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 I

HAZARD IDENTIFICATION, HISTORICAL REVIEW AND PROBABILISTIC ANALYSIS

<u>TECHNICAL REPORT TASK 1.3</u>

DATA QUALITY CONTROL AND PROBABILISTIC MODELLING

CEPREDENAC

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1 Seismic hazard

1.1 Introduction

This chapter presents the evaluation of seismic hazard in Belize, using the new material presented in the regional project RESIS II (Norsar et al, 2008), which is the most advanced study to date in relation to the evaluation of seismic risk in Central America. Belize is not included in the scope of RESIS II, but the model of sources and attenuation developed is perfectly applicable to that country. Based on the seismotectonics of the region, and the seismicity recorded or remembered, a series of seismogenic sources were defined, which cover the entire territory of Central America, and conserve the general conditions of seismicity and regional variation.

1.2 The local context of the hazards

1.2.1 *Seismotectonics of Belize*

Central America is an ample region of tectonic interaction, in which the Caribbean, North American, Cocos and Nazca plates interact. Most of the territory is located on the Caribbean plate. To the north, in Guatemala, the introductory interaction of the Caribbean and North American plates is transcurrent, generating a lateral dip fault zone, with a capacity to generate highly destructive earthquakes, whose principal characteristic is the Chizoy-Polochic and Motagua systems. To the south, in Costa Rica, there is the "triple point" or zone of convergence of the Cocos, Caribbean and Nasca plates in the region of Golfo Dulce, and the deformed belts of the north and south of Panama (see Figure 1-1).

The territory of Belize stands on the North American plate. The principal tectonic characteristics provide a hazard to that country with the interaction of the Caribbean and North American plates, which is transcurrent, with important fault systems such as Motagua in Guatemala and the Walton undersea fault to the southeast of the country, which may generate high-magnitude earthquakes (7+). The subduction zone, or Mesoamerican trench, does not represent an important seismic source for Belize, since it is some 400 km to the west of the country.

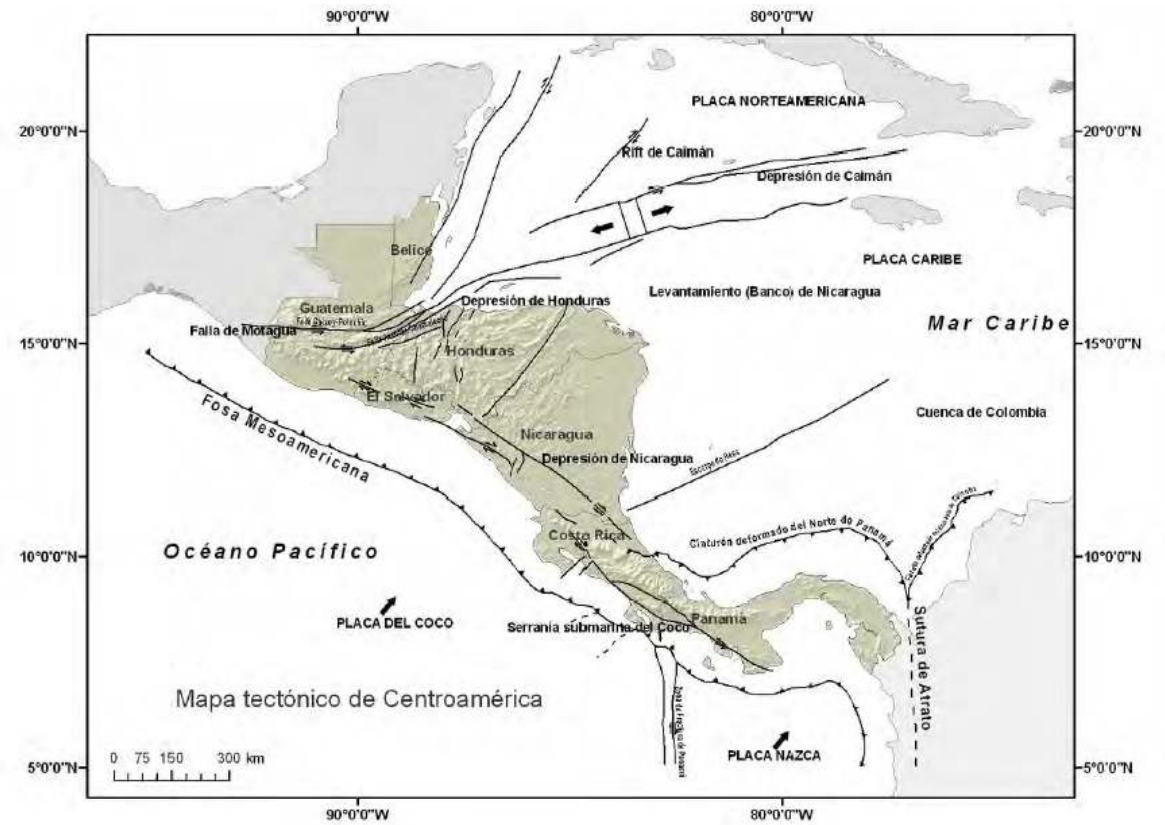


Figure 1-1
Seismotectonic context of Central America

1.3 Information used in modelling

1.3.1 *Seismic catalogue*

Work was done with a regional seismic catalogue (RESIS II), compiled on individual catalogues collected up from the Central American Seismological Centre (CASC), and national catalogues for Guatemala, El Salvador, Nicaragua, Costa Rica and Panama, which contains 29,918 earthquakes of Mw magnitude of 3.5 or more. Figure 1-2 presents the complete catalogue of events, as used by the project RESIS II.

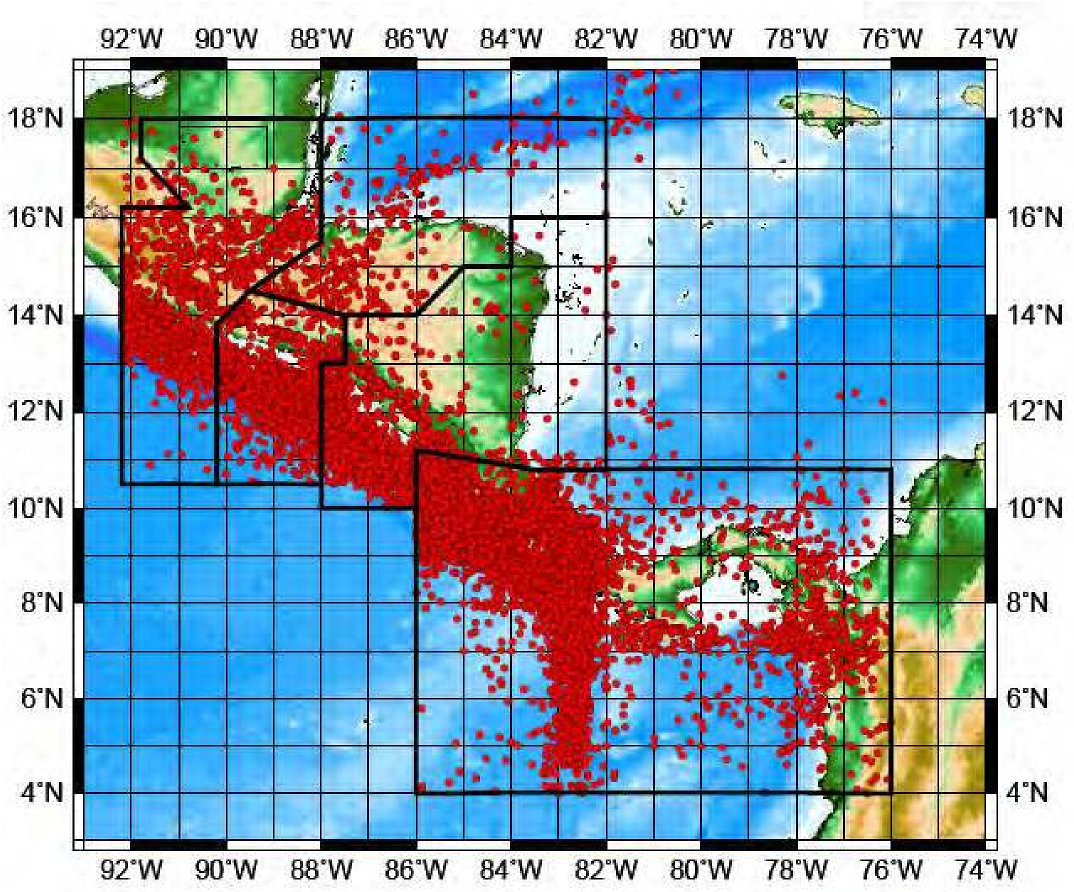


Figure 1-2
Regional seismic catalogue for the RESIS II prove project
(Taken from the RESIS II project, evaluation of seismic hazard in Central America, 2008)

1.3.2 *Parameters of seismicity*

Each of the seismic and any sources was characterised through a series of seismicity parameters which were determined on the basis of available seismic information. The parameters are the following:

- Magnitude recurrence: this was identified by using the β parameter, which represents the average slope of the magnitude recurrence curve (curve of the number of events with a magnitude greater than M., versus seismic magnitude M.) in the low magnitude zone.
- Maximum magnitude: this was estimated on the basis of the longest possible rupture of each of the sources, and on other morphotectonic characteristics.

- Recurrence rate for earthquakes with a magnitude greater than 4.5: this corresponds to the average number of events per year of earthquakes with a magnitude of more than 4.5 occurring in a given source.

1.3.3 *Seismic sources used*

The model for calculating seismic hazard is based on information from seismicogenic sources, at regional level. The parameters of the national seismic sources are the same as those determined in the RESIS II study. The model of seismic hazard is formed by 53 regional sources, 37 of which are cortical and 16 are deep. Table 1-1 presents the parameters of characterisation of the sources used in this study. Figure 1-3, Figure 1-4, and Figure 1-5 presents the geographical distribution of the seismogenic sources at regional level.

Table 1-1
Seismicity parameters of sources

Zone name	Code	Prof (Km)	λ0	β	Mu	Mo
Guat. Pacífico Ctral.	G1	20	3.51	2.05	7.5	4.5
Guat-El.Salv.Antearco.Ctrl	G2-S2	20	1.6	2.22	6.3	4.5
Guat. Acrc.Volc.Oeste	G3	10	0.18	1.35	6.7	4.5
Guat. Arc.Volc.Este	G4	10	0.65	1.63	7	4.5
Guat-Sal-Hon. Depresión ctrl.	G5-S5-H1	10	0.97	1.94	6.8	4.5
Guat. Polich-Motagua Oeste	G6	10	1.32	1.88	7.8	4.5
Guat. Poloch-Motagoa NE	G7	10	0.93	1.8	7.8	4.5
Guat. Norte (Peten-Belice)	G8	10	0.75	1.71	6.7	4.5
Hond. Altiplano Central	H2	10	0.73	2.62	6.3	4.5
Hond-Nic.Zona Gayape	H3-N11	10	0.36	2.38	6.3	4.5
El Salv.Pacífico Central	S1	20	9.77	3.42	7.5	4.5
El Salv. Arco Volcánico ctrl.	S3	10	1.18	1.92	7	4.5
Salv.Nic.ArcVolc (G.Fonsec)	S4-N5-H4	10	0.52	2.11	6.6	4.5
Nic. Pacífico Oeste	N1	10	13.73	2.67	8	4.5
Nic. Pacíf. SE- CR Papagayo	N2-C1	20	25.03	3.28	7.4	4.5
Nic. Antearco Oeste	N3	20	1.35	1.96	6.8	4.5
Nic. Antearco Este	N4	20	1.05	3.42	6.8	4.5
Nic. Arco Volc. O-Ctral	N6-N7	10	1.68	2.07	6.5	4.5
Nic. Arco Volc. SE	N8	10	0.27	1.4	6.8	4.5
Nic. Depres. Tras Arco	N9-N10	10	0.24	0.97	6.8	4.5
Nic. Caribe Sur	N12	10	0.44	2.53	6.2	4.5
Nic. Caribe Noroeste	N13-N14	10	0.57	2.2	6.2	4.5
CR. Antearco Noroeste	C2	20	2.2	2.27	7.2	4.5
CR. Ante Acto Pac. Ctral.	C3	15	4.56	2.11	7.3	4.5
Pan-CR.ZFP-Burica	P1-C4	5	19.61	2.37	7.5	4.5
CR. Arc.Voc.Guanacaste	C5	10	1	2.04	6.6	4.5
CR. Cord. Volc. Ctral	C6	10	1.09	2.02	7.1	4.5
CR-Talamanca.	C7	10	2.76	2.73	7.1	4.5

Zone name	Code	Prof (Km)	$\lambda 0$	β	Mu	Mo
CR. Trascarco Norte	C9	10	0.25	1.99	6.3	4.5
CR. Carib.Ctral-Parismina	C10	20	0.44	2.41	6.2	4.5
Pan. Cint.Def.Sur-Pan	P2	10	2.97	2.05	7.1	4.5
Pan. Antearo Colombia	P3	20	0.73	1.95	7	4.5
Pan. Zona de Sutura Atrato	P4	10	1.93	2.2	7.2	4.5
Pan Occidental	P5	10	0.89	3.12	6.5	4.5
Pan. Central	P6	10	0.08	2.23	6.7	4.5
Pan. Este-Darien	P7	10	1.12	1.61	7.4	4.5
Pan.Cint.Def.N.Pan-Limón	P8-C8	15	2.6	1.94	7.8	4.5
Guat. Interplaca	Gsi9	26 -70	2.14	1.89	7.9	4.5
El Salv. Interplaca	Ssi5	26 -70	3.93	2.27	7.9	4.5
Nic.Interplaca Noroeste	Nsi15	26 -70	4.32	3.09	7.9	4.5
Nic. Interplaca Sureste	Nsi16	26 -70	1.94	1.8	7.9	4.5
CR. Interplaca Nicoya	Csi11	26 -63	0.38	1.14	7.8	4.5
CR. Interplaca Quepos	Csi12	26 -51	0.65	2	7	4.5
CR. Interplaca Osa	Csi13	26 -52	0.14	1.02	7.4	4.5
Pan. Interplaca Sur.Pan	Psi9	26 -50	0.58	2.08	7.1	4.5
Pan.InterpS.Blas.Darién -Chocó	Psi10	50 Fijo	1.16	1.72	7.5	4.5
Guat. Intraplaca	Gsp10	61- 250	5	2.11	7.9	4.5
El Salv. Intraplaca	Ssp6	61- 200	4.49	2.4	7.9	4.5
Nic. Intraplaca	Nsp17	61- 200	13.76	2.78	7.3	4.5
CR. Intraplaca NW	Csp14	40- 177	0.98	2.42	7	4.5
CR. Intraplaca Central	Csp15	40- 155	0.54	1.56	7.4	4.5
CR. Intraplaca SE	Csp16	40- 82	0.11	1.45	6.8	4.5
Pan. Intraplaca Sur	Psp11	50- 100	0.14	1.2	7.1	4.5

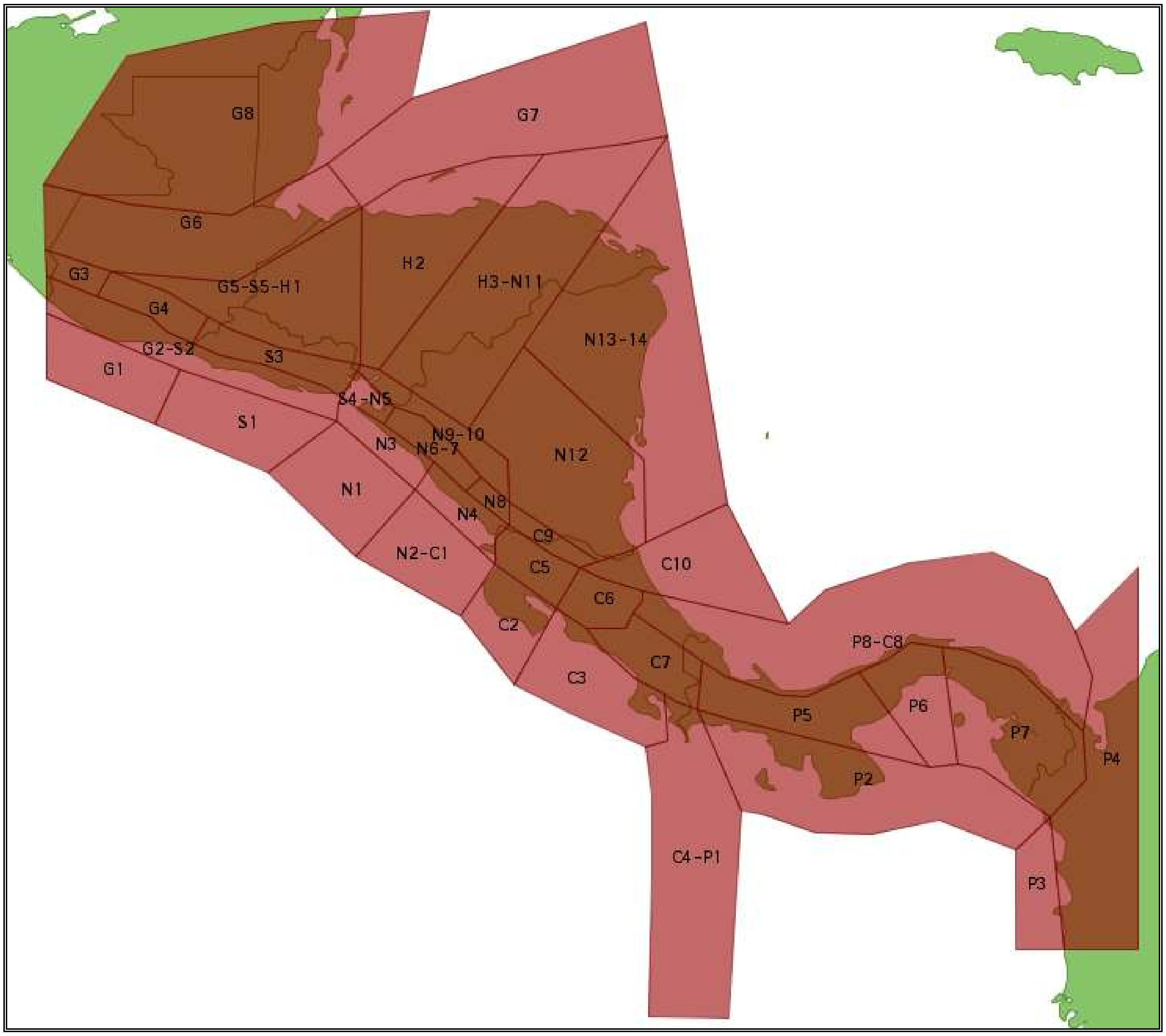


Figure 1-3
Cortical Sources. RESIS II Project

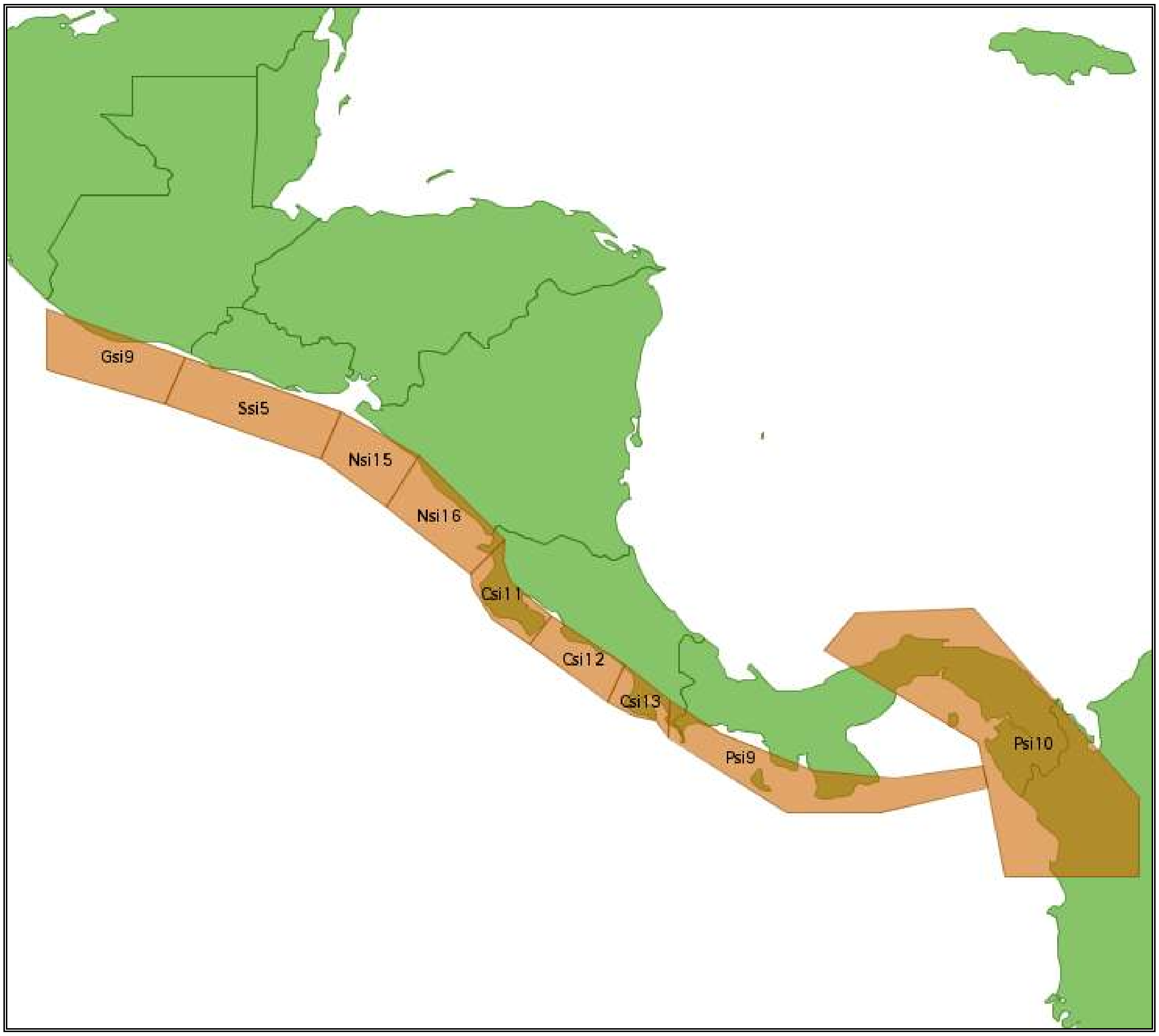


Figure 1-4
Interface type sources RESIS II project

Figure 1-5
Inter-plate type sources, RESIS II project

1.3.4 *Model attenuation of strong motion*

The models of RESIS II were used to model of attenuation of seismic waves: these were the model proposed by Climent et al (1994) for cortical earthquakes, and Youngs for interface and deep intraplate earthquakes.

The Climent model (1994) was developed based on accelerograph records of earthquakes occurring in the region and in other regions with similar tectonics. The function of attenuation is based on the following general equation:

$$\ln A = c_1 + c_2 M + c_3 \ln R + c_4 R + c_5 S \qquad \textbf{(Ec. 1)}$$

Where M is the magnitude of momentum, R is the hypocentral distance, and S is the soil factor, which is equal to 0 for rock sites, and one 1 soft soils. The coefficients c are shown in Table 1-2.

Table 1-2
Coefficients of Climent et al 1994 attenuation model

A	T [sec]	c1	c2	c3	c4	c5	σ
PSV	4	-7.441	1.007	-0.601	-0.0004	0.496	0.73
PSV	2	-7.348	1.128	-0.728	-0.00053	0.536	0.79
PSV	1	-6.744	1.081	-0.756	-0.00077	0.588	0.82
PSV	0.5	-5.862	0.917	-0.726	-0.00107	0.566	0.82
PSV	0.2	-4.876	0.642	-0.642	-0.00156	0.47	0.82
PSV	0.1	-4.726	0.483	-0.581	-0.00199	0.381	0.8
PSV	0.05	-5.487	0.447	-0.55	-0.00246	0.309	0.78
PGA		-1.687	0.553	-0.537	-0.00302	0.327	0.75

1.4 Available data quality

The seismic hazard information available and presented in the preceding sections of this chapter, has a good resolution and quality for analysis at the country level. The geometry of proposed sources, their associated seismicity and attenuation functions used for the estimation of ground motion intensities, meet the quality requirements for a model of regional and national seismic hazard.

Moreover, the resolution of the seismic hazard not usually depends on the characteristics of the available information. The spatial hazard modelling is performed by defining a grid of arbitrary size. Excessively refining the grid does not necessarily imply an improvement in the results. The resolution of the grid must be commensurate with the size of the seismic sources of the model. Normally, the area of influence of seismic events has a radius of about 200 km, area that must be covered by the grid of calculation employed. All results are expressed as hazard point values in each of the nodes of the grid. The final resolution of the hazard is the size of the grid used.

The resolution for the analysis of hazard must be compatible with the resolution of the exposure information and the final desired resolution of the risk assessment analysis.

1.5 Seismic hazard maps for Belize

The calculation was made of the seismic hazard for Belize for several structural periods and several return periods. The uniform hazard maps which appear below show the distribution of probable maximum intensities due to the occurrence of simultaneous earthquakes in all generating sources, for the related period of return. They are indicative hazard maps for the specific danger in the zone, and that application may be used to adopt criteria for zoning the hazard, as input for standards in design and plans to socialise the risk.

We now present the hazard maps castigated for Belize for minimum and maximum ground acceleration (PGA) and spectral acceleration, for a period of one second, for return periods of 500, 1000, and 2500 years. The calculations were made using the program CRISIS 2007 (Ordaz et al, 2007).

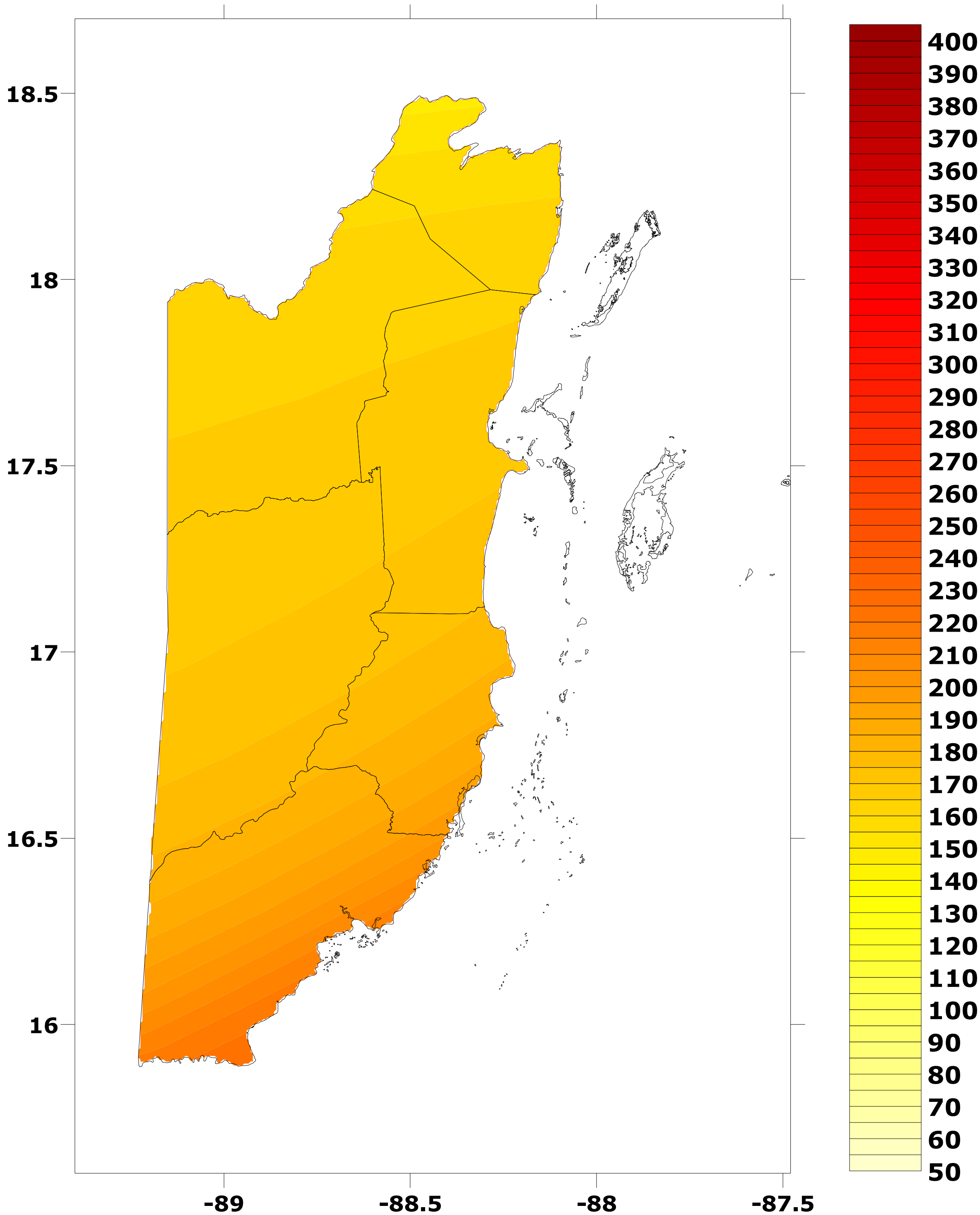


Figure 1-6
Spatial distribution of PGA (cm/s²) for 500 years of return period

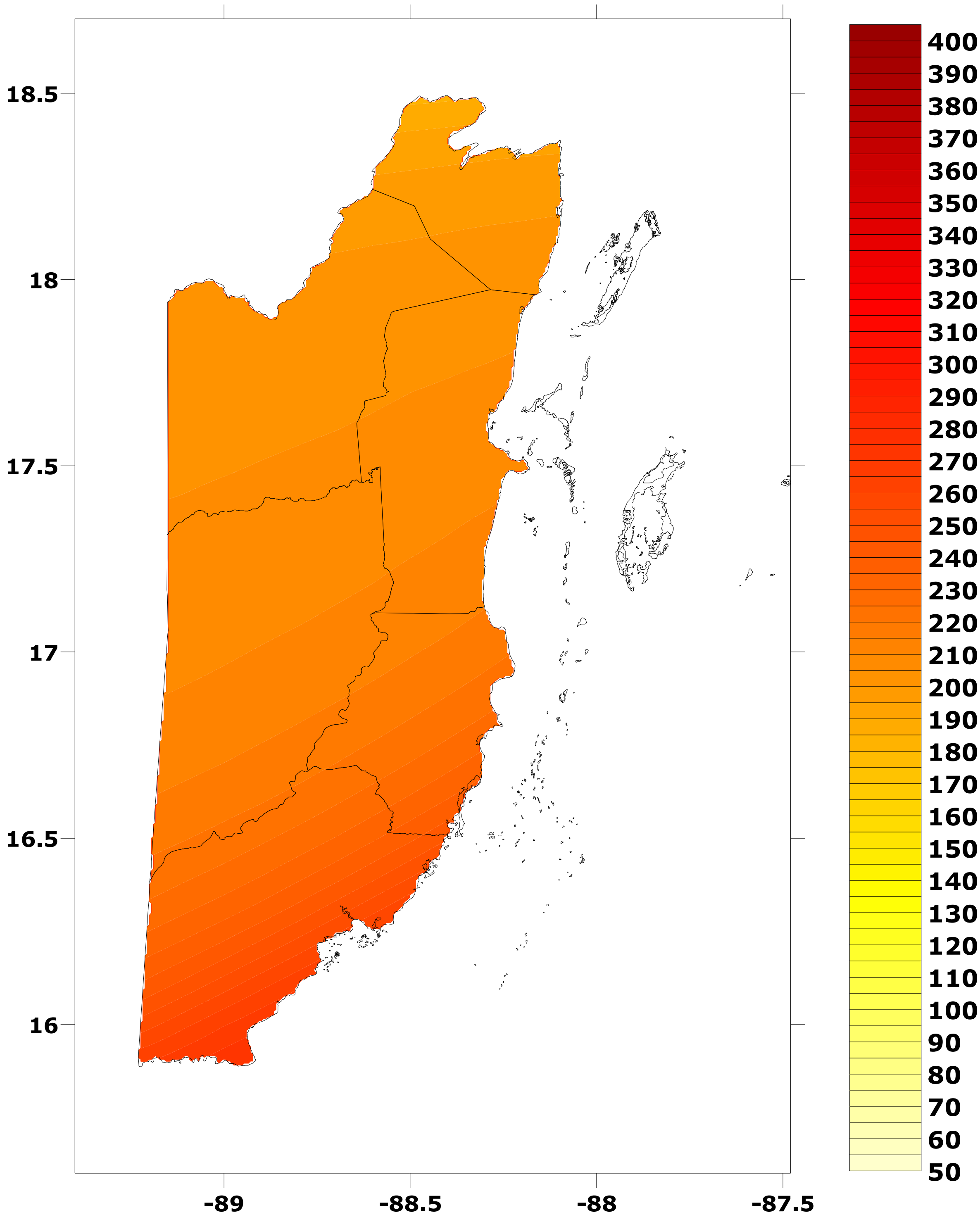


Figure 1-7
Spatial distribution of PGA (cm/s²) for 1000 years of return period

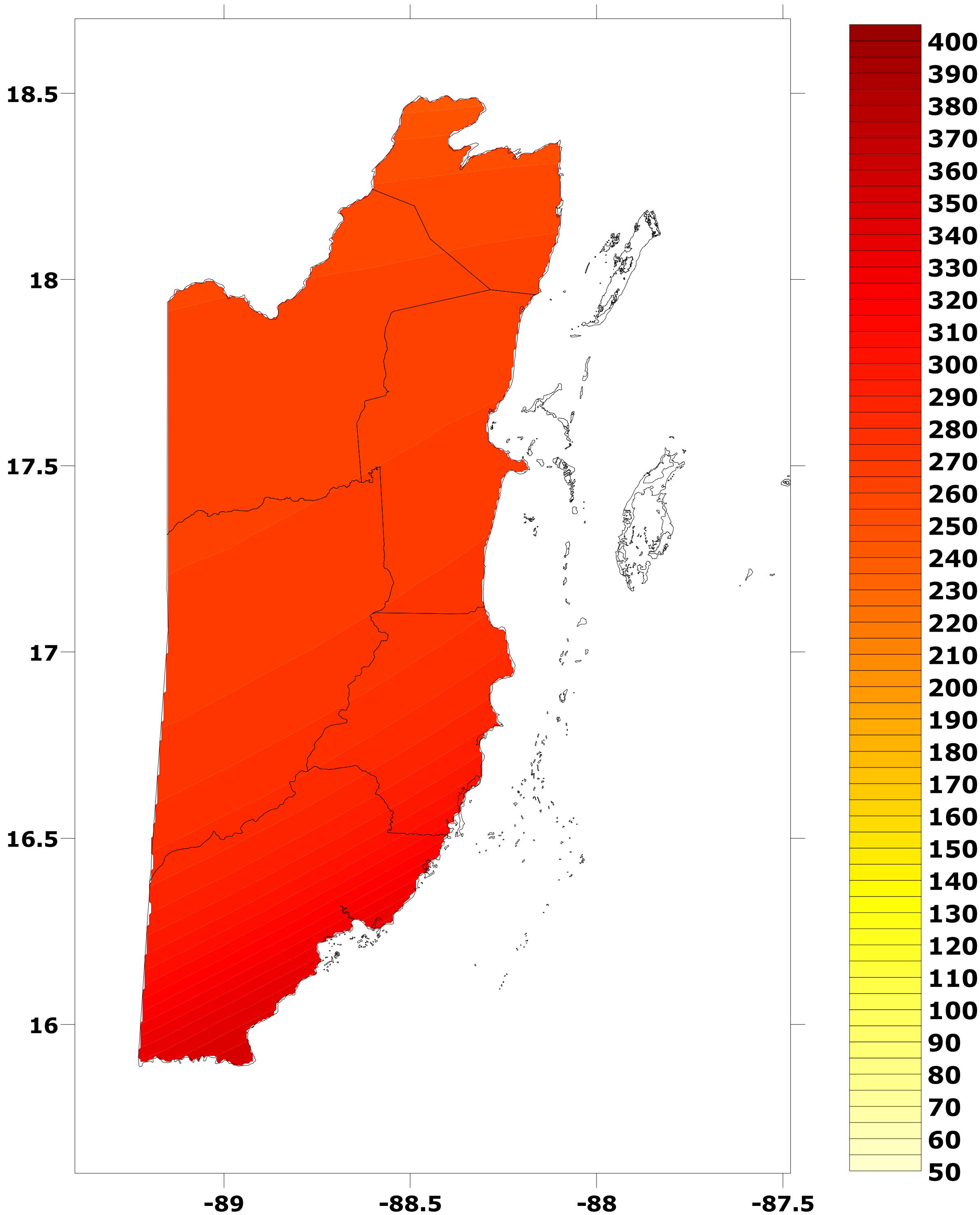


Figure 1-8
Spatial distribution of PGA (cm/s²) for 2500 years of return period

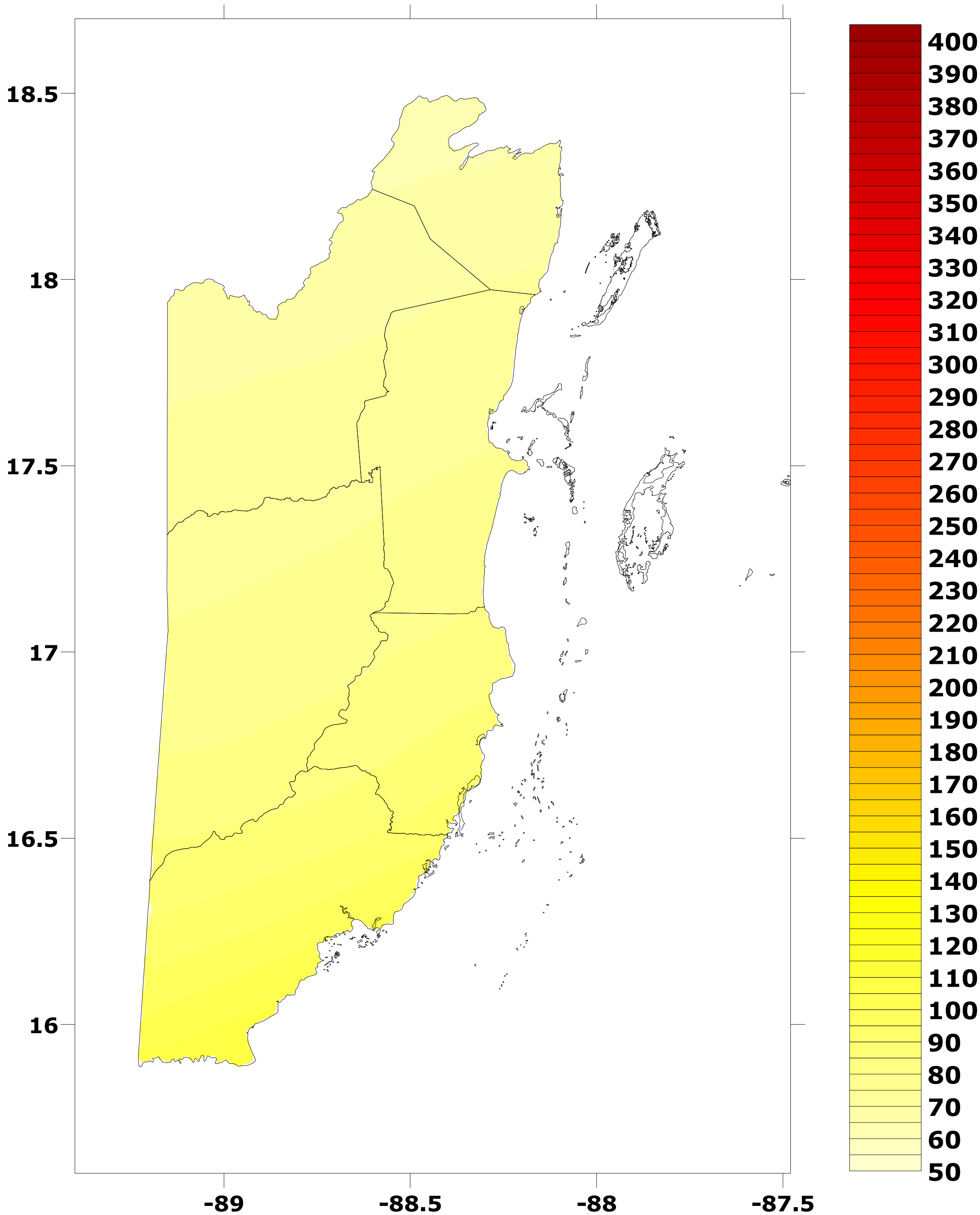


Figure 1-9
Spatial distribution of Sa(T=1 sec) (cm/s²) for 500 years of return period

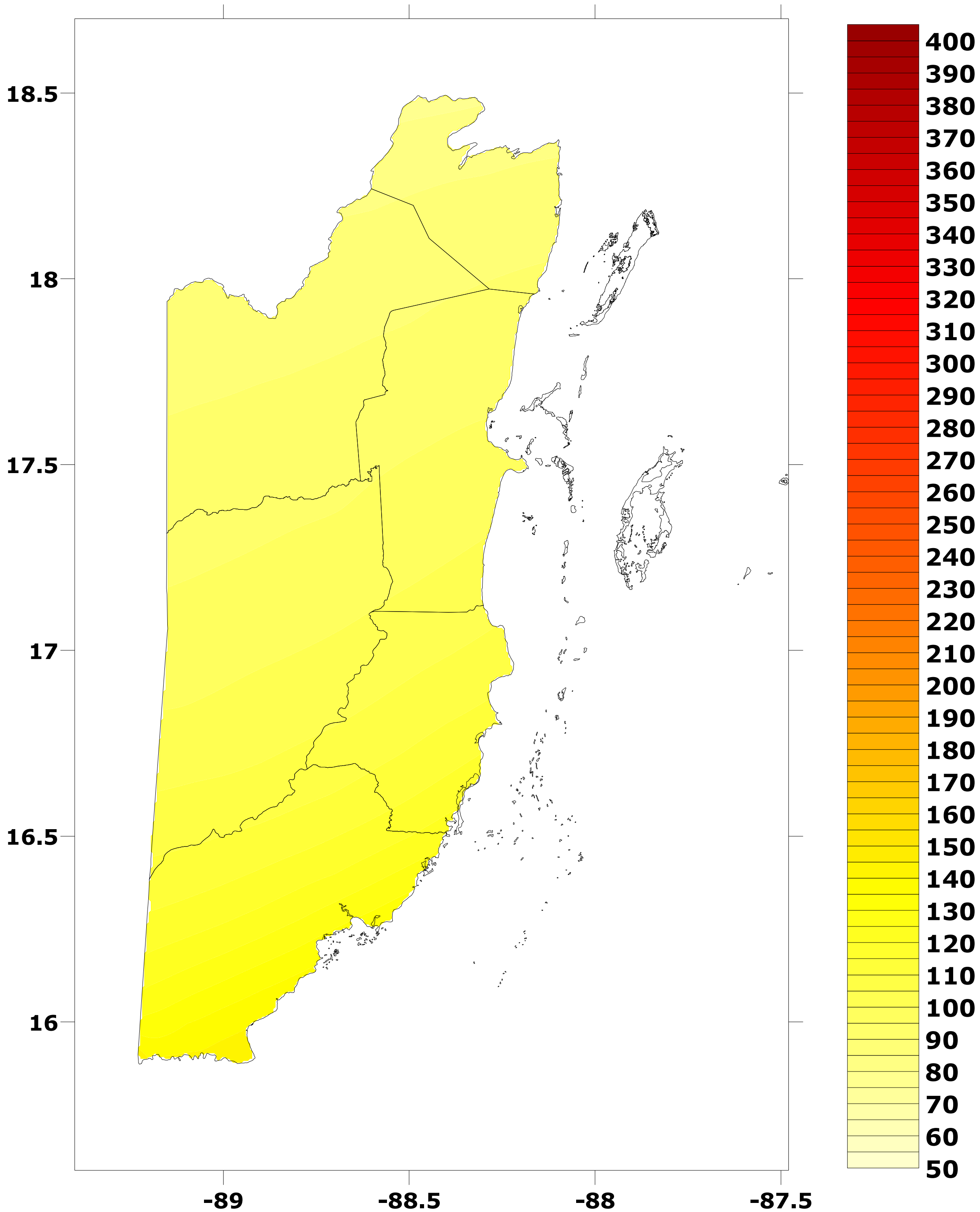


Figure 1-10
Spatial distribution of Sa(T=1 sec) (cm/s²) for 1000 years of return period

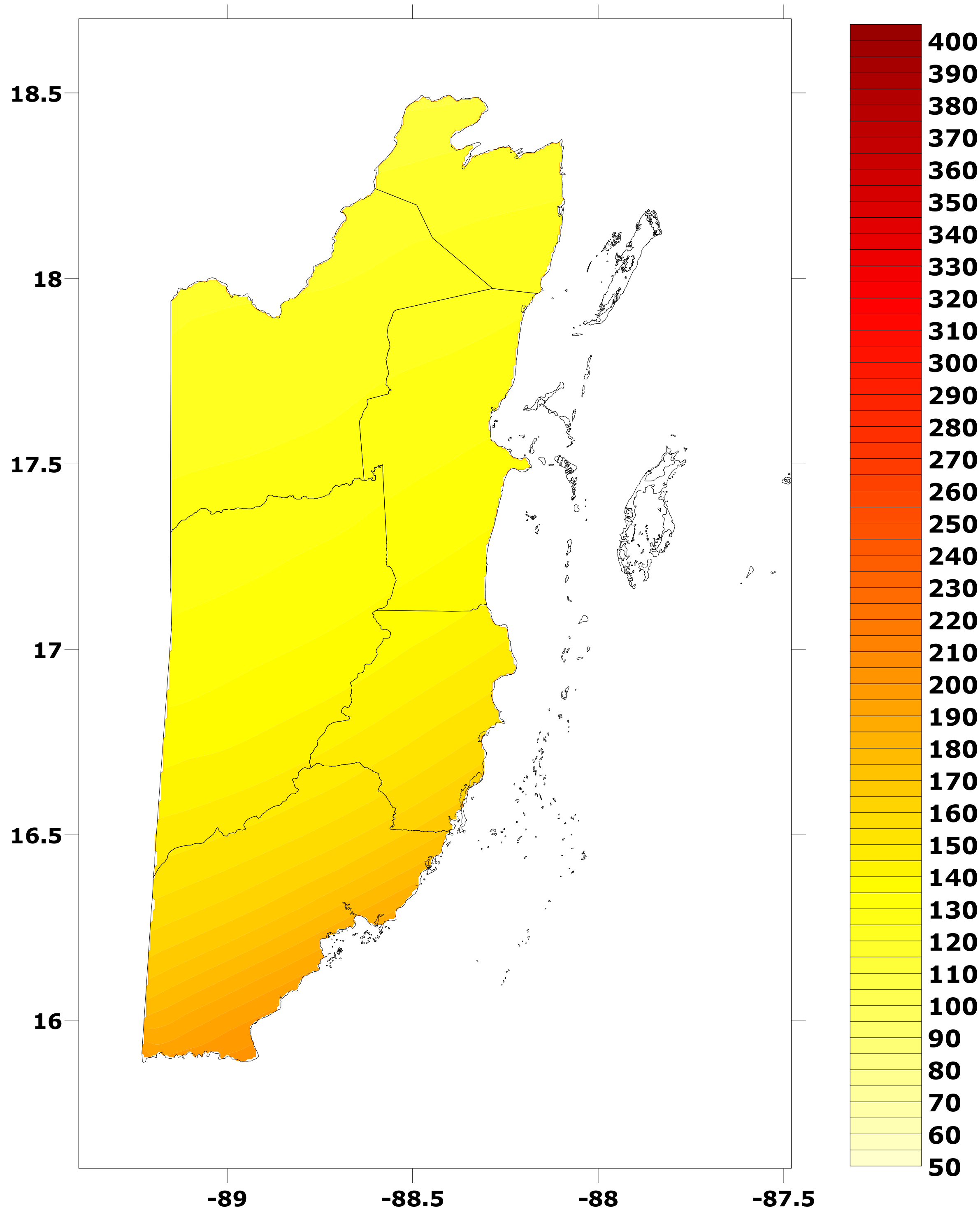


Figure 1-11
Spatial distribution of Sa(T=1 sec) (cm/s²) for 2500 years of return period

2 Tsunami hazard

2.1 Introduction

Tsunamis are directly associated with tectonic activity of the Caribbean shift zone in Belize, as a product of the interaction between the Caribbean and North American plates. The conditions proper to this intraplate interaction suggest a potential for the generation of medium-destructive earthquakes of magnitude greater than 6.

The generation of a tsunami may happen at any point down the zone of interaction of the Caribbean and North American plates. The impact of any particular tsunami depends greatly on bathymetric conditions, local topography, and the exact location of a population or infrastructure exposed, in relation to the coast and its vulnerability to this kind of hazard.

The analysis of tsunami hazard was made in two main stages. Initially, the conditions of generation were defined, has been associated with rates of occurrence of high-magnitude earthquakes in the subduction. The earthquakes which set off a tsunami are those which induce a significant lifting of the seabed. Once the conditions of generation had been established, there was an analysis of propagation and arrival of the tsunami, a phenomenon which is associated with the displacement of gravitational waves by the ocean, and a modification of their characteristics of arrival as a function of local bathymetric characteristics.

2.2 Information used in modelling

2.2.1 *Bathymetry and topography*

Bathymetry and coastal topography define the way in which the amplitude of the wave *("run-up")* will expand in order to calculate the particular conditions of impact of the tsunami. A digital bathymetry model was used, with a resolution of one minute, which corresponds to a pixel size of 1.8 km. The information was obtained from the ETOPO1 Global Relief Model (2009), from the US agency NOAA. Figure 2-1 presents a digital model of elevation used.

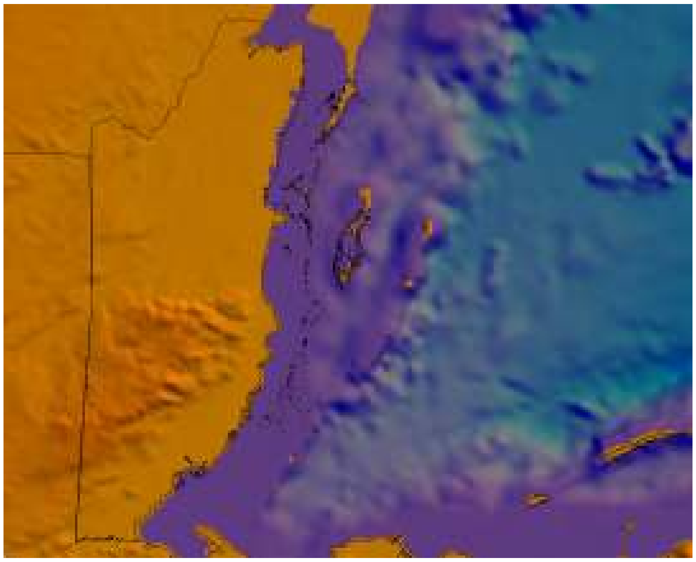


Figure 2-1
Bathymetry image used for the tsunami model in Belize.

A digital topography model was used with a resolution of 30m. The information was obtained from the ASTER Global Digital Innovation Model database (2009), from the US agency NASA. Figure 2-2 presents the digital elevation model.

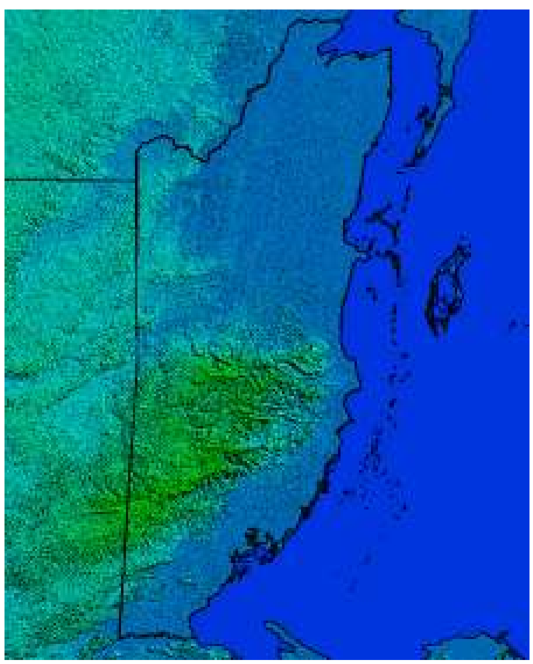


Figure 2-2
Topography image employed for the tsunami model in Belize.

2.3 Parameters of the model

In order to automate the calculation process, wave heights for each of the scenarios had to be calculated in advance.

2.3.1 *Events*

The model considers the presence of a sufficient number of earthquakes with magnitudes 6-7, which represent historical and postulated earthquakes obtained from the Module for seismic hazard. The frequency of occurrence of each scenario was assigned in accordance with the act seismic activity in the region. The modelling of the seismic component of the analysis was produced by using the CAPRA module for seismic threat, in CRISIS 2007.

2.3.2 *Calculation points and effects on bays*

125 bays were selected on the coast of Belize to estimate the maximum height of the tsunami, location of these points appears in Figure 2-3. In order to simulate the height of the tsunami on the coast appropriately, and its penetration inland, an approximate procedure as of isobath 100, which consisted of applying a tsunami amplification factor offshore, to calculate the height of the tsunami when it approaches the coast. This factor should also be entered together with a list of calculation points.

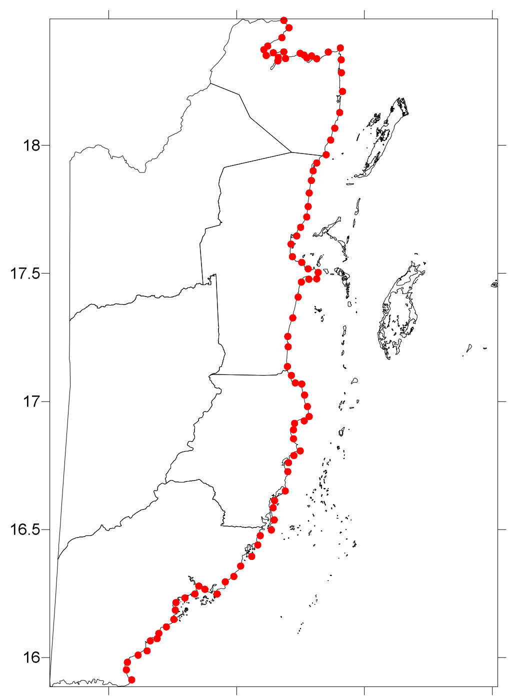


Figure 2-3
Calculation points for tsunami.

2.4 Available data quality

The quality and resolution of the available data is considered acceptable for indicative analysis at national level. A detailed analysis of tsunami hazard, using the proposed model, requires topographic and bathymetric information of higher quality and resolution. The desirable minimum resolution for topographic information is about five meters, and for bathymetric information is about 90 meters. The resolution of the calculation grid can be chosen arbitrarily, so the final resolution of the results depends exclusively on the resolution of the input information to the model.

2.5 Tsunami hazard maps in Belize's Caribbean coast

The maps were prepared using the information mentioned above, and the frequency of occurrence of different scenarios was allocated in accordance with the seismicity proper to the generating sources. Uniform hazard maps for tsunami were calculated, taking the flood height as the measure of intensity, as explained in a report ERN-CAPRA-T1-2 (models for the evaluation of natural hazards and selection, ERN 2009) and the return periods of 50, 100, 500 and 1000 years. The calculation's were made using the CRISIS 2007 program (Ordaz et al. 2007).

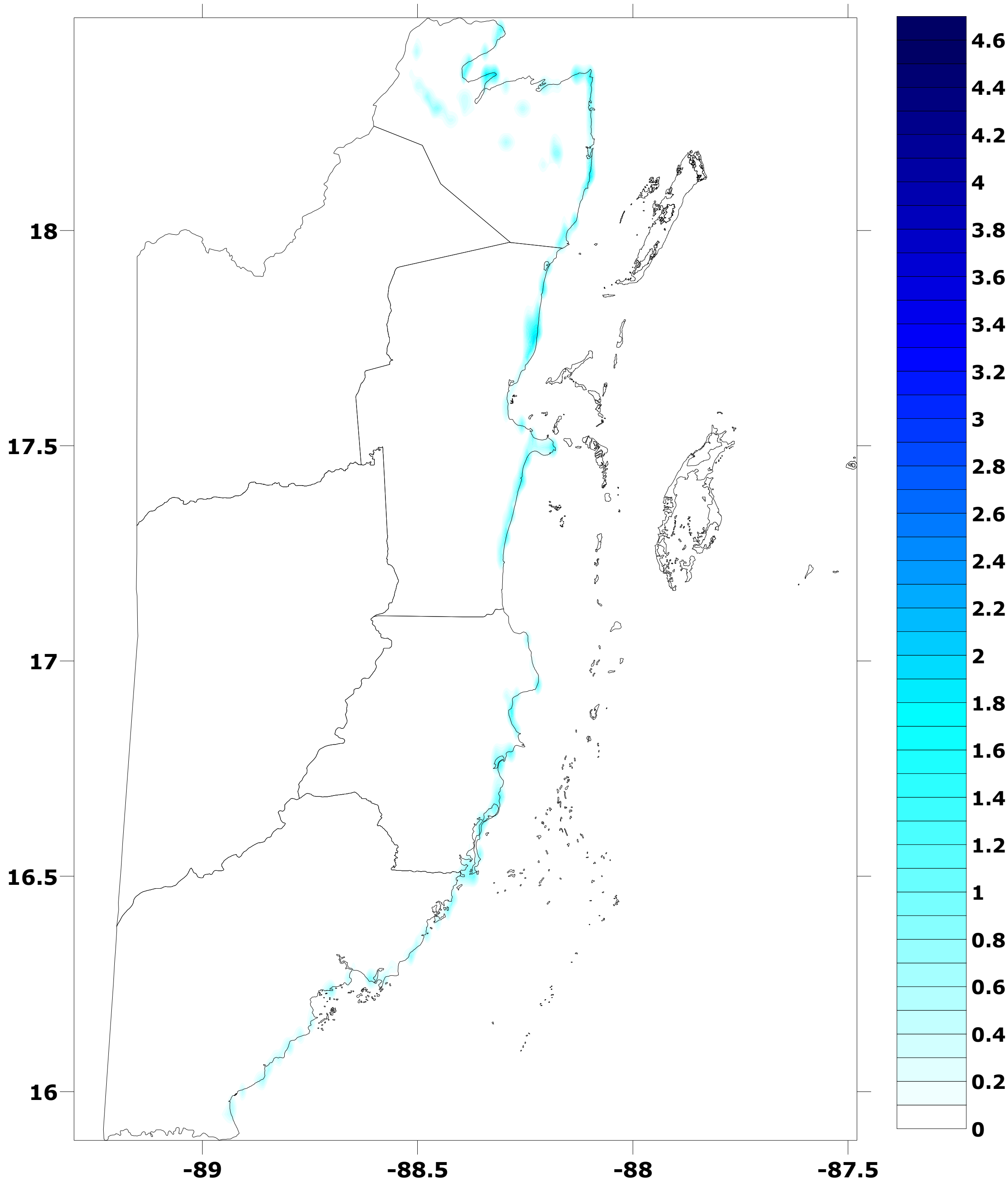


Figure 2-4
Spatial distribution map of flooding (metres) for 50 years of return period

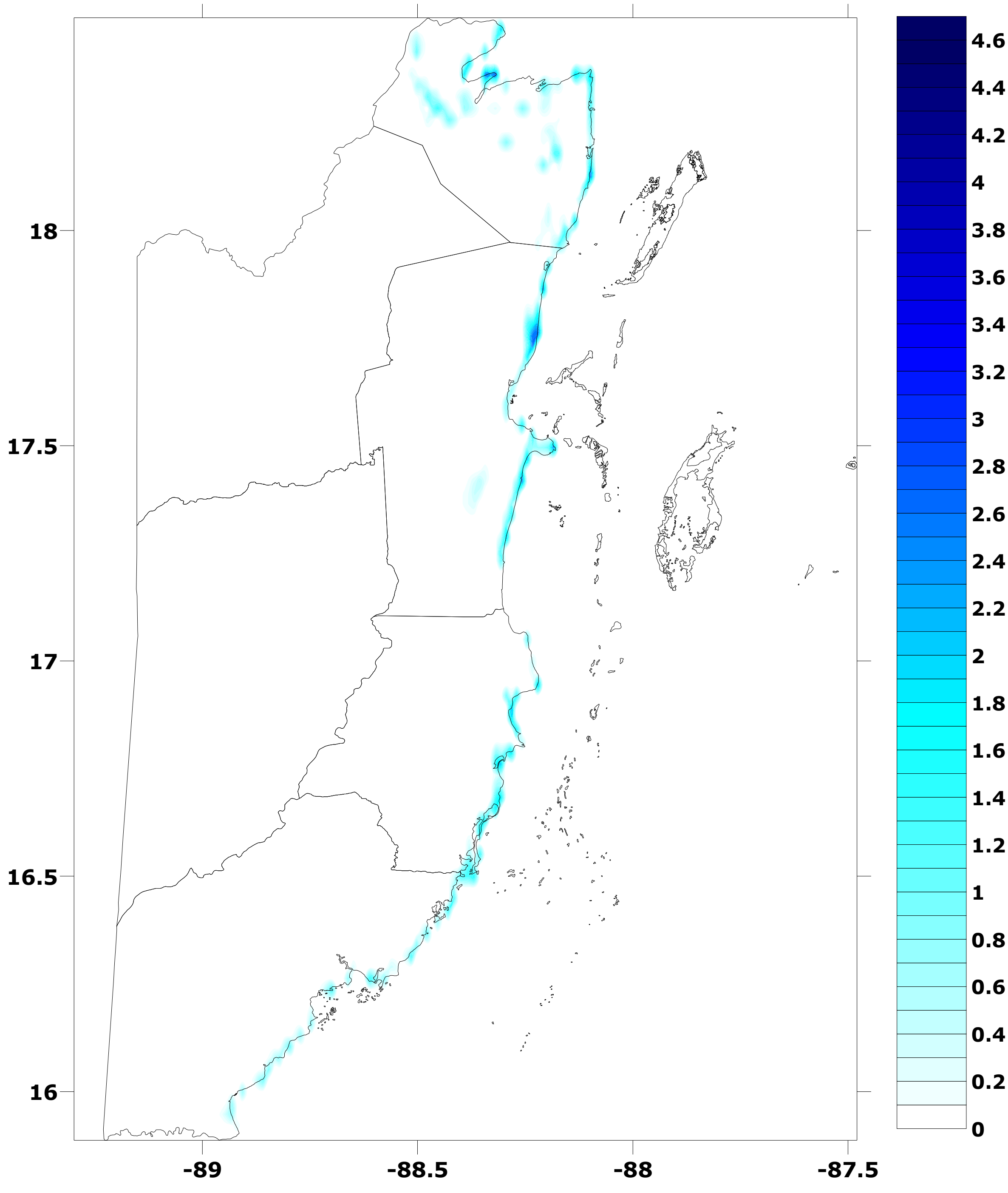


Figure 2-5
Spatial distribution map of flooding (metres) for 100 years of return period

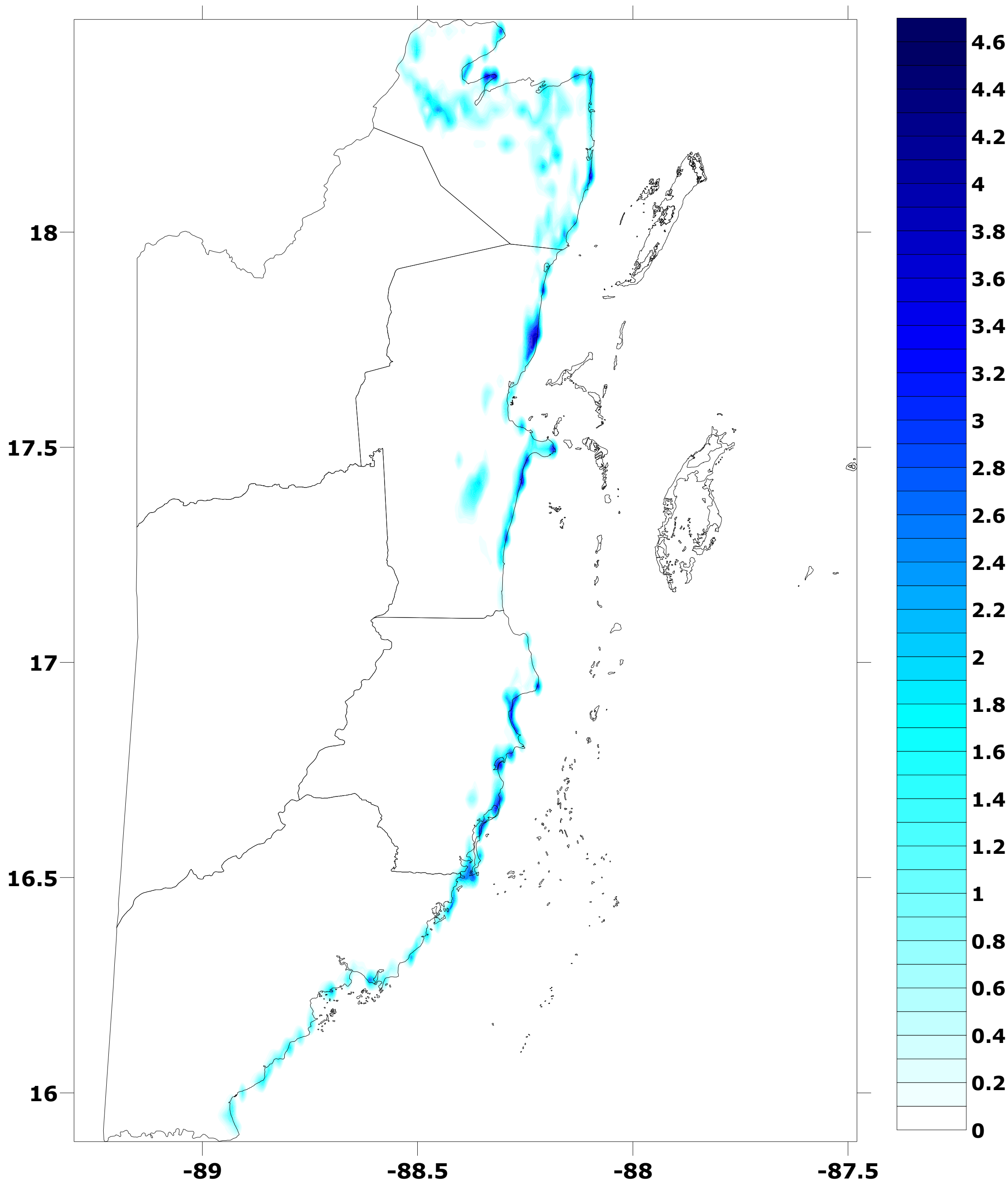


Figure 2-6
Spatial distribution map of flooding (metres) for 500 years of return period

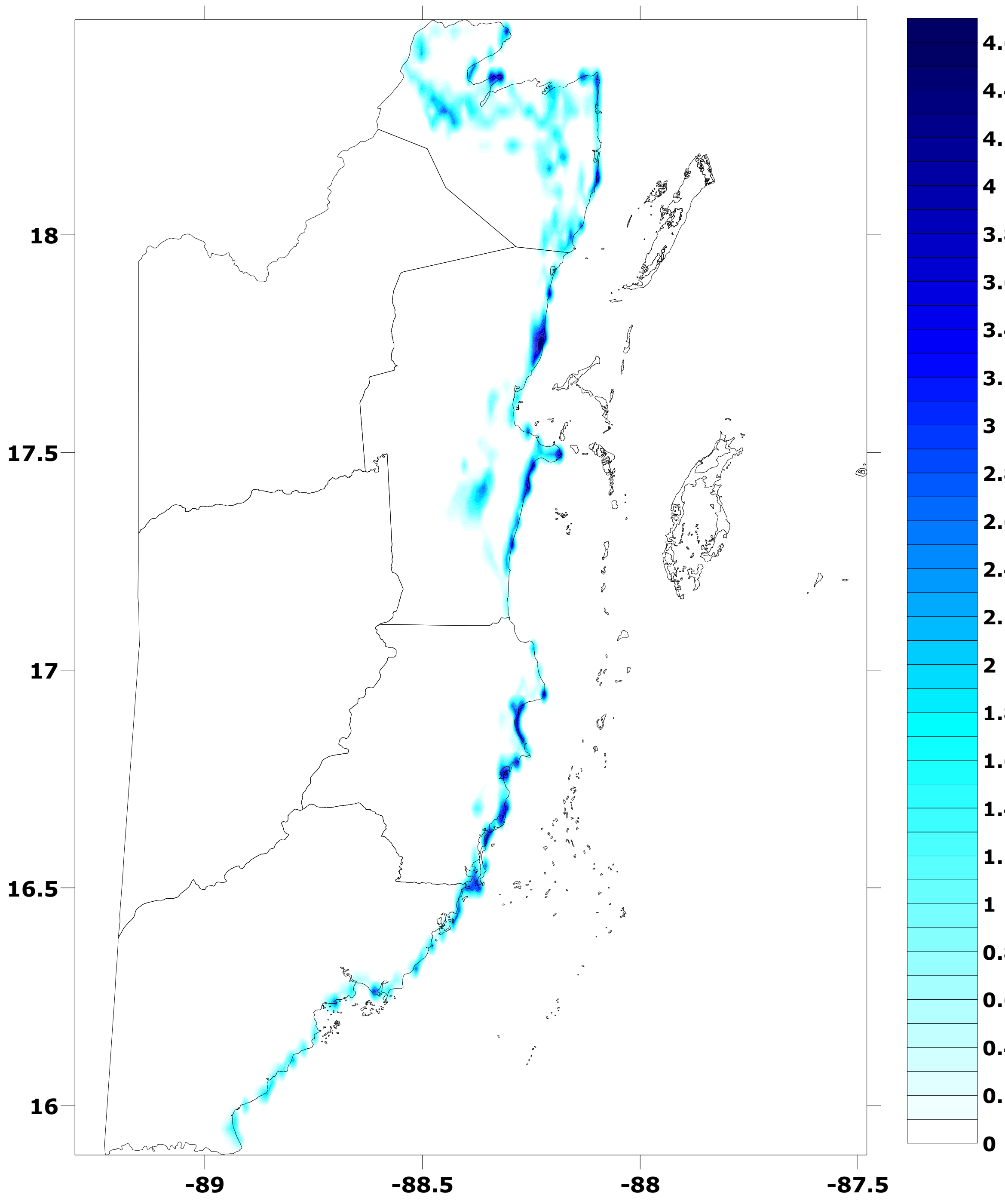


Figure 2-7
Spatial distribution map of flooding (metres) for 1000 years of return period

3 Hurricane hazard

3.1 Introduction

Hurricanes have the particular characteristic of being highly destructive, and with a high frequency of occurrence. The modelling of the hurricane hazard takes account of effects related to wind speed and storm surge. The model predicts maximum intensities associated with the possible occurrence and the passage of a hurricane across the territory analysed (Belize and 200 km in all directions off its coasts), based on a statistical procedure known as *perturbation*, which allows random tracks to be generated concerning the principal characteristics of identified historical tracks.

3.2 Information used in modelling

The hurricane hazard model requires specific information, which is available to a certain level of detail. The quality of the modelling will depend on the detail obtained in all the information collected. The following layers of geographical information are required to apply the hurricane hazard model for Belize:

a) Topography.
b) Bathymetry.
c) Open areas and soil use.
d) Records of wind speed and the heights of tides.
e) Catalogue of hurricanes

The information which we were able to obtain for modelling the hurricane hazard is described below:

3.2.1 *Topography*

Wind currents shape themselves to the topography of the area, passing around existing orographic obstacles. Therefore, the uniformity of the wind field changes, generating zones with wind speeds higher or lower than the average established for a hypothetical zone without obstacles. The capacity of the model to detect greater detail in a variation of wind speed depends greatly on the quality of topographical information available. The digital innovation model for Belize was obtained from the ASTER Global Digital Elevation Model (2009) database from NASA, with a resolution of 30m, which is acceptable for a national and subnational analysis. Figure 3-1 shows the digital elevation model used.

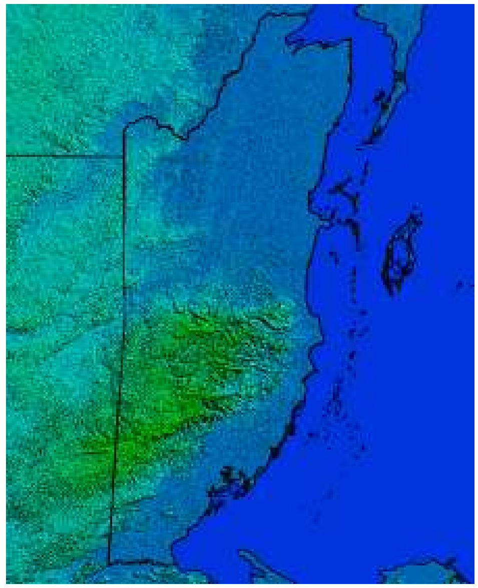


Figure 3-1
Digital elevation model for Belize

3.2.2 *Bathymetry*

Bathymetry is required to calculate the over-elevation of the sea and subsequent storm tides which are originated during the passage of a hurricane across a coastal zone. Bathymetric information corresponds to a digital model for bathymetry-topography, with a resolution of 1 minute, or a pixel size of 1.8 km. Information was obtained from the ETOPO1 Global Relief Model (2009), belonging to NOAA. While the information does not have the resolution desired, it is common for bathymetric information not to be of a quality comparable with topographical information available, and for this reason the resolution is considered to be acceptable here also. Figure 3-2 presents the digital model for bathymetry.

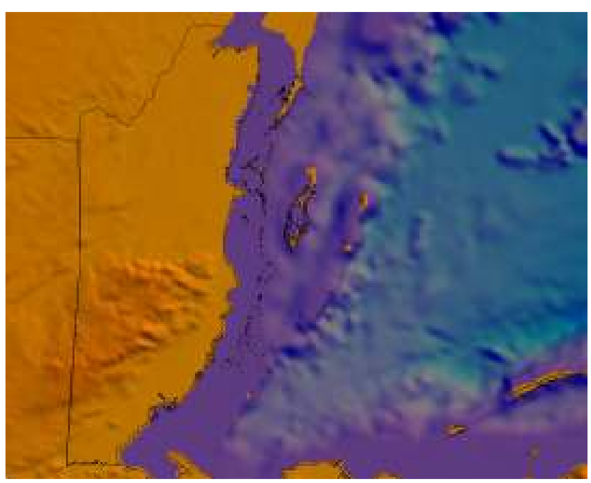


Figure 3-2
Bathymetry image used to model storm surge in Belize

3.2.3 *Urban areas and soil use*

The rapidity with which windspeed increases with height is a function of the rugosity of the ground. Therefore, the gradient of velocity must be based on geographical information on soil use, which will allow the conditions specific to rugosity to be established. The information for Belize in urban areas and soil uses was obtained from the GIS data for Mesoamerica, from the *Central American Commission for Environment and Development* - CCAD. Figure 3-3 shows the surveys of urban areas and soil use.

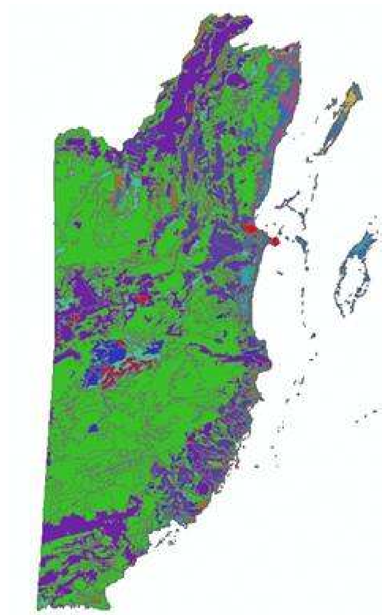


Figure 3-3
Surveys of urban areas and soil use for Belize

3.2.4 *Records of windspeed and the heights of tides*

Records of historical intensities are extremely useful in the calibration of the calculation models. In the case of Belize, it was not possible to find historical records and information of this kind, and therefore no particular considerations were included in modelling the phenomenon.

3.2.5 *Hurricane catalogue*

The tracks of past hurricanes, and the different parameters of intensity associated with them, and their variation over the track, were obtained from the HURDAT database of the National Hurricane Centre, belonging to NOAA. This database has the following information:

- Date (time, date, month y year)

- Central pressure of the cyclone (millibars)
- Geographical position (latitude, longitude)
- Maximum sustained winds speed on average at one minute

For the Caribbean/Atlantic, the HURDAT database records 1394 tropical cyclones between 1851 and 2008. For the Pacific, the database has 853 tropical cyclones between 1949 and 2008. Figure 3-4 shows the track of tropical cyclones for the Atlantic/Caribbean and Pacific contained in the HURDAT database up to 2008.

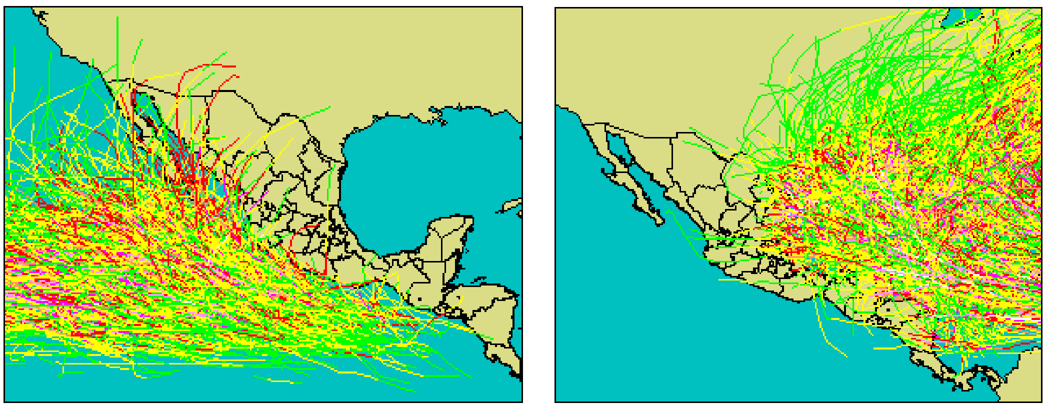


Figure 3-4
Track of tropical cyclones for the Pacific (left) and Atlantic (right) up to 2008, information from the HURDAT/NOAA databaes.

3.3 Parameters of the model

3.3.1 *Filtering the hurricane catalogue*

Using the HURDAT database, the hurricane catalogue was filtered so that account was only taken of tropical cyclones which have affected Belize. The criteria for filtering used were the following:

- Events with a category ≥H1 (119 kph) on the Saffir-Simpson scale (SS).
- Events in which at some point of the track, the eye of the hurricane had been less than 200 km from the Caribbean coast of Belize.

These criteria, applied to the database for tropical storms for the Atlantic, brought a total of 102 Hurricanes in the category ≥H1 SS. Table 3-1 shows the principal parameters (maximum wind speed, category, name and date) of each of the 102 Hurricanes considered for the study.

Table 3-1
Parameters (maximum wind speed, category, name and date) of hurricanes considered for this study.

#	Name	Date	Top speed [Km/h]	Category
1	NOT NAMED	23/09/1857	166.5	H2
2	NOT NAMED	25/08/1864	129.5	H1
3	NOT NAMED	12/08/1866	166.5	H2
4	NOT NAMED	04/10/1868	166.5	H2
5	NOT NAMED	29/10/1870	129.5	H1
6	NOT NAMED	25/09/1873	185.0	H3
7	NOT NAMED	24/09/1874	148.0	H1
8	NOT NAMED	20/09/1877	185.0	H3
9	NOT NAMED	18/08/1879	166.5	H2
10	NOT NAMED	03/08/1880	240.5	H4
11	NOT NAMED	04/10/1880	129.5	H1
12	NOT NAMED	15/08/1881	129.5	H1
13	NOT NAMED	14/07/1886	138.8	H1
14	NOT NAMED	19/07/1887	157.3	H2
15	NOT NAMED	11/09/1887	157.3	H2
16	NOT NAMED	30/08/1888	203.5	H3
17	NOT NAMED	11/09/1889	175.8	H2
18	NOT NAMED	30/10/1890	148.0	H1
19	NOT NAMED	04/10/1892	157.3	H2
20	NOT NAMED	04/07/1893	157.3	H2
21	NOT NAMED	04/09/1893	157.3	H2
22	NOT NAMED	27/09/1893	212.8	H4
23	NOT NAMED	21/08/1895	175.8	H2
24	NOT NAMED	8/6/1903	194.3	H3
25	NOT NAMED	10/8/1906	194.3	H3
26	NOT NAMED	10/14/1908	166.5	H2
27	NOT NAMED	8/20/1909	194.3	H3
28	NOT NAMED	10/11/1912	157.3	H2
29	NOT NAMED	6/22/1913	157.3	H2
30	NOT NAMED	8/12/1916	203.5	H3
31	NOT NAMED	8/27/1916	157.3	H2
32	NOT NAMED	10/12/1916	194.3	H3
33	NOT NAMED	11/10/1916	129.5	H1
34	NOT NAMED	7/31/1918	166.5	H2
35	NOT NAMED	8/22/1918	129.5	H1
36	NOT NAMED	9/16/1920	166.5	H2
37	NOT NAMED	6/14/1921	157.3	H2
38	NOT NAMED	10/13/1922	157.3	H2
39	NOT NAMED	9/5/1931	203.5	H3
40	NOT NAMED	9/8/1931	157.3	H2
41	NOT NAMED	9/25/1932	194.3	H3
42	NOT NAMED	9/10/1933	138.8	H1

#	Name	Date	Top speed [Km/h]	Category
43	NOT NAMED	9/16/1933	175.8	H2
44	NOT NAMED	6/4/1934	129.5	H1
45	NOT NAMED	10/18/1935	138.8	H1
46	NOT NAMED	8/15/1936	129.5	H1
47	NOT NAMED	8/28/1936	129.5	H1
48	NOT NAMED	8/9/1938	157.3	H2
49	NOT NAMED	8/23/1938	157.3	H2
50	NOT NAMED	9/23/1941	194.3	H3
51	NOT NAMED	8/21/1942	185.0	H3
52	NOT NAMED	11/4/1942	157.3	H2
53	NOT NAMED	8/16/1944	194.3	H3
54	NOT NAMED	9/19/1944	129.5	H1
55	NOT NAMED	6/20/1945	185.0	H3
56	NOT NAMED	10/2/1945	157.3	H2
57	NOT NAMED	10/5/1946	212.8	H4
58	NOT NAMED	8/9/1947	175.8	H2
59	CHARLIE	8/12/1951	212.8	H4
60	HOW	9/28/1951	175.8	H2
61	HILDA	9/10/1955	203.5	H3
62	JANET	9/21/1955	277.6	H5
63	FLOSSY	9/21/1956	148.0	H1
64	ABBY	7/9/1960	157.3	H2
65	ANNA	7/19/1961	185.0	H3
66	CARLA	9/3/1961	277.6	H5
67	HATTIE	10/27/1961	259.0	H5
68	ISBELL	10/8/1964	203.5	H3
69	BEULAH	9/5/1967	259.0	H5
70	ABBY	6/1/1968	120.3	H1
71	FRANCELIA	8/28/1969	185.0	H3
72	LAURIE	10/16/1969	166.5	H2
73	ELLA	9/8/1970	203.5	H3
74	EDITH	9/5/1971	259.0	H5
75	AGNES	6/14/1972	138.8	H1
76	BRENDA	8/18/1973	148.0	H1
77	CARMEN	8/29/1974	240.5	H4
78	FIFI	9/14/1974	175.8	H2
79	ELOISE	9/13/1975	203.5	H3
80	GRETA	9/13/1978	212.8	H4
81	HENRI	9/14/1979	138.8	H1
82	ALBERTO	6/2/1982	138.8	H1
83	GILBERT	9/8/1988	296.1	H5
84	KEITH	11/17/1988	120.3	H1
85	DIANA	8/3/1990	157.3	H2
86	GERT	9/14/1993	157.3	H2
87	ALLISON	6/2/1995	120.3	H1

#	Name	Date	Top speed [Km/h]	Category
88	OPAL	9/27/1995	240.5	H4
89	ROXANNE	10/7/1995	185.0	H3
90	DOLLY	8/19/1996	129.5	H1
91	MITCH	10/21/1998	286.8	H5
92	GORDON	9/14/2000	129.5	H1
93	KEITH	9/28/2000	222.0	H4
94	IRIS	10/4/2001	231.3	H4
95	ISIDORE	9/14/2002	203.5	H3
96	CLAUDETTE	7/6/2003	138.8	H1
97	EMILY	7/10/2005	250.0	H5
98	STAN	10/1/2005	129.6	H1
99	WILMA	10/15/2005	277.8	H5
100	DEAN	8/13/2007	268.5	H5
101	FELIX	8/31/2007	268.5	H5
102	DOLLY	7/20/2008	157.4	H2

Table 3-2 presents the distribution by category in the Saffir-Simpson scale, of the 102 Hurricanes which formed the filtered database for the Atlantic Ocean, whose tracks came within 200 km of the Caribbean coast of Belize, in the category $\geq$H1 SS

Table 3-2
Distribution by category on the Saffir Simpson scale of tropical cyclones considered on the Atlantic coast.

Category	Number of storms
H5	11
H4	9
H3	22
H2	33
H1	27

3.3.2 *Factors of topographical exposure to wind for Belize*

Given the effect of topography of the place where construction is located, there will be variations in windspeed generated by a hurricane. Topographical factors allow account be taken of the increased wind speed due to topographical characteristics of the place where construction is located, for example on a promontory, sloping land, islands, or enclosed valleys. In this study, in order to take account of the changes in windspeed due to the effect of the surrounding topography close to the site of a construction, a factor was defined for increased speed, which acts as as a multiplier of wind speed considered on flat ground. These topographical factors were allocated on the basis of the determination of areas exposed to wind (Avelar, 2006)

A procedure was adopted for the calculation of areas exposed to wind, which would allow digital elevation models to be used to obtain digital maps with values of the topographic factor for Belize (see Table 3-3). These factors are calculated for each of the pixels which forms the digital elevation model, following exposure to wind flow for them, located by geographical coordinates of the Centroid. This type of information provides the particular topographic factor of the infrastructure to be evaluated, by simply knowing its geographical location. The definition and characteristics of exposure to wind flow are indicated in Figure 3-5.

Table 3-3
Factors of of topographical exposure to wind for Belize

Site	Topography	Color	F_T
Protected	Closed valley	Yellow	0.8
Flat	Flat terrain, open field, lack of important orographyc structures, slopes lower than 5%	Blue	1.0
Exposed	Hills or mountains, tarrain with slope higher tan 5%	Red	1.2

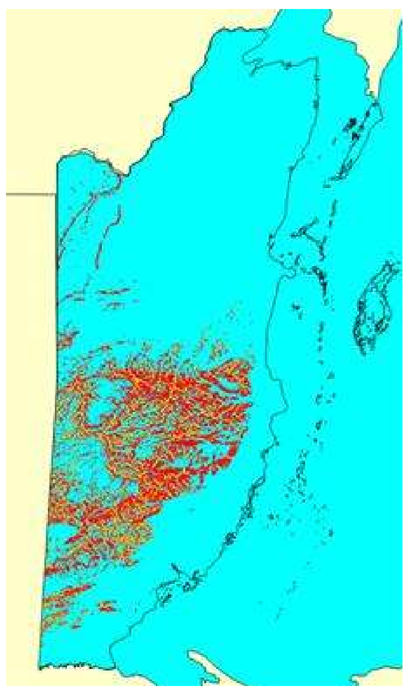


Figure 3-5
Factors of topographic exposure to wind in Belize

3.3.3 *Variation of windspeed with height*

The movement of air masses is restricted by friction with the surface of the ground, and this means that speed will be almost when nil in contact with it: but it will increase with height until it reaches an unperturbed flow speed, known as the *gradient speed*. For very smooth ground, as in open country with very low vegetation, the wind maintains a very high speed even quite close to the surface, while in the centre of large cities with tall buildings, wind speed fallsrapidly from a few dozen metres above the surface. The expression which allows an estimate to be made of the variation in windspeed with height, and for different types of ground, is represented as follows:

$$Frz = 1.56\left(\frac{Z}{\delta}\right)^{\alpha} \quad si \quad 10 < Z < \delta$$

$$Frz = 1.56 \left(\frac{10}{\delta}\right)^{\alpha} \quad si \quad Z \le 10 \quad m$$

$$Frz = 1.56 \quad si \quad Z \ge \delta$$

(Ec. 2)

Where Z is the attitude in metres at which windspeed is to be determined. Parameters α and δ for common types of terrain in Honduras are presented Table 3-4.

Table 3-4
Parameters for a and δ for different types of terrain

Type	Description	α	δ (m)
1	**Flat open ground** (open ground, almost flat without obstructions, for example flat coastal strips, swampland, airfields, pasture, and crops not surrounded by enclosures)	0.099	245
2	**Trees or standard construction** (crops or farms with two destructions, such as enclosures, trees and scattered constructions)	0.128	315
3	**Trees, residential district.** (land covered by a number of closely spaced obstructions, for example urban areas, suburbs, woodland. The size of constructions corresponds to housing)	0.156	390
4	**Many obstructions, city centre** (land with a number of large high buildings, closely spaced, such as in the centre of major cities and developed industrial complexes)	0.170	455

Figure 3-6 shows a variation with height above ground of the *Frz*. It can be seen that for an altitude of 10m above the surface of the ground, the highest value for the *Frz* factor is 1.137, which occurs on Type 1 land (open ground, almost flat and with no obstructions). The lowest factor for a height of 10m is 0.815, which is found on Type-4 ground (land with a large number of obstructions).

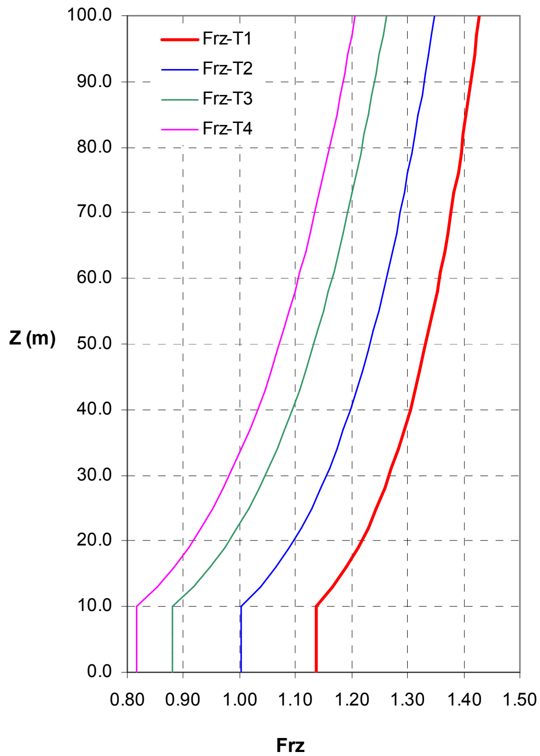


Figure 3-6
Variation of wind speed with height and for different types of terrain.

3.4 Available data quality

In regard to topography, bathymetry and distribution of land uses, quality and resolution of available data is considered acceptable for an indicative hazard analysis al national level. There are no calibration parameters from historical measurements of intensity, for which results have not been calibrated.

Particularly for the calculation of the intensity values for hurricane winds and rainfall, information and has a good resolution given the geographical range covered by the associated intensity distribution. Moreover, in the case of storm surge, the available information allows indicative scans only, since a detailed analysis of storm surge hazard, using the proposed model, requires topographic and bathymetric information of higher quality and resolution. The desirable minimum resolution for topographic information is about five meters, and for bathymetric information is about 90 meters.

3.5 Hurricane hazard maps for Belize

Independent maps were calculated for the hazard of strong winds, storm surge, hurricane rainfall and flooding. The results appear below
.

3.5.1 *Hazard maps for strong winds*

Uniform hazard maps for strong winds were calculated, the measure of intensity being the 3-second peak speed of gusts of wind, as explained in the report of the ERN-CAPRA-T1.2 (models for the evaluation of natural hazards, ERN 2009), and for return periods of 20, 50, 100, 500 and 1000 years. Calculations were made using the ERN-Hurricane programme (ERN 2009)

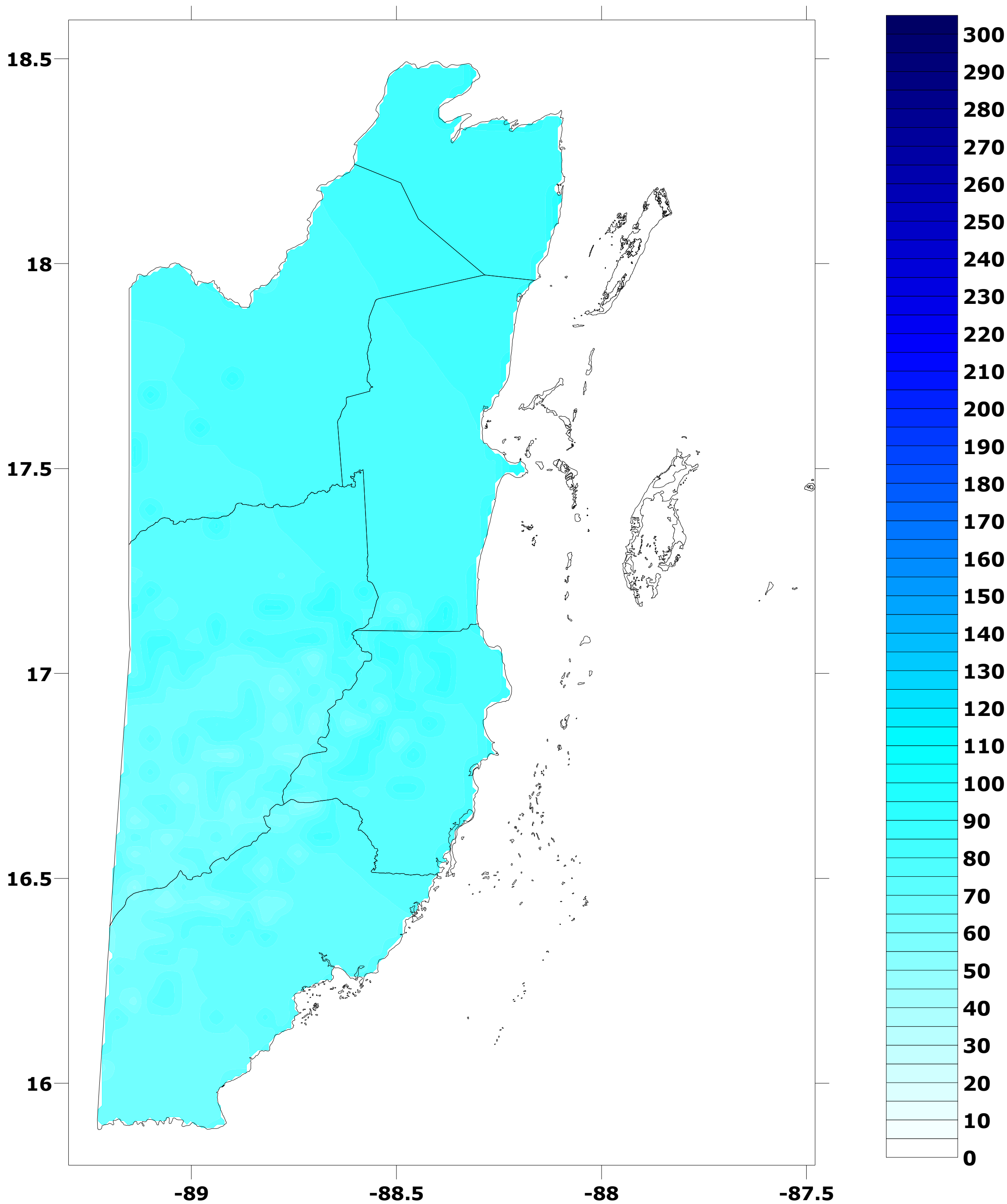


Figure 3-7
Spatial distribution map for maximum windspeed (kph) for 20 years of return period

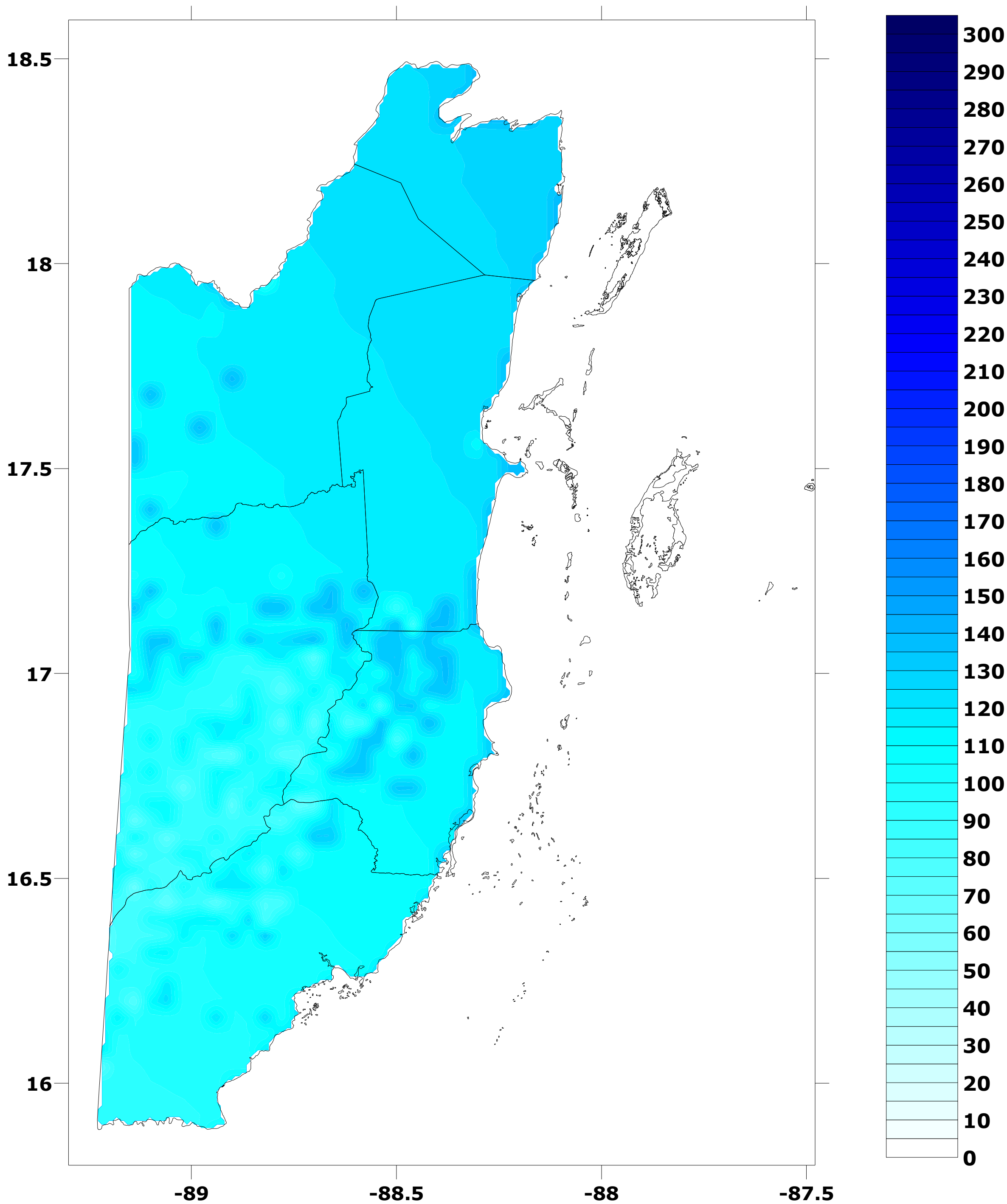


Figure 3-8
Spatial distribution map for maximum windspeed (kph) for 50 years of return period

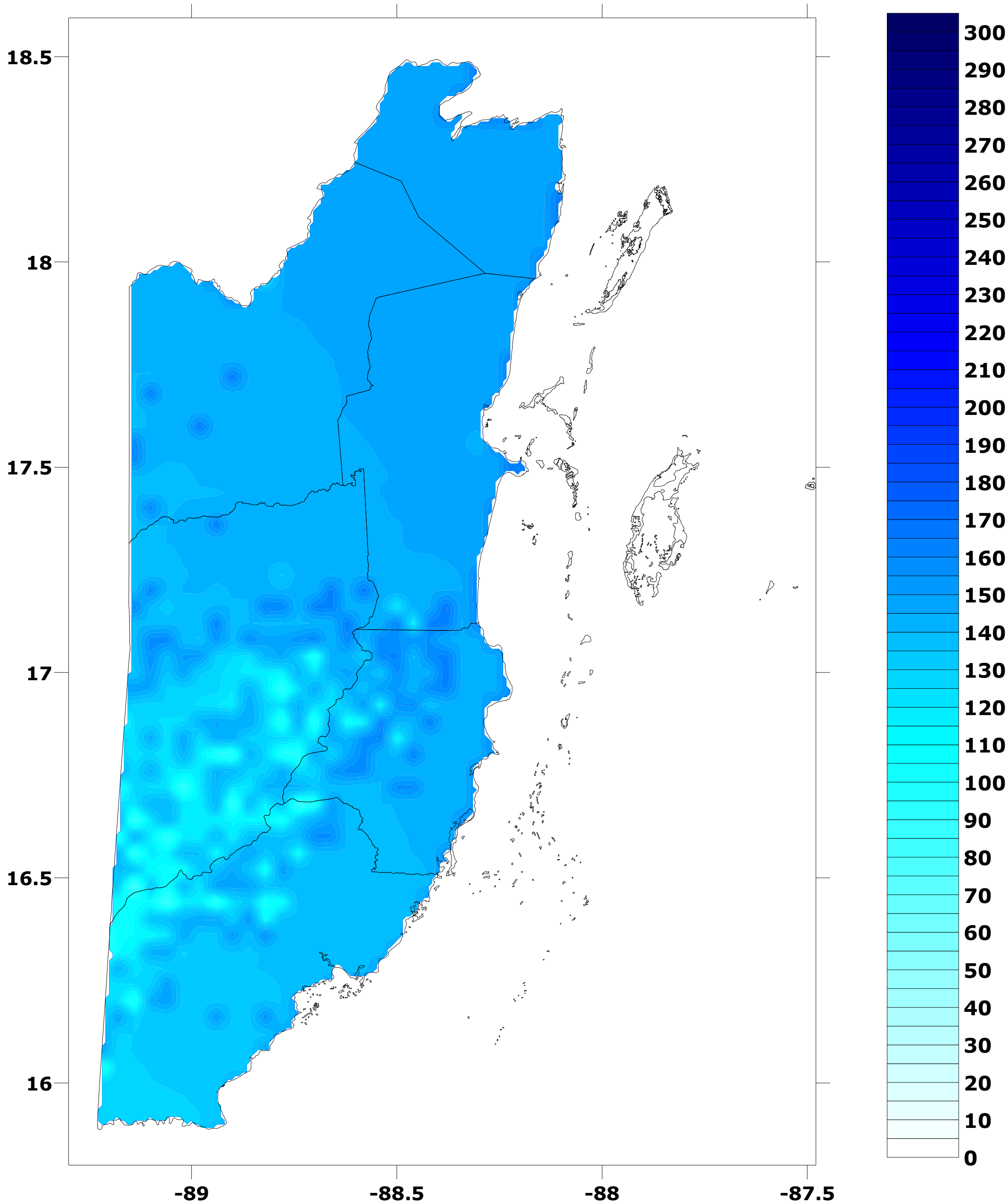


Figure 3-9
Spatial distribution map for maximum windspeed (kph) for 100 years of return period

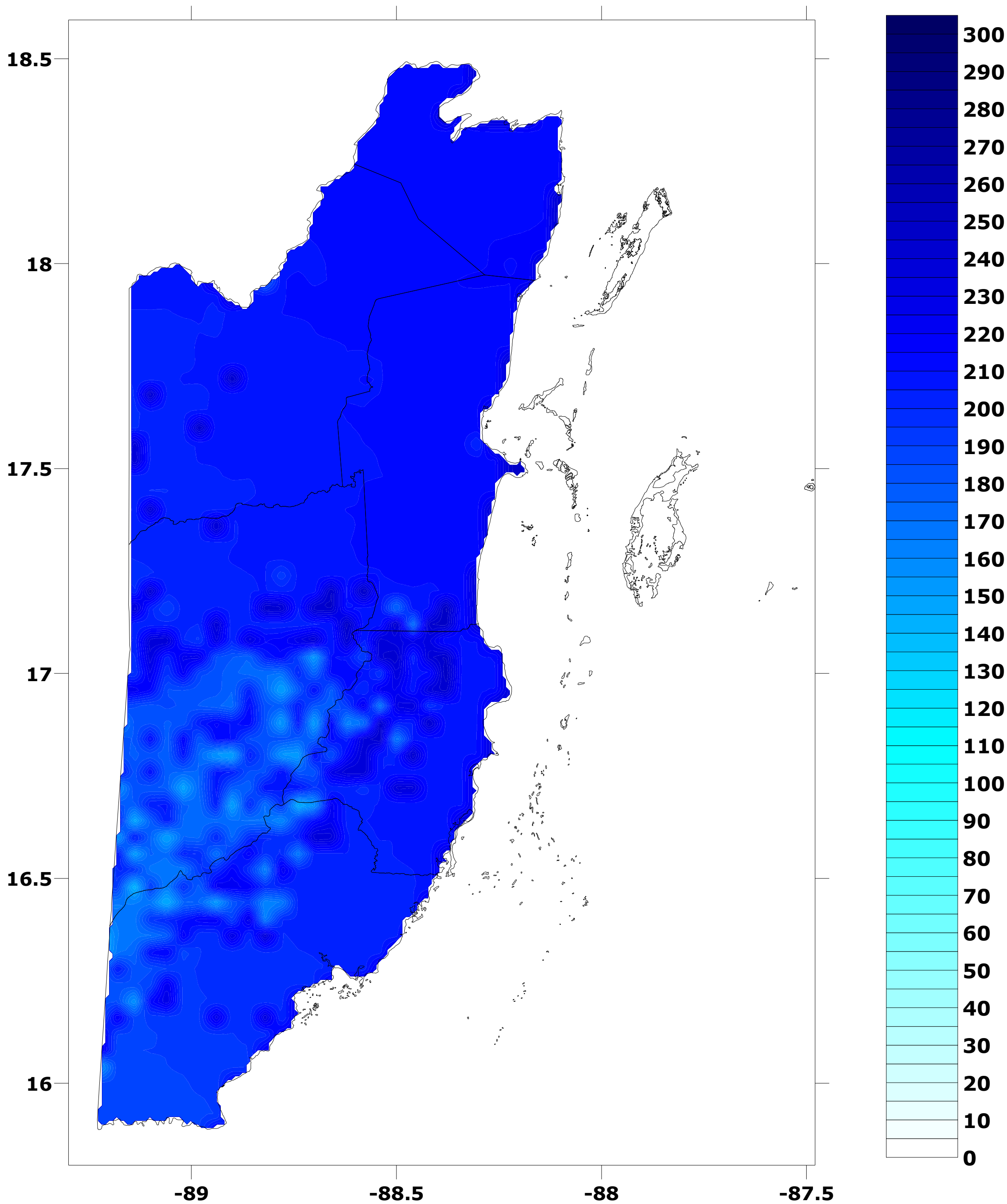


Figure 3-10
Spatial distribution map for maximum windspeed (kph) for 500 years of return period

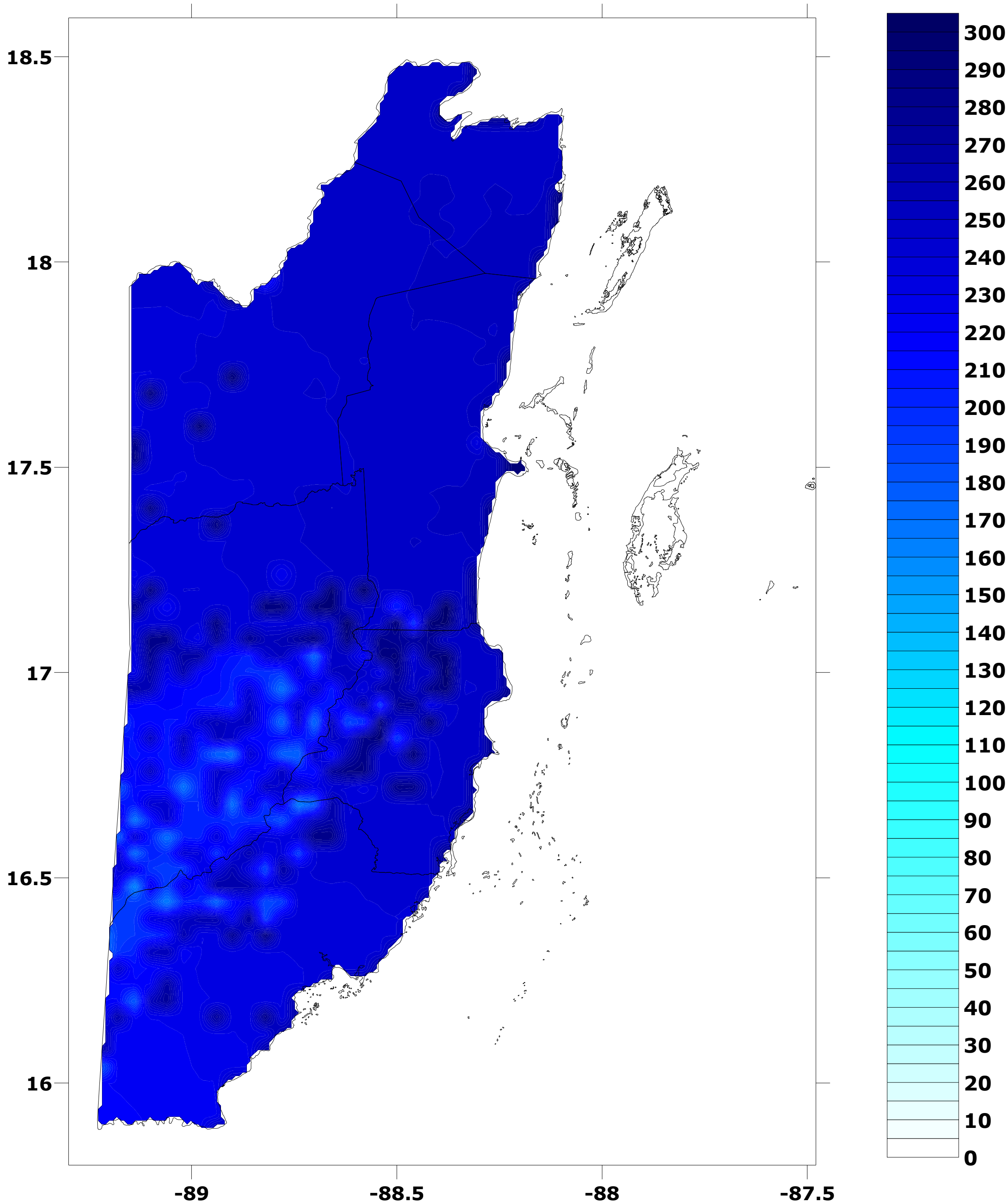


Figure 3-11
Spatial distribution map for maximum windspeed (kph) for 1000 years of return period

3.5.2 *Hazard map for storm surge on the Caribbean coast*

Calculations were made for uniform hazard maps for storm surge on the Caribbean coast of Belize, the measurement being taken as the intensity of flood height, as explained in a report ERN-CAPRA-T1-2) Evaluation models for natural hazards, ERN 2009), and for return periods of 100, 500 and 1000 years. The calculations used the ERN-Hurricane program (ERN 2009)

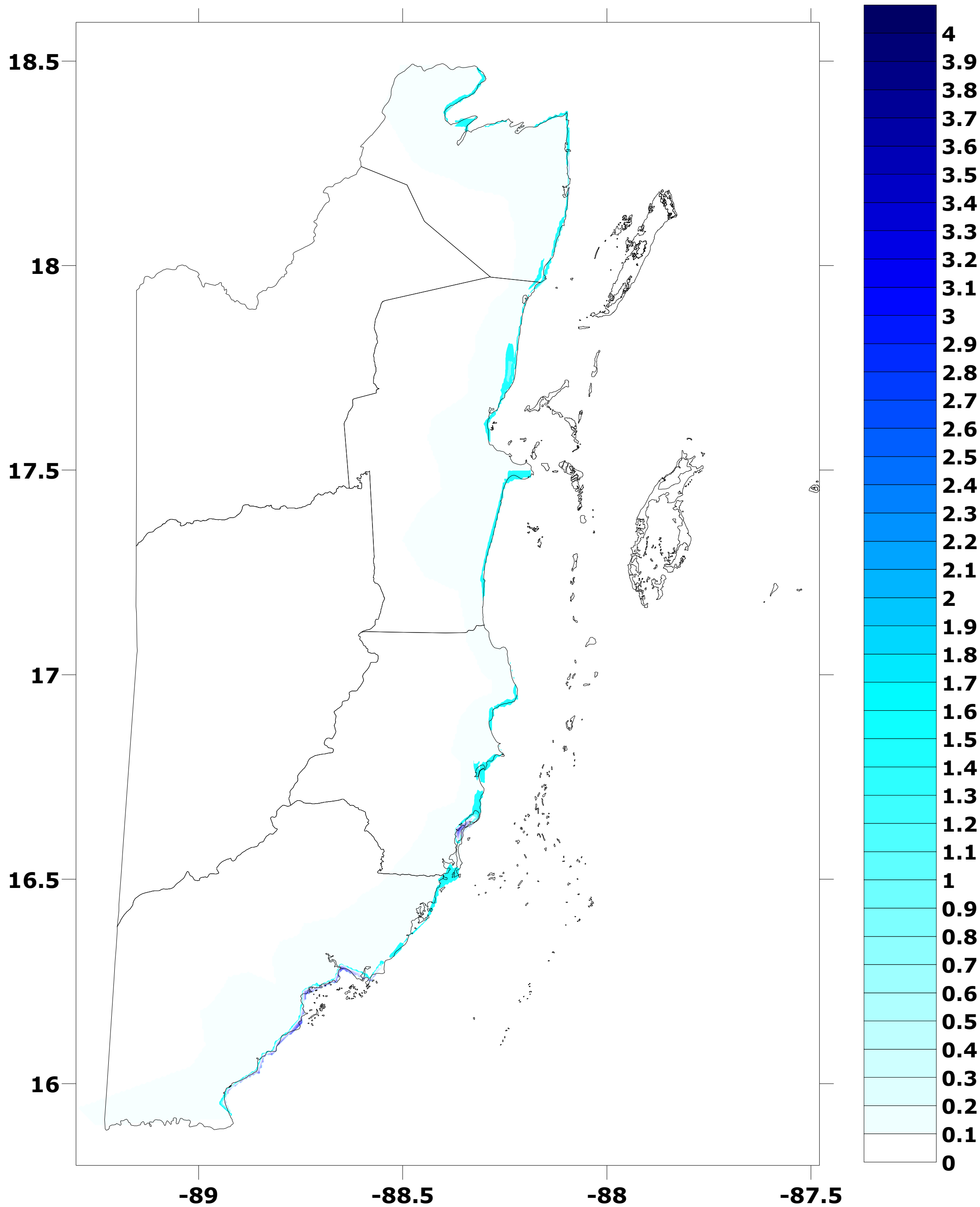


Figure 3-12
Spatial distribution map of the flood height (m) for 100 years of return period

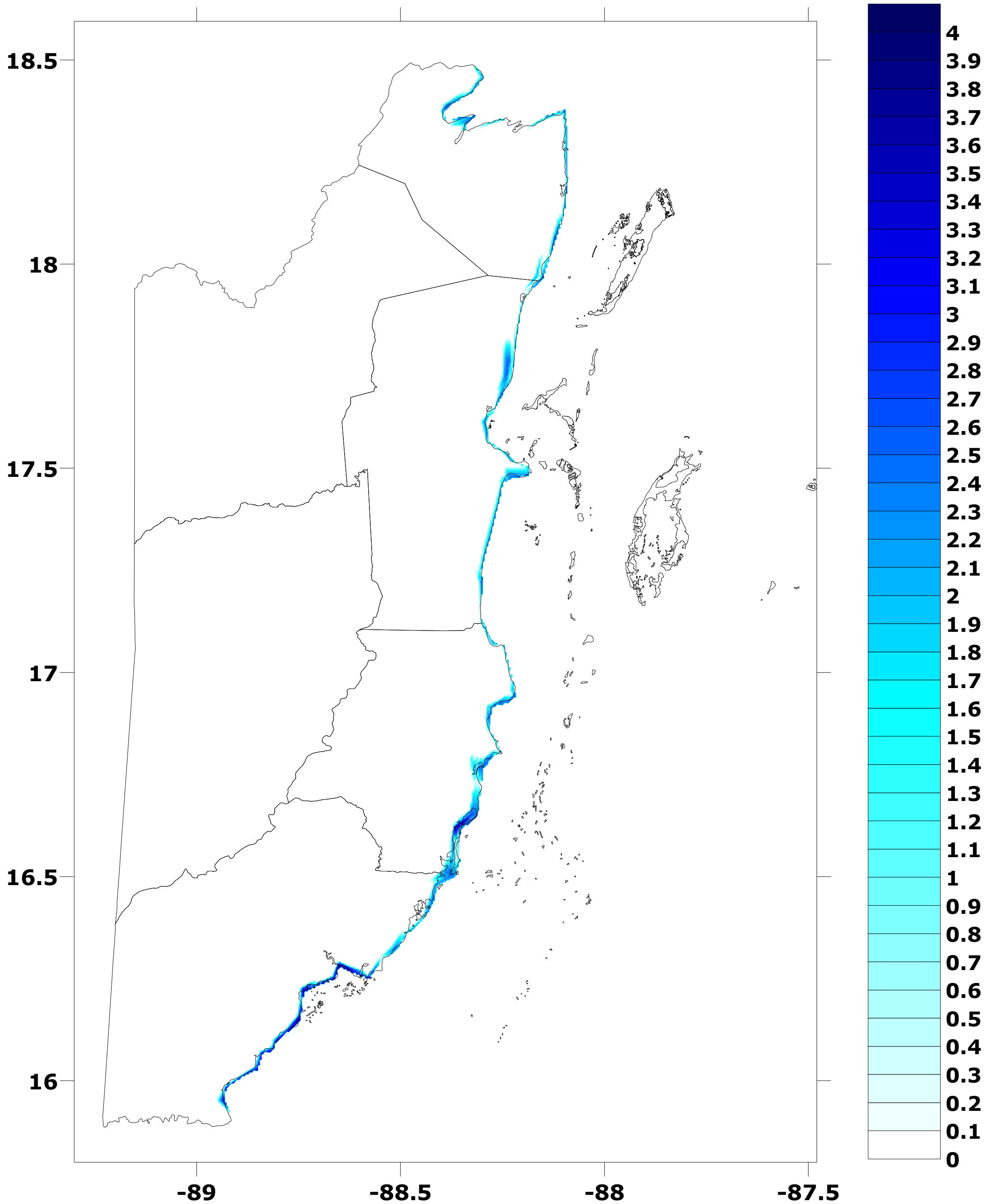


Figure 3-13
Spatial distribution map of the flood height (m) for 500 years of return period

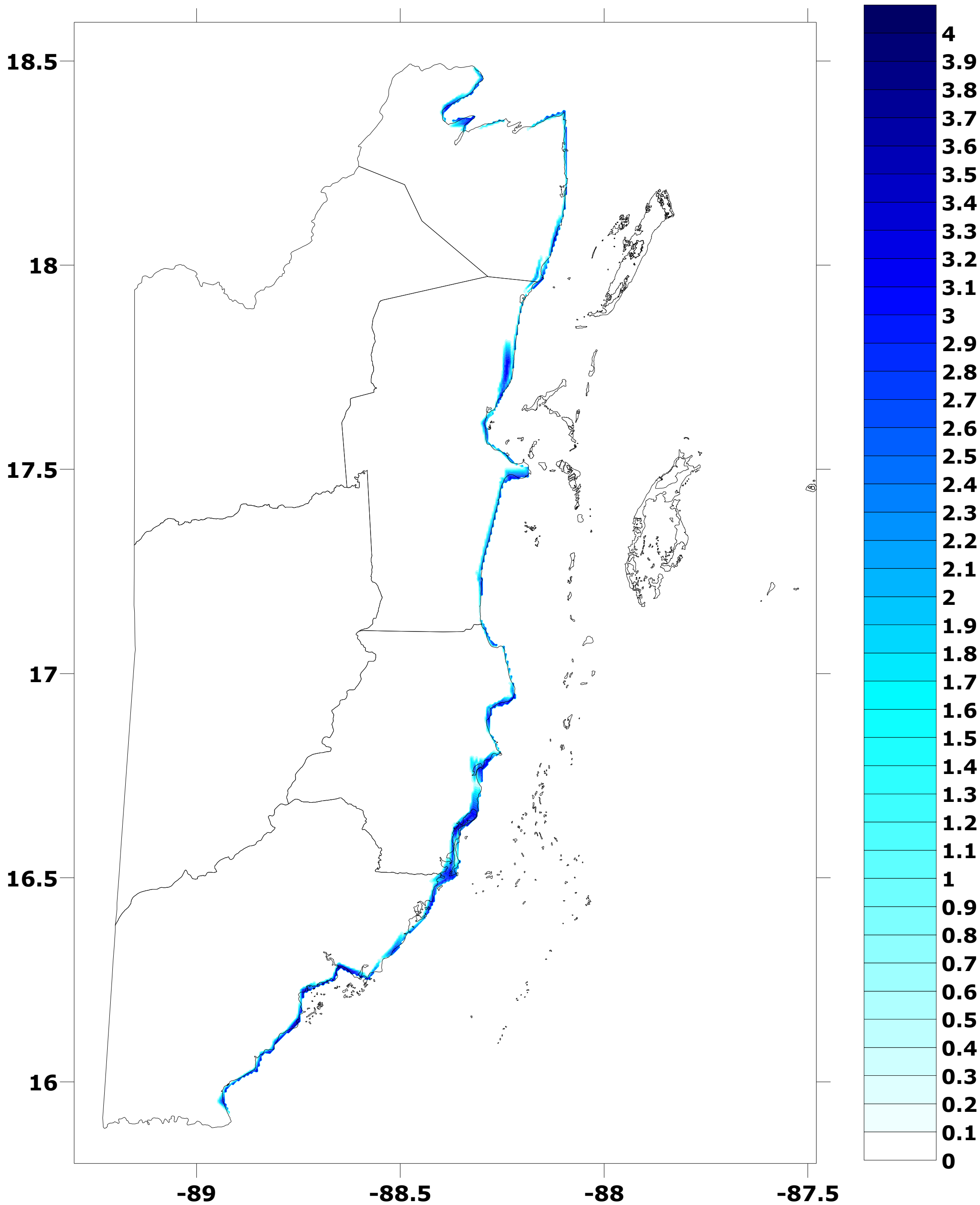


Figure 3-14
Spatial distribution map of the flood height (m) for 1000 years of return period

3.5.3 *Hazard maps for hurricane rain*

A uniform hazard map was calculated for hurricane rains, the measure of intensity being the level of rainfall, as explained in the report ERN-CAPRA T1.2 (Evaluation models from natural hazards, ERN 2009) and for return periods of 20, 50, 100, 500 and 1000 years. The calculations were made using the ERN-Hurricane programme (ERN 2007)

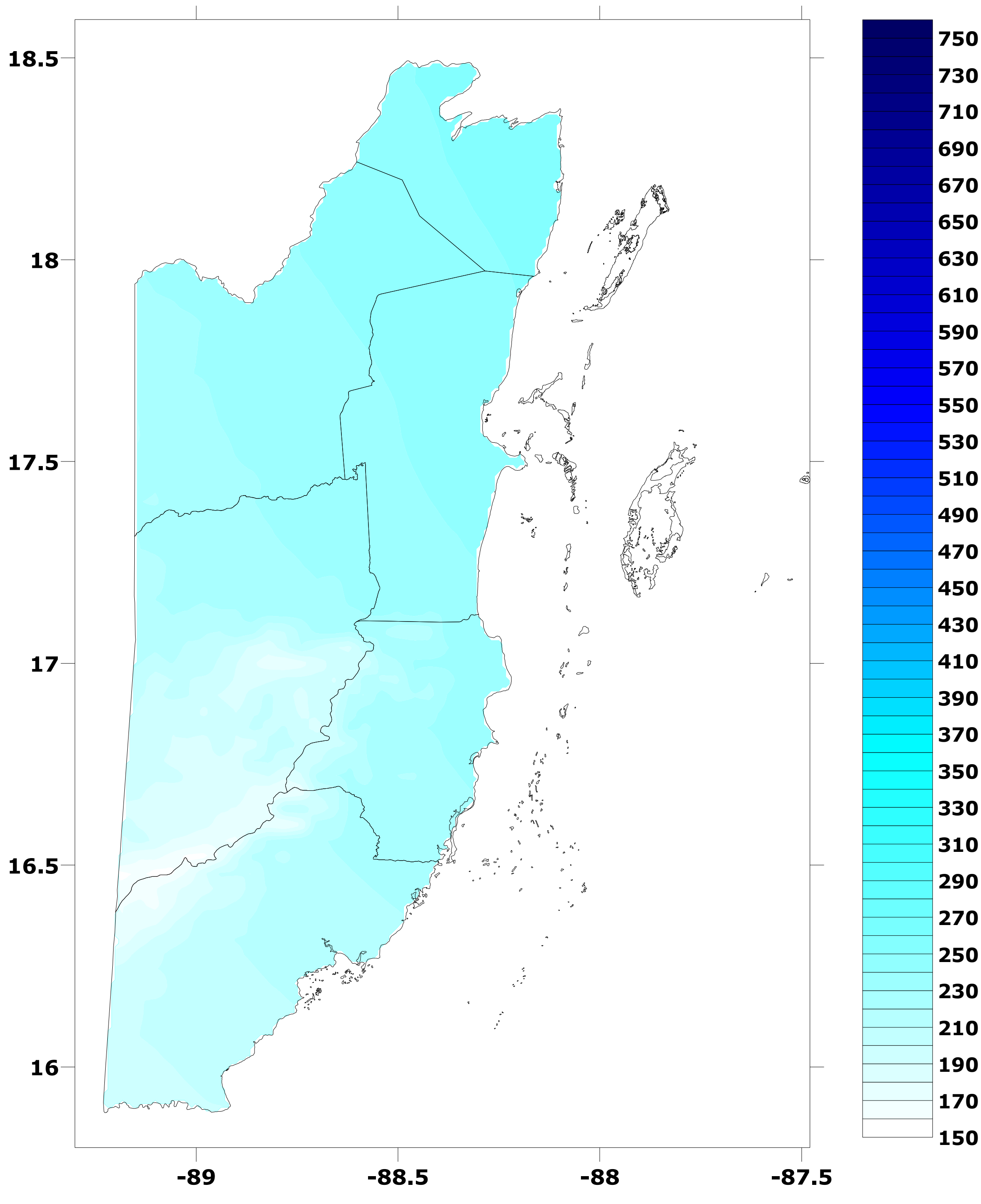


Figure 3-15
Spatial distribution map of rainfall depth (mm) for 20 years return period

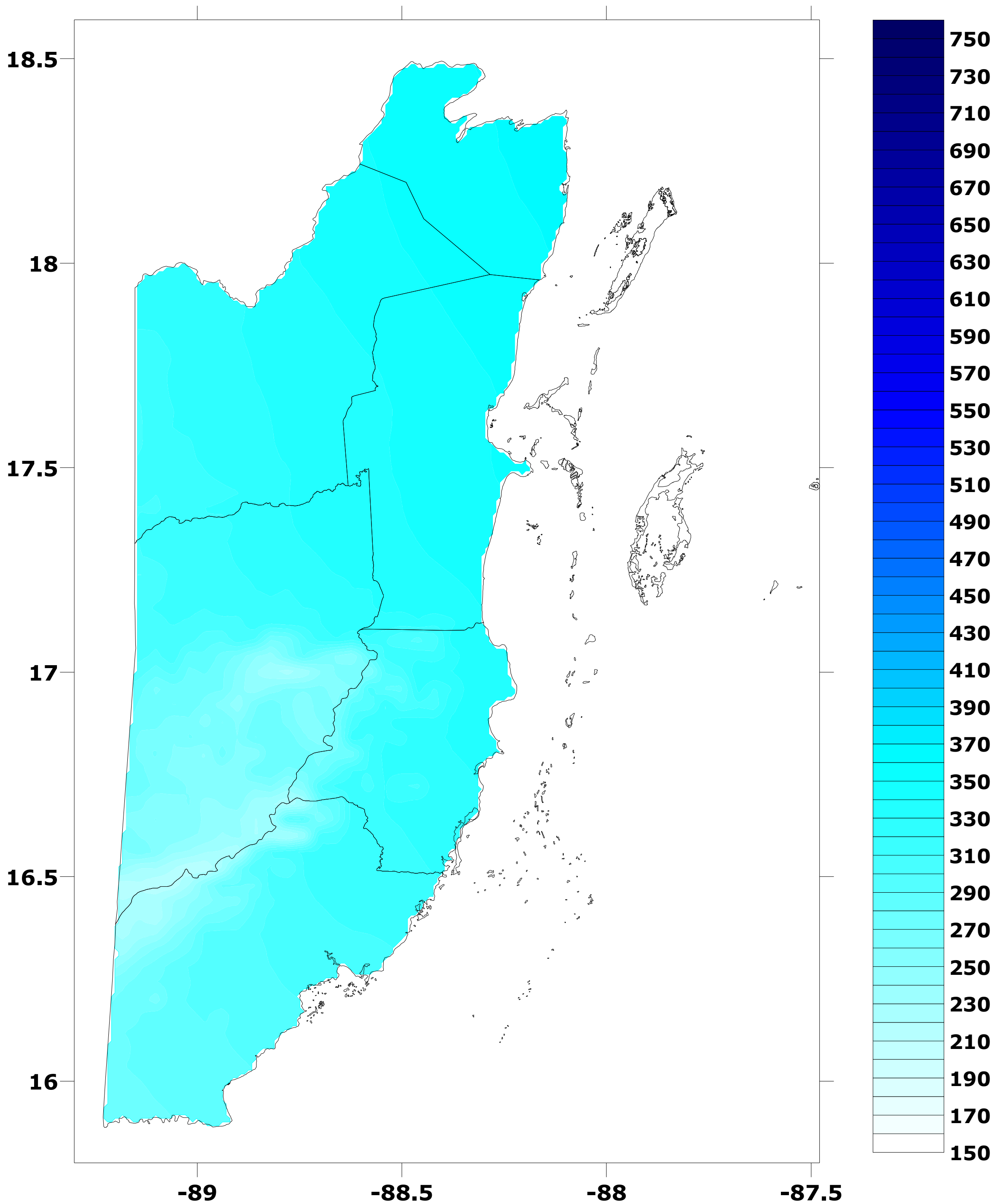


Figure 3-16
Spatial distribution map of rainfall depth (mm) for 50 years return period

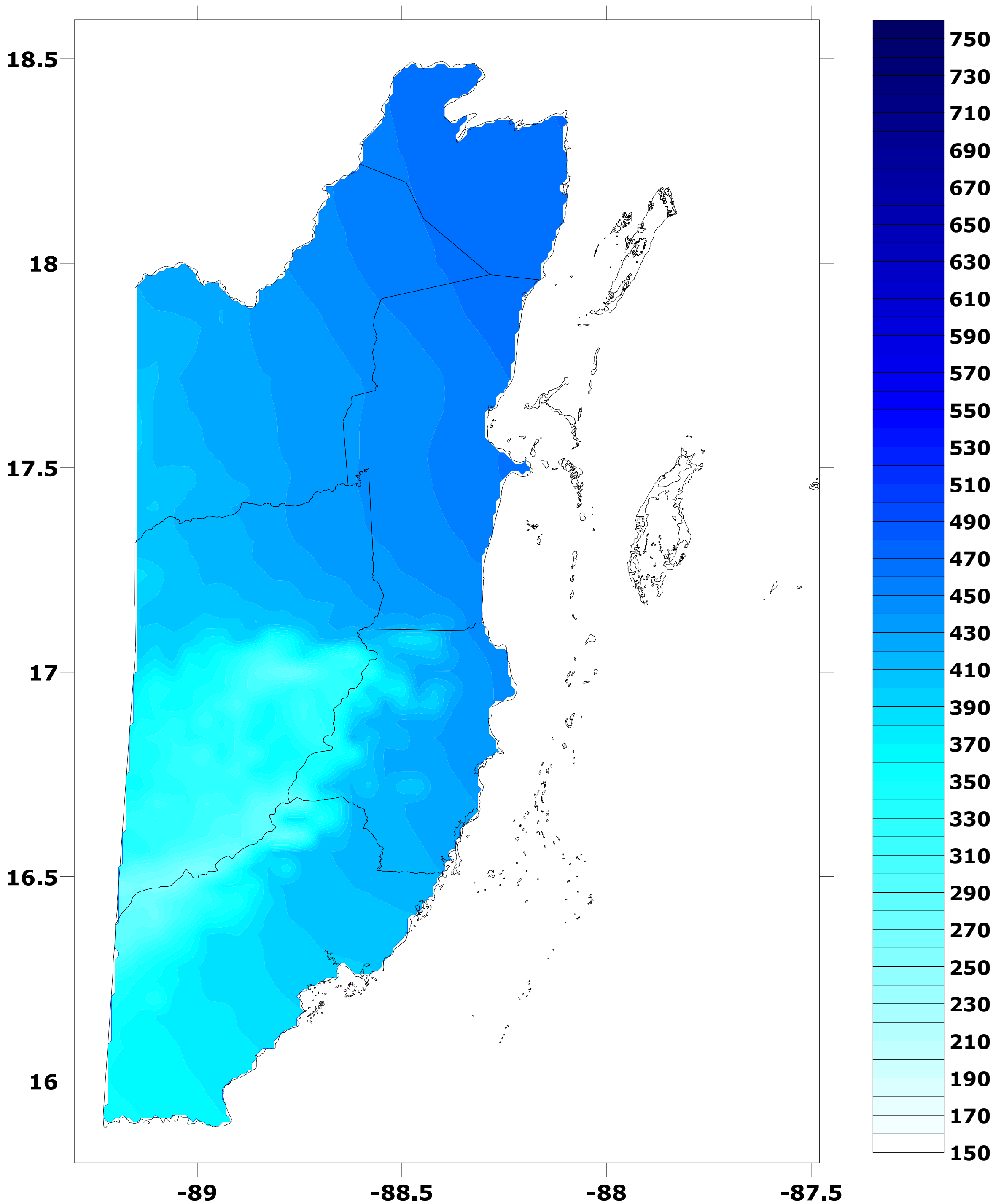


Figure 3-17
Spatial distribution map of rainfall depth (mm) for 100 years return period

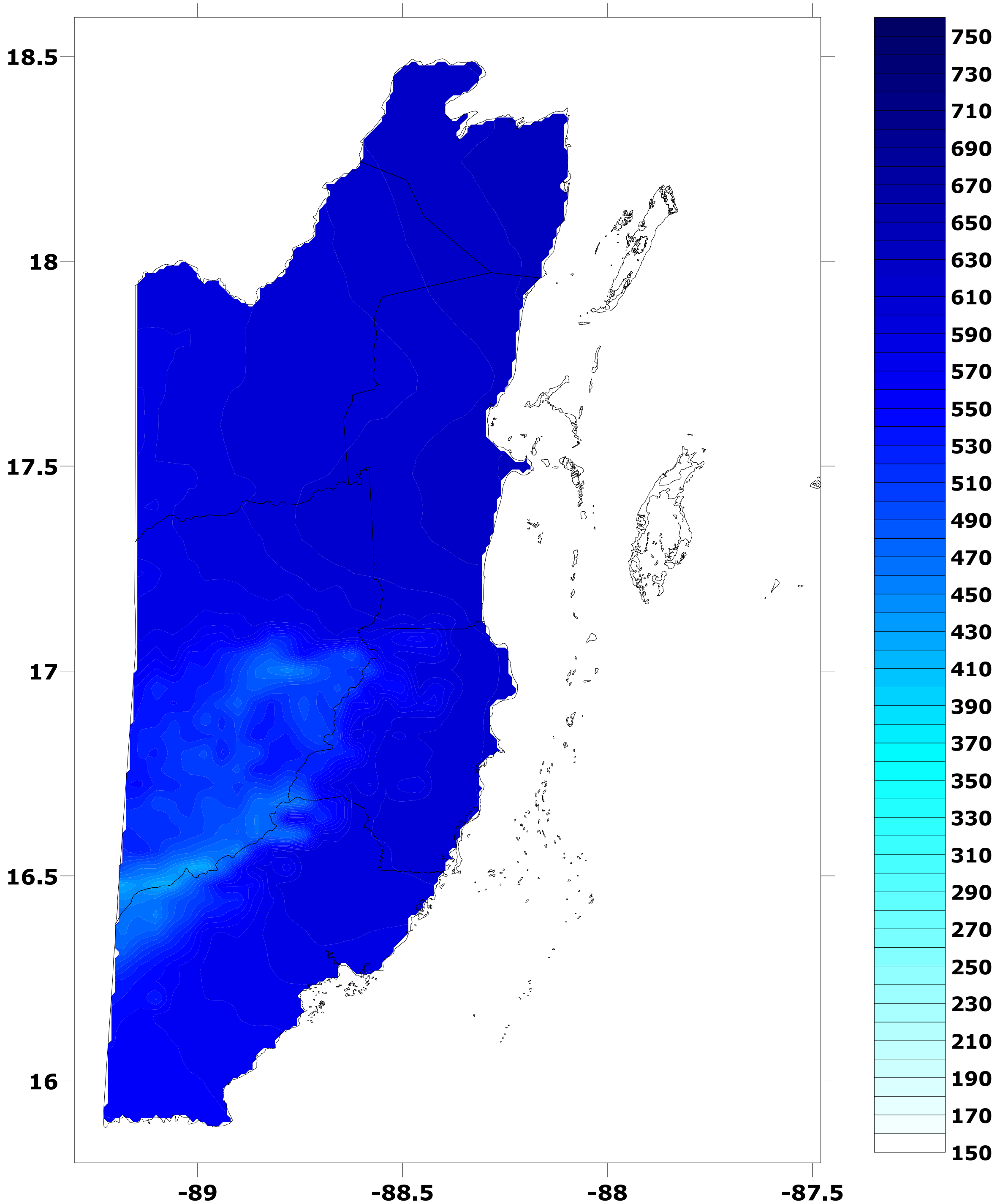


Figure 3-18
Spatial distribution map of rainfall depth (mm) for 500 years return period

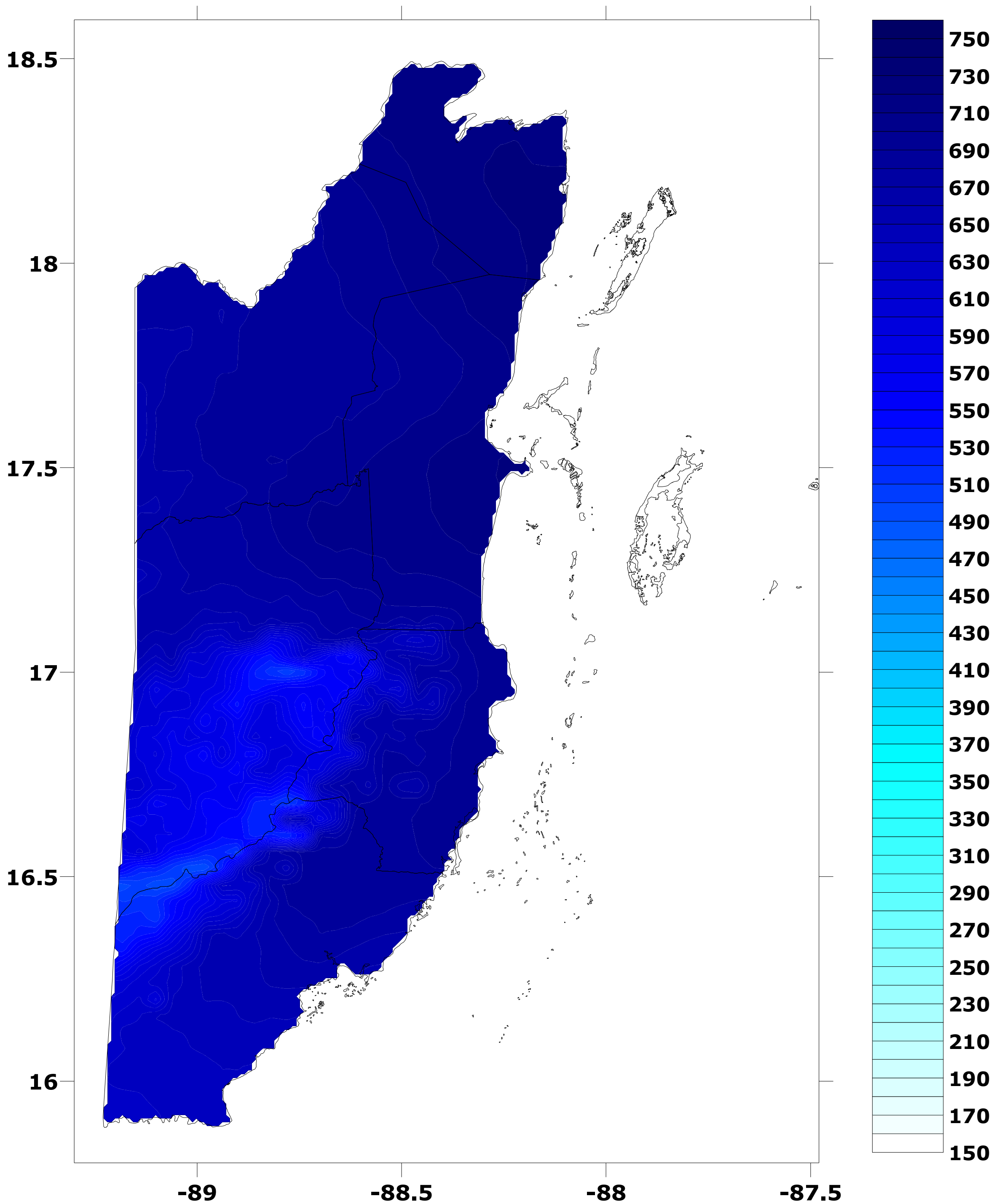


Figure 3-19
Spatial distribution map of rainfall depth (mm) for 1000 years return period

3.5.4 *Flood hazard maps associated with hurricane rains*

The model for trigger events proposed in the study ERN-CAPRA-T1-1 (Principal components of risk analysis, ERN 2009) was applied, to calculate the hazard of floods associated with hurricane rains, the measure of intensity being the depth of flooding, for return periods of 20, 50, 100, 500 and 1000 years. Calculations used the program ERN-Flood (ERN 2009)

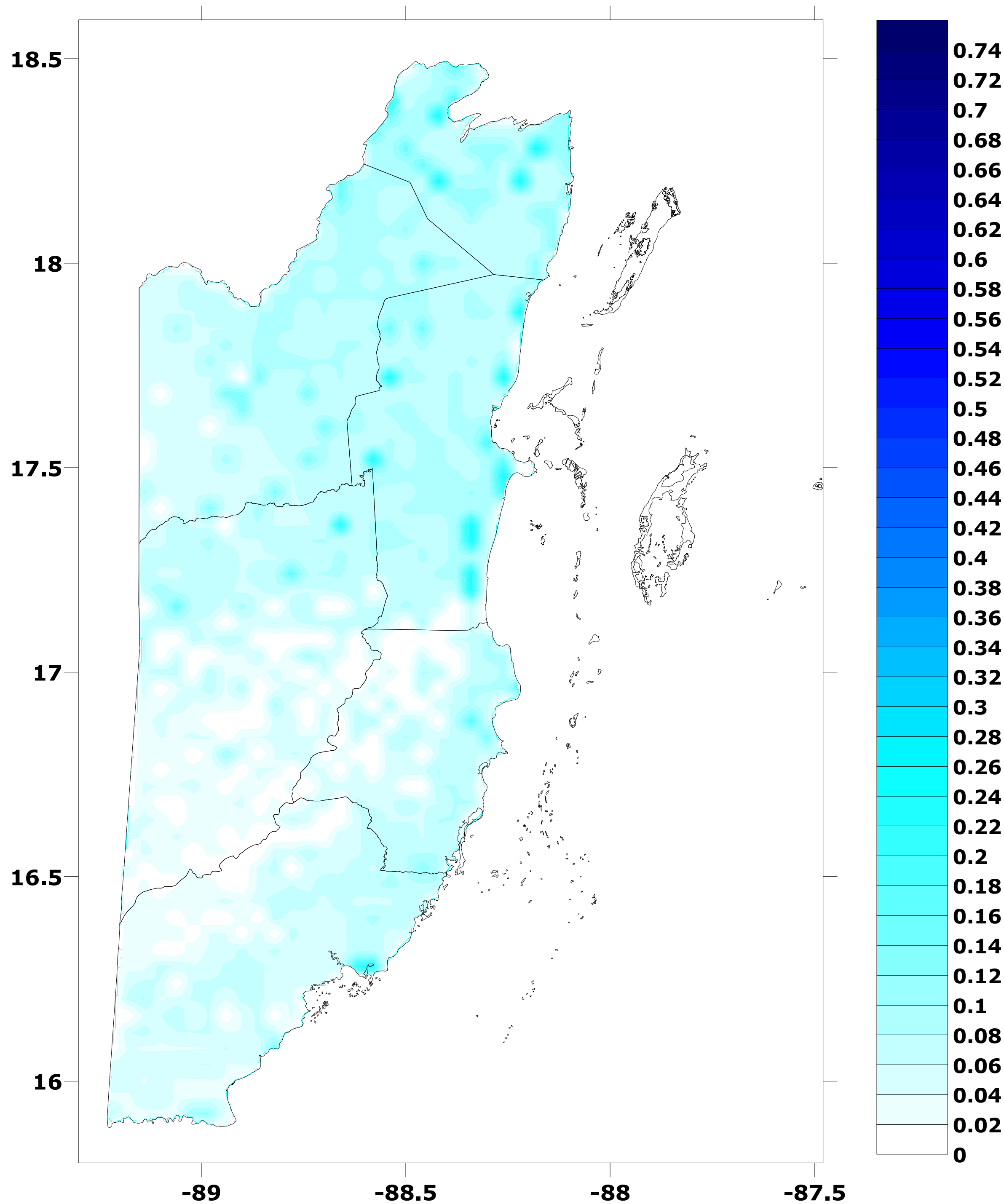


Figure 3-20
Spatial distribution map of flooding depth (m) for 20 years return period

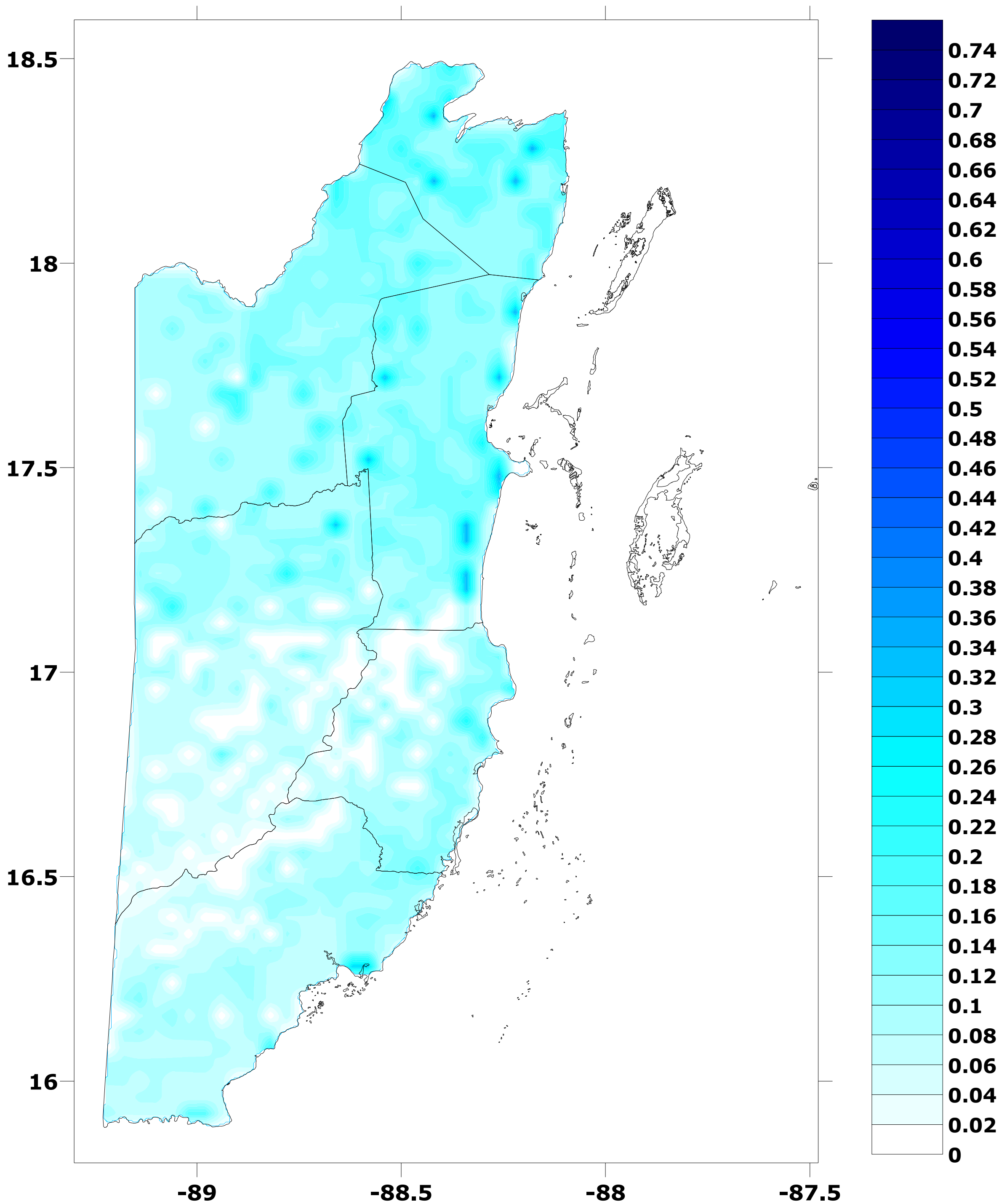


Figure 3-21
Spatial distribution map of flooding depth (m) for 50 years return period

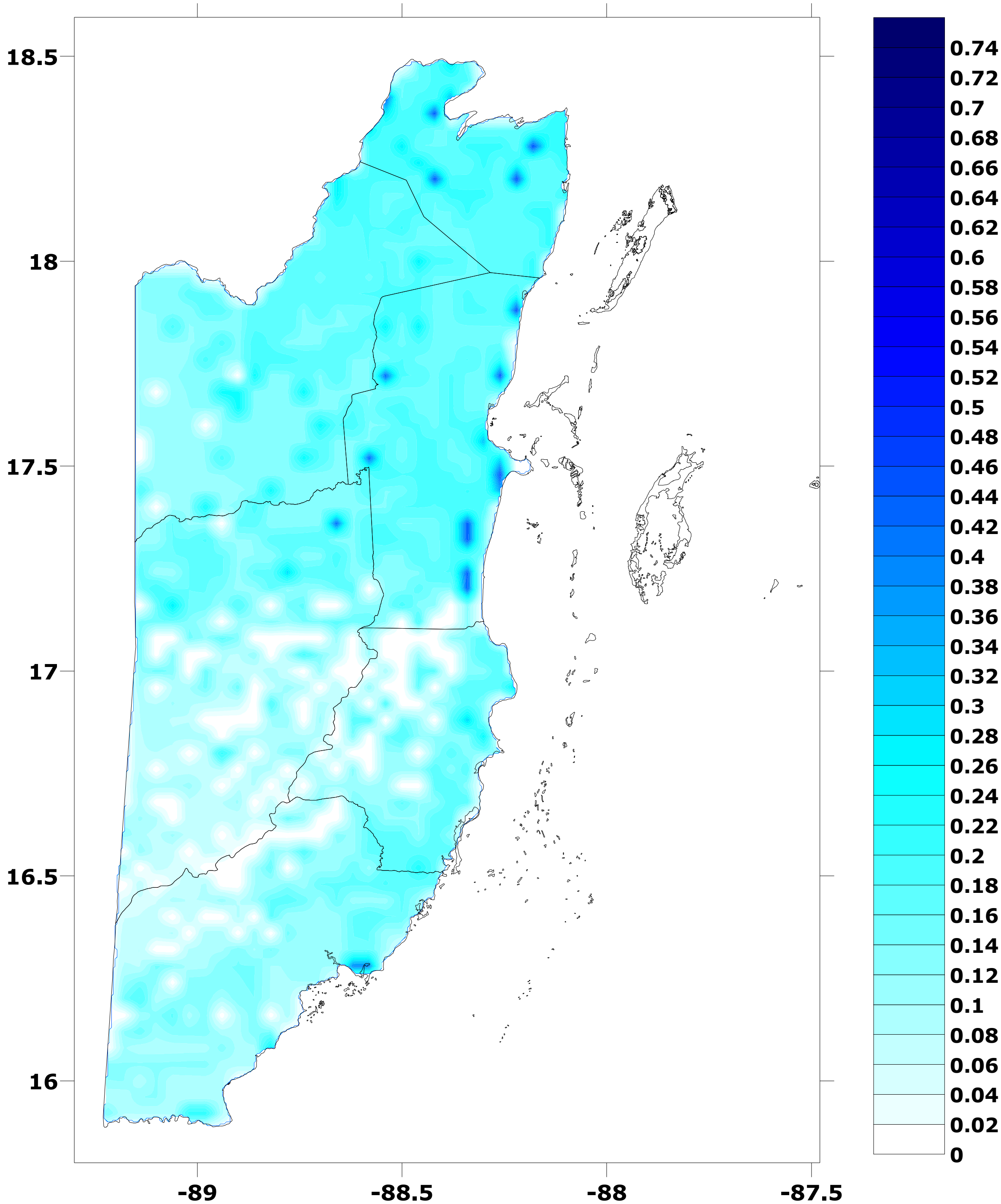


Figure 3-22
Spatial distribution map of flooding depth (m) for 100 years return period

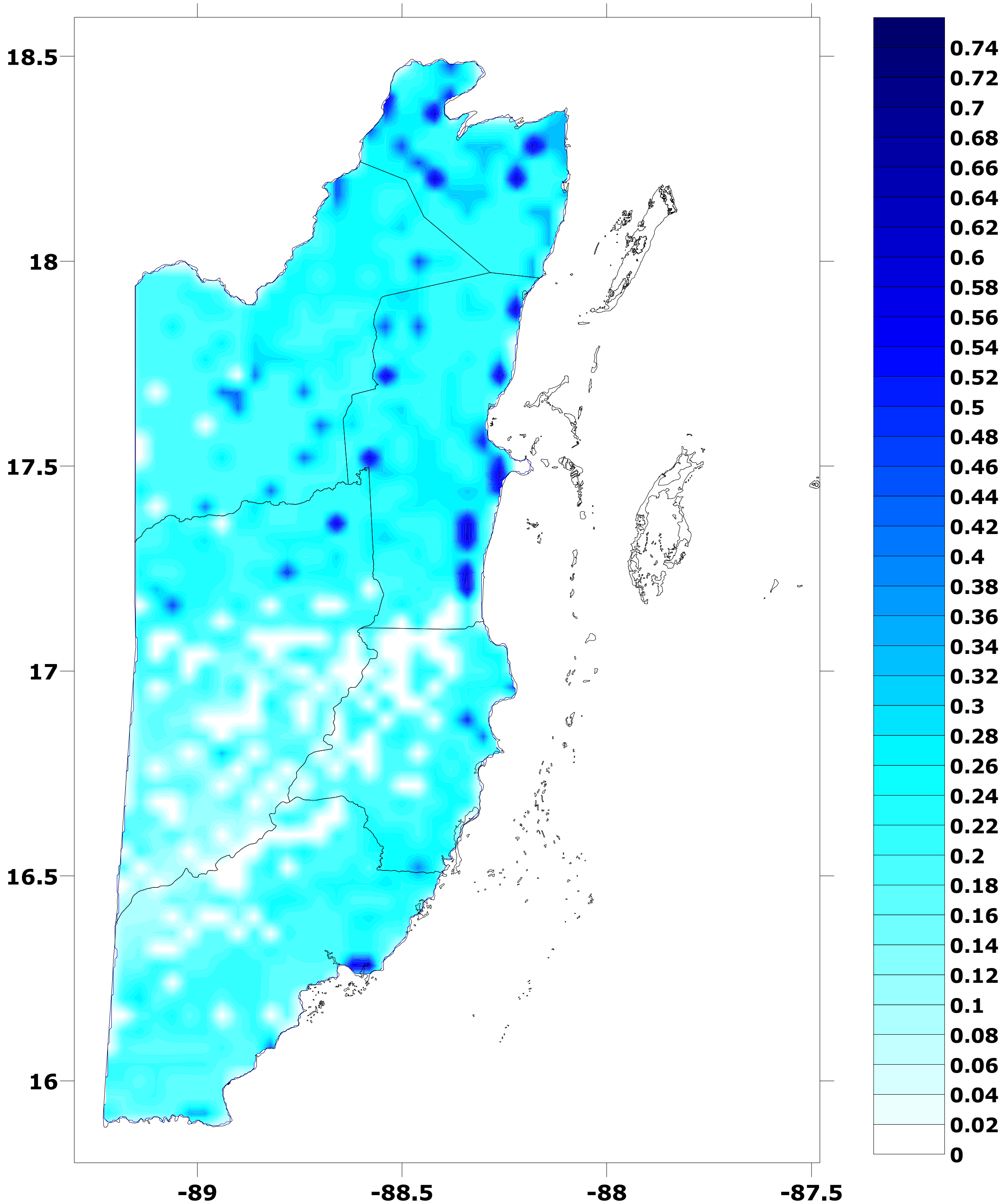


Figure 3-23
Spatial distribution map of flooding depth (m) for 500 years return period

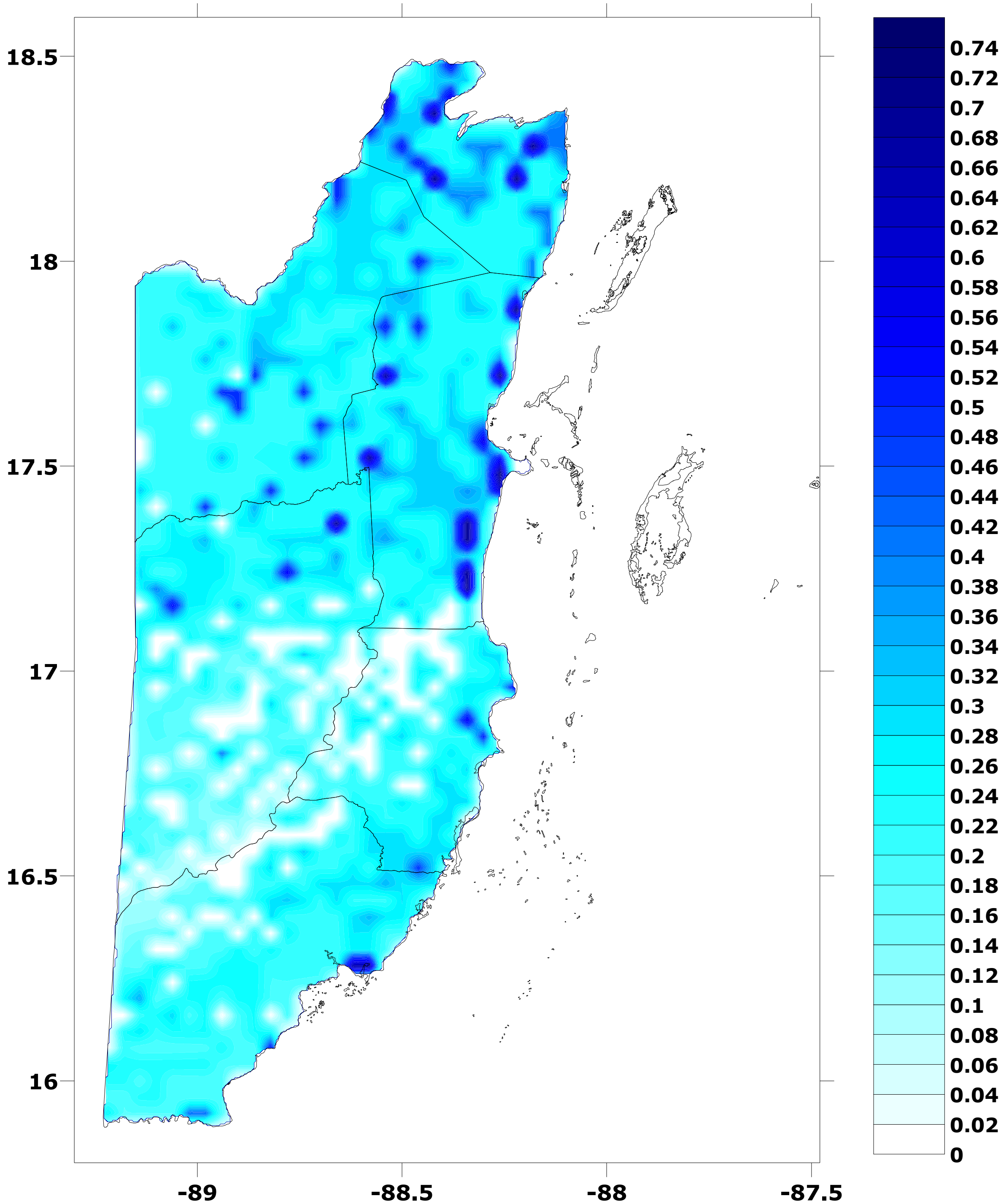


Figure 3-24
Spatial distribution map of flooding depth (m) for 1000 years return period

4 Rainfall and flooding hazard

The analysis of heavy rain hazard made reference to a review of all weather information available. The appropriate modeling of rainfall which may occur in a particular territory depends greatly on the quality of information. There must be a period of measurement of daily rainfall values over about 30 years in order to provide a correct characterization of the rainfall regime in a region. In the particular case of Belize, the weather information made available so far is of a quality which will not allow a prediction of climatic conditions using the models proposed (see report ERN-CAPRA-T1.2, Evaluation models for natural hazards, ERN 2009).

5 Landslide hazard

5.1 Introduction

Landslides are very common in tropical countries with a high density of mountain areas, and high levels of rainfall. The magnitude of a given landslide may not lead to catastrophe, but the high frequency of occurrence makes them one of the most common and important hazards in Belize.

The emphasis of the calculation made here is based on a point-to-point modelling of stability, to make it to give spatial coverage of general conditions of the stability of the region.

5.2 Information used in modelling

Detailed information of the studies and needs to be available for the evaluation of the landslide hazard, as specified in the report ERN-CAPRA-T1.2 (Evaluation models for natural hazards, ERN 2009). We here list the information available to form input data for the model, which is part of the existing geographical information for Belize:

- Topographic map, with grid resolution of 30m
- General geological map with information related to different types of rock, such as description, age formation, mineralogical composition, stratigraphy and symbology.
- Agronomic zoning map soils, with information showing the specific characteristics of evolution and creation of the soil, indicating horizons use, and origin (parent rock, textures and particle size). It should be noted that there is no accurate stratigraphic survey for soils in Belize, and therefore soil thickness must be inferred.

5.3 Parameters of the model

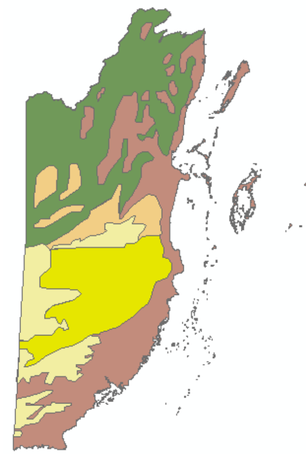
As specified in the report ERN-CAPRA-T1.2 (ERN 2009), calculation modules were developed for three different models of landslide hazard, and their applicability is a function of available information. In this case, modelling was conducted at national level, using the Mora-Varhson-1993 methods, and translational faults. The information used in the modelling is shown below.

5.3.1 *General information*

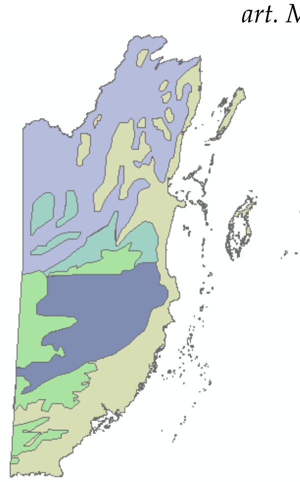
General information includes the topography of the country, geology, basins, and geotechnical information. Layers of properties of landslide-prone soils are generated based on geotechnical and geological information available, shown in Figure 5-1. Information required on landslide-prone strata and base strata corresponds to cohesion, angle of friction, specific weight and thickness. The general layers of information are as follows:

- Topography.
- Regional geology
- Division by basins
- Division of soils by originating material

Digital Elevation Model
(Source: NASA SRTM. Resolución de 30 m)



Regional Geology
(Source: Eastern Mexican/Central American rock art. Martin Kunne /Matthias Strecker)



Division of soils

Figure 5-1
Layers of general information available for Belize

5.3.2 *Information on trigger events*

Events considered as landslide triggers are specified in different ways. Seismic hazard must be included in the model, as a set of stochastic scenarios, each of them with a layer of intensities of movement, and annual frequency of occurrences.

Intense rain is not considered directly. What is wanted is the *state of humidity* of soils potentially involved in landslides, based on the thickness of the soil layer. If the soil is entirely saturated, the state of humidity has a value of 0, while a completely dry soil has a value of 1. Humidity conditions may vary between these values, and each scenario will be assigned a humidity value and an annual frequency of occurrence. Based on this information, the groundwater level in the potentially dangerous substratum can be located.

5.4 Available data quality

The calculation of the landslide hrequires highly detailed information, which is not available at national or subnational levels. Currently available information is acceptable for indicative analysis only.

A detailed analysis of landslide hazard involves first choosing a region of particular interest, usually at a scale well below the national or subnational levels. Secondly, it requires detailed topography and mechanical characterization of surface soils within the study area, as well as groundwater levels and variations in time (see report ERN-CAPRA-T1.2 Assessment Models Natural Hazards ERN 2009).

In this particular case, detailed information is unavailable. Therefore, inferences and assumptions must be made to allow the mechanical characterization of surface soils, which reduces the quality of the result. Also, given the high complexity in the modelling of changes in groundwater levels, conditions of soil moisture are modelled deterministically, from the definition of scenarios of soil saturation.

5.5 Landslide hazard maps

Landslide hazard maps for Belize were calculated using the two methods mentioned above. The Mora-Varhson method was used for two soil humidity conditions (completely saturated and completely dry), and a seismic scenario corresponding to a Mw 6.8-magnitude earthquake (calculated by the CRISIS 2007 program, or Ordaz et al 2007). The calculation with the translational faults method was made for the same two conditions of humidity and seismic hazard. The analysis appears in Table 5-1.

Table 5-1
Analysis of landslide hazard

N°	Analysis	Humidity scenarios	Earthquake scenarios	Landslide scenarios
1	Mora Vahrson	2	1	2
2	Panel fault	2	-	2
		2	1	2

The parameter of intensity used is the insecurity factor, which corresponds to the inverse of the security factor. The greater the insecurity, the greater the probability of occurrence of the landslide hazard. Calculations are made by applying the ERN-Landslide program (ERN 2009). The maps which appear below take account of the following scales:

Mora-Vahrson method scale: The classification of the hazard by this method is divided into several classes, described in the following colour scale, from insignificant to very high.

I	**II**	**III**	**IV**	**V**	**VI**
Very low	Low	Moderate	Moderate-High	High	Very high
<6	7-32	33-162	163-512	513-1250	>1250

Translational fault method: the graphic scale of these maps is a function of the insecurity factor, as shown below.

0	0.1	0.5	0.83	>1.11
Very low	Low	Moderate	High	Very high

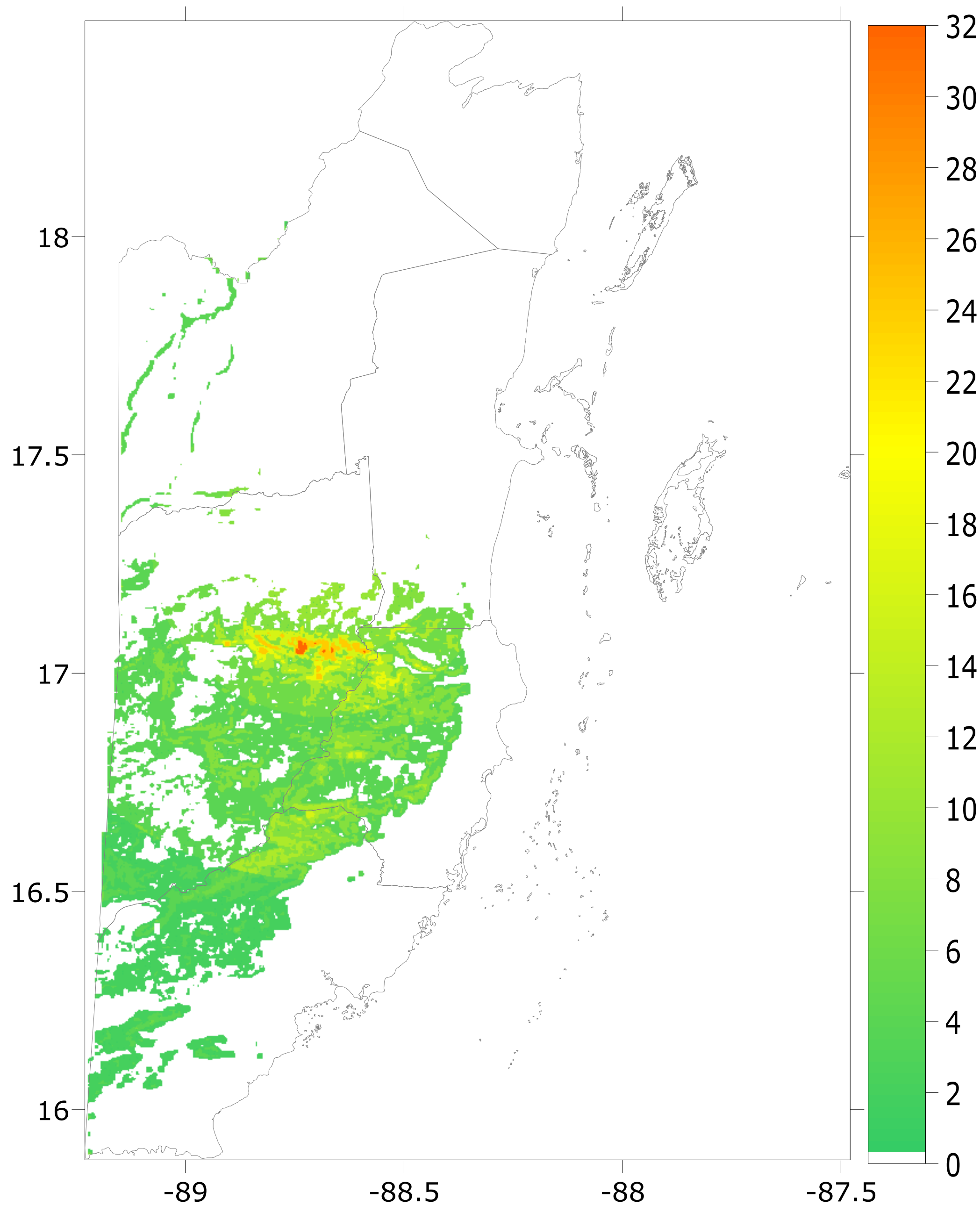


Figure 5-2
Landslide hazard maps in dry conditions with an earthquake, using the Mora Varhson method

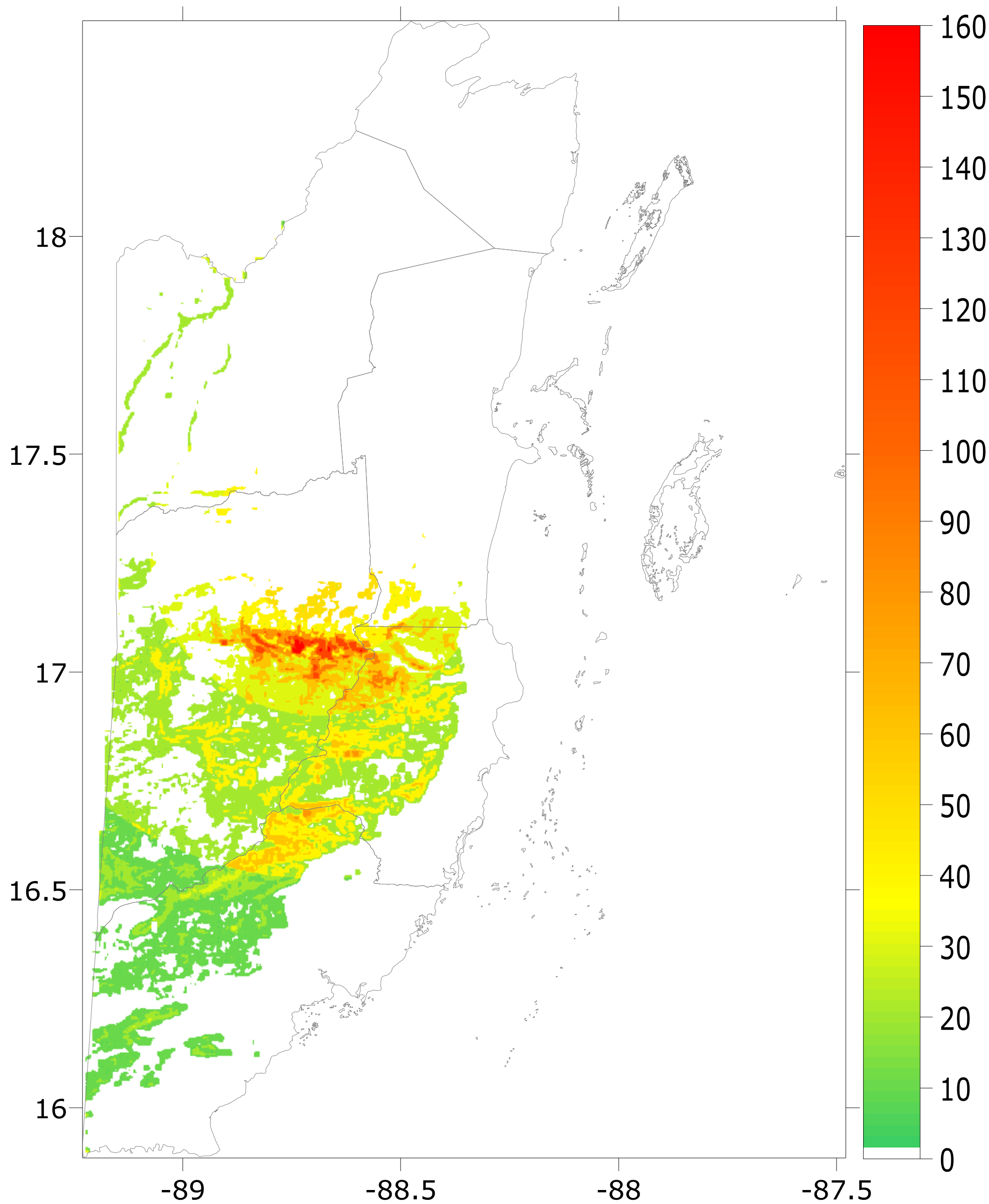


Figure 5-3
Landslide hazard maps in humid conditions with an earthquake, using the Mora Varhson method

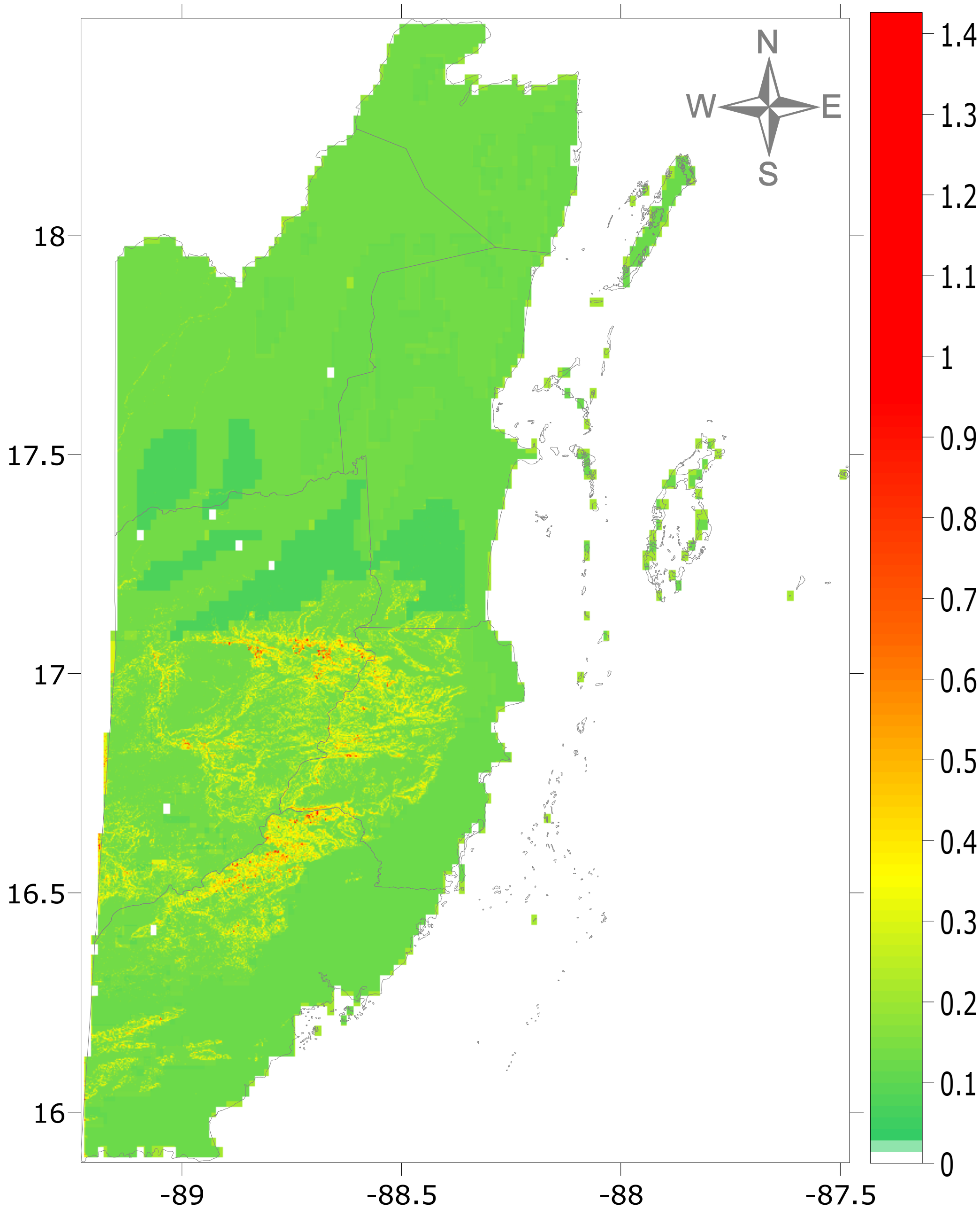


Figure 5-4
Landslide hazard maps in dry conditions without an earthquake, using the translational fault method

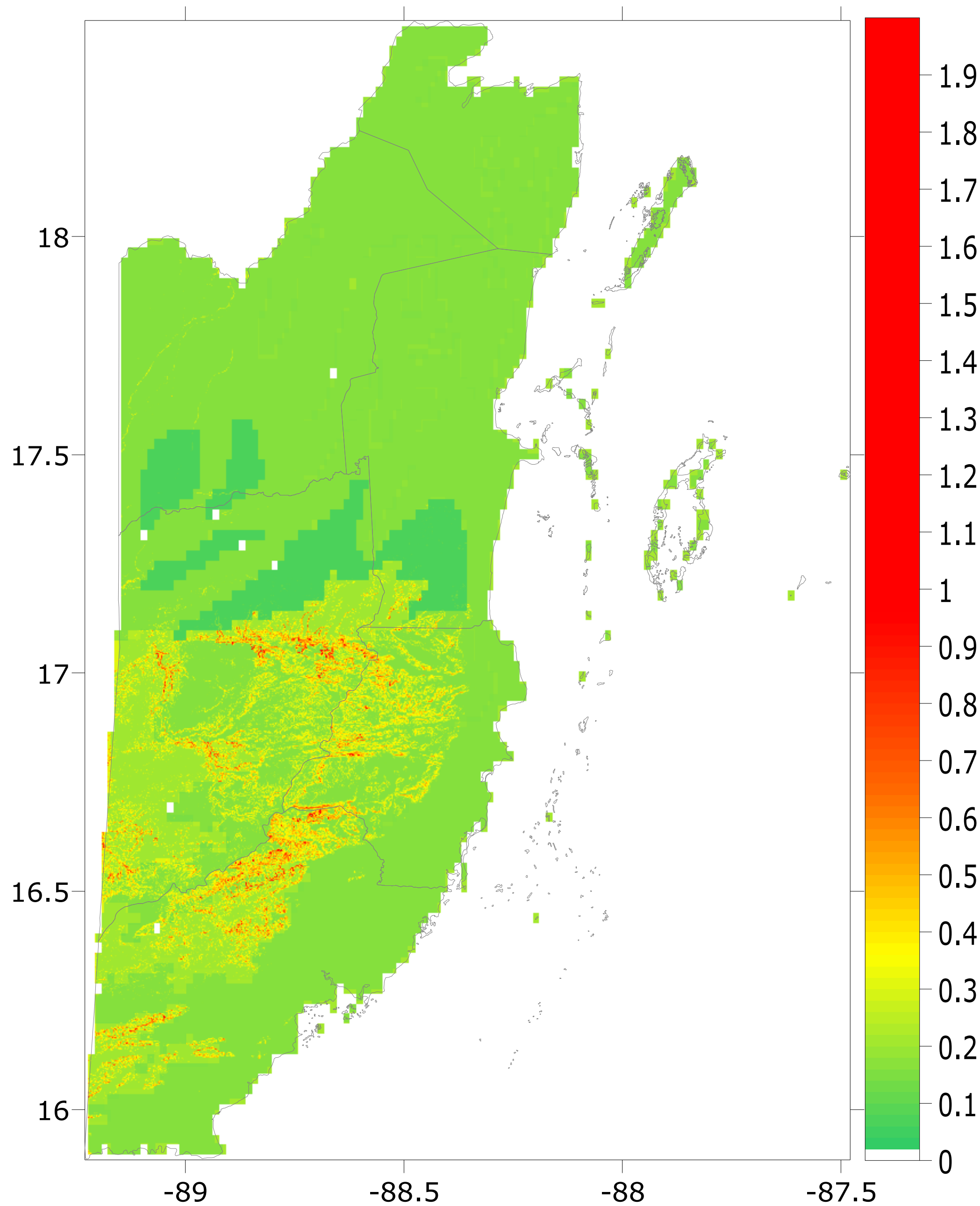


Figure 5-5
Landslide hazard maps in saturated conditions without an earthquake, using the translational fault method

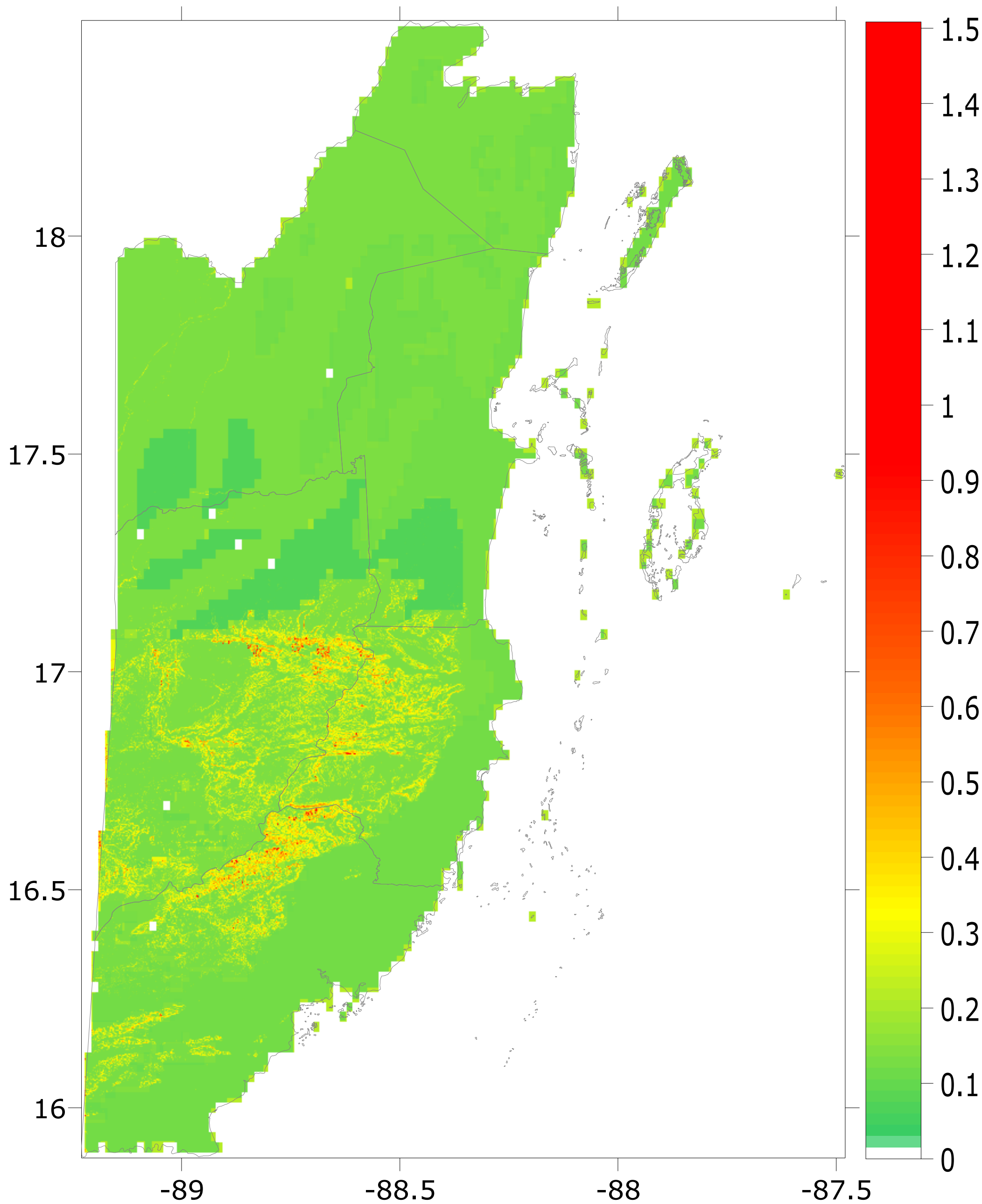


Figure 5-6
Landslide hazard maps in dry conditions with an earthquake, using the translational fault method

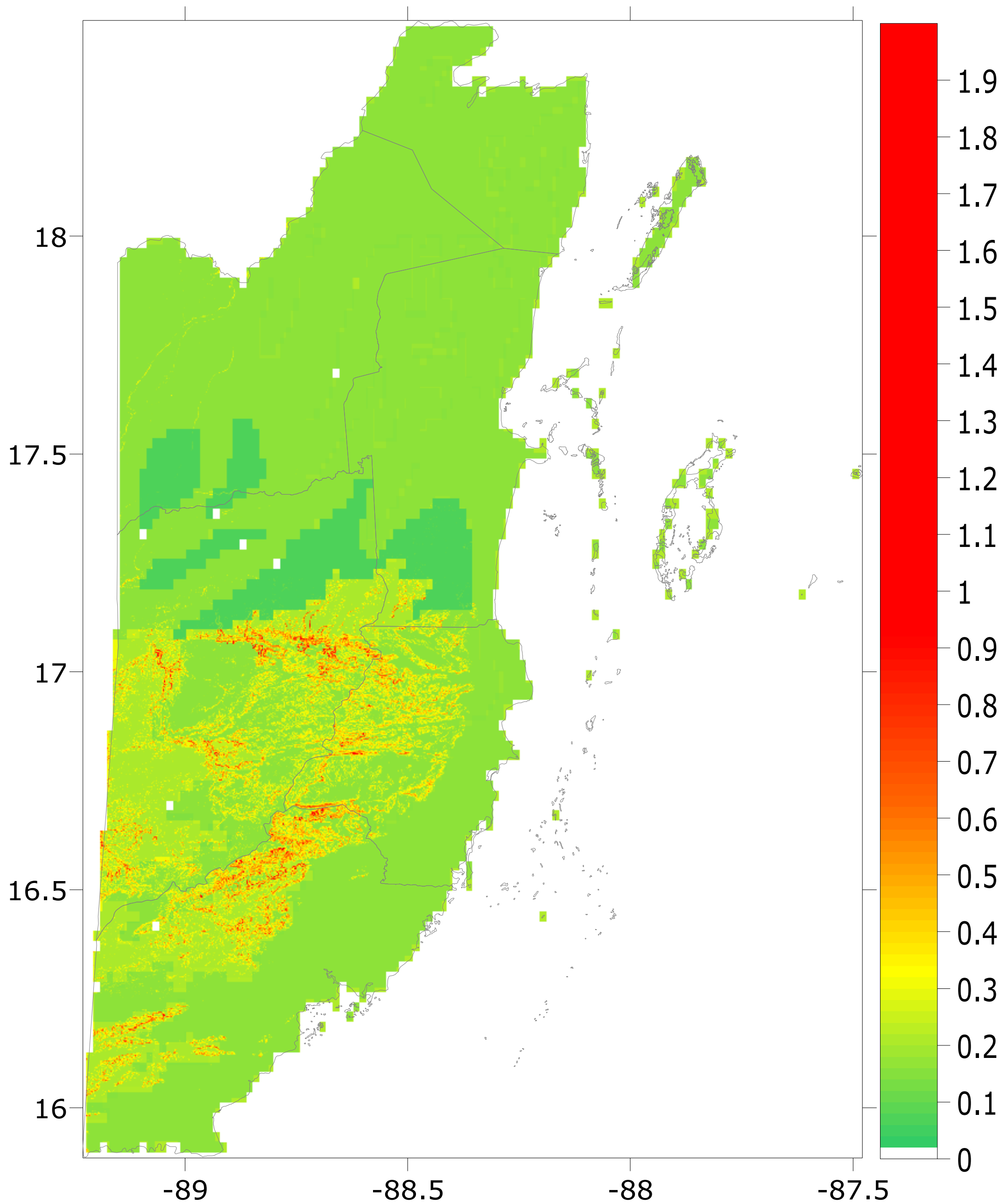


Figure 5-7
Landslide hazard maps in saturated conditions with an earthquake, using the translational fault method