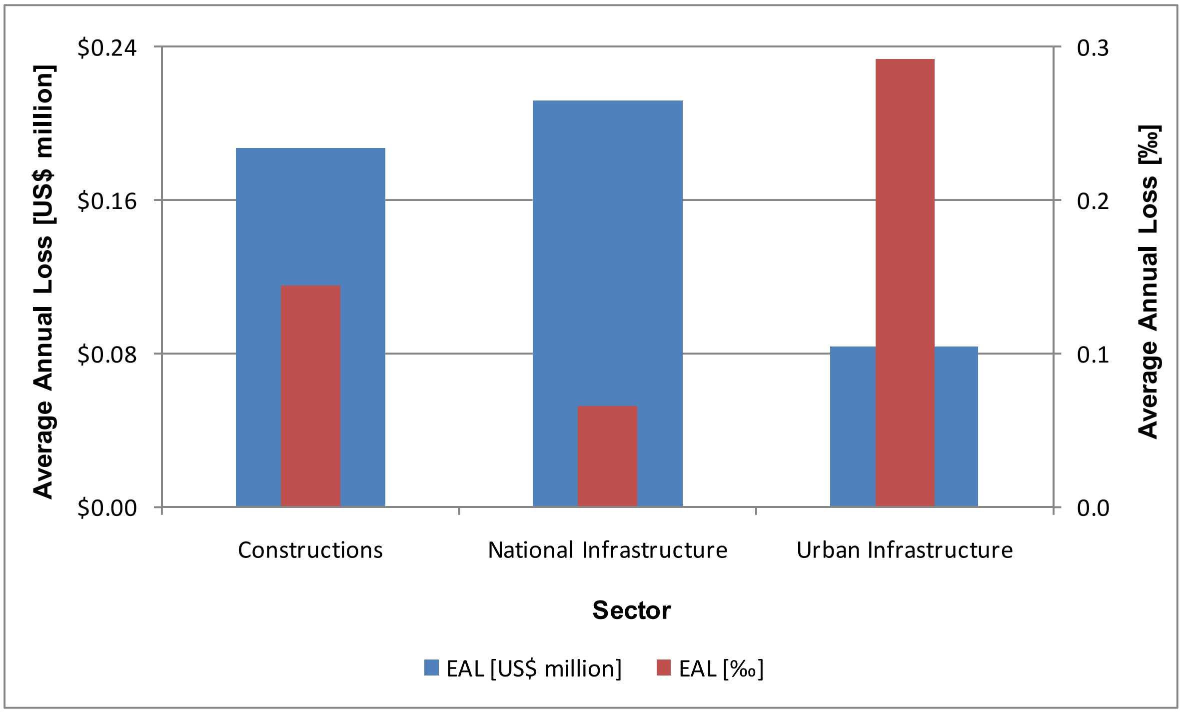

Figure 3-17
Summary for values of AAL for earthquakes and per sector

3.5.3 *Probable maximum loss for public and private sectors*

To assess the probable maximum loss for public and private sectors it is necessary to conduct analyses for each portfolio, because these types of results depend on the relative geographic distribution of the exposure values.

The public sector includes public urban constructions (health, educational –when they are property of the State- and government buildings) and the entire infrastructure. In turn, the private sector includes residential, commercial and industrial constructions, and the corresponding health and education constructions.

The Figure 3-18 shows the exposure values of the public and private sectors in the country.

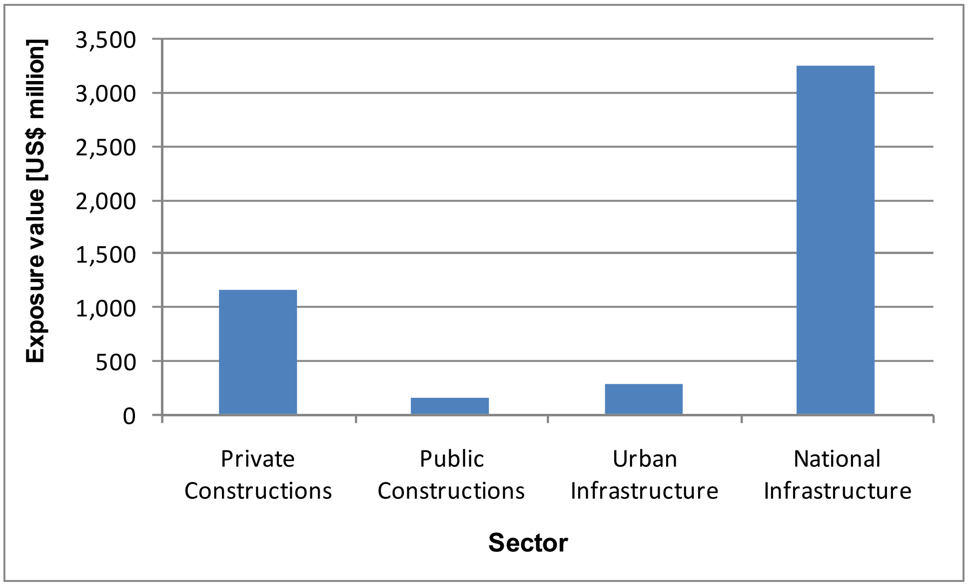

Figure 3-18
Exposure values per sector

Figure 3-19 and Figure 3-20 present the PML curve for each of these sectors.

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Public Constructions		Return Period	US$ x10⁶	%	20 years	50 years	100 years	500 years
			100 years	$0.49	0.33%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10⁶	$149.1	250 years	$1.12	0.75%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10⁶	$0.03	500 years	$1.88	1.26%	3.92%	9.52%	18.13%	63.21%
	‰	0.20	1000 years	$2.92	1.96%	1.98%	4.88%	9.52%	39.35%

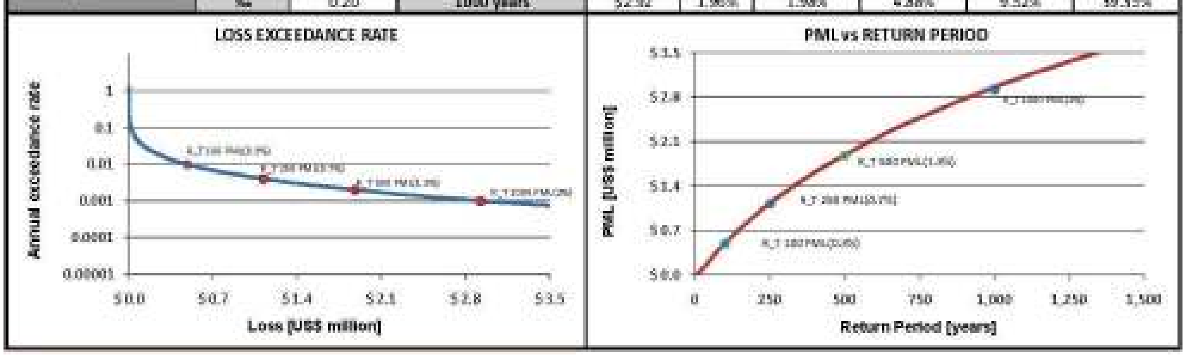

Figure 3-19
Loss exceedance and PML curve for earthquake and for public constructions

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Private Constructions		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$2.90	0.25%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$1,153.0	250 years	$7.20	0.62%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.16	500 years	$12.68	1.10%	3.92%	9.52%	18.13%	63.21%
	‰	0.14	1000 years	$20.50	1.78%	1.98%	4.88%	9.52%	39.35%

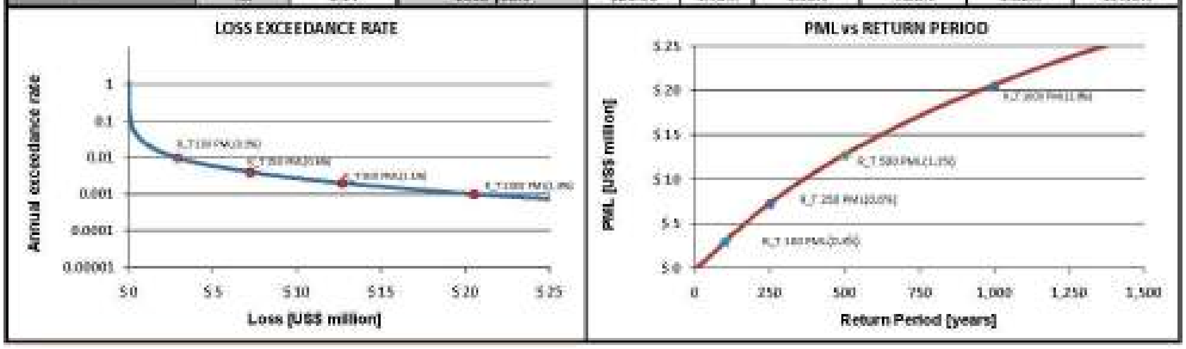

Figure 3-20
Loss exceedance and PML curve for earthquake and for private constructions

3.5.4 *Probable maximum loss for the national infrastructure*

A similar analysis to the previous one is carried out for the national infrastructure sector taking into account that individual analyses can be performed for:

- Power generation and distribution
- Communications
- Transportation (roads and bridges)
- Hydrocarbons

The results for the PML curves for each of these sectors are presented together with the return period and the global values of AAL, in exposed value and thousands of exposed value. Figure 3-21 to Figure 3-24 summarize such results. In Annex ERN-CAPRA-T3.3-3 presented individual results for the other sectors

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Production and distribution (Energy)		Return Period	US$ x10⁶	%	20 years	50 years	100 years	500 years
			100 years	$0.03	0.63%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10⁶	$4.3	250 years	$0.07	1.53%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10⁶	$0.00	500 years	$0.12	2.74%	3.92%	9.52%	18.13%	63.21%
	‰	0.00	1000 years	$0.20	4.56%	1.98%	4.88%	9.52%	39.35%

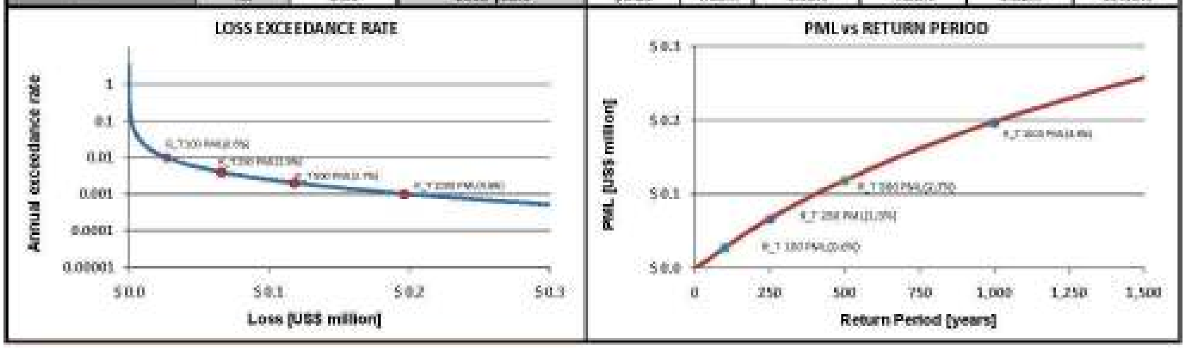

Figure 3-21
Loss exceedance and PML curve for earthquake for the energy sector

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Communications		Return Period	US$ x10⁶	%	20 years	50 years	100 years	500 years
			100 years	$0.00	0.18%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10⁶	$1.1	250 years	$0.00	0.42%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10⁶	$0.00	500 years	$0.01	0.75%	3.92%	9.52%	18.13%	63.21%
	‰	0.00	1000 years	$0.01	1.25%	1.98%	4.88%	9.52%	39.35%

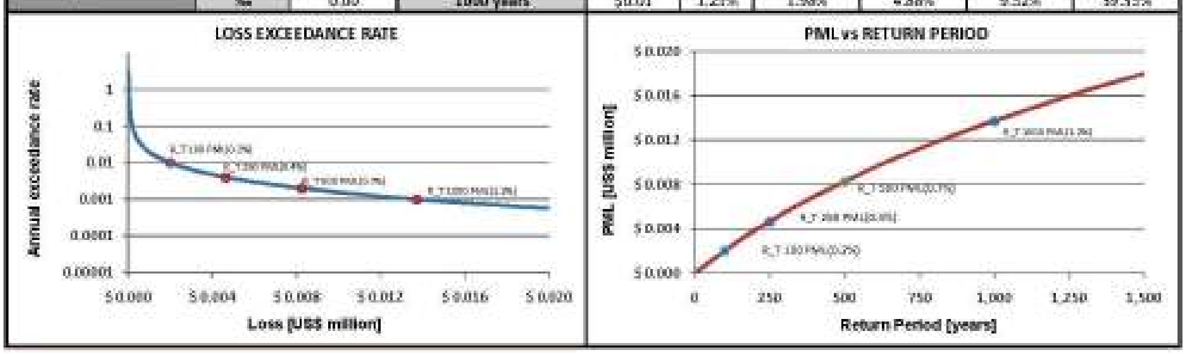

Figure 3-22
Loss exceedance and PML curve for earthquake for the communication sector

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	National Roads		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$0.02	0.00%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$3,122.2	250 years	$0.07	0.00%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.17	500 years	$0.26	0.01%	3.92%	9.52%	18.13%	63.21%
	‰	0.05	1000 years	$1.11	0.04%	1.98%	4.88%	9.52%	39.35%

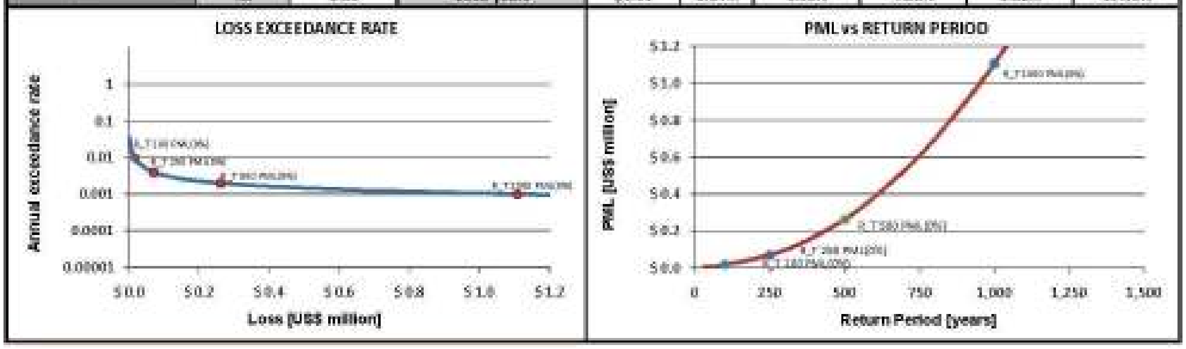

Figure 3-23
Loss exceedance and PML curve for earthquake for the transportation sector

COUNTRY	BELIZE		HAZARD	EARTHQUAKE		DATE OF ANALYSIS	01/07/2009		
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Hydrocarbons		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$0.54	0.49%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$110.8	250 years	$1.29	1.16%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.04	500 years	$2.40	2.17%	3.92%	9.52%	18.13%	63.21%
	‰	0.36	1000 years	$4.22	3.81%	1.98%	4.88%	9.52%	39.35%

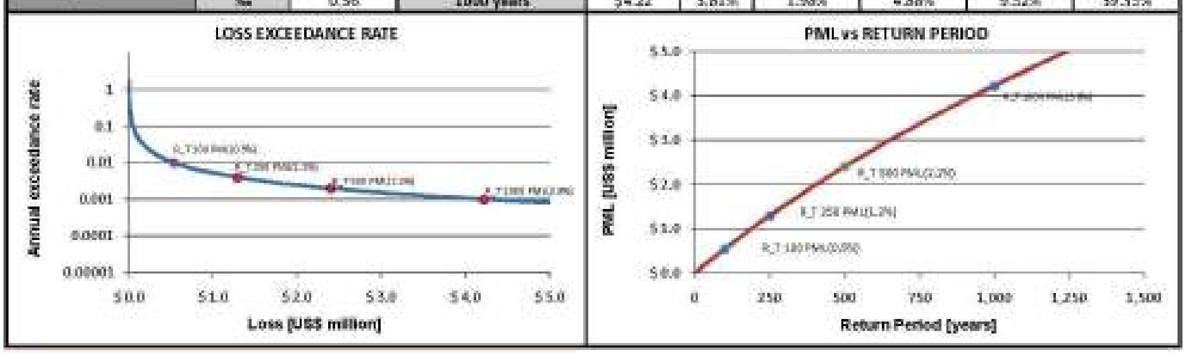

Figure 3-24
Loss exceedance and PML for earthquake for the hydrocarbon sector

4 Hurricane catastrophic risk profile

4.1 Hurricane hazard (wind)

Hurricane hazard (wind) for Belize is assessed from the statistical perturbation of historical hurricane trajectories. The hazard assessment can be found on the report ERN-CAPRA-T1.2 (Evaluation models for natural hazards, ERN 2010) and on the website www.ecapra.org.

4.2 Inventory of assets in the country

The inventory of exposed elements corresponds to the presented on the report ERN-CAPRA-T2.1 (Inventory of elements exposed, ERN 2010) which is also available at the website www.ecapra.org.

4.3 Vulnerability of assets to hurricane winds

4.3.1 *Generals aspects*

For the case of hurricane-force winds, vulnerability is suggested to be the relationship between the maximum wind velocity in the location of the analyzed exposed element and the level of damage to the physical that can be expected with that maximum wind speed.

(a) Typification of the more representing and predominant constructions classes of the portfolio of exposed elements, based on existing information and the opinions and criteria obtained in the local level.
(b) Calculation of the vulnerability functions of characteristic construction classes. For this purpose, several analytical models have been developed and some previously published applicable functions have been used, according to preceding national or international experiences.
(c) Conformation of the database of constructions and main elements representing the national inventory of assets.
(d) Assignment of a characteristic construction class and an associated vulnerability function to each element of the exposed inventory of assets.

A summary of the vulnerability functions used for the different exposed elements is shown below; these curves are based either on the behavior of equivalent typical components obtained from previous studies or from specific analysis on design and construction conditions of the modeled elements regarding wind forces.

4.3.2 *Vulnerability functions for wind action*

The vulnerability functions for the different construction types of the buildings exposed to the wind actions depend on several factors, such as:

- Main structural system
- Shape of the structure, percentage of openings in the section, size of main spans and other geometric characteristics.
- Elements that make up the front of the structure and type of connection with the structural elements.
- Parts that make up the windows, doors and their fastening systems to other elements.
- Roof system and elements of fastening and connection to the roof structure.

The evaluation of vulnerability of exposed elements to wind forces must be assessed through the weighing of the effects that can occur on the different components of the construction and its structure.

The generation of the vulnerability functions is conducted with the module ERN-Vulnerabilidad (ERN 2010), and based on the information available. In the link http://www.ecapra.org/es/ (wiki – vulnerabilidad) is presented the calculation methodology for vulnerability, according to the dominant national constructive types.

4.3.3 *Vulnerability functions for exposed elements*

The analysis demands vulnerability functions for each one of the types of elements that make up the national inventory of assets. The types of elements are the following:

Characteristic urban and rural constructions

(a) Residential LP: low economic capacity
(b) Residential MP: moderate economic capacity
(c) Residential HP: high economic capacity
(d) Commercial
(e) Industrial
(f) Private health
(g) Private education
(h) Public health
(i) Public education
(j) Governmental

Urban infrastructure

a) Energy substations and annexed networks

b) Communication substations and antennas
c) Dams, tanks and aqueduct plants and sewage
d) Aqueduct networks, sewage
e) Gas networks
f) Airports
g) Ports
h) Urban bridges

National infrastructure

(a) Primary roads network (roads and bridges)
(b) Secondary roads network (roads and bridges)
(c) Hydroelectric plants (dams and machinery sites)
(d) Thermal and geothermal plants
(e) Energy substations and annexed networks
(f) Communication substations and antennas
(g) Fuel and gas substations and annexed networks

The vulnerability functions for each one of these components are calculated using the module ERN-Vulnerabilidad (ERN 2010). The functions are generated in terms of maximum wind velocity. The curves are modified with factors that take into account particular aspects of the local constructive types such as material quality, general condition of constructions, design practices and characteristic construction, and in general the specific characteristics of the predominant structural types. It must be emphasized that several infrastructure components such as hydroelectric plants, pipe systems, road networks and others are in general lightly susceptible to the direct effect of the wind, reason why their vulnerability is assumed as null for the analysis. Figure 4-1 shows the vulnerability functions used for the analysis. At the link http://www.ecapra.org/es/ (wiki - vulnerabilidad) are presented the mentioned functions.

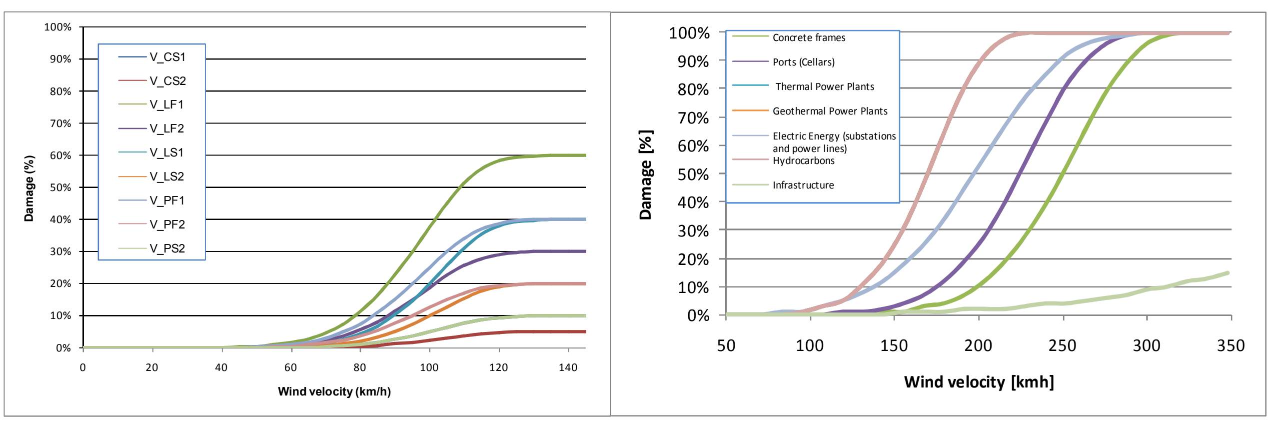

Figure 4-1
Vulnerability Functions for hurricane (wind)

4.4 Hurricane risk evaluation

4.4.1 *Generals aspects*

Based on the probabilistic hazard models proposed and on the inventory and assessment of exposed assets, with their corresponding vulnerability functions, a probabilistic risk modeling was developed for hurricane winds in the country using CAPRA-GIS (ERN 2010).

The calculation risk methodology follows the same methodology as the one used for the case of earthquakes, for further reference see the link http://www.ecapra.org/es/ (wiki – riesgo).

4.4.2 *Total losses at national level*

First of all, Table 4-1 shows the consolidated information nationwide, with the total exposure value, the average annual loss in value and in thousands (also known as technical risk premium) and the values that indicate probable maximum loss for different return periods.

Table 4-1
General results of PML for hurricane (wind)

Results		
Exposure Value	US$ x10^6	$4,829
Average Annual Loss	US$ x10^6	$23
	‰	4.8
PML		
Return Period	**Loss**	
Years	**US$ x10^6**	**%**
50	$182	3.8%
100	$225	4.7%
250	$282	5.8%
500	$332	6.9%
1000	$364	7.5%

Figure 4-2 shows the exceedance curves of losses at country level due to hurricane winds.

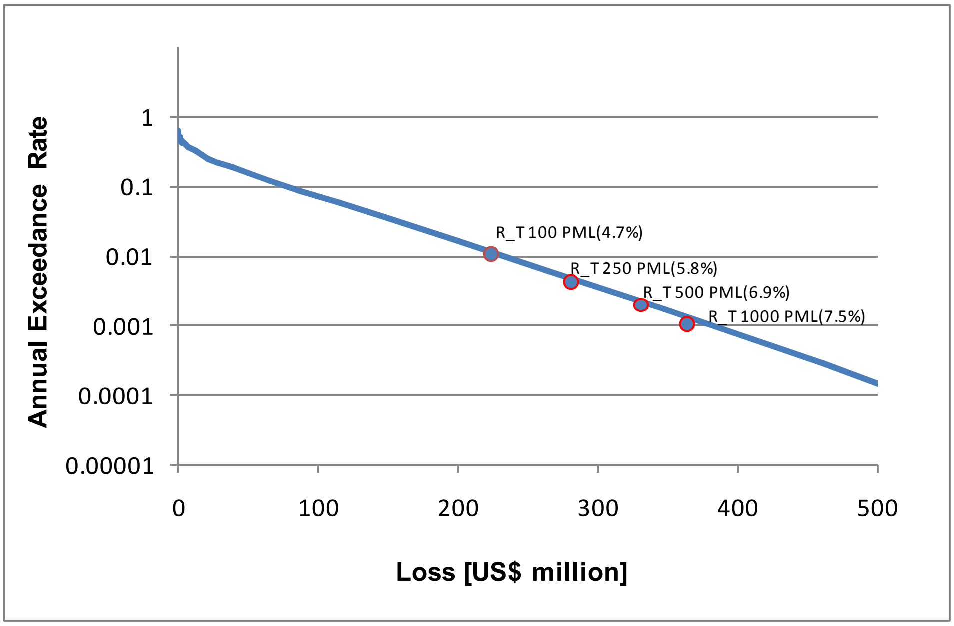

Figure 4-2
Loss exceedance due to hurricane (wind)

Figure 4-3 shows the curve of probable maximum loss showing values and percentages for different return periods. Figure 4-4 the probability exceedance curves of different PML values are presented in percentage for different exposure periods, in particular 20, 50, 100 and 200 years.

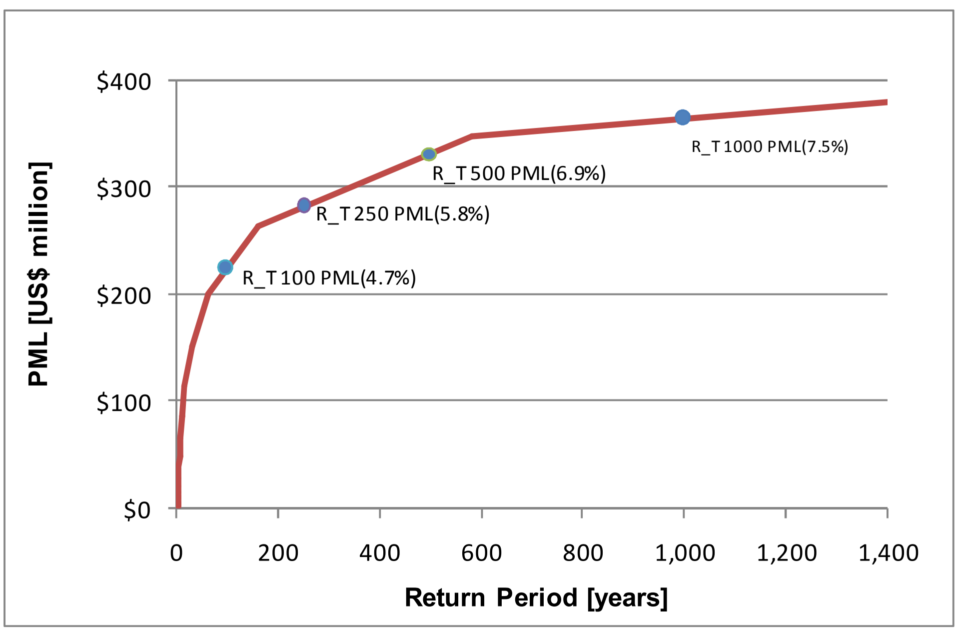

Figure 4-3
PML curve for hurricane (wind)

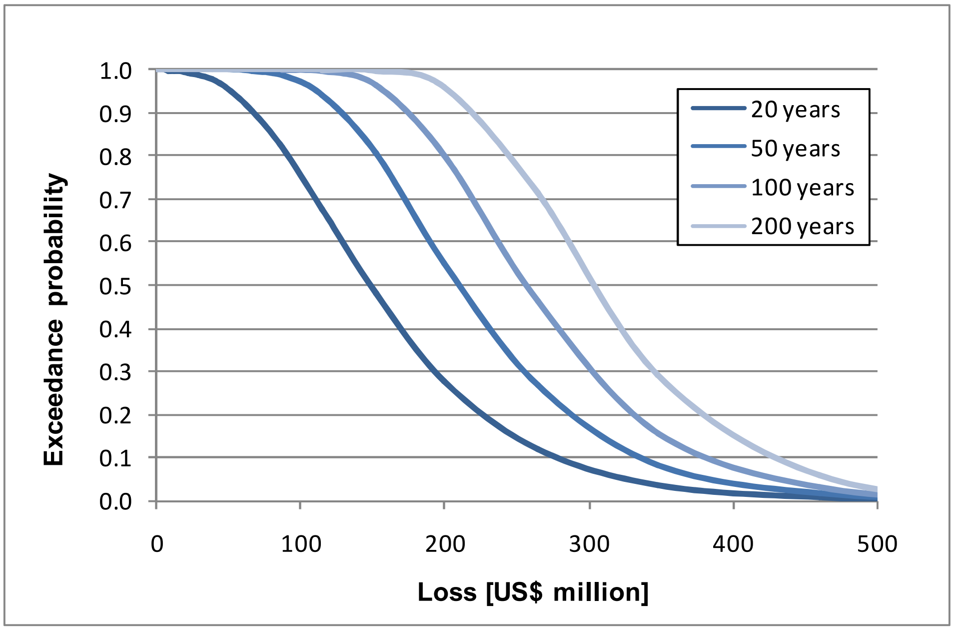

Figure 4-4
Exceedance probability curves of different PML values for different times of exposition for hurricane (wind)

Table 4-2 summarizes the resulting group of simulations or "family" of critical scenarios, that is, the scenarios with the greater expected economical losses for effects of hurricane winds.

Table 4-2
Group of simulations of the critical scenarios of analysis for hurricane winds

N°	Scenario sources	Loss [US$ x 10^6]	Loss %	Frequency	Ret. Period scenario
20	NOT NAMED	97.03	5.57%	6.58E-03	152
93	KEITH	95.31	5.47%	6.58E-03	152
5	NOT NAMED	85.91	4.93%	6.58E-03	152
32	NOT NAMED	81.24	4.66%	6.58E-03	152
25	NOT NAMED	81.08	4.65%	6.58E-03	152
56	NOT NAMED	80.81	4.64%	6.58E-03	152
91	MITCH	76.96	4.42%	6.58E-03	152
67	HATTIE	74.95	4.30%	6.58E-03	152
78	FIFI	70.85	4.07%	6.58E-03	152
39	NOT NAMED	70.75	4.06%	6.58E-03	152

4.5 Concentration of hurricane risk

The analysis of risk concentration is carried out at district level, for the different sectors of use for the public and private sectors and as well for the main components of infrastructure at national level.

4.5.1 *Comparison of losses for districts*

Losses are evaluated by district as geographical units of analysis. Figure 4-5 shows a comparison of exposure values between the different districts.

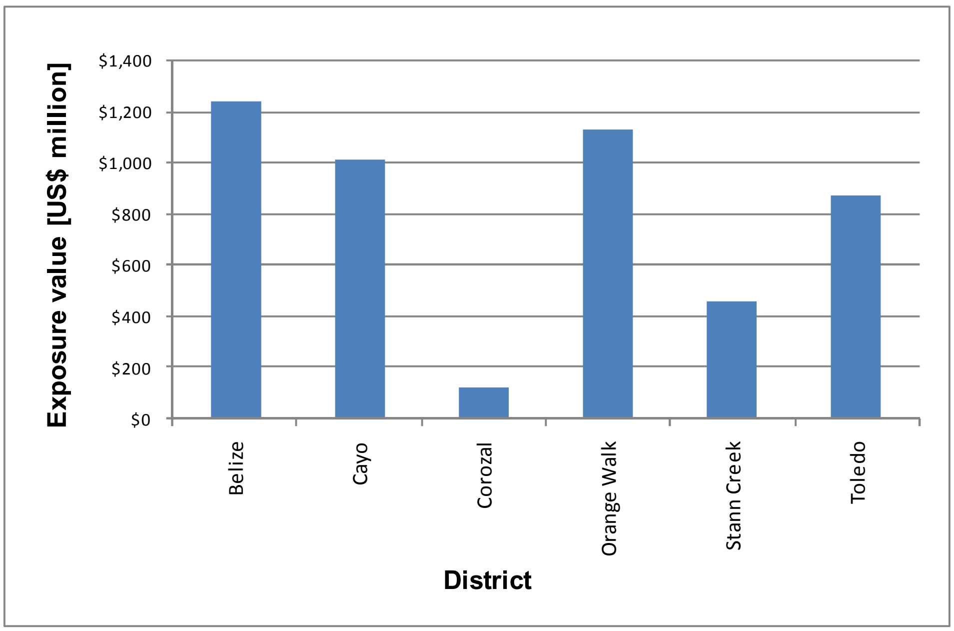

Figure 4-5
Exposed values per district

For each district, a complementary individual analysis is conducted, that allows estimating the probable maximum loss and the individual premium level by district. For each case, results are presented as follows:

- Summary table of the average annual loss (AAL) and the probable maximum loss (PML)
- Curves of loss exceedance rates and PML with different return periods.
- Bar diagrams showing the AAL in exposed values and thousands of exposed values, for each sector of use.

Figure 4-6 shows an example of the format used to present individual results for each district. Annex ERN-CAPRA-T3.3-2 shows individual results for the other districts

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS	30/07/2010		
Results			Probable Maximum Loss			Exceedance probability of PML values			
District	Belize		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$150.56	12.15%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$1,239	250 years	$195.70	15.80%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$12.78	500 years	$229.49	18.52%	3.92%	9.52%	18.13%	63.21%
	‰	10.32	1000 years	$258.86	20.89%	1.98%	4.88%	9.52%	39.35%

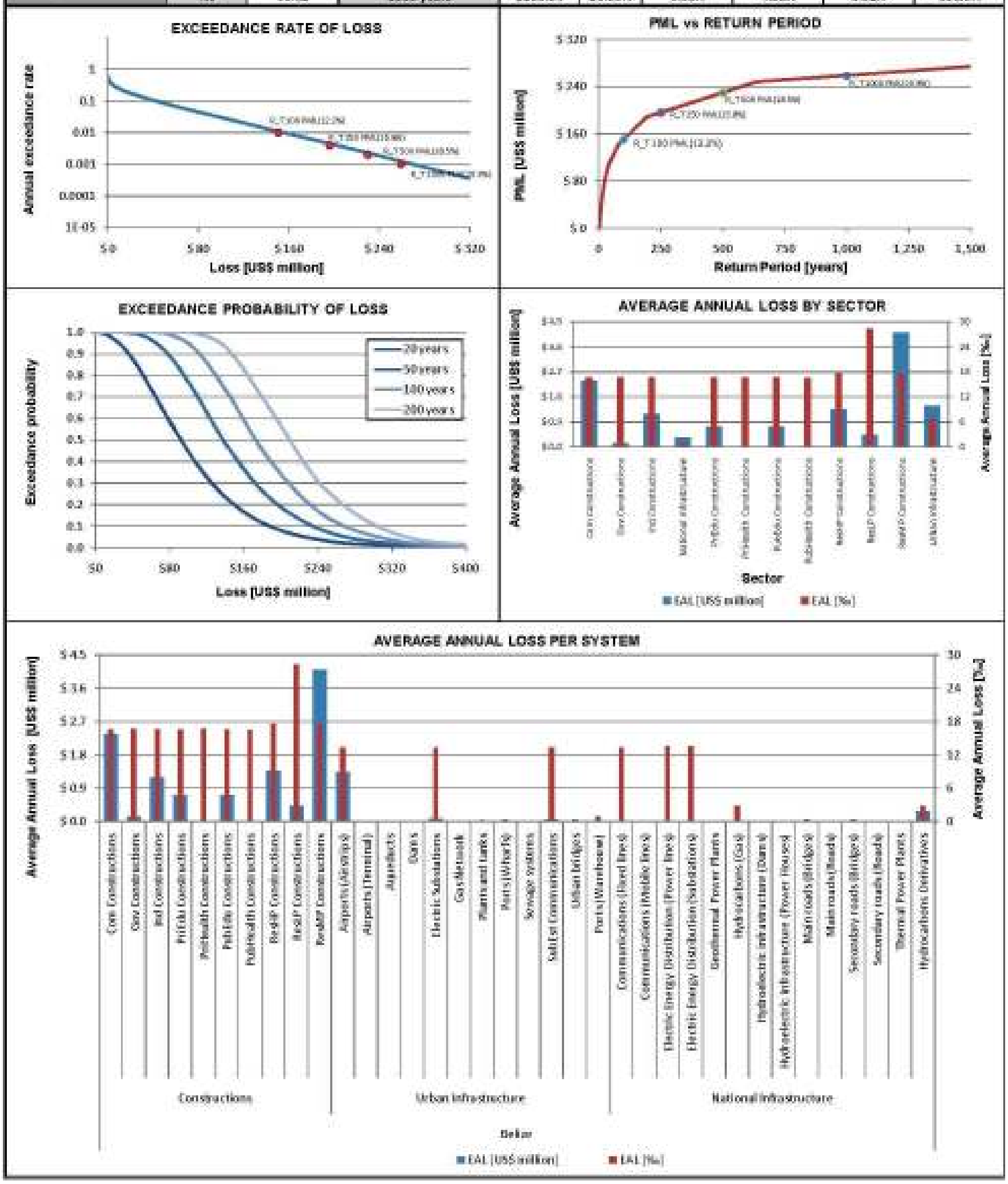

Figure 4-6
Example of results due to hurricane (wind) for Belize

Figure 4-7 summarizes PML values for return periods of 250, 500 and 1000 years for each district in values as well as in percentage.

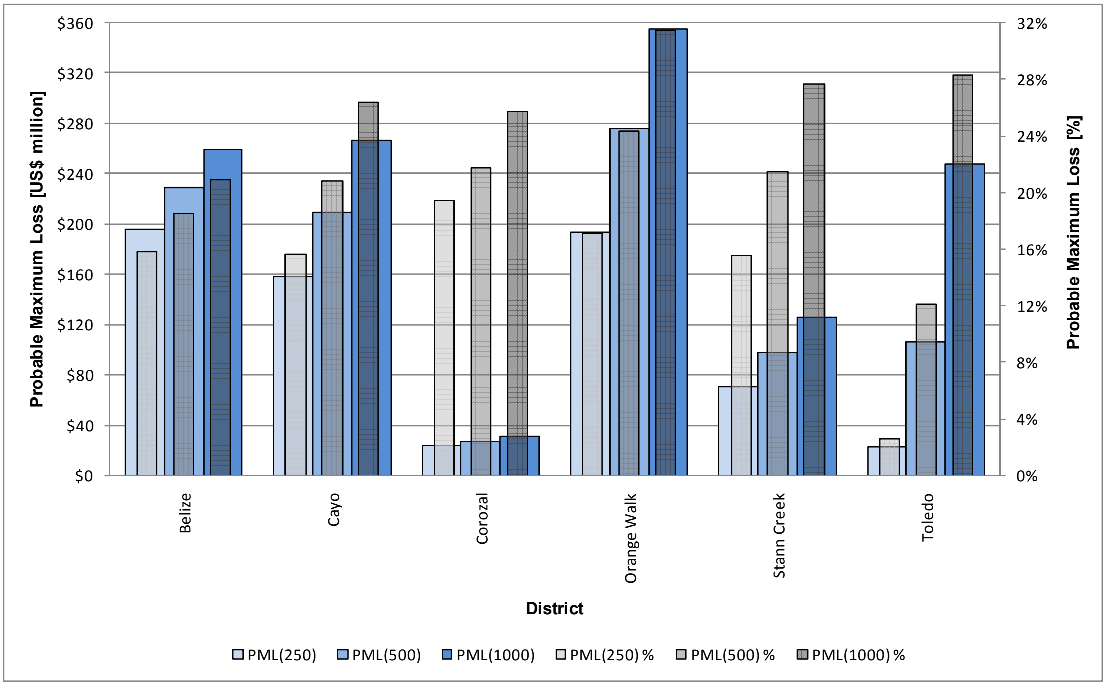

Figure 4-7
PML values for several return periods for hurricane (wind) per district

On the other hand, Figure 4-8 shows the values corresponding to AAL showing in values and thousands.

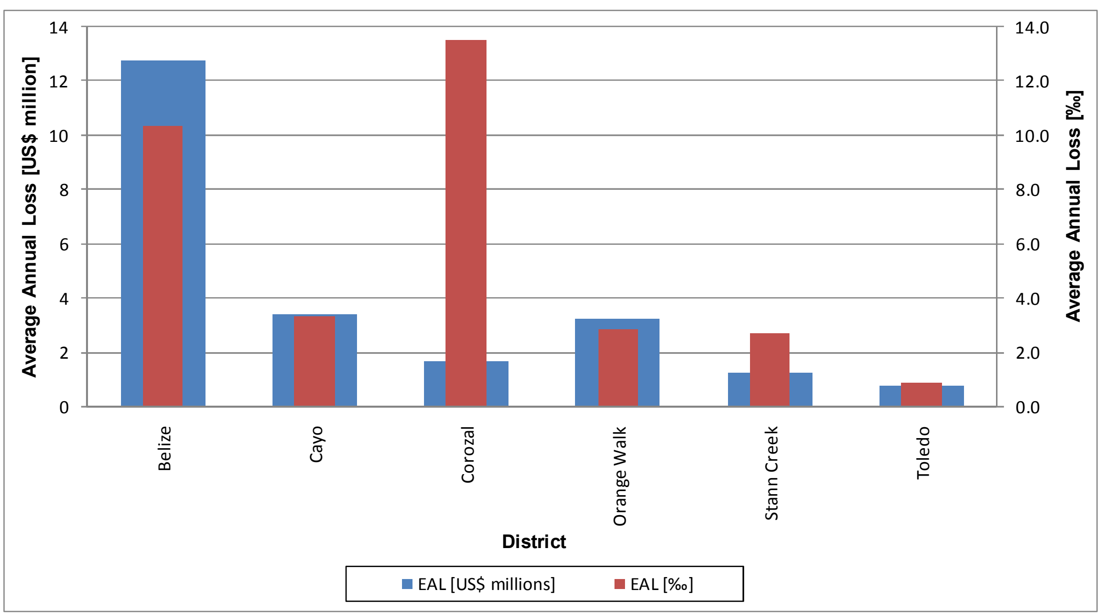

Figure 4-8
Values of AAL per district for hurricane (wind)

Figure 4-9 also shows the expected annual losses by sectors for each district. Urban constructions, urban infrastructure and the national infrastructure associated to each district are considered.

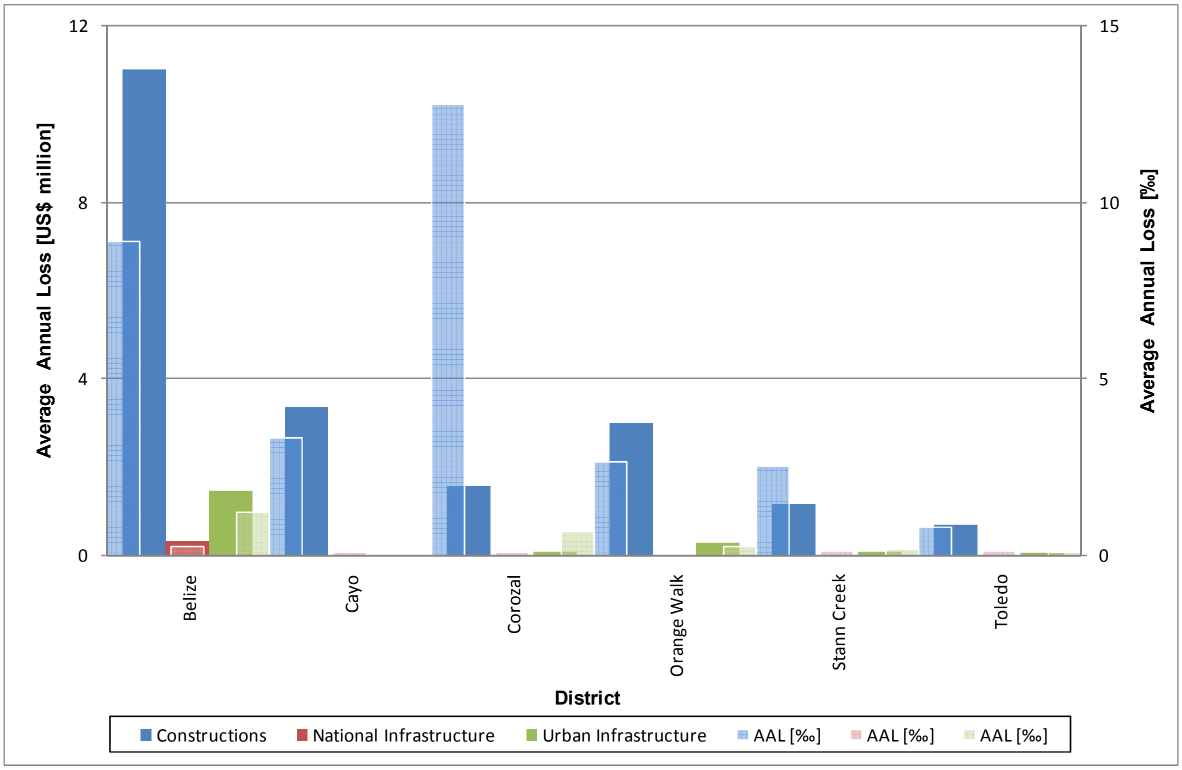

Figure 4-9
Values of AAL per district discriminated by sectors of use for hurricane (wind)

Finally, Figure 4-10 and Figure 4-11 show the geographical distribution of average annual losses in value and in thousands, for each district. Figure 4-12 and Figure 4-13 show probable maximum losses in value and in percentage, for each district.

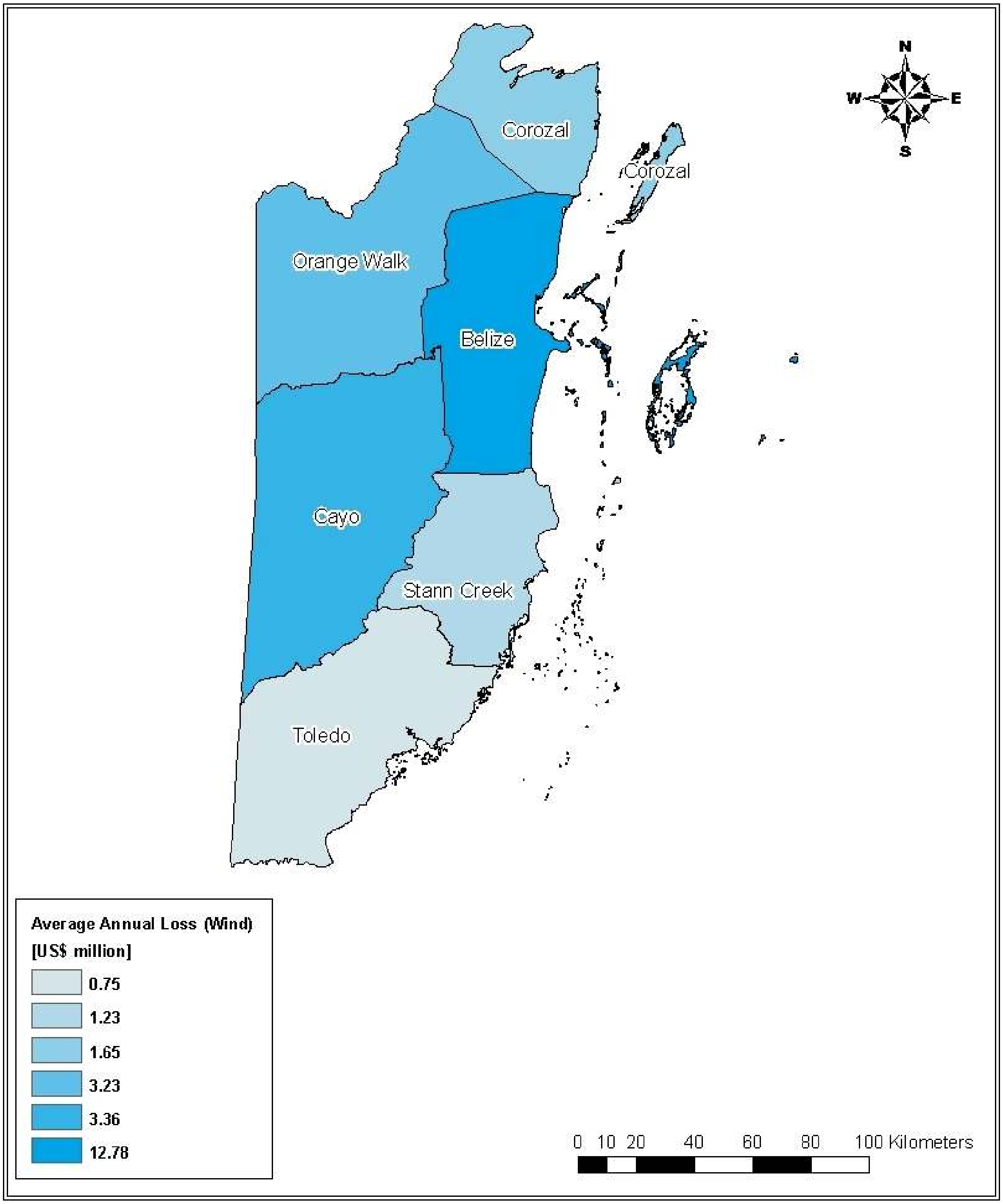

Figure 4-10
Geographical distribution of AAL (values) per district for hurricane (wind)

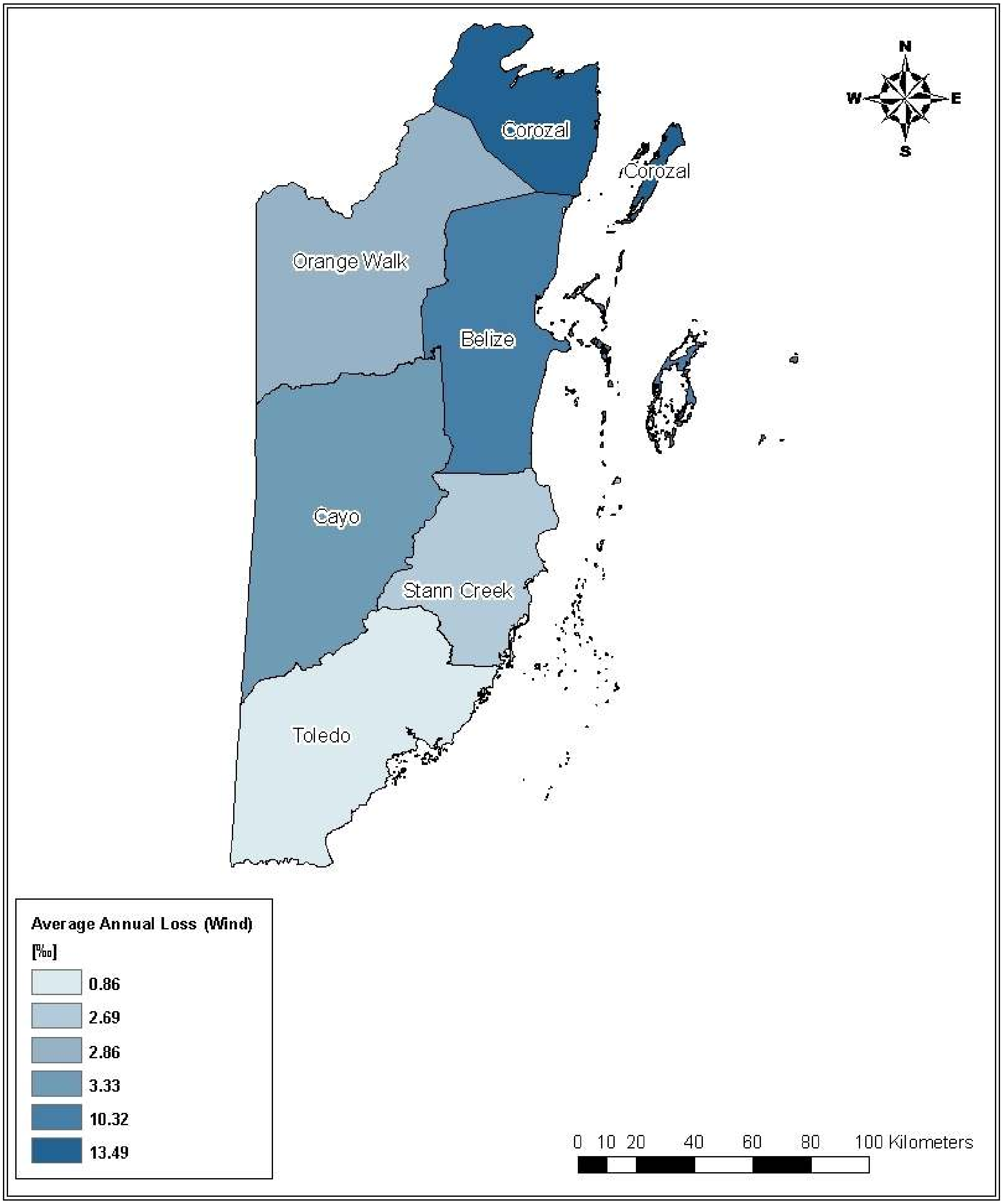

Figure 4-11
Geographical distribution of AAL (‰) per district for hurricane (wind)

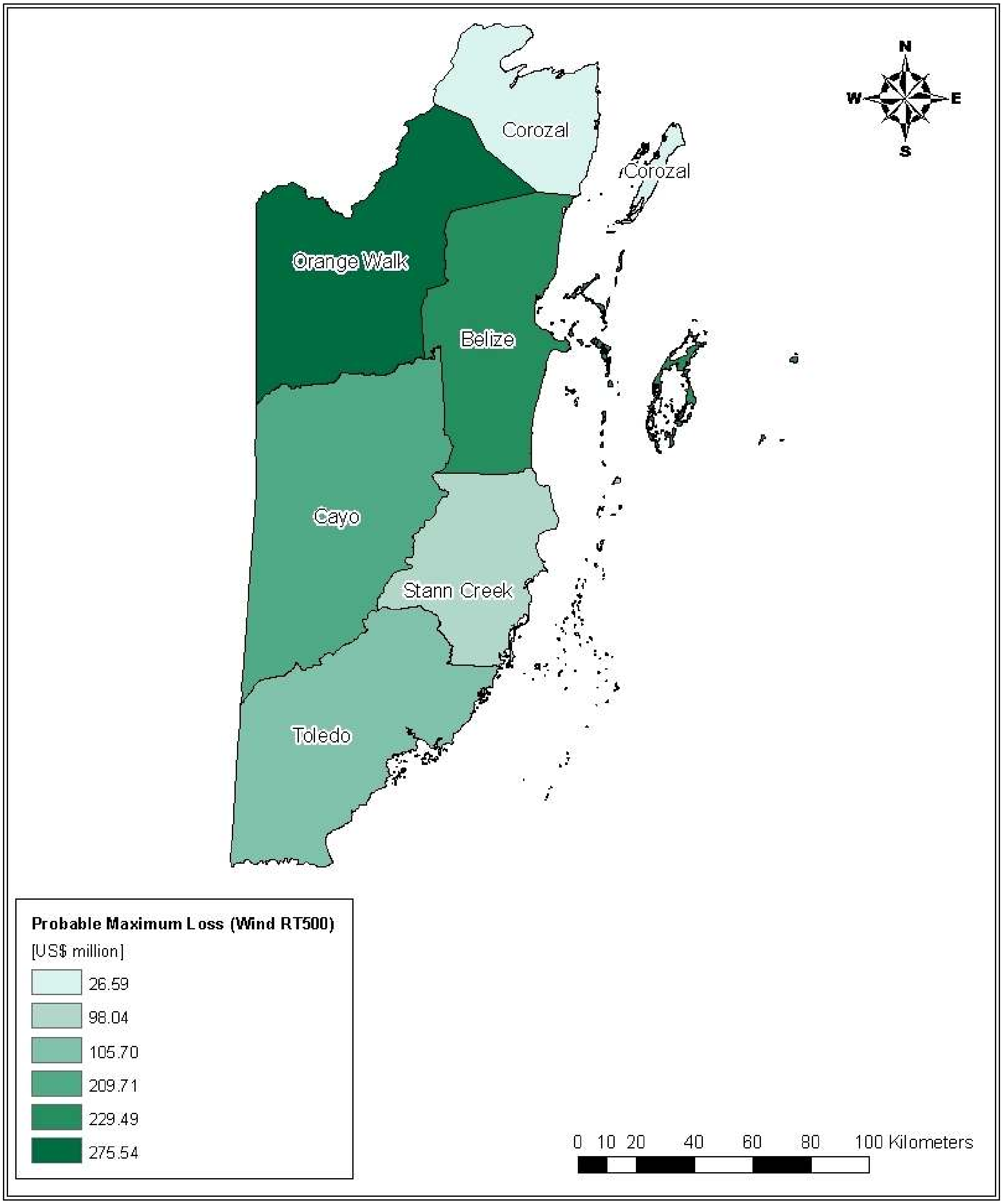

Figure 4-12
Geographical distribution of PML (value) per district for hurricane (wind)

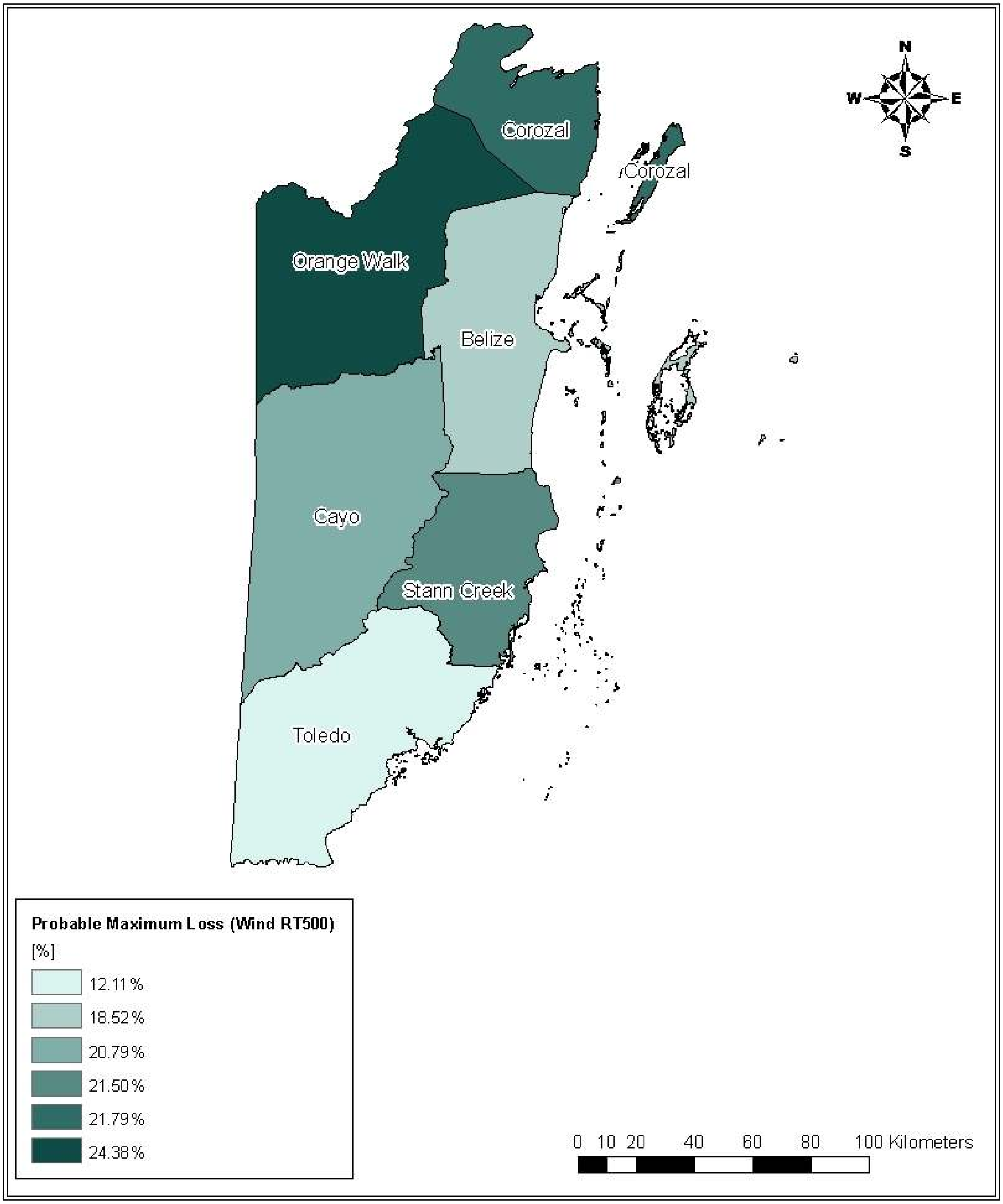

Figure 4-13
Geographical distribution of PML (%) per district for hurricane (wind)

4.5.2 *Comparison of losses by sector*

Figure 4-14 shows a comparison between the exposure values by sector at a national scale.

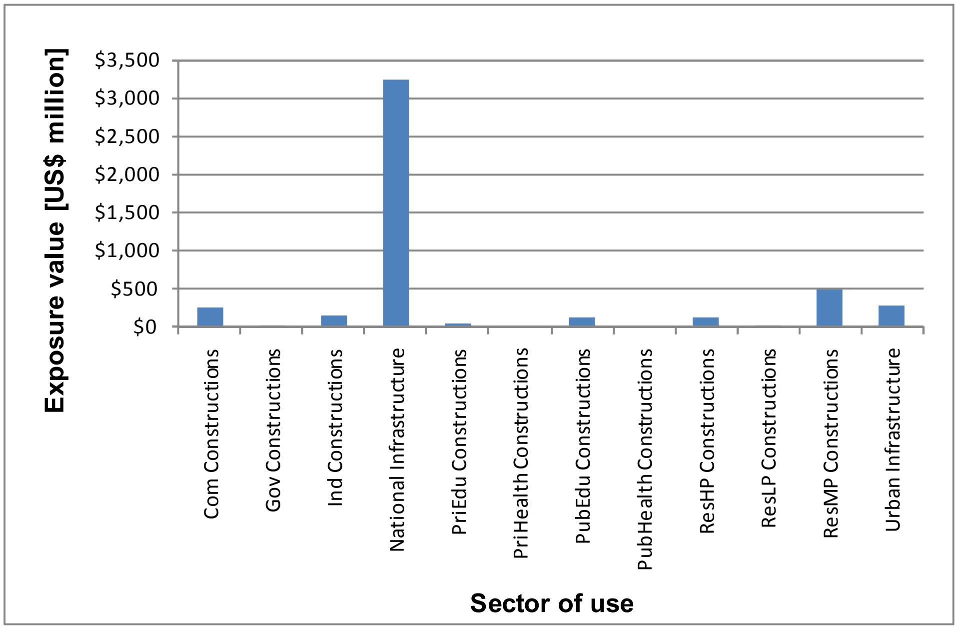

Figure 4-14
Exposure values by sector of use

Figure 4-15 totalizes the average annual losses in exposed value and thousands of exposed value for each sector of use and for the whole country.

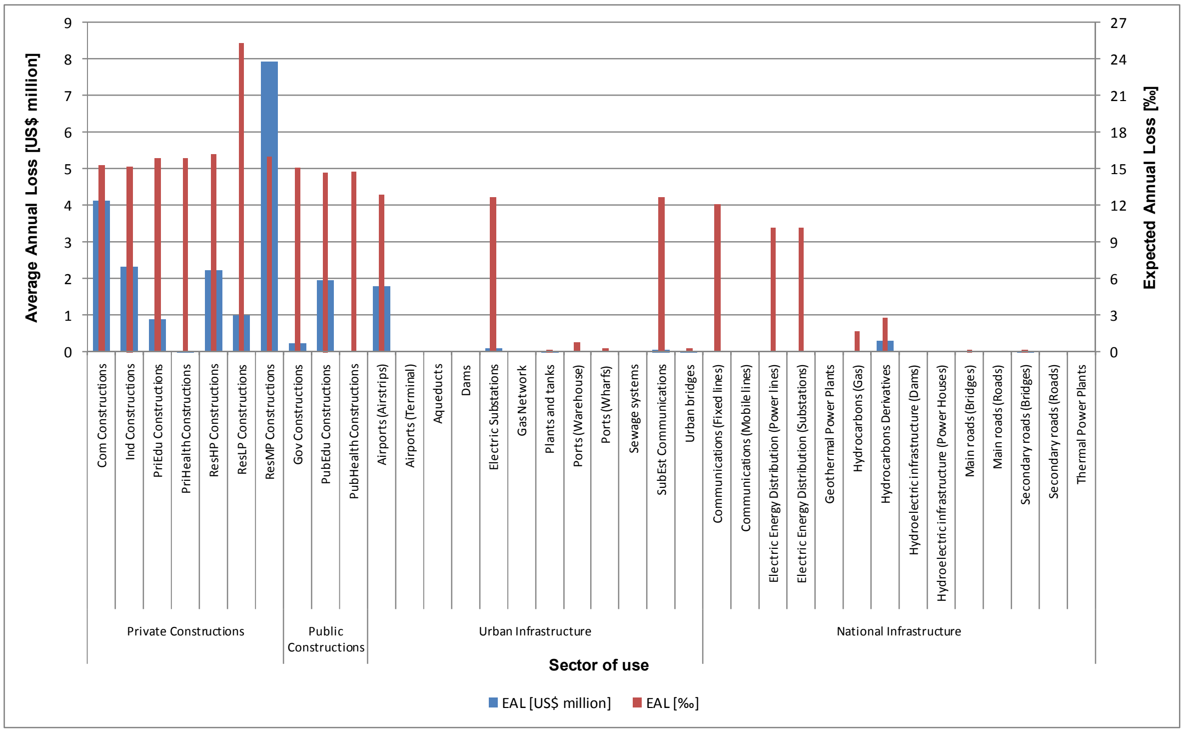

Figure 4-15
Values of AAL per sectors of use for hurricane (wind)

Figure 4-16 totalizes the results for the three main sectors of use corresponding to urban constructions, urban infrastructure and national infrastructure.

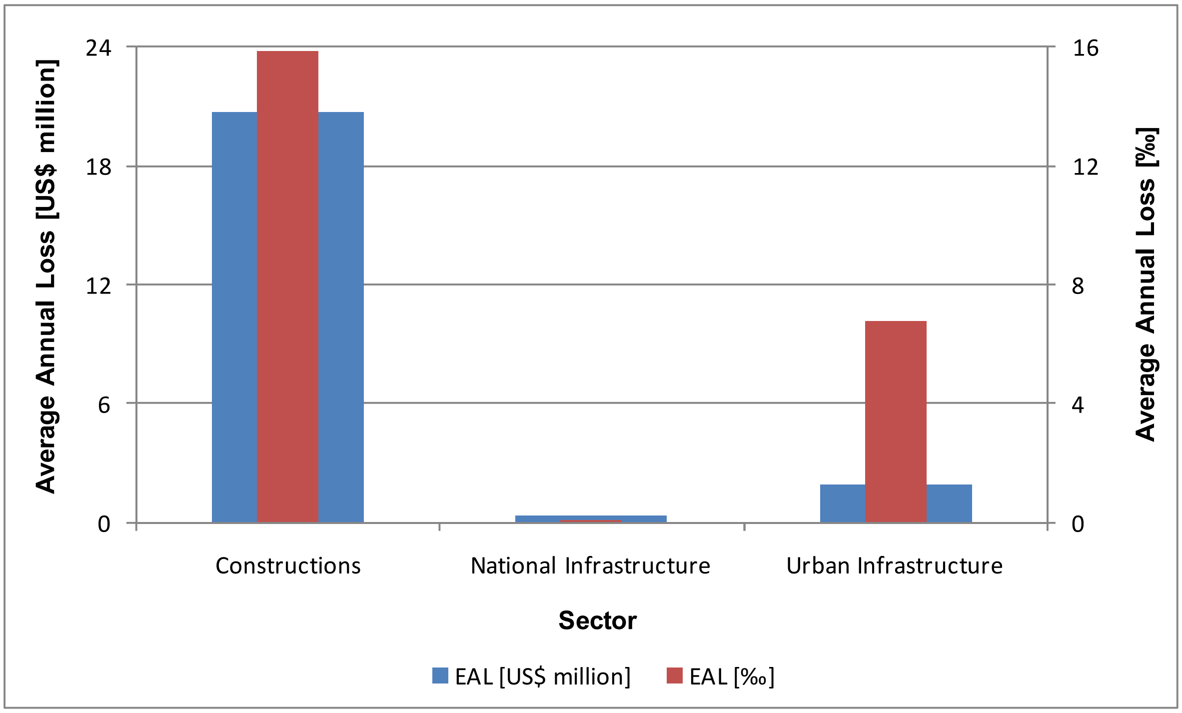

Figure 4-16
Summary of the distribution of AAL per sectors of use for hurricane (wind)

4.5.3 *Probable maximum loss for public and private sectors*

To assess the probable maximum losses for public and private sectors, it is necessary to conduct analyses for each portfolio due to the results of this type of analysis depending on the relative geographical distribution of the exposed values.

The public sector includes public urban constructions (health, education –when they are State's property- and government buildings) and the entire infrastructure. The private sector, on the other hand, includes residential, commercial, industrial constructions and the ones corresponding to the education and health sectors.

Figure 4-17 shows the exposure values for public and private sectors nationally.

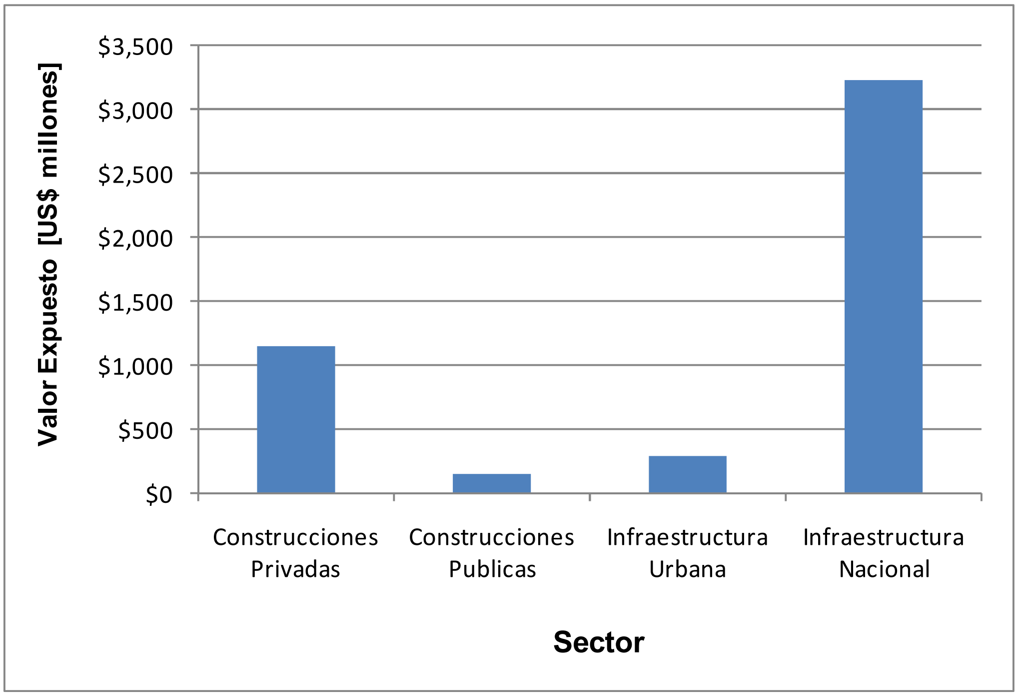

Figure 4-17
Exposure values by sector

Figure 4-18 and Figure 4-19 show the PML curves for each of these sectors.

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS		01/07/2009	
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Public Constructions		Return Period	US$ $\times10^6$	%	20 years	50 years	100 years	500 years
			100 years	$23.07	15.48%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ $\times10^6$	$149.07	250 years	$29.63	19.88%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ $\times10^6$	$2.19	500 years	$32.66	21.91%	3.92%	9.52%	18.13%	63.21%
	‰	14.69	1000 years	$38.45	25.80%	1.98%	4.88%	9.52%	39.35%

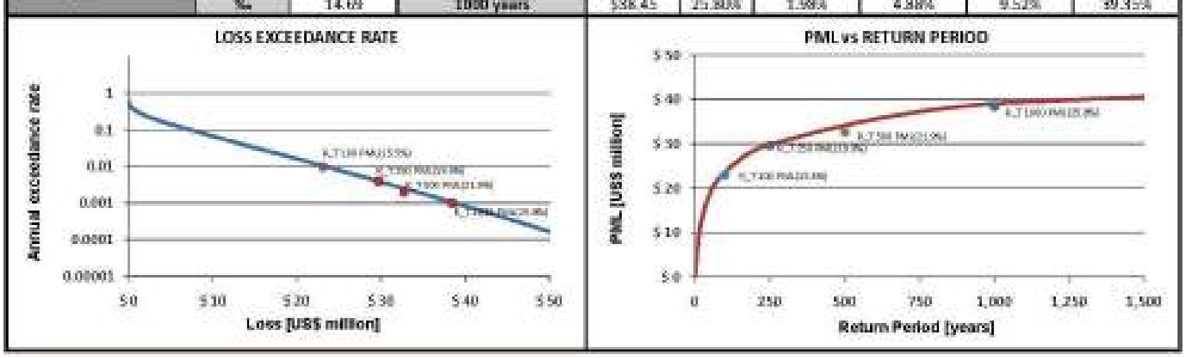

Figure 4-18
Loss exceedance curve and PML for public constructions for hurricane (wind)

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS		01/07/2009	
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Private Constructions		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$184.07	15.96%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$1,152.95	250 years	$233.54	20.26%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$18.48	500 years	$260.26	22.57%	3.92%	9.52%	18.13%	63.21%
	‰	16.03	1000 years	$305.41	26.49%	1.98%	4.88%	9.52%	39.35%

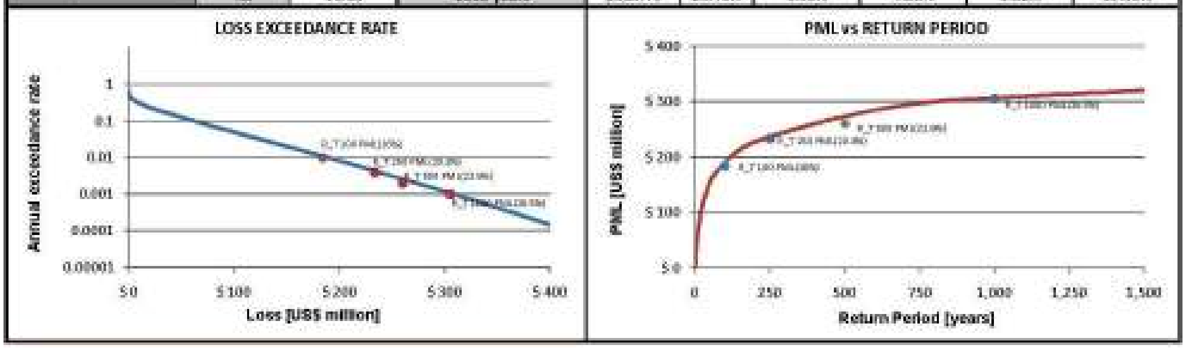

Figure 4-19
Loss exceedance curve and PML for private constructions for hurricane (wind)

4.5.4 *Probable maximum loss for the national infrastructure*

A similar analysis is conducted for the national infrastructure sector, taking into account the following analyses:

- Energy generation and distribution
- Communications
- Hydrocarbons

Results of the PML curves with the return period and global AAL values in value and in thousands are shown for each sector. Figure 4-20 to Figure 4-22 summarize these results. In Annex ERN-CAPRA-T3.3-3 are presented individual results for the other sectors.

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS		01/07/2009	
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Production and distribution (Energy)		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$0.80	18.59%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$4.30	250 years	$1.32	30.59%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.04	500 years	$1.74	40.38%	3.92%	9.52%	18.13%	63.21%
	‰	9.30	1000 years	$2.12	49.29%	1.98%	4.88%	9.52%	39.35%

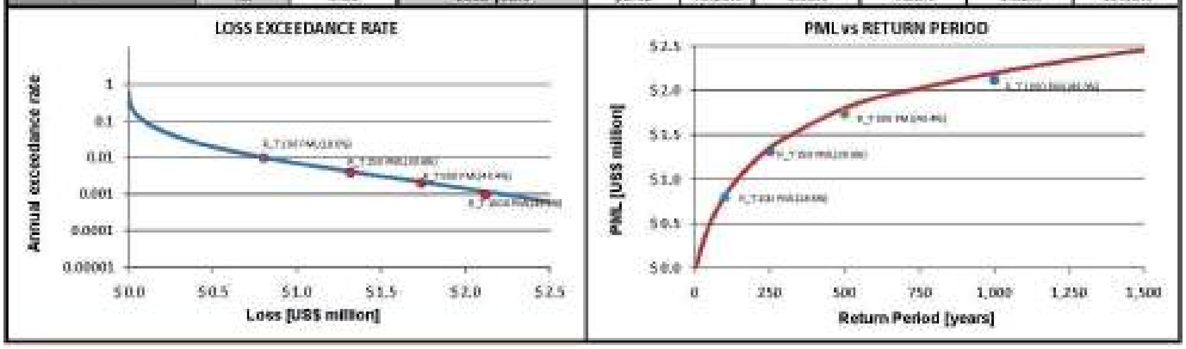

Figure 4-20
Loss exceedance curve and PML for the energy sector for hurricane (wind)

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS		01/07/2009	
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Communications		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$0.17	15.90%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$1.10	250 years	$0.23	20.82%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.01	500 years	$0.27	24.59%	3.92%	9.52%	18.13%	63.21%
	‰	9.09	1000 years	$0.30	27.66%	1.98%	4.88%	9.52%	39.35%

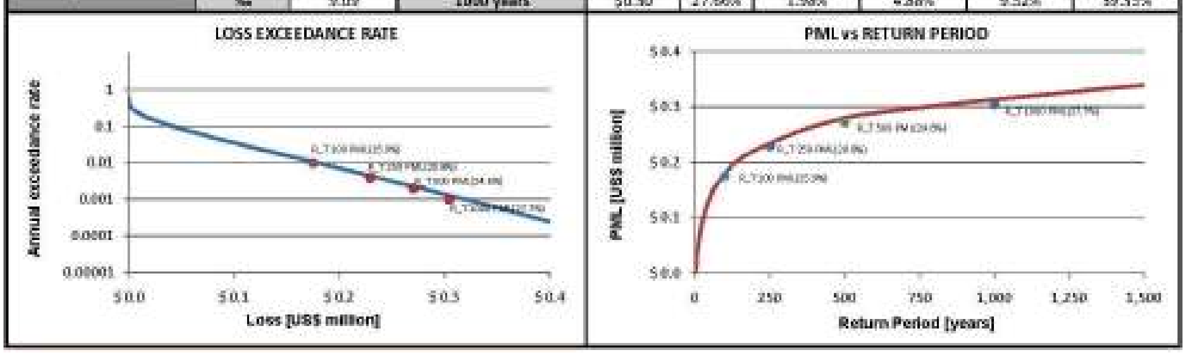

Figure 4-21
Loss exceedance curve and PML for the communication sector for hurricane (wind)

COUNTRY	BELIZE		HAZARD	HURRICANE (WIND)		DATE OF ANALYSIS		01/07/2009	
Results			Probable Maximum Loss			Exceedance probability of PML values			
Sector	Hydrocarbons		Return Period	US$ x10^6	%	20 years	50 years	100 years	500 years
			100 years	$5.11	4.61%	18.13%	39.35%	63.21%	99.33%
Exposed value	US$ x10^6	$110.78	250 years	$15.85	14.30%	7.69%	18.13%	32.97%	86.47%
Average annual loss	US$ x10^6	$0.29	500 years	$31.85	28.75%	3.92%	9.52%	18.13%	63.21%
	‰	2.62	1000 years	$53.43	48.23%	1.98%	4.88%	9.52%	39.35%

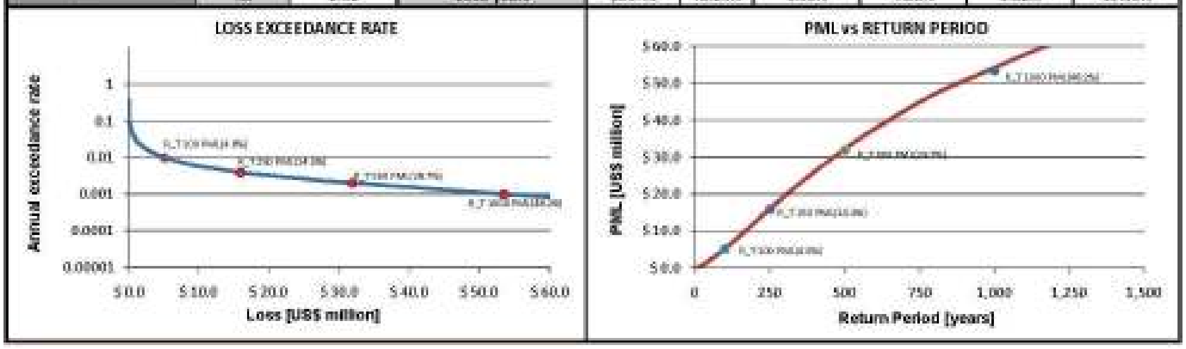

Figure 4-22
Loss exceedance curve and PML for the hydrocarbon sector for hurricane (wind)

5 Comparison of risk results

5.1 Average annual loss and probable maximum loss

Based on the results presented in the previous chapters, Table 5-1 summarizes results at country level for a comparative risk analysis for earthquake and hurricane (wind).

Table 5-1
Comparison of results of AAL and PML for earthquake and hurricane (wind)

Results					
Hazard		**Earthquake**		**(wind) Hurricane**	
Exposure Value	US$ x10⁶	$4,828.77			
Average Annual Loss	US$ x10⁶	$0.50		$23.00	
	‰	0.10		4.76	
PML					
Return Period		**Loss**			
Years		**US$ x10⁶**	**%**	**US$ x10⁶**	**%**
50		$4.51	0.09%	$181.67	3.76%
100		$9.13	0.19%	$224.71	4.65%
250		$19.27	0.40%	$281.90	5.84%
500		$30.77	0.64%	$331.76	6.87%
1000		$45.80	0.95%	$364.35	7.55%

5.2 Average annual loss per district

Figure 5-1 compares the average annual losses for earthquake and hurricane (wind) for each district.

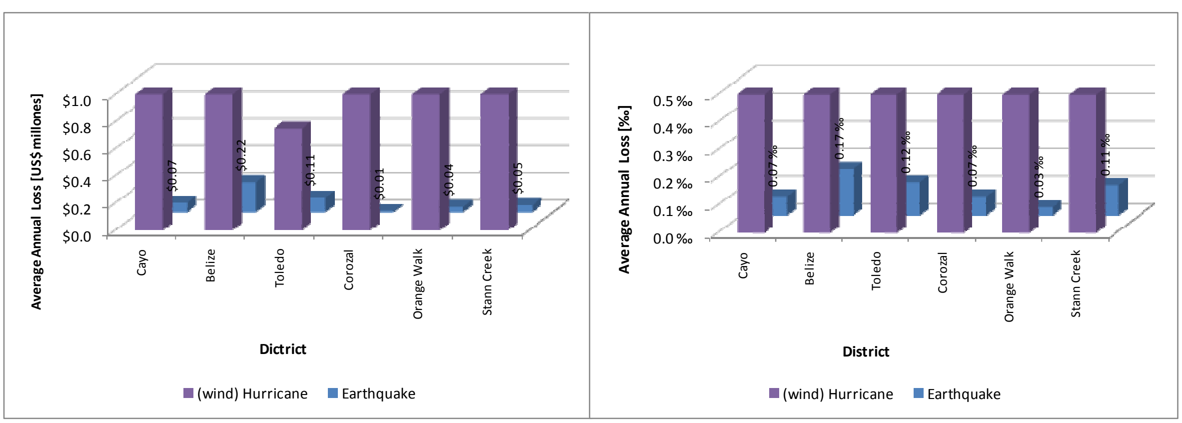

Figure 5-1
Values of AAL for earthquake and hurricane (wind) for each district

5.3 Average annual loss per sector

Figure 5-2 shows a comparison of average annual losses for earthquake and hurricane (wind) for the different sectors.

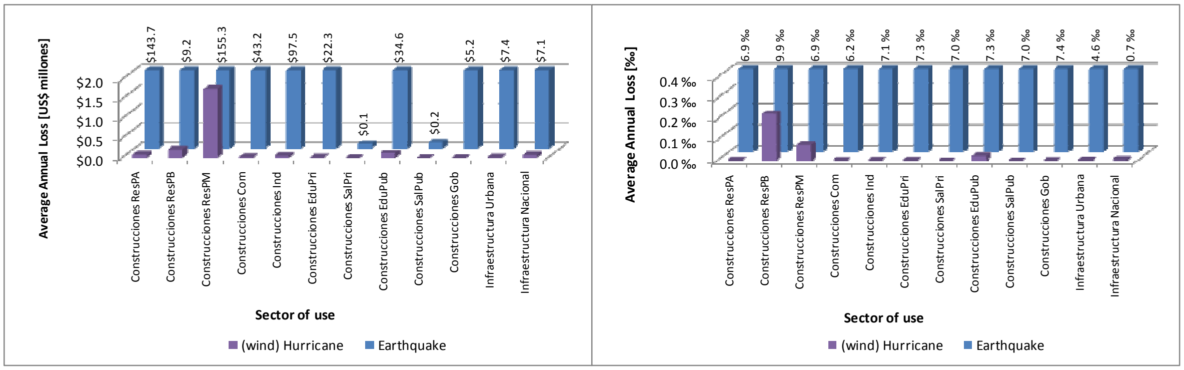

Figure 5-2
Values of AAL for earthquake and hurricane (wind) for the different sectors

5.4 Average annual loss for the public and private sector

Figure 5-3 compares the average annual losses for earthquake and hurricane (wind) for the public and private sectors.

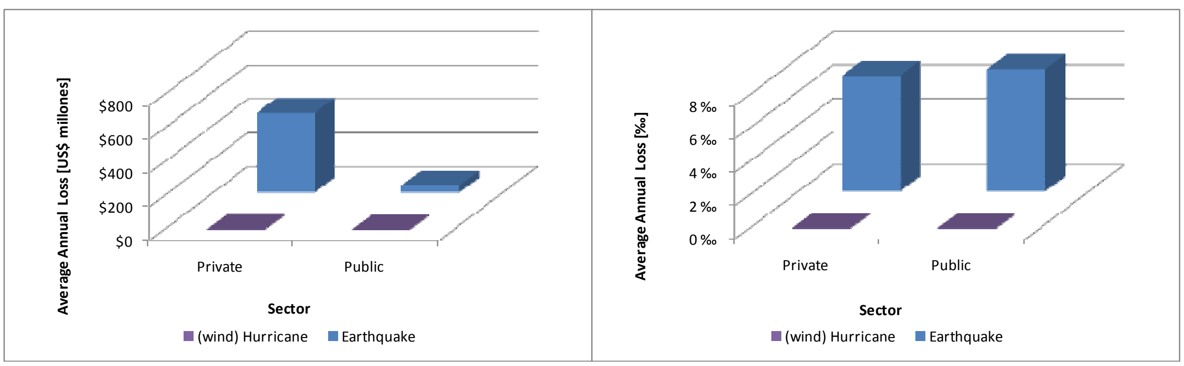

Figure 5-3
Values of AAL for earthquake and hurricane (wind) for the public and private sectors

5.5 Probable maximum loss per district

Figure 5-4 compares the probable maximum loss for earthquake and hurricane (wind) for district.

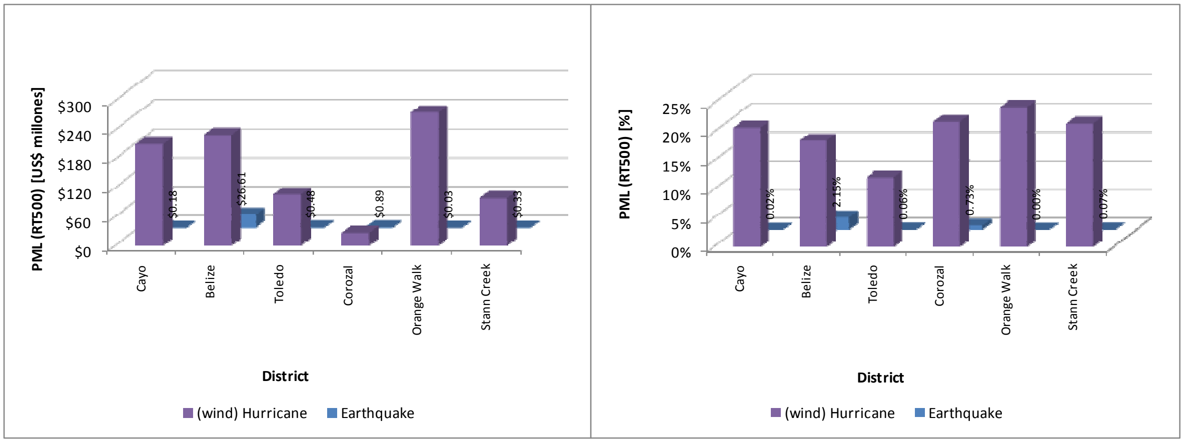

Figure 5-4
Values of PML for earthquake and hurricane (wind) per district

6 References

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ANNEX ERN-CAPRA-T3.3-1
Available geographic information

ANNEX ERN-CAPRA-T3.3-2
Results for districts

ANNEX ERN-CAPRA-T3.3-3
Results for sectors